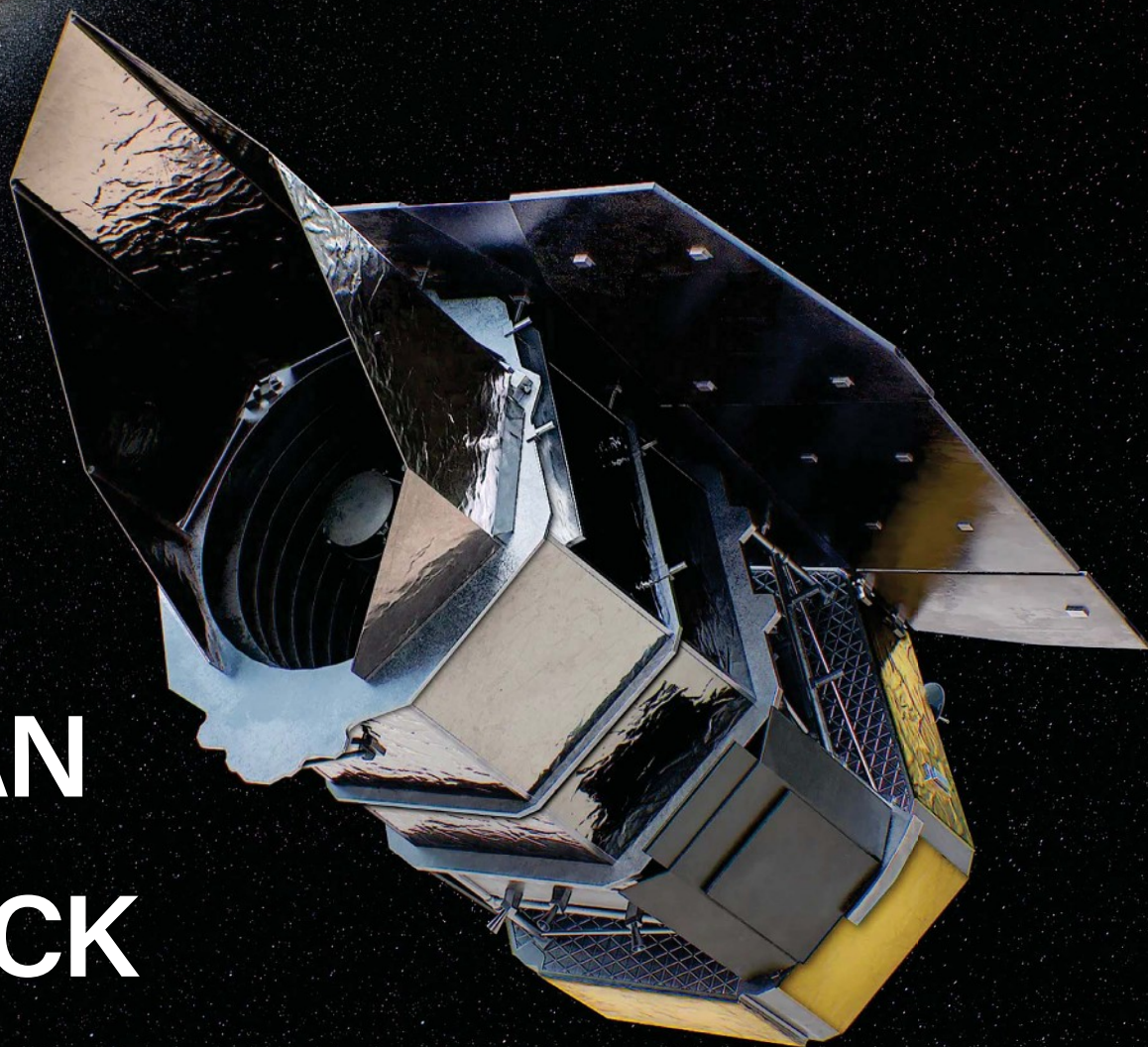


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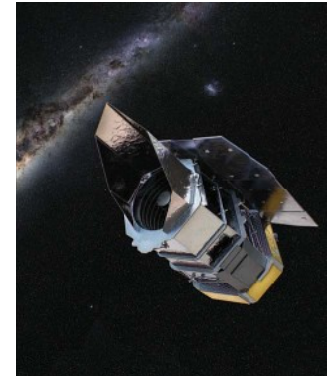
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ON THE COVER

The Nancy Grace Roman Space Telescope will reveal the cosmos in new ways with a huge infrared field of view and Hubble-like image quality. *ASTRONOMY*: ROEN KELLY, AFTER NASA; BACKGROUND IMAGE: ESO/S. BRUNIER

CONTENTS

24

FEATURES

14 COVER STORY

How Roman will unlock the universe

This next-generation space telescope will blow past its predecessors to answer questions about everything from stars and planets to dark matter and dark energy. **ALISON KLESMAN**

24

How Mars' largest rivers shaped the planet

Sixteen newly identified drainage systems suggest ancient habitable environments were widespread.

ASHLEY BALZER VIGIL

28

Sky This Month

Saturn at opposition.

**MARTIN RATCLIFFE
AND ALISTER LING**

30

Star Dome and Paths of the Planets

**RICHARD TALCOTT;
ILLUSTRATIONS BY
ROEN KELLY**

36

Orion's star factory

JWST focuses on the colorful outflows from young protostars in Orion the Hunter.

RICHARD TALCOTT

38

Jupiter and the Moon play hide-and-seek

A crescent Moon occulting our solar system's largest planet is a rare and brilliant sight. **JOE RAO**

42

Our 16th annual Star Products

We highlight 35 of the most interesting and capable products on the market today.

PHIL HARRINGTON

52

Ask Astro

How astronomers book telescope time, and what gravitational lensing reveals.

IN EVERY ISSUE

From the Editor 4

Astro Letters 6

Observing Basics 50

MOLLY WAKELING

Advertiser Index 51

Reader Gallery 54

Breakthrough 58

7 ASTRONEWS

Everything you need to know about the universe this month: a hidden supercluster, Mars' roving dust devils, and more.

**ONLINE FAVORITES**

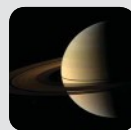
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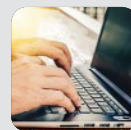
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Roman's revolution



Nancy Grace Roman poses with a model of the Hubble Space Telescope in this image dated circa 1980. AIP EMILIO SEGRÉ VISUAL ARCHIVES, ROMAN COLLECTION



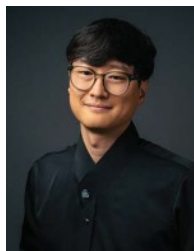
NASA's next flagship mission, set to launch around the time you read this, is named after one of the agency's founding figures: Nancy Grace Roman, its first head of astronomy. Roman, who died in 2018, is known as the "mother of Hubble" for leading the telescope through development. But her legacy is larger.

When Roman joined NASA in 1959 — just 16 months after Sputnik — many astronomers looked at the new organization with skepticism, even hostility. "There was a very strong section of the astronomical community in those days that felt that space was a mistake," she recounted in a 1980 oral history. Space-based telescopes were unproven, and some astronomers — especially at major West Coast observatories, she said — saw NASA as a threat to their funding. As NASA lagged the USSR, it fell to Roman to establish its scientific credentials.

In those early years, Roman managed small but increasingly ambitious space telescopes, and began carving out NASA's role in the field. At a December 1959 symposium, she declared, "NASA will act as a coordinating agency to enable astronomers to obtain the basic observations they need from outer space." The concept of a 3-meter-class space telescope emerged in the early 1960s; Roman felt the technology wasn't yet ready but began campaigning for it with allies like astronomer Lyman Spitzer. In 1971, she convened the steering committee that designed what became Hubble.

It's fitting that her name now graces NASA's newest telescope, built upon many of the principles and technologies that Roman championed. In our cover story, Senior Editor Alison Klesman details how the telescope will fulfill Roman's 1959 statement of purpose — delivering a firehose of observations from outer space, and ensuring that every astronomer has the opportunity to use it. I hope you enjoy the issue.

Mark Zastrow
Editor-in-Chief



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Globular cluster M3 is a dense collection of half a million stars.

PATRICK HOCHLEITNER/
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Parity protection?

I thought that a bit that flipped was detected by having a parity bit with each byte. Then a flip can be accommodated. But in “Our planet’s electronic vulnerability” (June 2026), that appears to not be the case? — **James Fradgley**, Wimborne, Dorset, U.K.

Story author Brooks Mendenhall responds: Parity bits and error correction codes (ECC) are radiation hardening by design safeguards — similar to triple modular redundancy — that can prevent a bit flip from corrupting a system’s output. The problem arises when these strategies fail or are bypassed.

A parity bit tallies whether the number of 1s in a byte is even or odd. A bit flip changes that count, and the parity bit flags an error — but parity alone can’t identify or fix the flip. ECC goes further, using an algorithm (e.g., Hamming code) to check the output against itself and determine which bit changed, so it can be corrected.

But ECC has limits. As Brian Sierawski, interim director of the Institute for Space and Defense Electronics at

Vanderbilt University, explains, it can be defeated if “a cosmic particle upsets multiple bits at the same time,” or if a second strike hits before the first error is corrected. Parity and ECC also take up extra space, since both require additional bits alongside the data itself — so to save space, power, and speed, not all electronics use these safeguards.

In cases like the Airbus A320 incident, protections like ECC were likely in place but bypassed, whether by a multi-bit strike or the software update. Once bypassed, ECC can’t help identify whether a bit flip caused the problem — or whether a cosmic ray caused the flip.

Seeing double

I couldn’t help but notice in your May issue, the photograph of M3 on page 41 is exactly the same as the photo of M53 on page 42. I’d like to believe I’m not the only one who has noticed this! — **John F. Maas**, Winsted, CT

The editors respond: You may not have been the only one who noticed, John, but you were the only one who wrote in! Thanks for that, and apologies for our error. The photo was indeed of M53; a correct photo of M3 has been added to the story online, and can be seen on this page at left.

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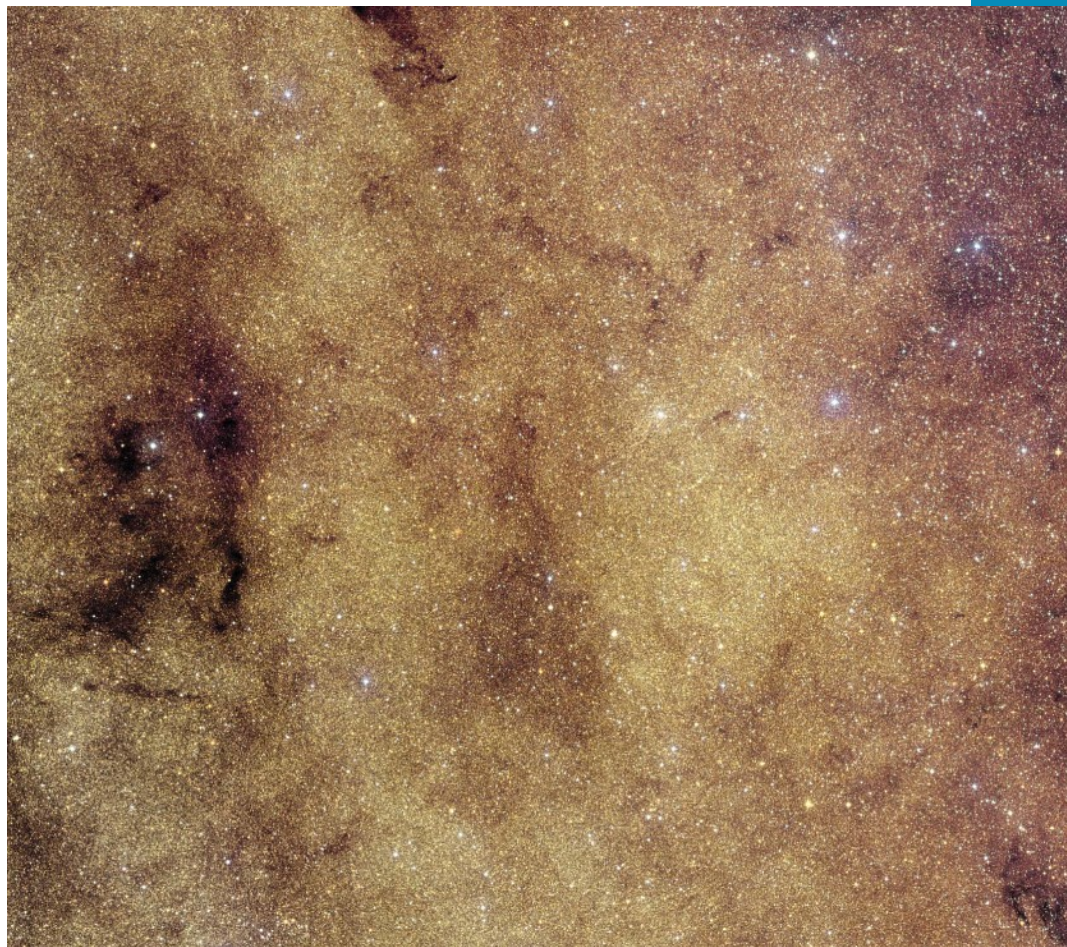
SNAPSHOT

JOURNEY TO THE GALACTIC CENTER

Euclid paves the way for exoplanet finds.

The European Space Agency recently released this stunning stellar vista: the most detailed image to date of our Milky Way's crowded galactic center. Captured in visible light by the Euclid mission with additional color data from the Canada-France-Hawaii Telescope on Maunakea, this photo comprises nine separate Euclid fields, each covering 270 times more sky than the Hubble Space Telescope's field of view. Altogether, the image represents 26 hours of exposure time and contains more than 60 million stars. Also visible are young clusters, glowing nebulae of gas, and dark regions where dust blocks the light from background stars. To reach a similar depth, the 10-meter Keck telescopes in Hawaii would require some 2,000 hours of observations.

This view also encloses the entire region of the galaxy's center that NASA's Nancy Grace Roman Space Telescope will study in infrared in its



Galactic Bulge Time-Domain Survey (see page 14 for more details on Roman). This survey will reveal planets in the bulge via microlensing, which occurs when a nearby star passes in front of a more distant one. Researchers will be

able to refer back to this Euclid image for the positions and motions of the stars before they crossed paths from our point of view, which will increase the accuracy of their exoplanet measurements.

—ALISON KLESMAN



HOT BYTES



IN ERNEST

NASA is developing ERNEST, a four-wheeled rover that uses decision-making software and an active suspension to travel faster with less human input than previous rovers.



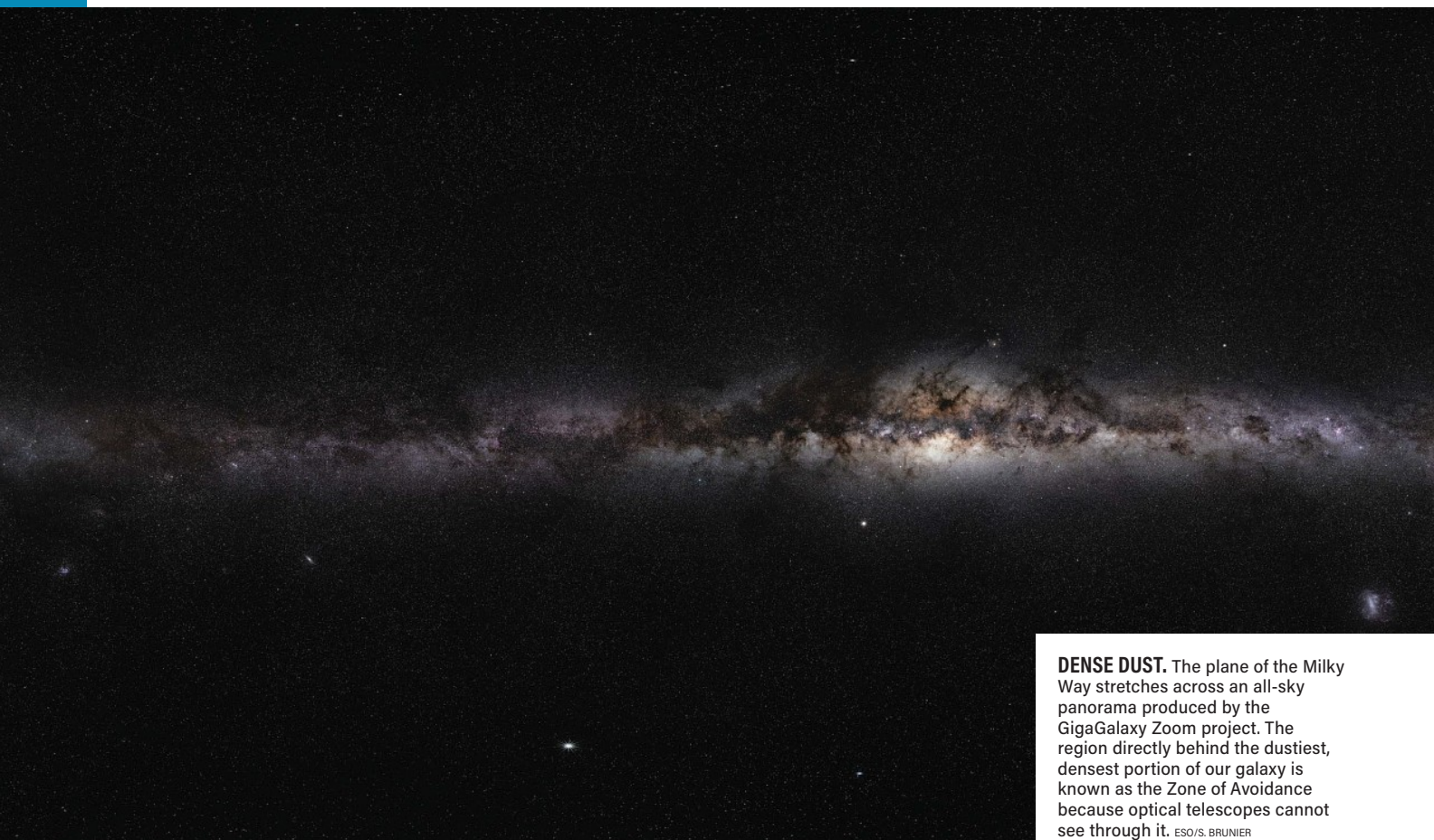
SHORT NOTICE

In January, the Submillimeter Array in Hawaii used a new rapid-response mode to pivot to a gamma-ray burst's location within minutes of its detection, taking the earliest radio data of such an event.



COSMIC CANDLE

Quasars, powered by feeding black holes, flicker as their consumption changes. Scientists just spotted the earliest flickering quasar, 850 million years after the Big Bang, offering clues to early black hole growth.



DENSE DUST. The plane of the Milky Way stretches across an all-sky panorama produced by the GigaGalaxy Zoom project. The region directly behind the dustiest, densest portion of our galaxy is known as the Zone of Avoidance because optical telescopes cannot see through it. ESO/S. BRUNIER

GIANT SUPERCLUSTER MAPPED BEHIND THE MILKY WAY

Radio observations reveal the extent of a major structure shaping galaxy motion in the local universe.

» For decades, astronomers suspected something vast lurked in the behind the Milky Way's dusty disk, in a region called the Zone of Avoidance. The motions of nearby galaxies showed subtle distortions caused by unexplained gravitational pulls, but the exact structures responsible remained a mystery.

Though the dense plane of the Milky Way blocks visible light in the Zone of Avoidance, obscuring nearly a fifth of the sky from optical telescopes, astronomers know several structures lie behind

it, including the Vela supercluster, discovered in 2016. Vela is roughly 800 million light-years away and stretches about 300 million light-years across.

Despite its general location being known, "Vela has been something of a ghost. We could infer its presence, but we couldn't trace its full extent," says Renée Kraan-Korteweg of the University of Cape Town in South Africa, who led the team that discovered the Vela supercluster. Kraan-Korteweg is also a co-author of a new study that has created

the most detailed view yet of this colossal assembly of galaxies, thanks to South Africa's MeerKAT radio telescope. The work is available on the *arXiv* preprint server and has been submitted to *Astronomy & Astrophysics*.

MeerKAT came online in 2018. Instead of observing starlight, which is snuffed by dust, it detects radio emission from a galaxy's neutral hydrogen, which has a wavelength of 21 centimeters and passes through dust largely unimpeded. So, astronomers used it to map Vela.

The wavelength of a galaxy's emission shifts depending on how fast it is moving away from us. That recession speed depends on distance, thanks to the universe's expansion, so measuring that shift reveals a galaxy's distance. The survey mapped more than 2,000 previously unseen galaxies in 3D, resolving what had been a glaring gap in cosmic charts into a massive structure with two dense cores, likely moving toward each other within a larger gravitational system.

A HIDDEN HEAVYWEIGHT

Vela contains an estimated 30 million billion solar masses of material, placing it among the most massive known features in the nearby universe.

"In cosmology, mass is destiny," says Konstantinos Kolokythas, a radio astronomer at the South African Radio Astronomy Observatory and affiliated with Rhodes University, who was not part of the study. "Structures like this create gravitational basins, regions that

MAPPING MASS. This 3D map shows the superstructures in the local universe. The curved regions enclosing each structure show "basins" where material collects, while the colored lines depict the motions of galaxies.

JÉRÔME LÉCA, RSA COSMOS, ST. ETIENNE, FRANCE (CC BY-ND 4.0)

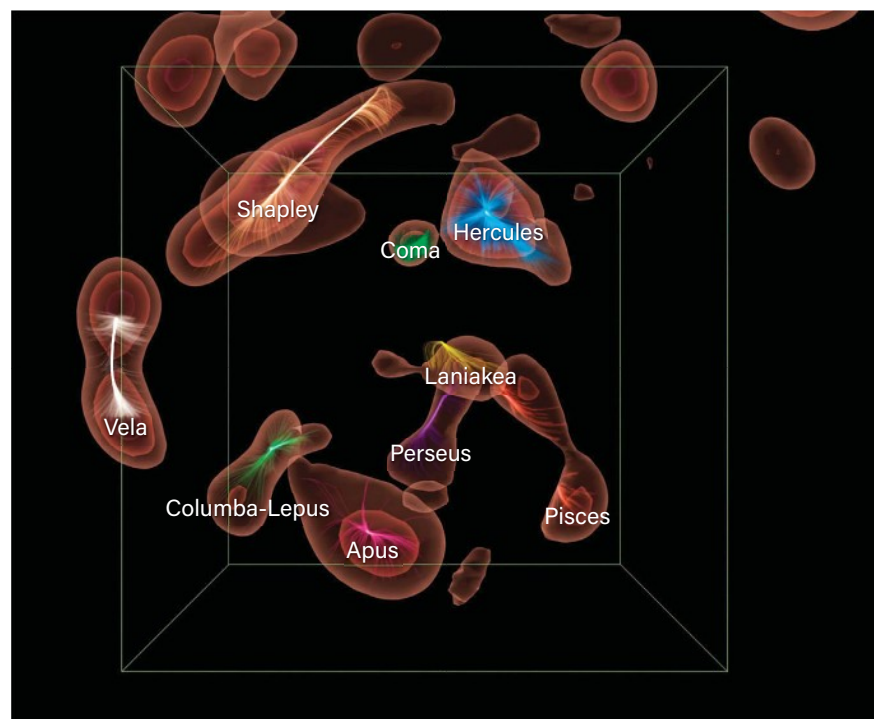
pull galaxies inward and drive large-scale flows."

Astronomers have long known that our Local Group of galaxies is moving through space at roughly 1.4 million mph (2.2 million km/h). The gravitational pull from previously known structures accounts for much of that motion. But not all of it. Vela appears to supply part of the missing pull, helping to resolve a longstanding discrepancy.

Vela also exposes the fact that our maps of the universe are incomplete. Historically, astronomers treated the Zone of Avoidance as a blank patch of little consequence. Vela overturns that assumption. "This is not a minor correction," Kraan-Korteweg says. "We're talking about structures on the scale of the largest known formations in the universe, hidden in plain sight."

The forthcoming Square Kilometre Array, under construction at sites in South Africa and Australia, will push radio surveys even deeper, detecting fainter galaxies and tracing the filaments that connect superclusters to the larger cosmic web strung throughout the universe. And in time, the Zone of Avoidance may completely disappear.

—AKASHNI RAGHUBAR-LATCHANNA



DISCLOSURE DAY

The International Academy of Astronautics has ratified the first update in 15 years to its protocols for confirming alien signals to encompass newer search methods and address the changing media landscape.

A NEARBY CHANCE FOR LIFE

Super-Earth GJ 3378 b, a mere 25 light-years away, sits in its red dwarf host star's habitable zone, where liquid water could exist. Researchers just found it's also likely rocky and not smothered by a thick, crushing atmosphere, increasing the odds it could host life.

MORE MISSING DARK MATTER

Keck Observatory data show that galaxy DF9 is the third galaxy within a larger chain found to contain almost no dark matter, strengthening the case that all three formed in a violent collision that separated the progenitors' ordinary and dark matter.

ICY ECHOES

A 13-year radar campaign to study Europa with NASA's Goldstone antenna and the Green Bank Telescope found that the moon's icy shell reflects radio waves differently than rocky worlds, helping to constrain the thickness and composition of its ice — a finding that will inform future missions to study its hidden ocean.

DSA ON THE WAY

Caltech's Deep Synoptic Array, a 1,650-dish radio telescope funded by the philanthropic Schmidt Sciences organization, has completed its final design review. Construction of the array, which will become the fastest and most sensitive radio telescope ever, can now begin. —BROOKS MENDENHALL



Astronomers spot first supernovae siblings

OVERLAPPING REMNANTS. The region containing IC 443, G189.6+3.3, and Sh 2-249 is shown in multiple wavelengths in this wide-field view. IC 443 is the compact cloudlike structure at right, Sh 2-249 is the diffuse structure in red above it, and G189.6+3.3 is traced by green (X-rays) and magenta (gamma rays). Optical light is in yellow, infrared light is in red, and radio data are in orange and brown. At G189.6+3.3's northern boundary just above center is a bright filament, showing where interactions between it and Sh 2-249 are generating intense gamma rays. NASA GODDARD SPACE FLIGHT CENTER AND M. MICHAILIDIS ET AL. 2026; OPTICAL: DSS; RADIO: MWSIP, ESA/PLANCK; INFRARED: NASA/WISE/JPL-CALTECH/UCLA; ULTRAVIOLET: NASA/SWIFT; X-RAY: SRG/EROSITA; GAMMA RAY: NASA/DOE/FERMI LAT COLLABORATION

Half of our galaxy's stars have a companion, yet a system of two supernova remnants — the end stage of massive stars — has never been found. Astronomers now have their first candidate.

A study led by Stanford University post-doctoral fellow Miltiadis Michailidis and published July 21 in *Nature Communications* shows that the Jellyfish Nebula (IC 443) — made up of supernova debris — has a second, fainter supernova remnant lurking in its glare, suggesting the objects came from a single binary system.

As outrushing material from a supernova collides with the surrounding interstellar medium, it forms a shock front that produces gamma rays, the most energetic form of light. IC 443 is one of the galaxy's brightest sources of gamma rays, as its shock front slams into Sharpless 2-249, a nearby cloud of hydrogen gas.

That bright emission long hid neighboring G189.6+3.3, a structure first spotted in X-ray data in 1994 but not confirmed as a distinct supernova remnant until 2023. This is where Michailidis' team stepped in: Using 16 years of Fermi Gamma-ray Space Telescope data, they found that while at lower energies, the region around

both remnants appears as one big blob, at higher energies two distinct gamma-ray sources appear. One lines up exactly with G189.6+3.3, showing that it produces its own gamma rays. Those gamma rays are brightest at its northern boundary, where it overlaps with Sh 2-249. There, a filament of gas marks a shock wave slamming into Sh 2-249, generating the same signature seen in places where IC 443 is pushing against the cloud. Two remnants interacting with the same object must lie at the same distance: 6,000 light-years away.

The team then ran simulations to show that massive binary star systems could produce this outcome, with the first explosion kicking the companion into space, where it explodes tens of thousands of years later. The chance of two unrelated supernovae this close in the sky and at the same distance is less than 1 in 1,000.

"We may be witnessing the final chapter of an evolution that started millions of years ago. Today, we see the result of two stars once [bound] by gravity orbiting each other, now as supernova remnants," Michailidis said during a presentation at the 248th American Astronomical Society meeting in Pasadena, California. —B.M.



X-RAY MYSTERY NEAR MILKY WAY'S HEART

Sagittarius C, a hydrogen cloud near the Milky Way's center, may be hiding the remains of a supernova. This composite combines X-rays (blue), radio data (red), and optical light. A circled clump of X-ray emission marks the suspected remnant. If confirmed, it would be the closest ever found to our galaxy's central supermassive black hole. There is a trail of evidence: NASA's now-retired SOFIA observatory detected a shell of expanding gas around Sagittarius C, a clue a star exploded there. And a supernova blast would heat its surroundings enough to radiate X-rays. But scientists expected to find elements like iron, oxygen, and silicon, scattered from the interior of the exploded star, and so far they haven't — but that could mean the debris has already mixed into the surrounding gas, diluting any trace. Winds from a cluster of massive stars could also heat gas enough to glow in X-rays. But the blob shines over 10 times brighter than known clusters, leaving this an imperfect alternative hypothesis. —B.M.

X-RAY: NASA/CXC/UC/LAZ. ZHU ET AL.; ESA/XMM-NEWTON; OPTICAL: PANSTARRS; RADIO: MEERKAT; IMAGE PROCESSING: NASA/CXC/SAO/L. FRATTARE AND P. EDMONDS

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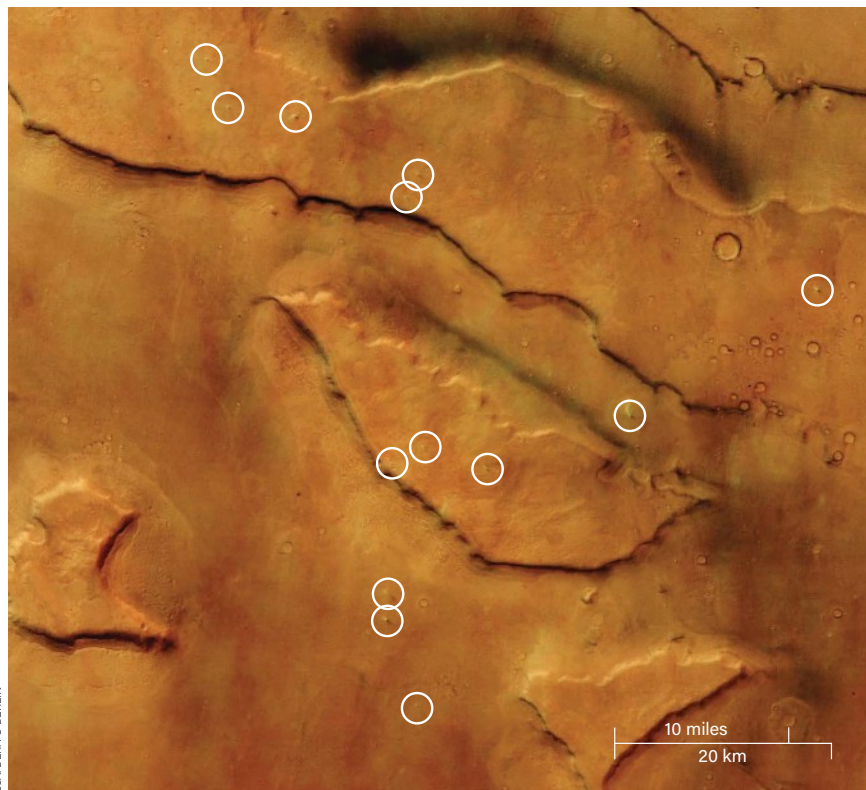
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Dozens of dust devils

Mars may have a thin atmosphere, but it's still enough to whip up dust devils that sweep across its surface. Occasionally these short-lived phenomena have been captured in photos by rovers or orbiting observatories — but have you ever seen so many at once? This is only a portion of a recent image from the European Space Agency's Mars Express orbiter, snapped Dec. 7, 2024, as it passed above the Mamers Valles region. Circled are all the dust devils caught simultaneously tracking through the ancient valley system. In all, Mars Express spotted more than 30 in the full image, which has a scale of roughly 66 feet (20 meters) per pixel. Martian dust devils are taller and longer-lived than their terrestrial counterparts, and play a critical role in transporting dust through the planet's atmosphere from one region to another. —A.K.

THE ROASTED PLANET HEATS UP

Using data from JWST, a new study found that HD 80606 b, nicknamed the roasted planet, is getting cooked by its host star at temperatures even more extreme than previously assumed.

The size of Jupiter and four times its mass, HD 80606 b spends most of its 111-day year far from its star before swinging close and enduring massive temperature spikes — unlike most hot Jupiters, which orbit on circular paths and bake continuously.

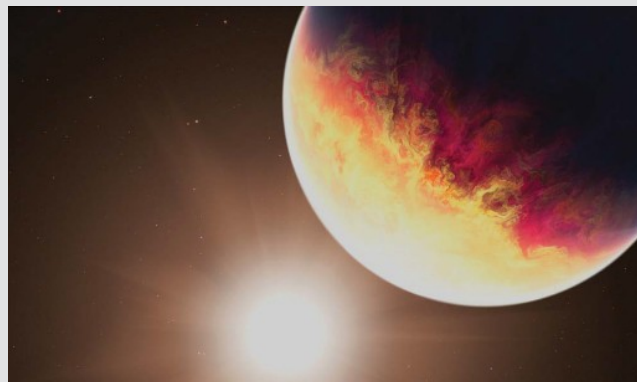
The team observed HD 80606 b continuously for roughly 24 hours through periastron (its closest stellar approach), capturing the heating before, during, and after the planet passed behind the star as seen from Earth. The observation took years of scheduling, coordinating the planet's orbital timing with JWST's seasonal viewing restrictions, in which the Sun and inner solar system must remain behind its sunshield. The most immediate finding was that the planet's temperature at periastron shot up by 1,100 degrees Fahrenheit (610 degrees Celsius) — a spike more severe than prior observations had indicated.

These flash heating events offer an enormous amount of data in just a few hours, said co-investigator Laura C. Mayorga of the Johns Hopkins Applied Physics Laboratory in a press release. Because HD 80606 b cycles through extreme conditions quickly, the planet functions as an efficient stand-in for both "other hot Jupiters [and] more conventional exoplanets."

The planet's infrared brightness also peaked earlier than predicted. Study leader Tiffany Kataria of NASA's Jet Propulsion Laboratory said in a talk at the 248th meeting of the American Astronomical Society in Pasadena, California, the discrepancy could reflect an underestimated rotation rate, an atmosphere shedding heat more efficiently than expected, or both. —B.M.

HOT SPOT. Recent JWST observations caught exoplanet HD 80606 b's temperature spiking by some 1,100 F (610 C) during periastron — the closest point to its host star in the world's eccentric orbit, illustrated here.

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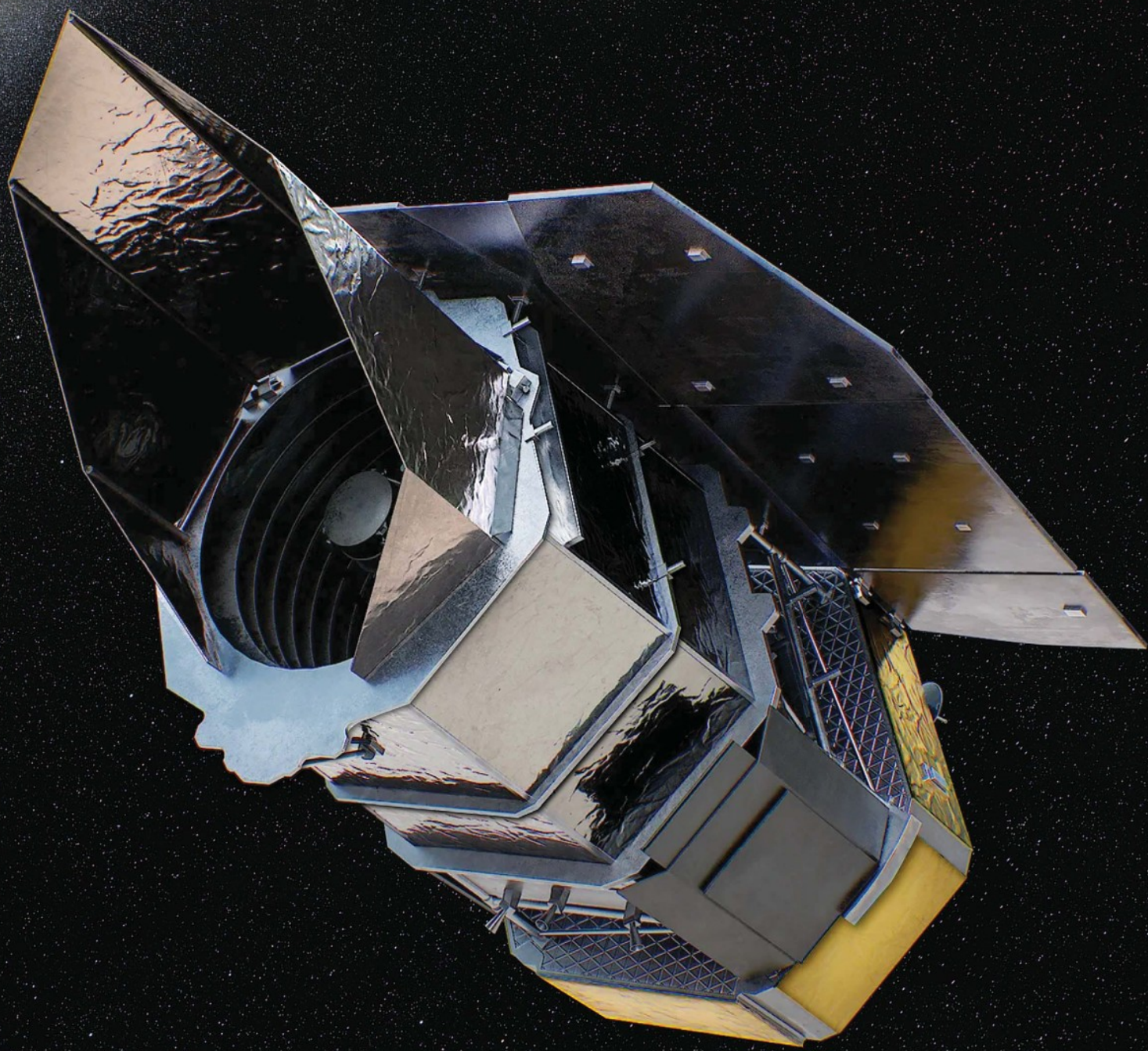
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HOW ROMAN WILL UNLOCK THE UNIVERSE

This next-generation space telescope will blow past its predecessors to answer questions about everything from stars and planets to dark matter and dark energy. **BY ALISON KLESMAN**

The Nancy Grace Roman Space Telescope is NASA's newest flagship mission. Designed with an enormous field of view and the ability to quickly move between fields, it is set to revolutionize our understanding of the cosmos, near and far. ASTRONOMY: ROEN KELLY, AFTER NASA. BACKGROUND IMAGE: ESO/S. BRUNIER





The Nancy Grace Roman Space Telescope — the first space observatory named for a woman — is poised to become one of astronomy’s biggest workhorses. With a field of view 100 times that of the Hubble Space Telescope and the ability to map the sky a thousand times faster at the same resolution, Roman will produce the equivalent of a thousand years’ worth of Hubble data every 10 months. Those data will touch nearly every branch of astronomy: dark matter and dark energy, exoplanet demographics, galaxy evolution, transient events, and more. And every observation will be immediately available to the entire scientific community.

In the more than two decades since its inception, Roman has undergone changes and weathered threats of cancellation. Yet not only will the telescope be lofted to space this year eight months ahead of schedule, but it will also come in under budget. And the final result will change the way we view our universe.

“Hubble and Webb are like looking through a keyhole at an individual object,” says Kristen McQuinn, who heads the Nancy Grace Roman Space Telescope mission office at the Space Telescope Science Institute (STScI) in Baltimore. “With Roman, it’s like opening the door, and now you see everything.”

From the beginning

Roman started life as NASA’s Wide Field Infrared Survey Telescope (WFIRST), a project recommended for funding in the 2010 Astronomy and Astrophysics Decadal Survey, an influential report produced every 10 years by the U.S. National Academy of Sciences. WFIRST prioritized three scientific goals, says B. Scott Gaudi of The Ohio State University, an expert in exoplanet detection who has been working on the mission since its inception. Those goals were to characterize dark matter and dark energy, survey the sky in infrared light, and build a galactic catalog of exoplanets. “All require almost the same hardware,” he says: a 1.5- to 2-meter infrared space telescope capable of seeing a lot of the sky at once.

But it was difficult for astronomers from disparate disciplines to agree on how

to share the mission, or even whether it *should* be shared, says Gaudi. Its small size also failed to garner excitement at a time when the 6.5-meter James Webb Space Telescope (JWST) was under development. And with JWST far behind schedule and over budget, NASA was facing political pressure to finish that long-awaited mission before building another flagship.

A turning point came in 2012, when the U.S. National Reconnaissance Office, which builds and operates the nation’s intelligence satellites, gifted NASA two space-qualified 2.4-meter telescopes — the same size as Hubble’s primary mirror. “NASA could do whatever they wanted with these telescopes except point them at the ground,” Gaudi says. One went to WFIRST and “gave the mission entirely new life. It gave it more capabilities” — particularly an aperture large enough to directly image exoplanets to test technology for NASA’s next-generation planet hunter, the Habitable Worlds Observatory.

The mission received another boost in 2020, when it was renamed the Nancy Grace Roman Space Telescope. Roman was hired by NASA in February 1959 — just six months after the agency’s creation, and at a time when few women were encouraged or allowed to be astronomers. She served as NASA’s first chief of astronomy and is perhaps best remembered for championing the creation of the Hubble Space Telescope.

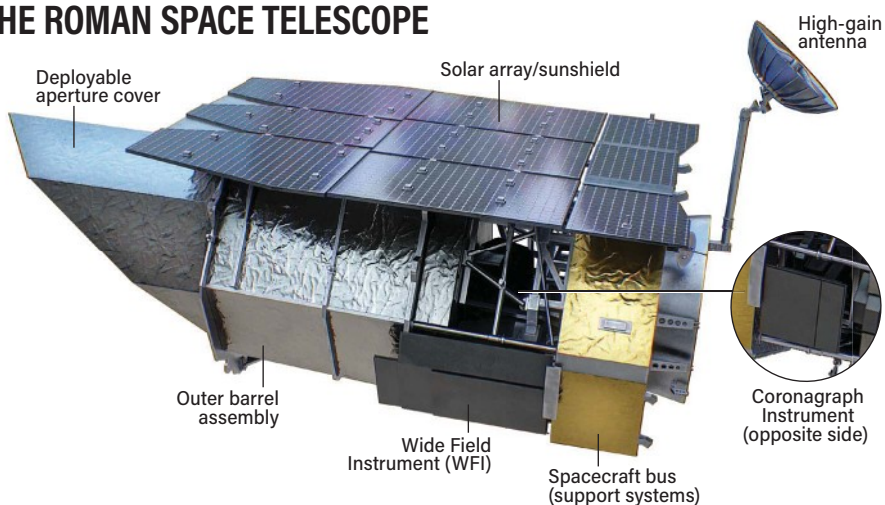
“Nancy Grace Roman was just a hero,” says Gaudi. Her name breathed new and necessary life into the project at a time when many astronomers were concerned about naming a space telescope after James Webb. It also allowed the project to shed the baggage WFIRST had accumulated through years of near-cancellations and disagreement over its goals.

The Roman Space Telescope is now ready to blaze its own trail. The mission is slated to launch Aug. 30. After lifting off from NASA’s Kennedy Space Center in Florida aboard a SpaceX Falcon Heavy rocket, Roman will be stationed at the L2 Earth-Sun Lagrange point 930,000 miles (1.5 million kilometers) beyond Earth, on the other side of our planet from the Sun. This is where JWST and the European Space Agency’s Euclid mission reside — an ideal place to put an infrared telescope, which must stay cool and thermally stable.

Roman will spend its first 90 days in the commissioning phase, including its trip to L2, says McQuinn. Then, provided all is well, “we roll right into science operations.”

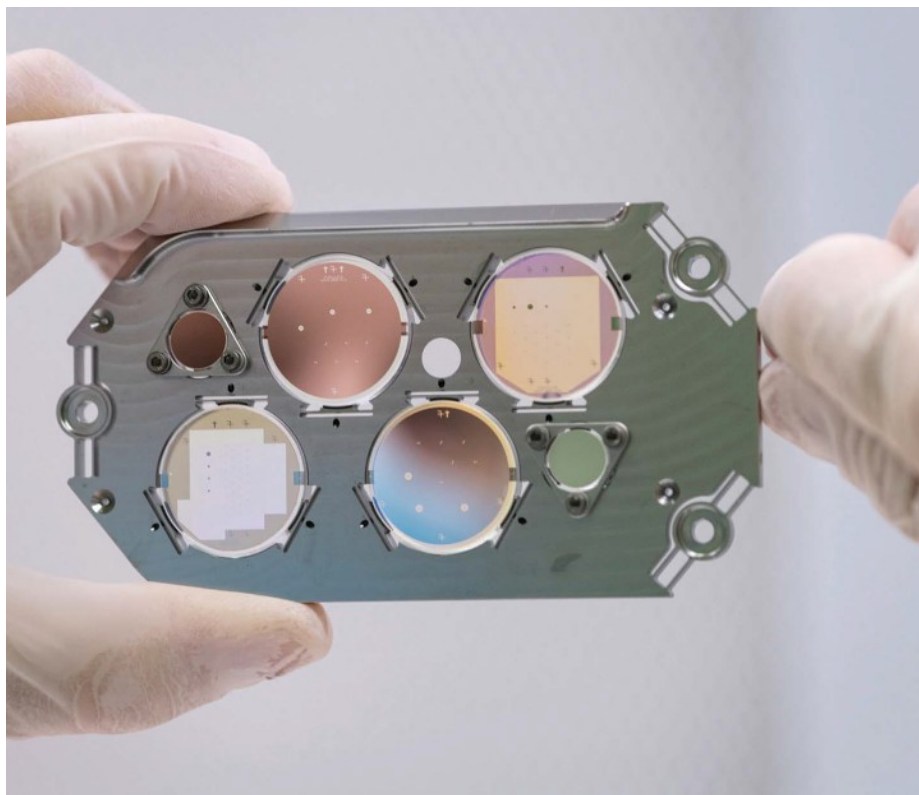
Roman’s primary science instrument is the Wide Field Instrument (WFI), a 300-megapixel camera that can take images and spectra in visible and near-infrared light, from 0.48 to 2.3 microns. (Visible light runs from about 0.4 to 0.7 microns, after which comes the infrared regime.) Its 18 detectors have a total

THE ROMAN SPACE TELESCOPE



The Nancy Grace Roman Space Telescope is an optical and infrared telescope with a primary mirror 2.4 meters across, the same size as Hubble’s. The telescope is more than 42 feet (12.7 m) long and 14 feet (4.4 m) wide — roughly the size of a semi-truck trailer or, according to NASA, an average *Tyrannosaurus rex*. Its six solar panels will generate power, while an aperture cover and sunshield will keep the telescope and its infrared instruments shaded and cool. Its two instruments, the Wide Field Instrument and Coronagraph Instrument, are installed on opposite sides of the spacecraft. They sit just forward of the bus, or main body, which contains electronics and other support systems. ASTRONOMY: ROEN KELLY, AFTER NASA’S GODDARD SPACE FLIGHT CENTER

LEFT: Engineers at NASA’s Kennedy Space Center rotate the completed Roman Space Telescope in preparation for final prelaunch inspection and testing in late June 2026. NASA/SYDNEY ROHDE (ROCZ)



TOP: Nancy Grace Roman takes notes while working at NASA's Goddard Space Flight Center, circa 1970. Roman served as the agency's first chief of astronomy and advocated so strongly for the development of space-based observatories that she is now known as the mother of Hubble. NASA

BOTTOM: In addition to deformable mirrors, Roman's next-generation coronagraph will implement custom masks to suppress starlight more effectively than current instruments. NASA/JPL-CALTECH

field of view of 0.281 square degree, larger than the apparent size of the Full Moon. Each image will have the same resolution as Hubble, and Roman can slew to and settle on adjacent fields in about a minute.

"We can survey regions of the sky over 1,000 times faster than Hubble with the same performance," says Julie McEnery, senior project scientist for the Roman Space Telescope at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Roman will use those impressive specs to reveal more than 10% of the sky in never-before-seen detail.

Uncovering exoplanets

At the heart of the mission are three Core Community Surveys, developed with input from the astronomical community. They will offer the deepest-ever look into the heart of our Milky Way Galaxy, as well as extend our view outward, mapping hundreds of millions of galaxies and charting the cosmos in real time.

One of these is the Galactic Bulge Time-Domain Survey, which will observe six fields in the Milky Way's center with a total area equivalent to eight and a half Full Moons, or 1.7 square degrees, for a total of 438 days. Roman will take data

Roman will produce the equivalent of a thousand years' worth of Hubble data every 10 months.

for 72 days at a time, snapping images every 12 minutes.

A primary goal is capturing microlensing events — the temporary brightening of a star as a nearer object passes between it and Earth, acting as a lens that bends and magnifies the light from the distant star. The interloper could be a star, neutron star, black hole, brown dwarf, or even a rogue planet without a sun. If an intervening star has planets, those also have an effect, causing tiny fluctuations in the way the background star brightens and dims.

"You would have to look at [one star] for about a hundred thousand years before it happened to be microlensed," says Gaudi. But in the galactic center, Roman will be looking at hundreds of millions of stars, and at any given time, one to 1,000 of them are being microlensed. These events are random, one-time occurrences,

lasting on the order of days to hundreds of days. A perturbation from a planet lasts hours to days. That's why Roman will spend months at a time snapping huge images of the galactic center so frequently. It is also why the near-infrared is vital, Gaudi adds, to cut through the dense dust in this region of the galaxy, which blocks visible light but allows longer wavelengths through, allowing us to see the stars hidden to visible-light telescopes like Hubble.

Roman may find thousands of new planets via microlensing, says Gaudi. And

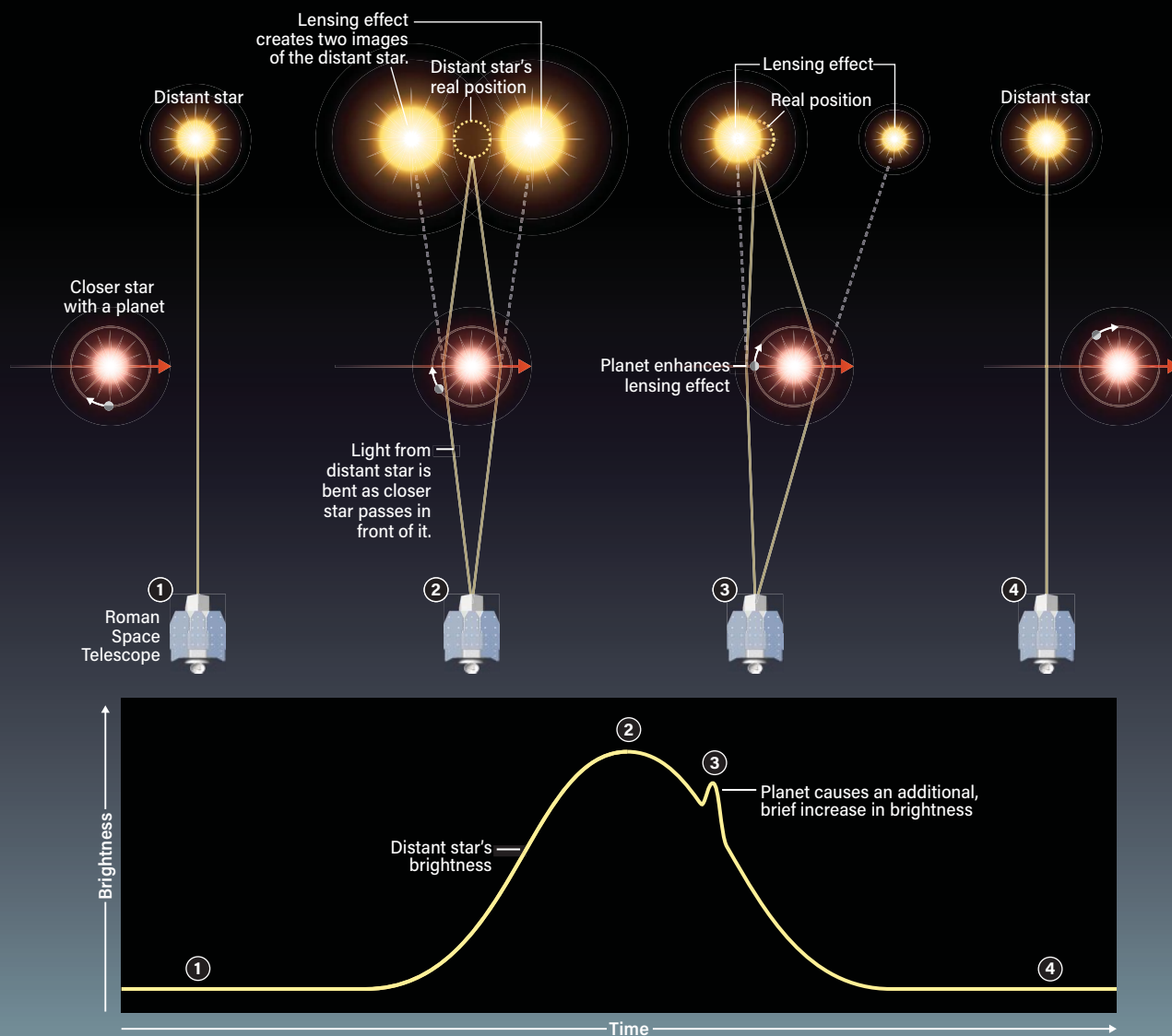
while these won't be worlds we can go back and study later because the chance alignment of stars that made the detection possible has passed, there will be planets we've never seen — those that are “really impossible to detect any other way,” Gaudi says. Other methods have limitations when it comes to finding planets with orbits longer than about a year, as well as difficulties spotting lower-mass worlds. But Roman could find worlds at the same distance from their host star as Jupiter is from our Sun, and with masses much,

much smaller — say, that of Jupiter's moon Ganymede, just twice the mass of Earth's Moon. “There's no other way you can do that,” Gaudi says.

Microlensing is incredibly powerful for building a fuller catalog of exoplanet demographics. Gaudi says that telescopes like Kepler and TESS have given us a good idea of what planets are like in our local part of the galaxy, the disk. But the bulge is a completely different environment, with “a very different population of stars where we think planet formation

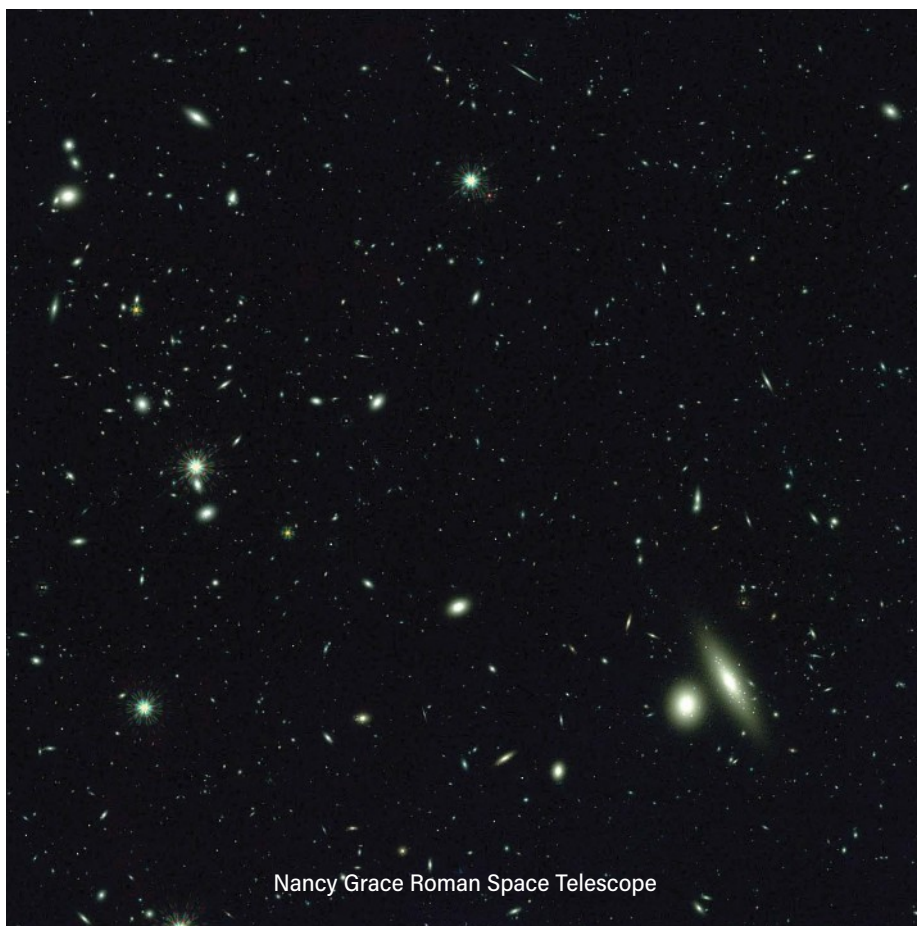
Microlensing occurs when a nearer object passes in front of a more distant star, bending and distorting its light. This both magnifies the light and creates multiple, shifting images of the background star in the sky. The way the star's light changes with time reveals details about the intervening object, such as its mass and physical size. If the nearer object is a star with a planet, the planet will also create a smaller, shorter lensing effect, allowing astronomers to also measure its mass and distance from the parent star. This technique can uncover very different planets than other more widely used methods, including small planets at roughly any separation from their star. ASTRONOMY: ROEN KELLY, AFTER ALICE HOPKINSON, LCO

FINDING PLANETS WITH MICROLENSING





Vera C. Rubin Observatory



Nancy Grace Roman Space Telescope

could have operated very differently than it does here,” he says.

Combining microlensing and other methods, “Roman is expected to find more than 100,000 exoplanets. That’s a game changer right off the bat,” McQuinn says. It will reveal the true breadth of planets that form in the Milky Way — a picture that today remains incomplete. “This is kind of the ultimate dataset with which you can use to try to test your theories for how planets evolve and grow and then move around in their planetary systems to help us really understand how planet formation works ... all across the galaxy,” Gaudi says. And from there, astronomers can gain a better foothold on habitability — and where to look for life.

Understanding the universe

Beyond our home is an entire universe of galaxies. But although our current best model — called Lambda-cold dark matter, or Λ CDM — is very successful in describing it, there are places it falls short. Over the past decade, combining measurements of the nearby universe with those from very early epochs has begun to hint that cosmic history is more complex than previously thought.

“Our understanding of the expansion of the universe itself is not quite right,” says McEnery. One area where it falls short is related to dark energy, the mysterious force that scientists invoke to explain why the universe’s expansion is not slowing down, but speeding up. “We have emerging evidence that the cosmological constant [which mathematically describes dark energy] is not, in fact, constant,” she says.

This is where the High-Latitude Time-Domain Survey steps in. It will address this question by focusing on an 18-square-degree area of sky (equivalent to 90 Full Moons) to collect some 180 days’ worth of data over five years, taken in 30-hour observations every five days.

Roman will pick up tens of thousands

Simulated images compare views of the same region of space using the ground-based Vera C. Rubin Observatory’s 8.4-meter telescope (top) and the Nancy Grace Roman Space Telescope. While Rubin has a larger field of view and is designed to survey the entire Southern Hemisphere sky in visible light every few days, Roman’s space-based, infrared view will be not just deeper but sharper as well, allowing astronomers to differentiate between multiple objects that may appear as a single source from the ground. J. CHIANG (SLAC), C. HIRATA (OSU), AND NASA’S

GODDARD SPACE FLIGHT CENTER

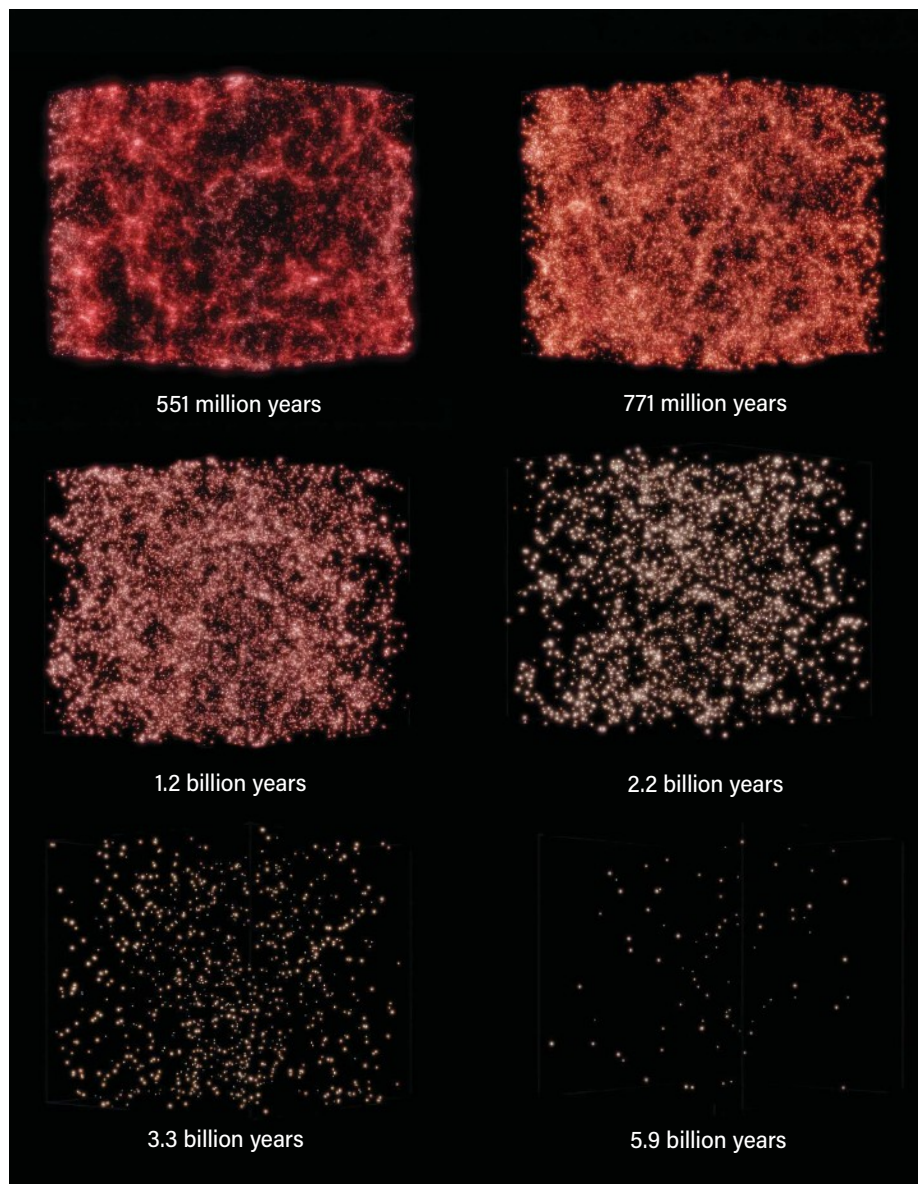
of type Ia supernovae at distances that correspond to about 8 billion to 11 billion years ago, says Rebekah Hounsell of the University of Maryland, Baltimore County, co-principal investigator for Roman's Supernova Cosmology Project Infrastructure Team. Type Ia supernovae occur when a white dwarf in a binary system explodes. White dwarfs are the dense remnants of Sun-like stars — so dense that they physically cannot be further compressed. If they steal material from a companion star and exceed a critical mass threshold of around 1.4 times that of the Sun, the white dwarf detonates. Because this always occurs at the same mass, the detonation always has similar brightness. They are an extremely powerful tool for measuring distance — in the 1990s, it was observations of type Ia supernovae in distant galaxies that showed that the expansion of the universe is accelerating.

All Roman data will be available to the public after only a few hours for initial processing by STScI, with no proprietary period.

Roman should increase our catalog of these events tenfold. Amassing so many across a broad swath of the cosmos with the same instrument will yield a robust sample that maps the expansion of our universe across time more precisely than ever before, Hounsell says. It will ensure astronomers are comparing apples to apples, rather than reconciling data from telescopes with varying capabilities.

In all, the High-Latitude Time-Domain Survey is expected to spot some 100,000 one-off events, what astronomers call transients. These will include not only supernovae, but also events like gamma-ray bursts, kilonovae from merging neutron stars, tidal disruption events as black holes tear apart stars, and more, McEnery says, including surprises astronomers aren't expecting.

Additionally, the High-Latitude Wide-Area Survey will image billions of galaxies over more than 5,000 square degrees (12% of the sky), with a greater focus on an area of some 2,500 square degrees. It will observe a total of 520 days, building a 3D map of the universe to look at structure and its evolution on a cosmological scale.

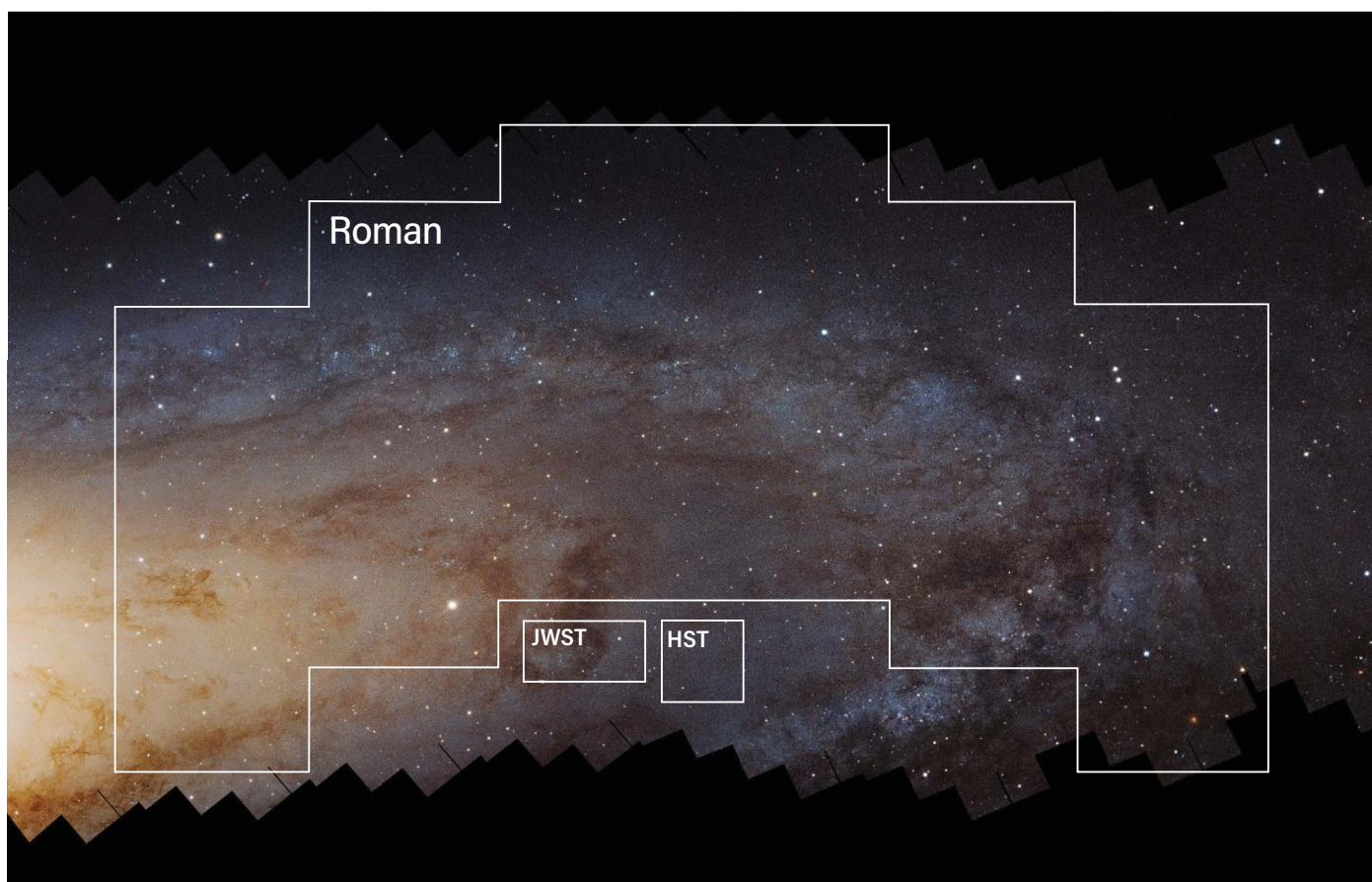


Each cube shown here, which represents a region of space 100 million light-years across, depicts a snapshot from a 3D simulation of the distribution of galaxies over time. Below each cube is the age of the universe at the time the snapshot was taken. As the universe ages, it expands, carrying galaxies farther apart and the density of galaxies in a given volume of space drops. But astronomers aren't yet sure exactly how this played out, or whether our simulations are correct. Roman will survey galaxies to map structure at times between about 8 billion and 11 billion years ago, or when the universe was nearly 3 billion to 6 billion years old. NASA'S GODDARD SPACE FLIGHT CENTER/F. REDDY AND Z. ZHAI, Y. WANG (IPAC) AND A. BENSON (CARNEGIE OBSERVATORIES)

From these maps, astronomers will be able to deduce the distribution of matter — including dark matter — by examining its effects on the apparent shapes of galaxies. Any intervening matter, seen or unseen, will bend the light from more distant galaxies, distorting their images. And because looking at more distant galaxies allows us to look farther back in time, the positions and concentrations of these galaxies trace the evolution of structure in the universe. This includes the cosmic web, the lattice of gas and galaxies strung throughout the universe, which not only

outlines where matter resides, but also shows how the space that contains it is expanding. Crucially, the wavelengths Roman will probe pick up galaxies roughly in the middle of the universe's history — a timeframe when astronomers believe dark energy's influence transformed into a major driver of expansion.

This puts Roman in "a very exciting position," says McEnery, to potentially show that the venerable Λ CDM model is incorrect. This would reveal something truly fundamental about our universe — and could only deepen our



Roman's Wide Field Instrument comprises 18 detectors that can view a total of 0.4° by 0.8° (0.281 square degree, excluding gaps between the chips) of the sky at once, with a resolution of $0.11''/\text{pixel}$. This is comparable in resolution to Hubble, but the field of view is 200 times larger than Hubble's infrared detector and 100 times larger than its visible-light footprint (shown here), as well as 100 times larger than JWST's infrared view. This composite image of the Andromeda Galaxy (M31), made of hundreds of Hubble pointings, is nearly entirely encompassed within one Roman field of view. NASA'S GODDARD SPACE FLIGHT CENTER

understanding of it. "It's very hard not to get excited by that," she says.

Roman is not the first or only effort to resolve this tension. But, says McEnery, Roman "can measure dark energy over much larger distances and much larger lookback times than any other facility," including the Vera C. Rubin Observatory and the Euclid mission, which both focus on the nearby universe. By combining Roman's data with Rubin and Euclid, "the sum is greater than the parts. ... You can characterize and understand galaxy structure and evolution far better than just doing one of [these missions] by themselves. I wouldn't even say it's an incremental difference. It's a huge leap up."

And there are far-reaching benefits beyond even this substantive goal. "If you're detecting 2 billion galaxies to study the universe," McEnery says of the High-Latitude Wide-Area Survey, "you also have a fantastic dataset to study galaxies themselves" over time, as well as the supermassive black holes they harbor.

But wait, there's more

While the three core surveys are Roman's main focus, about one-quarter of observing time is open to more traditional proposals from individuals or teams of researchers, McQuinn says.

Of that, some 700 hours have already been allocated to a survey suggested by

**"Hubble and Webb are like looking through a keyhole at an individual object. With Roman, it's like opening the door, and now you see everything."
— Kristen McQuinn**

the community to map one-third of the Milky Way's galactic plane, which will create the highest-resolution map of the galaxy yet. It will detect some 20 billion sources — "[more] than the cumulative sum of all cataloged astronomy objects in the history of humanity ... from this one survey," McQuinn says.

All this work will fall to the WFI. But Roman also carries a coronagraph, which uses masks to block the light from a star, revealing fainter objects — such as disks or planets — around it. Roman's first-of-its-kind coronagraph adds deformable mirrors, widely used in ground-based telescopes to compensate for atmospheric turbulence, creating sharper images. "We are adapting that technology for space, now not correcting the atmosphere, but correcting the polishing imperfections in the system, the small misalignments that can happen intrinsically or due to thermal variations," says Vanessa Bailey, instrument scientist for the Roman Coronagraph Instrument at NASA's Jet Propulsion Laboratory. Roman's coronagraph contains two hand-sized deformable mirrors, as well as next-generation masks designed to suppress unwanted light better than those in Hubble or Webb.

The coronagraph is primarily a technology demonstration for systems that could one day give a mission like the

Habitable Worlds Observatory its first look at an Earth-like planet, Bailey says. “First and foremost, our goal is showing that we can suppress the starlight better than any previous generation.” She estimates Roman will outperform Hubble by at least a factor of 100, suppressing starlight by a factor of 100 million.

But it is also a highly capable science instrument, she adds. Over three months during Roman’s first 18 months of operation, the coronagraph will look at hot, young super-Jupiters in the infrared, including at shorter wavelengths than JWST. In the best-case scenario, it might even capture reflected visible light from the cloud tops of older, colder Jupiter-sized planets in Jupiter-like orbits, Bailey says. The ability to analyze visible light will be critical when looking at potentially habitable planets down the road. “We think that looking at reflected visible light as opposed to emitted infrared light will give us the best handle on biomarkers with some future observatory,” she says. “We’re testing out those capabilities at visible wavelengths with Roman.”

Data for everyone

Unlike Hubble and JWST, which grant proposing researchers six months to a year of private access to their observations, all Roman data will be available to the public after only a few hours for initial processing by STScI, with no proprietary period.

Roman is also making another shift away from Hubble and JWST, whose data astronomers download to analyze using their own equipment. “That’s not going to work for Roman,” McQuinn says. The volume of data is just too large. Built and operated by STScI, and hosted on Amazon Web Services, the cloud-based Roman Research Nexus will house the mission’s data and tools to analyze it. This democratizes Roman data, removing barriers such as funding or equipment. “Anybody in the world is going to be able to look at this [data],” says Hounsell. “You don’t need a fancy computer.”

McEnergy hopes this will encourage more researchers to work with Roman data, including those with use cases not explicitly laid out by the mission. Roman’s surveys will capture many different types of events — from microlensing in the bulge to small bodies in our own solar

system streaking across the field. “People who have very different scientific interests [should be] able to simultaneously make use of Roman data,” she says.

Undiscovered country

Roman arrived in Florida June 21 to undergo final mission preparations. If all goes as planned, its first images could come by the end of the year. It will then join the workforce along with Hubble, JWST, Rubin, and Euclid. And astronomers are ready.

— including those we hadn’t even envisioned could exist. “Mother Nature is way more imaginative than we are,” he says.

Roman’s success will be a collective achievement — as will its discoveries. “‘Telescopes for the people’ is the phrase I like to use,” Gaudi says. “I’m doing [science] because I’m fascinated with what the universe has to tell us, and I think a lot of people in the public are as well. You should see people like me as a conduit for delivering that wonder and



Technician Billy Keim prepares to install the protective cover over the 18 detectors of Roman’s Wide Field Instrument at NASA’s Goddard Space Flight Center in Greenbelt, Maryland. NASA/CHRIS GUNN

“I love the fact that we’re going to have Roman, Hubble, and James Webb all together,” says Hounsell. “Roman is going to be conducting this amazing new infrared survey. And James Webb is kind of like this cosmic scalpel that goes to individual objects and does very, very precise observations. And then you have Hubble, — that’s been our legacy, our archive,” from which so many discoveries arose.

Gaudi is eager for Roman to find planets we’ve never seen before

those discoveries to them, not as the final end person this is getting delivered to.”

“Roman is for everybody,” says Hounsell. “It’s going to find all sorts of weird and wonderful things, things that we didn’t even think about. And it’s going to really open our eyes to what the universe is hiding. ... I’m really excited for all these potential unknown unknowns.”

Alison Klesman is senior editor of *Astronomy*.



How Mars' largest rivers shaped the planet

Sixteen newly identified drainage systems suggest ancient habitable environments were widespread.

BY ASHLEY BALZER VIGIL



Ancient valley systems such as this one expose how water once flowed over the surface of the Red Planet. This photo, taken by the Mars Reconnaissance Orbiter and artificially colored based on the camera's filters, shows only a small portion of a larger valley that cuts through a half-mile-wide (1 km) impact crater. Areas that appear reddish or orange are dominated by dust, while bluer regions show coarse-grained materials such as sand and rock. NASA/JPL-CALTECH/UNIV. OF ARIZONA

For more than a century, astronomers debated the existence of martian *canali* (“channels”), which Italian astronomer Giovanni Schiaparelli claimed to see on the Red Planet in 1877. Mistranslated into English as “canals,” the term suggested artificial waterways, perhaps built by an intelligent civilization engineering its survival. Sci-fi writers churned out thrilling stories inspired by the claims, but as spacecraft brought the Red Planet into focus, the canals dissolved; they were simply optical illusions caused by imperfect telescopes.

New research suggests channels might have existed after all — but not in the way Schiaparelli thought. We now know that Mars did indeed host running water, but in an environment different from Earth’s. On our planet, large rivers are widespread, moving vast amounts of sediment and acting as a cornerstone of many ecosystems. But whether Mars’

The floor of Mars’ Holden Crater displays many features characteristic of flowing water, including erosion and sedimentation. In this enhanced color image from the Mars Reconnaissance Orbiter, white- and lilac-colored areas highlight layered deposits of material on the crater floor. Tan and brown regions are materials associated with a fan-shaped deposit of sediment, called an alluvial fan, which may have been carried into the crater by runoff. NASA/JPL-CALTECH/UAR/IZONA

large rivers did the same has long been an open question.

Astronomers have now mapped 16 large river systems, each at least 38,600 square miles (100,000 square kilometers) in extent, that crisscrossed the surface of Mars about 3.7 billion years ago. The study, published in November last year in the *Proceedings of the National Academy of Sciences*, is the first to find such large-scale drainage systems across the planet. While they weren’t crafted by little green men and account for a much smaller area than large rivers on Earth, these rivers transported staggering volumes of sediment, carved out the martian landscape, and may have nurtured some of the planet’s most habitable environments.

A watershed moment

In the 1960s and 1970s, NASA’s Mariner 4 and 9 spacecraft visited Mars and dashed some people’s hopes — and relieved others’ worries — about finding cosmic neighbors; there were no signs of martian inhabitants. But there were signs of past surface water that had flowed billions of years ago. The Mars Global Surveyor mission, which began mapping the planet in 1997, clinched the theory by finding ancient deltas, dried-up lakebeds,

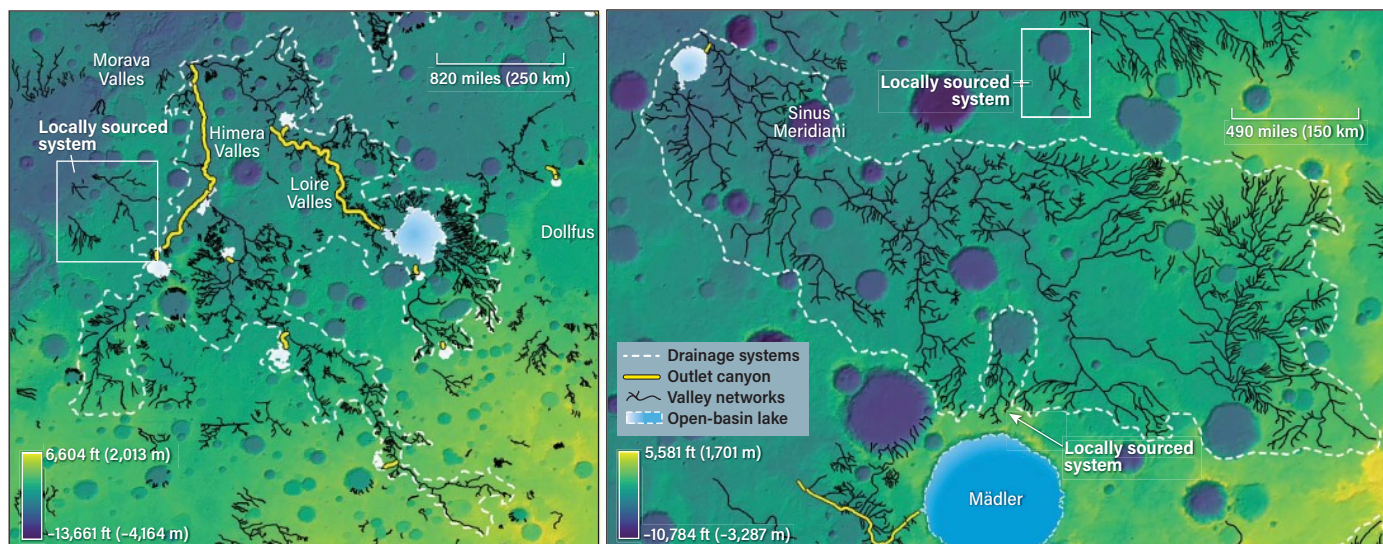
and layered sedimentary rocks. In the following decades, orbiters and rovers showed that early Mars was home to lakes, rivers, groundwater systems, and periodic floods.

“We already knew that valley networks on Mars fed lakes and that some of these lakes overtopped and carved large canyons during breach floods,” says Abdallah Zaki, a postdoctoral fellow at the University of Texas at Austin, who led the study. But no one knew how extensive the ancient river systems were, or how important they were for reshaping the martian surface.

“On Earth, our largest rivers and their drainage basins cover nearly half of the continents because climate and plate tectonics work together to build mountains and create space for rivers to flow,” Zaki says. “Mars, however, has no plate tectonics, but it still preserves compelling evidence of ancient valleys and river deposits. We wanted to know whether a planet without plate tectonics could still build large river systems, and how important these systems were for moving sediment and creating potentially habitable environments on early Mars.”

Almost half the land on Earth is part of a watershed, a region that funnels rain





These are two of the 16 large drainage systems mapped in the study, outlined by the white dashed lines and overlaid on terrain maps created using data from the Mars Orbiter Laser Altimeter instrument on Mars Global Surveyor. The system at left shows significant contributions from outlet canyons (shown in yellow) created when water overflowed from lakes. The system at right shows significantly less influence from outlet canyons. Also marked are smaller-scale, locally sourced systems. A.S. ZAKAJA, GOUDGE, & D. MOHRIG, LARGE DRAINAGE SYSTEMS PRODUCED HALF OF MARS' ANCIENT RIVER SEDIMENT, *PROC. NATL. ACAD. SCI. U.S.A.* 122 (48) E2514527122, [HTTPS://DOI.ORG/10.1073/PNAS.2514527122](https://doi.org/10.1073/PNAS.2514527122) (2025). (CC BY 4.0, MODIFIED TO ADD U.S. CUSTOMARY UNITS)

into a major river like the Mississippi or the Amazon. To find where these drainage systems were on Mars, researchers used global maps of valley networks, canyons, ancient lakes, and preserved river deposits.

Previous models included a range of possibilities, from a planet with sporadic trickles of meltwater to one with extensive global river networks. The new

findings suggest a middle ground: Large rivers did exist, but they were geographically limited. The team identified 16 expansive, interlaced river systems, dating back about 3.7 billion years to the early Hesperian period. Though large, they collectively cover only about 5% of the martian surface.

"Despite this small fraction of area, these large systems produced nearly half of the river sediments we can account for on ancient Mars," Zaki says. "This means that a relatively small number of very large rivers could have dominated sediment transport and landscape change on early Mars."

Clues in the clay

The early Hesperian period was a time of transition for Mars. The planet was getting colder and drying out, but water still flowed across the surface in places, eroding the landscape and carrying sediment across great distances. That means the sediment interacted with water for a long time, which offered lots of opportunities for chemical reactions associated with life to occur.

"The presence of liquid water certainly allows for life to have existed at the surface," says Bruce Jakosky, a professor emeritus at the University of Colorado Boulder and the principal investigator for the Mars Atmosphere and Volatile Evolution (MAVEN) mission. "It's even possible that life, if it existed then, could

still exist today," he says, perhaps underground.

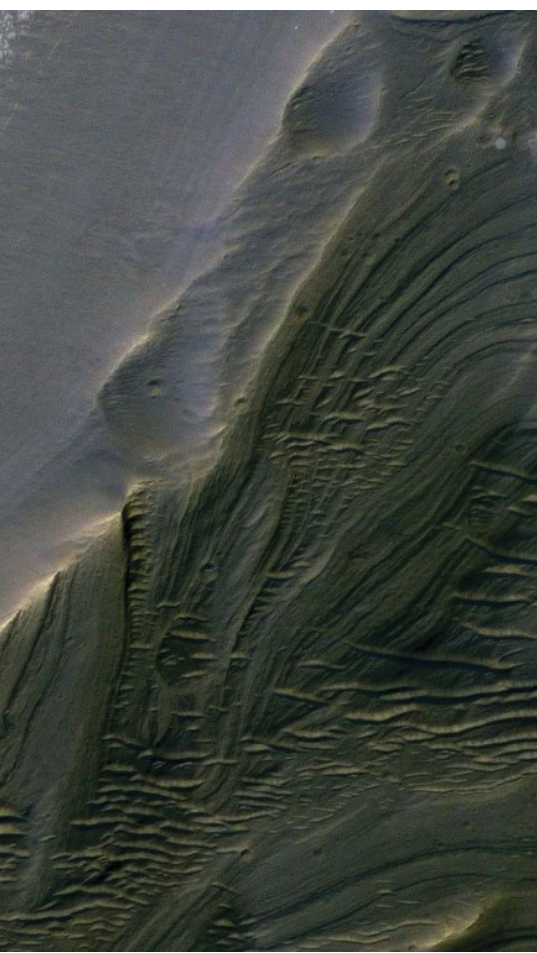
On Earth, sediments deposited by large rivers preserve rich records and sometimes even fossils or chemical traces of ancient life. It could be the same on Mars.

"If life ever existed there, our work shows how large river systems could have sustained habitable conditions over long distances and long periods of time, and where their sedimentary record might still be preserved," Zaki says. Now, scientists have a better idea of where to look for all that eroded sediment. "It's a valuable record of ancient habitable environments on Mars, and a key target for future missions looking for signs of past life."

Humans may soon explore the martian surface in person and bring back samples to study on Earth. That could answer several other questions about the Red Planet's past, including how (and how long) it held onto water in the first place.

"Future exploration of Mars will focus on understanding the history of liquid water, the climate that would have allowed it to be present, and whether there was ever life," Jakosky says. "Many scientists think that we won't be able to answer these questions until we send people to Mars to collect the right kinds of samples and bring them back to Earth." ❧

Ashley Balzer Vigil is a NASA science writer and freelancer with master's degrees in space studies and science writing.

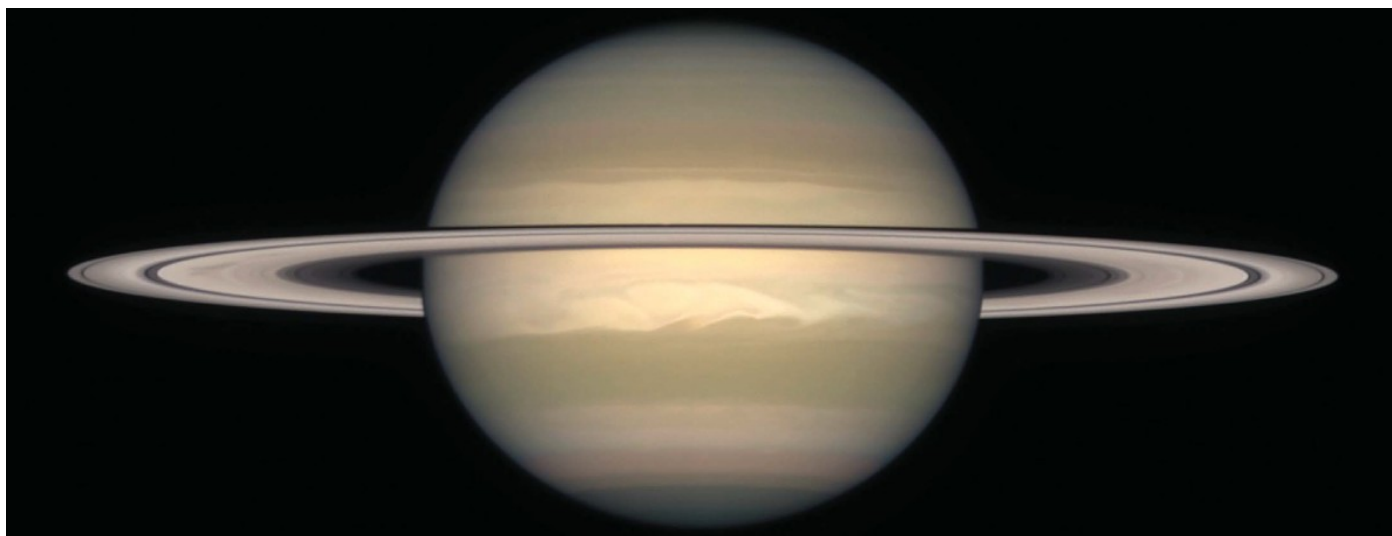


SKY THIS MONTH

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



OCTOBER 2026 Saturn at opposition

The Hubble Space Telescope captured this view of the ringed planet in October 1996. A similar orientation will greet observers through the eyepiece this month.

NASA/ESA AND THE HUBBLE HERITAGE TEAM STSCI/AURA

» Saturn reaches opposition this month, putting on a fine show. Mercury is briefly visible early in October, while Venus remains low after sunset. Neptune lingers near Saturn, and Uranus is well placed between the Pleiades and Aldebaran. Mars makes a magnificent transit of the Beehive Cluster, not to be missed. Jupiter dominates the morning sky and undergoes a lunar occultation. Let's dive in!

Mercury is best seen from the Southern Hemisphere because it is south of the ecliptic, which for northern observers is angled low to the western horizon after sunset. With a clear western horizon, Northern Hemisphere observers may catch a glimpse in the first two weeks of the month, when it glows around magnitude 0. On the 1st, Mercury is magnitude -0.1 and stands a

shade over 2° high 30 minutes after sunset. It sets 15 minutes later. Good luck!

On Oct. 5, Mercury stands 5° due north of **Venus**, but the latter is very difficult to spot. Venus is a brilliant magnitude -4.7 but barely 0.5° high 20 minutes after sunset. Only ideal circumstances — a clear, flat western horizon and perhaps higher elevation — will reveal it.

You might spot Venus soon after sunset if the sky is crystal clear, but it's gone quickly.

Venus moves toward inferior conjunction Oct. 23. It maintains a southerly path, more than 6° south of the Sun.

Neptune is a few days past opposition as October opens, visible in the eastern sky an hour or so after sunset. It's best to view the planet around

midnight, when it stands high in the south.

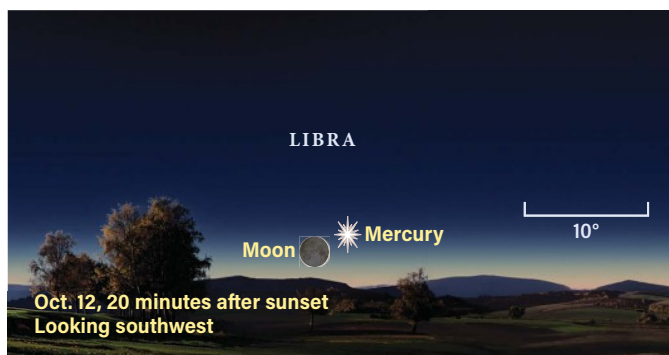
Neptune lies in southern Pisces with no bright stars close by, although Saturn is 8° east of the ice giant. You can also use the eastern side of the Square of Pegasus to guide you south with binoculars to the right location.

At magnitude 7.7, Neptune is challenging but within range of 7x50 binoculars. Aiding your view is a parallelogram of 4th- and 5th-magnitude stars: 27, 29, 30, and 33 Piscium. These four stars jump out in binoculars if you're in the right area. Neptune stands 3.6° northeast of 29 Psc on Oct. 1 — within the same field of view. This gap narrows to 2.9° by the end of the month.

The evening of Oct. 23, Neptune lies 4° due south of the nearly Full Moon. Saturn stands 8° southeast of the Moon.

Saturn is in Cetus; it rises around 7 p.m. local daylight time in early October and

Brief glimpse



Although Mercury is only briefly visible in the evenings, try on Oct. 12, when it is near the delicate crescent Moon. ALL ILLUSTRATIONS: ASTRONOMY: ROEN KELLY

OBSERVING HIGHLIGHT

SATURN reaches opposition
Oct. 4.



remains visible all night. It reaches opposition on the 4th, when it stands 780 million miles from Earth. Shining at magnitude 0.3, it's the brightest object in this region of the sky (except when the Moon visits). It's best viewed when highest above the southern horizon, in the hour on either side of local midnight.

The planet reveals a disk 20" across in a telescope. Resist the inclination for high magnification unless seeing conditions are particularly good. Eyepieces with 150x to 200x give the best results, but higher magnification causes the planet to become fuzzy. The ring tilt of 7.4° shows off the full southern hemisphere of Saturn, along with most of the northern hemisphere.

Titan sits closest to the planet Oct. 7/8 and 23/24 (north), and Oct. 15/16 (south). It's an easy target for any telescope.

On smaller orbits, fainter Tethys, Dione, and Rhea change position quickly. Tethys continues a series of challenging transits and shadow transits. It's a good target for observers with video imaging experience to capture, and near opposition the moon and its shadow are close together as they cross the disk. One event occurs the night of Oct. 14/15: Tethys begins transiting around 3 A.M. EDT on the 15th, its shadow joining about 13 minutes later. They leave the disk simultaneously just before 5:30 A.M. EDT, with the planet very low along the East Coast.

— Continued on page 34

RIISING MOON | A striking glance

A REALLY EASY FIND in the equatorial region of the Moon is a most unusual crater doublet called Messier. It was named in honor of the 18th-century comet hunter because of the long cometlike tail of material spreading westward across a darker background.

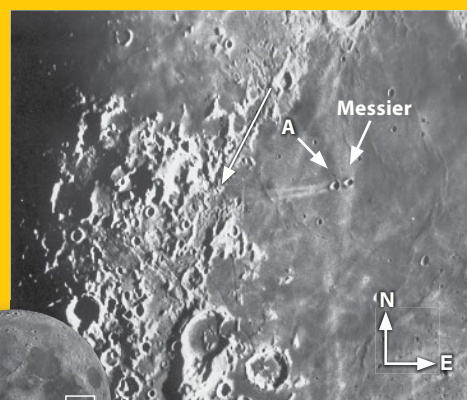
The origin of the barely diverging white rays puzzled astronomers for centuries. Their theories were bizarre and completely off-base until 1978, when Don Gault and John Wedekind's experiments plainly showed how Messier was made.

At the Ames Vertical Gun Ballistic Range, the scientists shot small pellets at mind-blowing speeds of 15,000 mph at different targets, observing how the craters and the spray change shape as the firing angle is adjusted. What may have brought the biggest smile to their faces was that they could create a double crater with only one pellet. There was no need to invoke the coincidence of a double impactor, although we now know that those do exist as contact binary asteroids.

Our first view can occur on the 14th, when the low Sun angle exaggerates the topography: Power up to 100x or more to see that the craters are distinctly out of round compared to



Messier 🔭



A comet nucleus may have created the Messier doublet, but a solid asteroid is the more likely cause. *CONSOLIDATED LUNAR*

ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

others nearby. To see the rays stretching westward, wait another night, when the higher Sun emphasizes albedo (brightness) differences. The rays remain visible until just before lunar sunset on the 28th. It might be two days after Full, but as it's only been a month since the equinox, our satellite rises early enough to be well placed at midevening in our earthly sky.

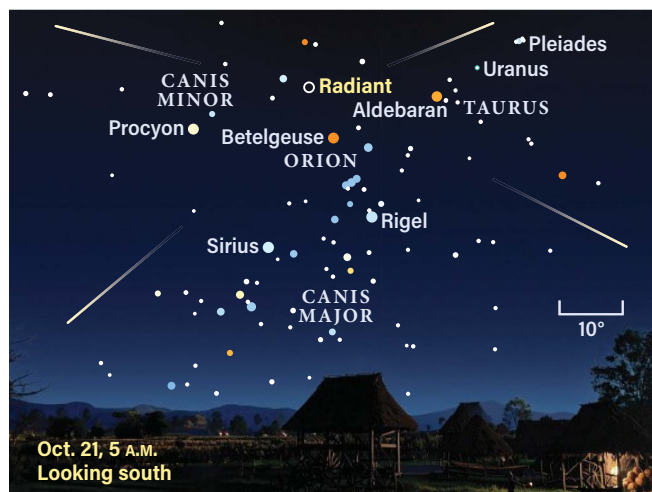
METEOR WATCH | Outlast the Moon

THIS YEAR'S Orionid meteor shower is partially affected by moonlight, but early-morning hours are the best for viewing it. The annual shower is active

from Oct. 2 through Nov. 7, with the peak occurring the morning of Oct. 21. The radiant is above the eastern horizon by 11 P.M. local daylight time on the 20th.

The brilliance of the gibbous Moon in Capricornus strongly affects the visibility of Orionid meteors until it sets soon after 1 A.M. The shower has a zenithal hourly rate of up to 20 meteors per hour on the maximum morning, corresponding to an observable rate of 15–18 per hour between 2 A.M. and dawn, the best time to watch the Orionids.

Orionid meteor shower 👁



ORIONID METEORS

Active dates: Oct. 2–Nov. 7

Peak: Oct. 21

Moon at peak: Waxing gibbous

Maximum rate at peak:
20 meteors/hour

Wait until after the Moon sets on the morning of Oct. 21 to catch the Orionids.

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. October 1
9 P.M. October 15
8 P.M. October 31

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.



OCTOBER 2026

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	 30	 31

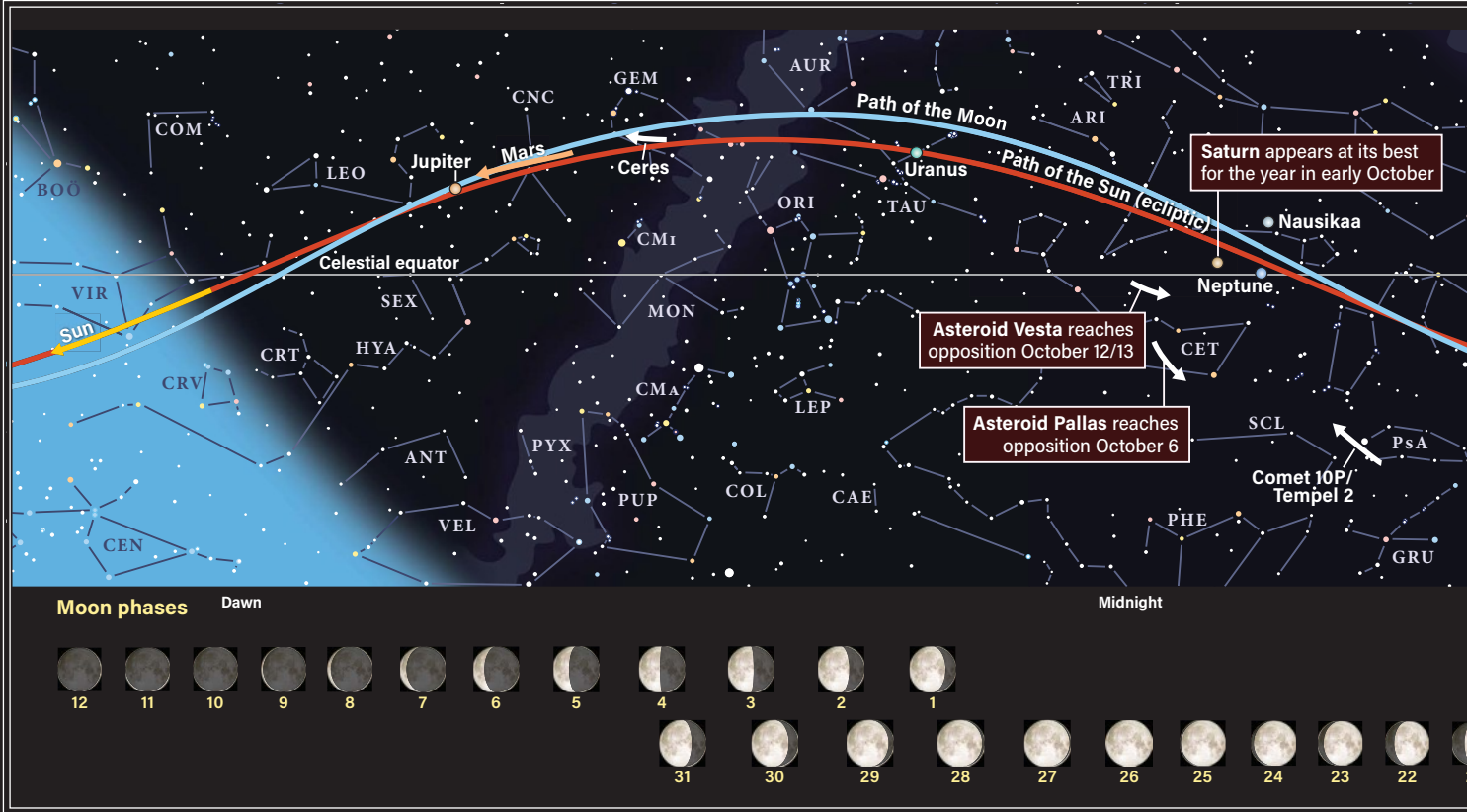
ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

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

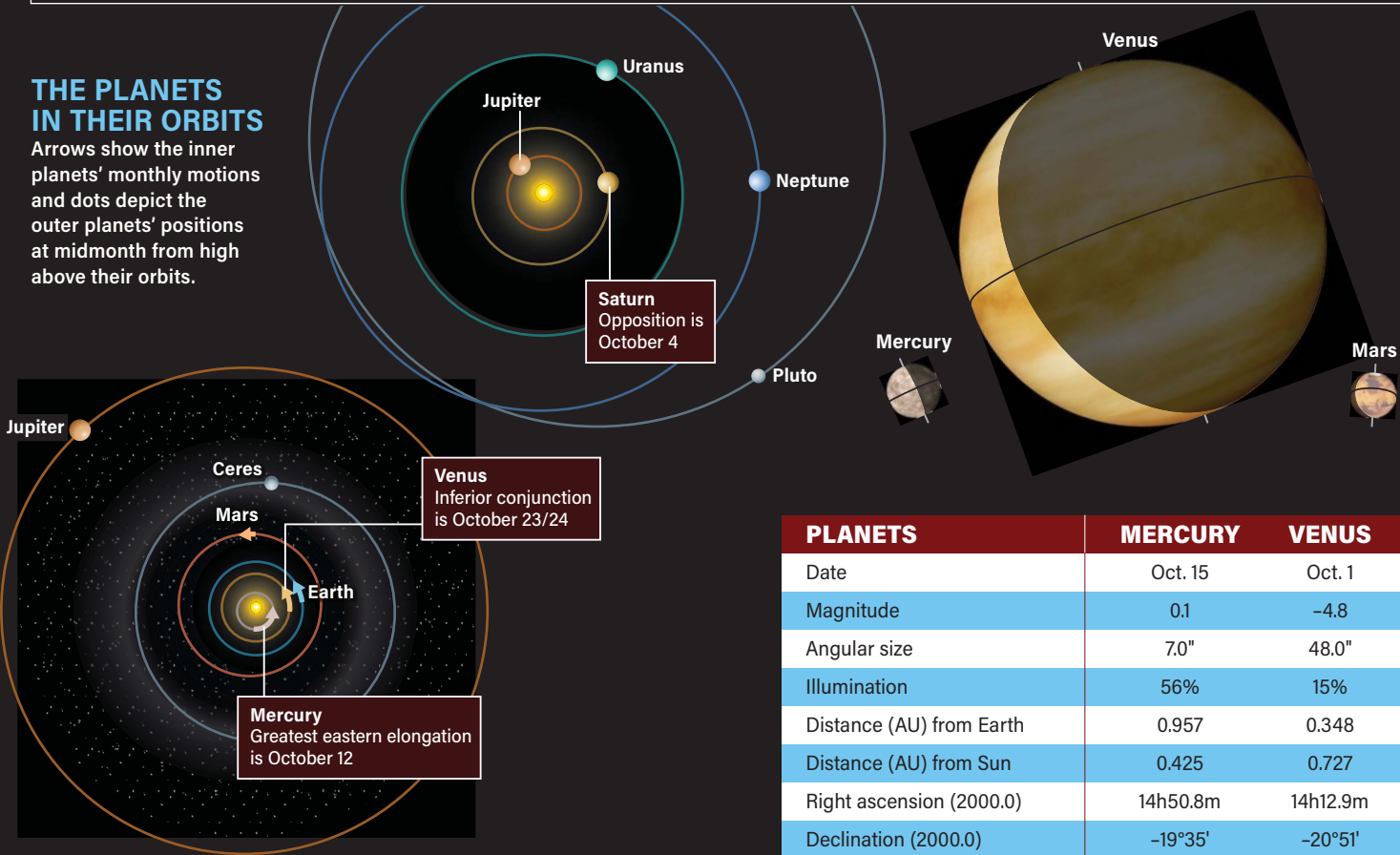
- The Moon is at perigee (229,494 miles from Earth), 4:52 P.M. EDT
- Venus is stationary, 10 A.M. EDT
-  Last Quarter Moon occurs at 9:25 A.M. EDT
- Saturn is at opposition, 8 A.M. EDT
- The Moon passes 1.2° north of Mars, 2 A.M. EDT
Mercury passes 5° north of Venus, 11 A.M. EDT
- The Moon passes 0.2° north of Jupiter, 6 A.M. EDT
Asteroid Pallas is at opposition, 7 P.M. EDT
The Moon passes 0.6° south of Regulus, midnight EDT
-  New Moon occurs at 11:50 A.M. EDT
- The Moon passes 3° north of Venus, 11 P.M. EDT
- Mercury is at greatest eastern elongation (25°), 6 A.M. EDT
The Moon passes 2° south of Mercury, 4 P.M. EDT
- Asteroid Vesta is at opposition, 2 A.M. EDT
- The Moon passes 0.4° south of Antares, 5 P.M. EDT
- Pluto is stationary, 7 A.M. EDT
The Moon is at apogee (251,434 miles from Earth), 6:56 P.M. EDT
-  First Quarter Moon occurs at 12:13 P.M. EDT
- Orionid meteor shower peaks
- The Moon passes 5° north of Neptune, 11 P.M. EDT
Venus is in inferior conjunction, midnight EDT
- Mercury is stationary, 8 A.M. EDT
The Moon passes 7° north of Saturn, 2 P.M. EDT
-  Full Moon occurs at 12:12 A.M. EDT
- The Moon passes 5° north of Uranus, 6 A.M. EDT
The Moon is at perigee (226,433 miles from Earth), 2:06 P.M. EDT
- The Moon passes 0.5° north of dwarf planet Ceres, 11 A.M. EDT

PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

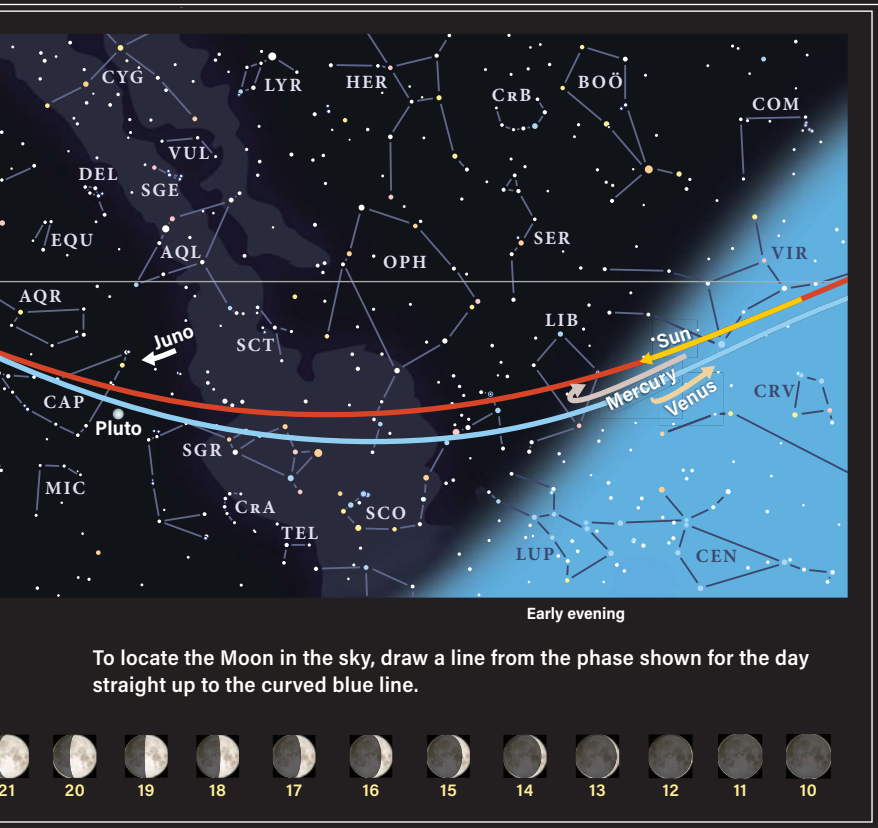
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.



PLANETS	MERCURY	VENUS
Date	Oct. 15	Oct. 1
Magnitude	0.1	-4.8
Angular size	7.0"	48.0"
Illumination	56%	15%
Distance (AU) from Earth	0.957	0.348
Distance (AU) from Sun	0.425	0.727
Right ascension (2000.0)	14h50.8m	14h12.9m
Declination (2000.0)	-19°35'	-20°51'

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.

OCTOBER 2026



Callisto



Europa



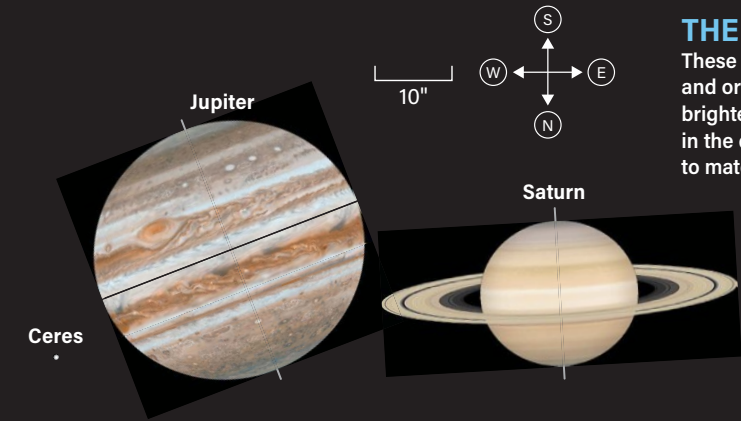
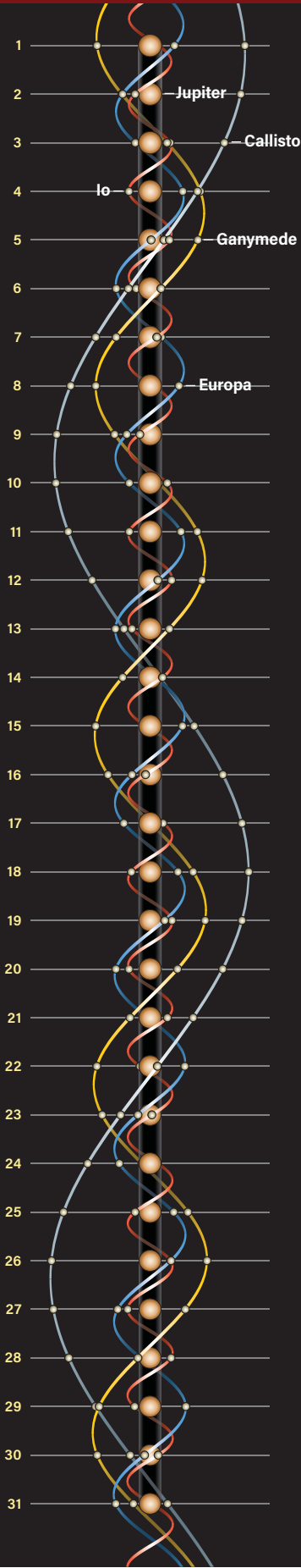
Io



Ganymede

JUPITER'S MOONS

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



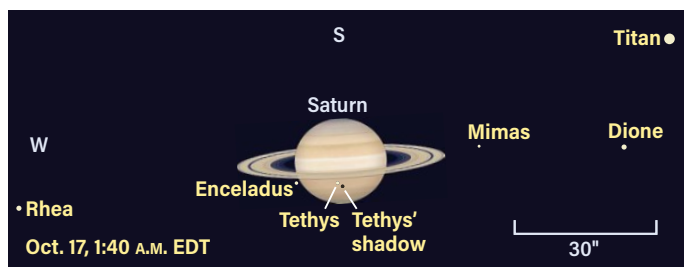
THE PLANETS IN THE SKY

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.

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
1.0	8.5	-1.9	0.3	5.6	7.7	15.2
6.0"	0.5"	34.3"	19.7"	3.8"	2.4"	0.1"
90%	96%	99%	100%	100%	100%	100%
1.565	2.431	5.744	8.451	18.704	28.934	35.410
1.575	2.663	5.311	9.430	19.439	29.878	35.620
8h48.2m	7h23.6m	9h36.6m	0h41.4m	4h11.7m	0h10.0m	20h24.2m
19°09'	23°28'	14°55'	1°30'	20°57'	-0°28'	-23°43'

SKY THIS MONTH — Continued from page 29

So many moons 🌙



Tethys and its shadow make several transits of Saturn's disk this month. Video capture is your best bet for spotting such an event, while other moons may be visible to telescopic observers.

Tethys begins a transit around 12:17 A.M. EDT Oct. 17 (still late on the 16th in all other U.S. time zones), the best-timed event this month for evening observers. Its shadow appears just after 12:30 A.M. EDT. The transit ends, again nearly simultaneously for moon and shadow, around 2:25 A.M. EDT. A third event on Oct. 18 starts at 9:35 P.M. EDT (still light in the Pacific time zone) and ends just after midnight EDT.

Dione transits the northern edge of Saturn this month. Again, video recording under the best conditions is necessary to capture the event, but there are six opportunities. The first is Oct. 1, from 6:07 A.M. EDT to 6:30 A.M. CDT (note the time zone change). Dione's shadow will be challenging to catch as it grazes Saturn's northern limb, just ahead of the moon. Dione repeats the trek Oct. 3 just before 11:45 P.M. EDT, ending shortly after 1 A.M. EDT (now Oct. 4 in the eastern half of the U.S.). The moon and its shadow will appear merged with Saturn near opposition and the Sun directly behind us.

Dione's shadow trails the moon Oct. 12: Dione begins its transit at 4:36 A.M. EDT, and its shadow appears at 5 A.M. EDT and leaves roughly an hour later. The best time to record the shadow is in the middle of this timeframe. Dione leaves the

disk about 10 minutes after its shadow.

Dione also transits Oct. 14 beginning at 10:12 P.M. EDT, Oct. 23 at 3:05 A.M. EDT, and Oct. 25 at 8:43 P.M. EDT.

Iapetus reaches western elongation Oct. 3, 9.7' west of Saturn. Its brighter face is turned earthward and the moon reaches magnitude 10.2. It's an easy target for small telescopes, but the challenge is its large distance from Saturn.

Iapetus' orbit carries it to superior conjunction Oct. 22; the now 11th-magnitude moon is 1.7' due south of the planet the night of Oct. 21/22.

Uranus is an easy binocular target, nicely placed between the Pleiades (M45) and Hyades star clusters. It's well above the horizon by 10 P.M. local daylight time. Begin by finding 5th-magnitude Omega (ω) Tauri and 4th-magnitude 37 Tauri, 3.3° apart. They're easy to spot along a line from Aldebaran to M45. Uranus stands 1.1° north-west of Omega on Oct. 1. The planet tracks west, ending the month 1.8° west of Omega.

Magnitude 5.6 Uranus is a month from opposition. You might spot it with the unaided eye from a dark location with a moonless sky. The pair of guide stars makes it easy to locate its position. Uranus' disk spans 4".

Mars rises before 1:30 A.M. local daylight time among the

WHEN TO VIEW THE PLANETS

EVENING SKY

Mercury (west)
Venus (west)
Saturn (east)
Neptune (east)

MIDNIGHT

Saturn (south)
Uranus (east)
Neptune (south)

MORNING SKY

Mars (east)
Jupiter (east)
Saturn (west)
Uranus (west)
Neptune (west)

stars of Cancer. The morning of Oct. 5, a waning crescent Moon crosses the northern edge of the Beehive star cluster (M44), with Mars 3.4° west of the cluster. Lucky observers with a telescope will see the Moon occult a number of the cluster's stars.

Wake early on Oct. 11 to find magnitude 1.1 Mars in the

COMET SEARCH | It's a two-fer tonight

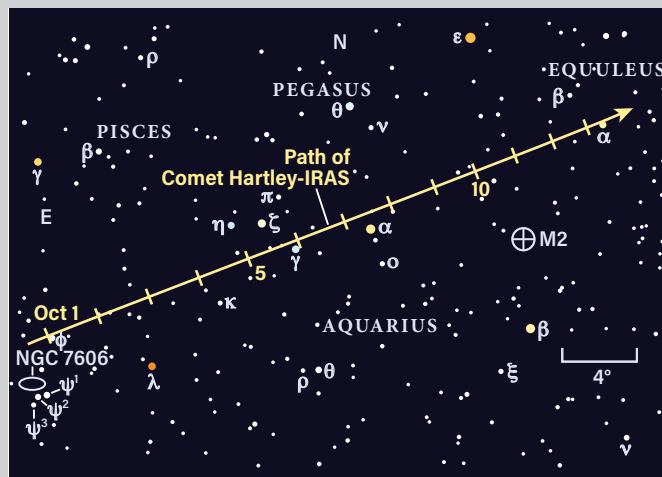
NOW AND THEN the random timing of cometary orbits offers us two telescopic targets. With both at 9th to 10th magnitude, we'll have to sidestep the Moon's glow and head out to the country during the first two weeks of October.

Inbound is 161P/Hartley-IRAS. Imagers will easily catch the green emission from the inner coma. Some may read this far enough ahead of time for an extra reward Sept. 24–25, when the dust fan is edge-on, sporting a short anti-tail.

This dirty snowball is vaulting north at 15" per minute, enough for a visual observer to see it move in just a few glances, and too fast for a standard one-minute sub. The orbit is inclined nearly 96° to the plane of our solar system. Its dust tail starts as a broad but stubby fan that gradually opens to a nice side view in a few weeks. Compare it to tilted spiral galaxy NGC 7606.

As midnight approaches, 10P/Tempel has arched off the southern horizon in its slow, eastward swim past Fomalhaut. Use the chart accompanying this article online at Astronomy.com to track it down.

Comet 161P/Hartley-IRAS 🌠

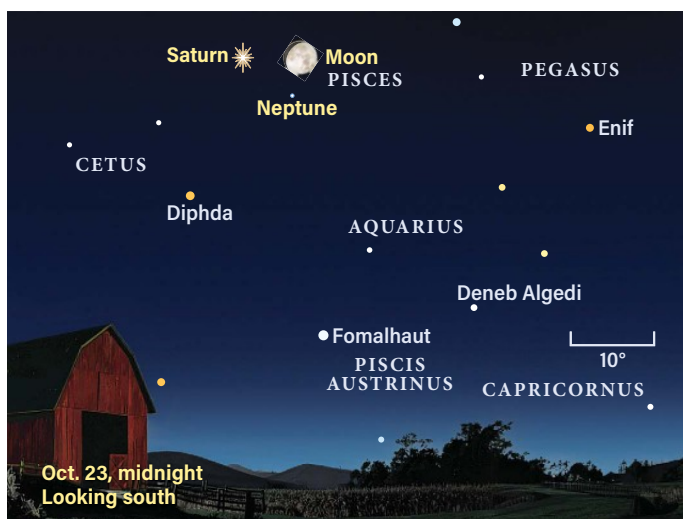


Comet Hartley-IRAS is covering a lot of sky this month. It is most readily visible in early October, shown here, but you can find charts for the rest of the month online.

LOCATING ASTEROIDS |

Back on easy street — mostly

Among giants   



Late in the month, the Moon forms a triangle with Saturn and Neptune — note the latter requires binoculars or a telescope to spot.

center of M44, a spectacular scene. The motion of Mars relative to the stars is evident within 10 minutes or so.

Mars reaches the eastern side of Cancer by Oct. 30, when it is just over 6° from Jupiter, across the border in Leo. Mars crosses into Leo the next day. The martian disk spans a mere $6''$ and its features remain challenging to view under most conditions.

Jupiter spends the month in Leo. Reaching magnitude -2.0 , it far outshines the Lion's brightest star, Regulus. Jupiter slowly approaches this star, leaving a gap of $6''$ on the 31st. The planet rises just before 3 A.M. local daylight time on the 1st, and by 1:30 A.M. on the 31st, offering many hours of observing time.

Through a telescope, Jupiter shows off a $33''$ -wide disk on the 1st, which grows to $36''$ by the 31st. Its banded atmosphere is on display, speckled by plumes, festoons, and spots.

The Galilean moons occasionally transit the disk. Europa transits Oct. 5, preceded by its shadow, as well as the shadow of

Callisto. The shadow transits are underway as Jupiter rises in the Central time zone, with Europa's shadow leading. Europa's transit begins at 4:56 A.M. EDT and ends at 5:50 A.M. MDT (just before sunrise in the Central time zone). The moon catches up with Callisto's shadow, which leaves the disk around 6:15 A.M. MDT and takes many minutes to disappear.

The next morning, Oct. 6, is Ganymede's turn, its shadow transiting from 5:37 A.M. EDT to 6:14 A.M. PDT. Before dawn in the Mountain time zone, attentive observers will notice Io lingering off Jupiter's western limb. Between 6:30 A.M. and 6:40 A.M. MDT, Io fades as it enters eclipse within Jupiter's shadow. West Coast observers will see the start of Ganymede's transit at 6:42 A.M. PDT.

Io passes in front of Callisto Oct. 14 between about 5:39 A.M. and 5:44 A.M. CDT (in bright twilight along the East Coast). Such mutual events are rare and difficult to observe in detail, with most observers simply

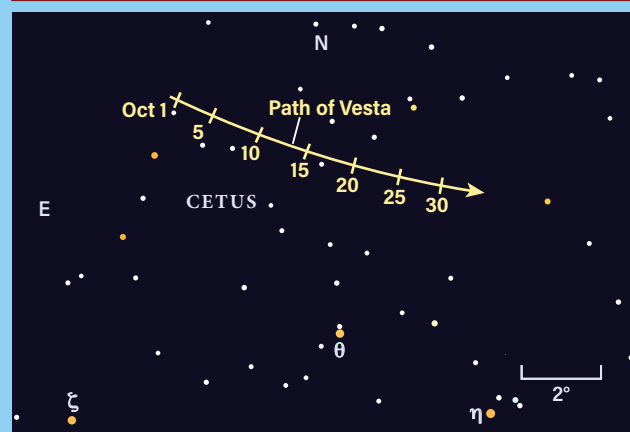
4 VESTA HAS RETURNED! The main-belt asteroid can be tracked with binoculars from the suburbs — no hunting amongst dim stars with a scope for the next four months. It reaches opposition on the 13th, peaking at magnitude 6.5. Wait until 10 P.M. local daylight time for Vesta to rise above treetops and fences.

There is a challenge — it is swimming this month across the open ocean between Pisces and Cetus, with no nearby bright stars to act as easy guideposts. However, Theta (θ) and Eta (η) Ceti (both mid-3rd magnitude) fit nicely in a binocular field, and along with a few fainter stars, they form a recognizable pattern to anchor your one-field sweep to their north.

If you're unsure which dot is Vesta, make a quick sketch of four or five stars, note the date, and come back the next clear evening to peg which one has moved. Heinrich Olbers (of the "why is the night sky dark?" paradox) discovered Vesta in 1807.

Keep an eye out for "intruder" stars not on the chart. This is the season and the zone where geostationary satellites reflect sunlight to northern midlatitudes for a few minutes. As the angles line up, they can brighten to 2nd magnitude! They don't move, so the stars slowly shift past. To figure out the azimuths where they might be, just look at where the big satellite dishes in your city are pointing.

Swimming near bright stars  



While Vesta is not immediately near any bright stars, you can use Theta and Eta Ceti to its south to orient your view.

seeing the moons appear to merge. Experienced photographers might catch more detail. Jupiter is approaching a December equinox, so a number of these events occur over the next few months. Some are merely close passes: The eastern half of the U.S. sees Ganymede and Callisto $1''$ apart (almost a grazing occultation) Oct. 4 around 4:40 A.M. EDT.

Jupiter is occulted by our Moon Oct. 6. Visible from the eastern portion of the U.S., the event begins around 4:20 A.M. EDT, with Jupiter nearly 20°

high along the East Coast. During the five minutes prior, three of Jupiter's moons are occulted (Europa, Callisto, then Io), and Ganymede is occulted within two minutes following Jupiter. See "Jupiter and the Moon play hide-and-seek" on page 38 for more details. 

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.

Orion's star factory

JWST focuses on the colorful outflows from young protostars in Orion the Hunter.

BY RICHARD TALCOTT

Few sights thrill backyard observers as much as the Orion Nebula (M42). The brightest stellar nursery visible from mid-northern latitudes resolves into a complex web of luminous gas and dusty tendrils even through modest telescopes. And at its core, you'll see the brilliant young stars of the Trapezium Cluster that provide the energy to set the nebula aglow.

Astronomers likewise study M42, looking for clues about how stars form. But not all of them focus on the glowing clouds that so enamor visual observers. The young stellar embryos known as protostars hide inside thick clouds of cold molecular gas and dust, and are still hundreds of thousands to millions of years from reaching the main sequence and official stardom. To make the observational challenge even worse, much of the action takes place slightly behind M42.

Piercing the murk

That's where the James Webb Space Telescope (JWST) comes in. It sees infrared light, which largely penetrates cold gas and dust to reveal what lies inside. The telescope recently examined a tiny portion of the vast Orion A complex, which harbors several molecular clouds, bright nebulae, and young star clusters.

JWST's target lies within the so-called Integral-Shaped Filament. At infrared and

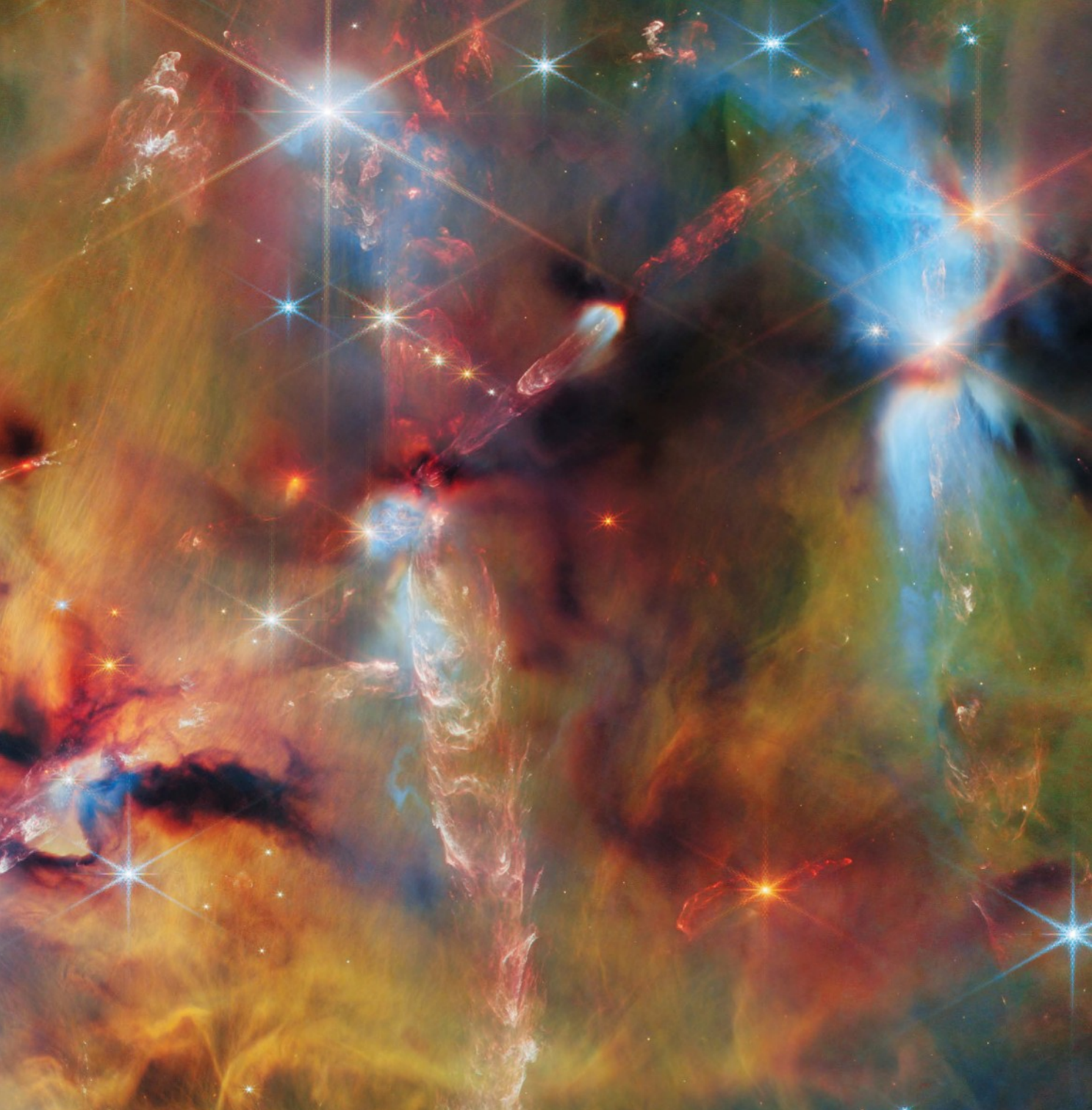


radio wavelengths, this region resembles an elongated letter S, so scientists named it after the similar-looking mathematical symbol for an integral. The Orion Nebula sits at the center of the filament. Just behind M42 dwells a chain of four cold molecular clouds called, appropriately, the Orion Molecular Clouds. OMC-1 lies directly behind M42, while OMC-2 and OMC-3 reside to its north and OMC-4 to its south.

JWST imaged a small piece in the northern part of OMC-2. This region lies 1,270 light-years from Earth, close enough

to allow astronomers a detailed view of the early stages of star formation. This specific slice of the cloud spans 2.5 by 1.5 light-years.

A protostar develops in a high-density molecular cloud like OMC-2 when gravity starts to win a tug of war against gas pressure. The nascent star slowly pulls in material from its surroundings, growing more massive while also shrinking in size. To conserve angular momentum, the contracting cloud must spin faster. The infalling matter forms an accretion disk in the budding star's equatorial plane and, like



water circling a drain, the gas continues to accumulate on the stellar embryo.

The disk's inner part boasts powerful magnetic fields, which channel some of the material into high-speed jets that escape along the protostar's rotation axis. When these jets collide with their dense surroundings, they create shock waves that heat the gas and cause it to glow.

OMC-2 dazzles

JWST's infrared eye captures the resulting maelstrom. The jets, which travel hundreds

of thousands of miles per hour, create the sharp-edged glows that dot the image. Most of these appear reddish, but you also see a few that veer closer to white. The smaller outflows emanate from younger protostars that have yet to kick into high gear. A small number remain totally hidden — not even JWST can pierce their thick dusty cocoons.

The few "stars" visible in the image, those dots sporting six symmetric diffraction spikes, have largely cleared away their birth clouds. Some may be pre-main sequence stars in OMC-2, while others could lie a bit

A small slice of the molecular cloud known as OMC-2 in Orion explodes to life in this new JWST image. Young protostars and their powerful outflows highlight a region chock full of cold gas and dust. ESA/WEBB, NASA & CSA, T. MEGEATH (UNIVERSITY OF TOLEDO), M. ZAMANI (ESA/WEBB); ACKNOWLEDGEMENT: M. H. ÖZSARAC

in the foreground. In either case, they show what the molecular cloud's protostars will one day become. ▀

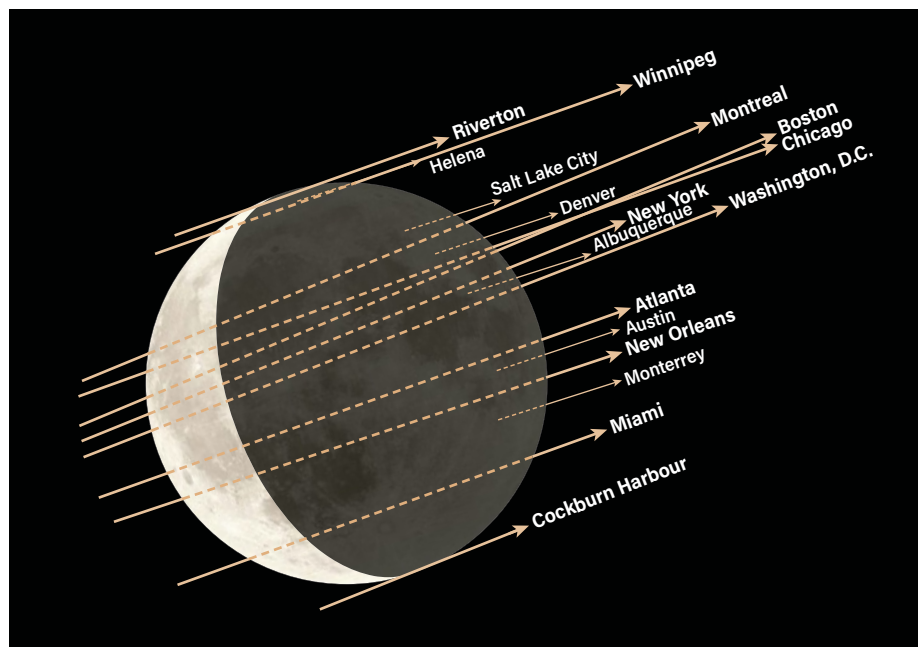
Contributing Editor Richard Talcott wrote about JWST and Hubble imaging of young star clusters in nearby galaxies in the September issue.

Jupiter and the Moon play hide-and-seek

A crescent Moon occulting our solar system's largest planet is a rare and brilliant sight. **BY JOE RAO**



Jupiter and its four Galilean moons — (from left to right) Ganymede, Io, Callisto, and Europa — sit near the Moon's limb in this photoillustration depicting the jovian system's orientation a few minutes before occultation. ASTRONOMY: ROEN KELLY; NASA'S SCIENTIFIC VISUALIZATION STUDIO; NASA, ESA, AMY SIMON (NASA-GSFC); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)



Make sure to set your alarm clock early on the morning of Tuesday, Oct. 6, so that you won't miss a rare and spectacular celestial event. The brilliant planet Jupiter and its retinue of Galilean satellites will pass behind the waning Moon, a 20%-illuminated crescent just $4\frac{1}{4}$ days before New. Astronomers call this phenomenon an occultation, taken from the Latin word *occultāre*, meaning "to conceal." This eye-catching sight will be visible in complete darkness across the eastern and much of the central U.S. as well as adjacent southern Canada, making it the best Jupiter occultation for North America since 2004.

On this special morning, the slender crescent Moon will rise in the east at around 2:30 A.M. local daylight time with Jupiter shining close by its sunlit side. As the pair rises higher in the sky, the Moon will slowly draw closer to the planet. Observers in the eastern and central U.S. will then see Jupiter disappear behind the Moon's bright limb. The planet will reappear from behind the Moon's dark — albeit dimly Earth-lit — eastern limb approximately an hour later.

Region of visibility

Because the Moon and Jupiter will have such a wide separation (53°) from the Sun, this occultation takes place for most observers before dawn twilight brightens the eastern sky. Eastern New York State, New England, and Atlantic Canada will be particularly favored with the Moon

Jupiter's track behind the Moon on the morning of Oct. 6th is depicted here as viewed from locations in the U.S., Canada, and Mexico. Thin arrows are used for locations where only the reemergence of Jupiter will be visible, as the disappearance will occur when both the Moon and Jupiter are below the horizon. Celestial north is up and east is to the left. ASTRONOMY: ROEN KELLY, AFTER JOE RAO

around 20° high when it covers Jupiter. (Your clenched fist held at arm's length spans about 10° .) The Moon will have risen to 30° above the eastern horizon by the time Jupiter begins to reappear.

The Moon's altitude gradually diminishes as you move south and west. Across the western Great Lakes, the eastern Great Plains, and down into the central Gulf Coast, for example, the emergence of Jupiter occurs with the Moon about 15° to 20° high.

Along a line from approximately central Montana down into southeastern Texas, Jupiter's disappearance will roughly coincide with moonrise, but when Jupiter is ready to emerge, the Moon will have climbed to an altitude of 5° to 10° .

West of this line, viewers will only be able to see Jupiter's reappearance, with the Moon quite low; prospective observers in this region might want to scout out an observing site in advance that has a clear view toward the east. Along a line running just west of Helena, Montana, and Salt Lake City, down to east of Tucson, Arizona, Jupiter's emergence occurs at moonrise. Farther west, unfortunately, no occultation will be visible.

LOCAL CIRCUMSTANCES OF THE OCT. 6, 2026, OCCULTATION OF JUPITER

The data in the table below is based on predictions made by Rob Robinson of the International Occultation Timing Association. Over a large metropolitan area, times may differ by half a minute or more from the listed times. Dashes indicate where Jupiter's disappearance behind the Moon occurs prior to moonrise; hence, the time and altitude data are omitted.

For more detailed information, go to <http://www.lunar-occultations.com/iota/bstar/1006jupiter.htm>.

Location	Time zone	Jupiter disappears	Altitude	Jupiter reappears	Altitude
Helena	MDT	—	—	3:01:13 A.M.	1°
Monterrey	CST	—	—	3:05:49 A.M.	5°
Salt Lake City	MDT	—	—	3:09:28 A.M.	1°
Albuquerque	MDT	—	—	3:11:01 A.M.	3°
Denver	MDT	—	—	3:11:08 A.M.	6°
Austin	CDT	—	—	4:09:42 A.M.	9°
New Orleans	CDT	3:14:26 A.M.	4°	4:11:03 A.M.	16°
Chicago	CDT	3:22:14 A.M.	10°	4:17:23 A.M.	20°
Winnipeg	CDT	3:45:27 A.M.	9°	4:03:52 A.M.	12°
Atlanta	EDT	4:15:41 A.M.	9°	5:16:42 A.M.	22°
Washington, D.C.	EDT	4:20:32 A.M.	17°	5:24:29 A.M.	30°
Miami	EDT	4:20:48 A.M.	12°	5:09:02 A.M.	23°
New York	EDT	4:23:35 A.M.	20°	5:27:28 A.M.	32°
Boston	EDT	4:26:45 A.M.	23°	5:29:55 A.M.	35°
Montreal	EDT	4:30:37 A.M.	22°	5:25:46 A.M.	31°

Location	Time zone	Time	Separation
Tucson	MST	2:19 A.M.	5'
Phoenix	MST	2:22 A.M.	6'
Las Vegas	PDT	2:30 A.M.	1'
Vancouver	PDT	2:35 A.M.	14'
Seattle	PDT	2:36 A.M.	15'
Portland	PDT	2:43 A.M.	17'
Los Angeles	PDT	2:47 A.M.	21'
Calgary	MDT	2:57 A.M.	3'
San Francisco	PDT	2:58 A.M.	26'
Boise	MDT	3:20 A.M.	6'

A swath of the western U.S. and Canada lies outside of the occultation zone but, as a consolation prize, will be treated to the rare sight of the planet passing very closely above the upper edge of the lunar disk — not an occultation but still a head-turning celestial tableau.

The suggested viewing times in the table above are several minutes after local moonrise; the listed separation is of Jupiter relative to the Moon's upper edge given in arcminutes for the listed times. Make sure you have a clear and unobstructed view toward the eastern horizon. As the Moon and Jupiter ascend, the gap between them will slowly widen, with the Moon receding from Jupiter at approximately one lunar diameter per hour.

Keep in mind that the apparent diameter of the Moon is 32', so (as an example) a separation of 4' is equivalent to only one-eighth the Moon's diameter.

But even there, Jupiter hovering just above the lunar crescent as they rise into full view will still make for a very striking sight.

What to expect

As Jupiter has a discernible disk, as seen in telescopes and even binoculars, it will not disappear or reappear in an instant like the pinpoint light of a star, but rather it will take a longer interval of time to fully disappear or reappear. In most cases, Jupiter's disappearance and reappearance will each take about a minute, while the Moon's edge advances across the planet's 34"-wide face.

The sunlit lunar crescent is nearly 400 times brighter than Jupiter (magnitude -1.9), so you're likely going to need binoculars or a telescope to watch the planet's disappearance next to the Moon's bright daylit landscape. In contrast, the gradual reappearance of Jupiter from behind the Moon's dark limb will be easily visible to the naked eye, brightening against the Moon's dark limb. That will likely be the most memorable part of this sky show — and binoculars or a telescope will provide an even more impressive view.

If you are observing with a telescope, just prior to Jupiter's disappearance you might be struck by its relatively dim surface brightness compared to that of the sunlit portion of the Moon. Jupiter, of course, is perpetually covered by clouds possessing an average albedo, or reflectivity, of 52% compared to the Moon's dark gray surface with a much smaller albedo of just 12%. But Jupiter is more than five times farther from the Sun compared to the Moon and consequently is illuminated by sunlight that's only about 1/7 as intense.

The amount of time that Jupiter will be completely hidden behind the Moon depends on your location, but will reach just over an hour at the high end.

A partial occultation

A most interesting sight will be seen from two 35-mile-wide (56 kilometers) strips at the northern and southern limits of the occultation's visibility. The northern strip stretches northeast from northern Montana into lightly settled southern Canada and up through northern central and northeastern Canada. The southern

edge crosses from southern Mexico northeast through the Yucatán Peninsula and across south-central Cuba and the Greater Antilles, including Inagua, Turks, and Caicos Islands.

Within these zones the Moon's mountainous edge will be silhouetted against Jupiter for several minutes or more, but the planet will never be completely covered. This is called a grazing occultation. Along the northern limit, a spectacular graze will take place along the Moon's dark limb near the crescent's northern cusp. Riverton, Manitoba (population 475), located 68 miles (110 km) north of Winnipeg, will see Jupiter partially covered from 3:50 A.M. to 4:01 A.M. CDT.

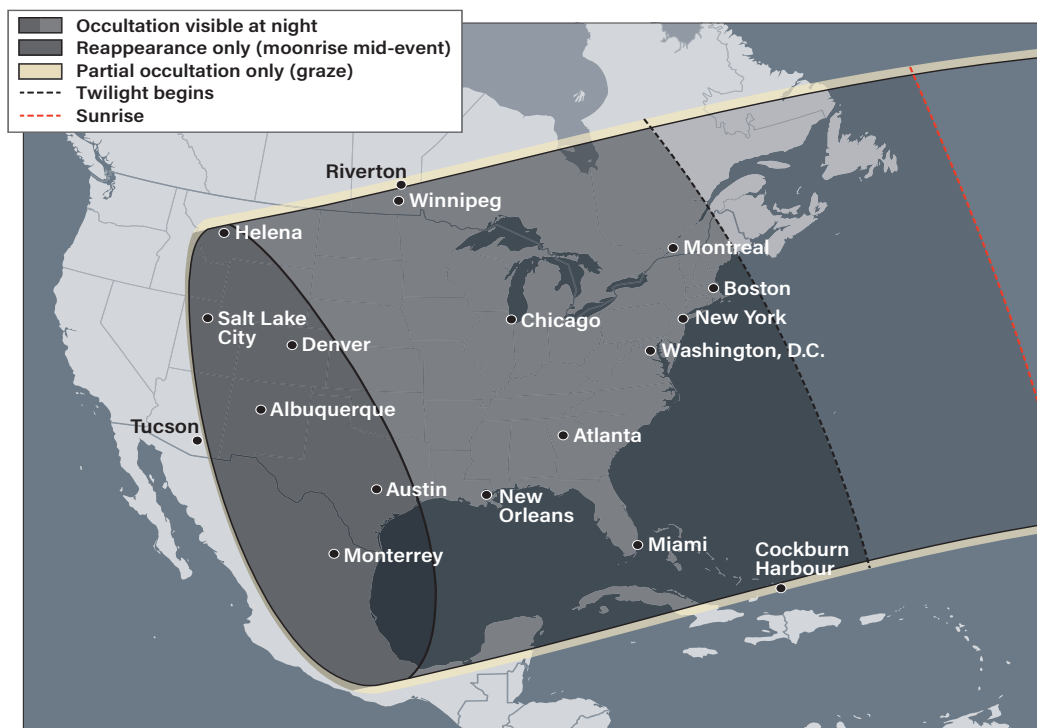
Along the southern limit, as seen from Cockburn Harbour (population 811) on South Caicos Island, the graze will take place along the Moon's dark limb very close to the crescent's southern cusp, with Jupiter partially covered from 4:46 A.M. to 4:58 A.M. EDT. Farther west, across Mexico and Cuba, the graze occurs along the crescent's bright southern limb.

Jupiter's moons

In addition to Jupiter, occultations of the four bright Galilean satellites will also be seen. Except for in large telescopes, they might be lost in the glare of the bright lunar crescent just prior to disappearing behind the Moon, but their emergence from behind the Moon's dark limb should be especially dramatic.

Going in, Europa (magnitude 6.1) will be occulted about five minutes before Jupiter. It will be followed by Callisto (magnitude 6.7) and then Io (magnitude 6.0) about three minutes before Jupiter, and about 15 seconds apart. Then, about two minutes after Jupiter itself disappears, Ganymede (magnitude 5.5) will disappear.

Coming out, Europa will be first, about five minutes before Jupiter, followed by Callisto about two minutes later, accompanied roughly 45 seconds later by Io. Since Io revolves around Jupiter in only 1.8 days while Callisto takes nearly 17 days, the gap between it and Callisto will have noticeably widened even during the short time span of the occultation. Finally, two minutes after Jupiter fully returns to view, Ganymede will emerge.



Since the satellites each measure about 1" in apparent diameter, they will all gradually brighten as they reappear from behind the Moon. Unlike stars, which when occulted instantaneously pop back into view, it will take perhaps one to three seconds on average for each satellite to fully emerge.

A rare event

Lunar occultations of Jupiter are rather rare. Simulations turn up 123 occultations of this giant world visible anywhere on the globe between 1980 and 2040. But if we confine our search to a specific location and only include those instances when the Sun is below the horizon, such an event occurs on average once about every 13 years.

Still, there are occasional quirks: In 2037, as seen from Portland, Oregon, the Moon will occult Jupiter on Nov. 27, the morning after Thanksgiving. Portland's next dark-sky occultation of Jupiter will come less than a month later, near the break of dawn on Christmas Eve, Dec. 24.

Conversely, prior to this year, New York City's last dark-sky occultation of Jupiter occurred nearly 22 years ago, on Dec. 7, 2004. Incredibly, before that date we must go back 115 years, to the late 19th century — Sept. 3, 1889 — for the previous time a dark-sky occultation of Jupiter was visible from the five boroughs!

The Oct. 6 lunar occultation of Jupiter will be visible in darkness across most of the eastern and central U.S. and parts of southern Canada. For parts of the American West and eastern Mexico, the Moon and Jupiter will not yet have risen when the occultation begins; they will see only the reemergence of Jupiter from behind the Moon's dark limb. Strips across northern Montana and southern Canada, and across southern Mexico, southern Cuba, and the Greater Antilles, will see a partial occultation of Jupiter, with the Moon grazing the planet's disk. ASTRONOMY: ROEN KELLY, AFTER DAVID DUNHAM/INTERNATIONAL OCCULTATION TIMING ASSOCIATION

Final thoughts

As Jupiter and the Moon are both well-characterized, this occultation is not rich in scientific value. However, it certainly will be an unusual observing project for skywatchers as well as a memorable eye-catching spectacle wherever it can be seen.

The next good dark-sky occultation of Jupiter will be visible from the western half of North America on Sept. 28, 2034, and most of the continent will be able to partake of the occultation in November 2037.

Good luck, and make the most of this upcoming opportunity! ☾

Joe Rao is an instructor and guest lecturer at New York City's Hayden Planetarium. He writes about astronomy for *Space.com*, *Natural History magazine*, *The Old Farmer's Almanac*, and other publications. In July 2023, the International Astronomical Union named 2.3-mile-wide asteroid 200009 Joerao in his honor.

OUR 16TH ANNUAL STAR PRODUCTS

Each year, new astronomy equipment reflects advances in technology and the evolving ways observers engage with the night sky. Traditional designs such as Dobsonian reflectors and apochromatic refractors continue to deliver dependable performance, while smart telescopes and integrated imaging systems are expanding access to astrophotography. Portability remains a central theme, as compact optical tubes, lightweight mounts, and modular systems allow observers to assemble capable setups for backyard use, outreach, or travel to darker skies. At the same time, experienced amateurs continue to seek specialized equipment, from fast astrographs to refined accessories that enhance performance. The 35 products highlighted here reflect this diversity, representing some of the most interesting and capable creations available today.

BY PHIL HARRINGTON



Altair Starwave 60ED Imaging Refractor

The Starwave 60ED is a compact 2.4-inch f/6 ED doublet refractor designed specifically for astrophotography, using FCD100 glass to deliver strong color correction across the field. Its 360mm focal length supports wide-field imaging, while a dual-speed rack-and-pinion focuser with integrated rotator allows precise focus and easy framing with modern cameras. The system is configured around standard 55mm back-focus spacing and can be paired with a dedicated reducer to operate at f/4.8 for faster imaging. Weighing about 3.9 pounds (1.8 kg), its lightweight, modular design makes it particularly well suited for experienced astrophotographers traveling to dark-sky sites who require a portable setup optimized for imaging.

£399.00 / altiraastro.com

Analog Sky Magic binocular kit and video course

Analog Sky's Magic binocular kit combines hands-on construction with a distinctive optical design that emphasizes flexibility and user understanding. Unlike most binocular systems, it accepts standard eyepieces and filters. A particularly clever slide-on cartridge system lets filters be inserted or removed without taking out the eyepieces, making it far easier to make changes while observing. The included video course guides users through assembly while explaining the underlying optical principles, making it as much an educational experience as a functional instrument.

\$539.99 / analogsky.co



Apertura 8-inch f/4 Imaging Newtonian optical tube assembly

Apertura's 8-inch f/4 Newtonian was designed from the outset for deep-sky astrophotography. Features such as a dual-speed Crayford focuser for precise focusing and a center-marked primary mirror for accurate collimation are ideal for astroimagers. The package includes essential accessories such as tube rings, a Vixen-style dovetail bar, and a 2" extension adapter to support a range of camera configurations. This makes it a strong choice for intermediate users stepping up from smaller instruments.

\$629.95 / highpointscientific.com



Askar 80ED refractor

The Askar 80ED is a 3.1-inch f/7 ED doublet refractor designed as a compact and versatile optical tube for both visual observing and astrophotography. Its two-element objective includes one ED glass element to reduce chromatic aberration and improve contrast and color fidelity. The tube measures about 16 inches (400 mm) with the dew shield retracted and weighs roughly 3.7 pounds (1.7 kg), making it easy to transport and mount. The optical tube assembly includes a dual-speed rack-and-pinion focuser, tube rings, and a Vixen-style dovetail bar. A finder, star diagonal, and mount are sold separately. Optional field flatteners and focal reducers are also available to extend its performance for astrophotography.

\$399.00 / sharpstar-optics.com



Askar SQA130 130mm f/4.8 Quintuplet Petzval APO refractor

The SQA130 is a 5.1-inch f/4.8 astrograph optimized for wide-field astrophotography. Its quintuplet Petzval optical design delivers a flat, well-corrected field without requiring a separate field flattener. Its 3.2" dual-speed rack-and-pinion focuser with integrated rotator supports precise framing and focusing with modern cameras. The package includes tube rings, a 12-inch (300 mm) Losmandy-style dovetail plate, multiple rear adapters, dual finder bases, a retractable dew shield, and a cloth case. Optional accessories include a height extension, a top-bar-mounted carrying handle, and camera-specific adapters.

\$4,799.00 / sharpstar-optics.com



Astro-Physics StarFire CS 155mm f/6 APO refractor

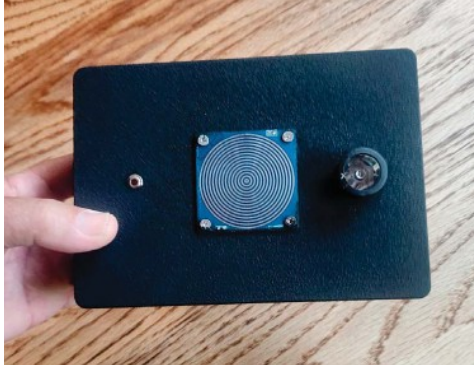
The StarFire CS is a 6.1-inch f/6 apochromatic refractor designed for high-performance imaging and visual use. Its "Christen Superachromat" objective delivers high contrast and excellent color correction across a large 51mm image circle. The standard 3.5" focuser features a Starlight Instruments Feather Touch 9:1 Micro dual-speed mechanism for precise, backlash-free focusing, while a rotating Doveloc system allows smooth camera framing. A dedicated field flattener is also included.

\$12,800.00 / astro-physics.com



Astro Devices Nexus eFinder and DSC Pro

From Australia comes this unique way to navigate the sky. Astro Devices' Nexus eFinder is an electronic finder that uses a built-in camera and plate solving to determine exactly where a telescope is pointing by matching star fields to an internal database. Its partner, the Nexus DSC Pro, is a specialized computer known as a digital settings circle (DSC) that reads the telescope position and then guides users to their desired targets. Used together, the two pieces of equipment provide continuous, high-precision pointing. They can also operate with planetarium software such as SkySafari Plus/Pro, Starry Night, Cartes du Ciel, and TheSky on Wi-Fi-enabled devices. **Nexus eFinder: \$349.95 / DSC Pro: \$399.95 / astrodevices.com**



Astro-Smart SMP-R2 Astro Weather Station

The SMP-R2 is a computerized weather station that combines data from multiple sensors. The system can connect to standard astronomy software, work on its own or as part of a remote-controlled observatory, and integrate with virtually any computerized telescope. Sensors include cloud detection, sky quality (SQM), sky brightness (lux), rain and snow detection, and more. Optional features include GPS integration and relay output control for dome or observatory automation.

SMP-R2 USB: \$299.00 / SMP-R2 RF: \$349.00 / astro-smart.com



CATSEYE BLACKCAT XLV Wired Video Collimation System

The BLACKCAT XLV Wired Video Cheshire system adapts CATSEYE's traditional collimation tools for Newtonian reflectors. It integrates a color CCTV camera directly into the Cheshire, allowing axial alignment cues to be viewed on a 4.3-inch LCD monitor in real time. This eliminates the need to move between the focuser and the rear of the telescope while making adjustments. The system streamlines collimation into a single-operator procedure with immediate feedback. Included components consist of the Video Cheshire with cap and storage bag, LCD monitor with power supply, CCTV pinhole camera with interchangeable lenses, interface cables, extension cable, USB power adapter, and a zippered storage case.

\$269.00 / catseyecollimation.com



Celestron Lumina 130mm Tabletop Dobsonian Telescope

The Lumina 130mm is a collapsible 5.1-inch f/5 Newtonian reflector ideal for beginners of all ages. It uses a parabolic primary mirror with aluminum and silicon dioxide coatings for excellent image quality. The telescope is mounted on a compact tabletop Dobsonian base that provides simple, manual alt-azimuth motion. Included accessories include 25mm and 10mm eyepieces and a StarPointer red-dot finderscope. Its optical tube measures 24.3 inches (616 mm) when extended, but collapses to 18 by 14 inches (46 by 36 cm) for easier transport and storage. For every Lumina sold, Celestron donates an identical telescope to a K-12 school in the U.S.

\$299.00 / celestron.com



Celestron NexImage 20 Solar System Color Imager

Celestron's NexImage 20 continues the evolution of a camera line that has introduced many amateurs to solar system astrophotography. Designed for lunar, planetary, and solar work (with proper filtration), it delivers detailed results when paired with proper technique and post-processing. The camera is built around an Onsemi AR2020 back-illuminated 20-megapixel CMOS sensor with fast USB 3.0 data transfer. Celestron's iCap software provides intuitive control over exposure, gain, frame rate, and region-of-interest settings. The NexImage 20 is well suited for both beginners and experienced users alike.

\$449.95 / celestron.com



Celestron Origin Mark II Intelligent Home Observatory

The Origin Mark II pairs a 6-inch (152mm) f/2.2 Rowe-Ackermann Schmidt Astrograph with an integrated mount and onboard processing, delivering real-time views through a mobile device. Equipped with the Sony IMX678 sensor, it improves sensitivity and image quality over earlier configurations. The system automates alignment, tracking, and image stacking, greatly simplifying deep-sky imaging. The Origin Mark II is a streamlined, all-in-one approach to electronically assisted astronomy for users seeking convenience while still capturing detailed astronomical photos. Its automation allows observers to focus on exploration rather than setup and calibration.

\$4,299.00 / celestron.com



Celestron RASA 6-inch optical tube assembly

For those who prefer placing the Origin's optical tube on their own mount, Celestron offers the RASA 6 optical tube assembly, which uses the same 6-inch f/2.2 Rowe-Ackermann Schmidt Astrograph design. With a 335mm focal length, the RASA 6 is optimized for wide-field work with short exposure times. Although a camera is not included, it comes with an M42-threaded adapter that allows compatibility with a range of CMOS imagers. The telescope includes a CG-5 dovetail bar for mounting.

\$1,699.00 / celestron.com



Celestron SkyMaster Gemini 2x40 binoculars

Sometimes, less magnification reveals more of the sky. Celestron's SkyMaster Gemini binoculars use 2x magnification to provide a broad 24° field of view, allowing observers to take in large portions of the sky at once. Their modest magnification can help reveal fainter stars that complete the outlines of some constellations and bring out broad stretches of the Milky Way that are difficult to see with the unaided eye, especially under light-polluted skies. The 40mm objectives and fully multicoated optics use individually focused eyepieces in a compact Galilean design.

\$129.95 / celestron.com



Explore Scientific 8-inch Dobsonian Reflector Telescope (Red)

An 8-inch reflector has long been considered an ideal first telescope, and Explore Scientific's 8-inch f/5.9 Dobsonian reflects that notion well. The optical tube is paired with a simple alt-azimuth rocker-box mount with a spring-tension system for smooth, balanced manual operation. It features a 2" Crayford-style focuser with a 1¼" adapter. Standard equipment includes a 70° Series 25mm eyepiece, a 10mm Plössl eyepiece, a 2x Barlow lens, a red-dot finder, a smartphone adapter, and a dust cover.

\$649.99 / explorescientific.com



Explore Scientific 92° ED Waterproof Eyepiece (14mm)

Explore Scientific's 92° Series 14mm eyepiece delivers an ultra-wide apparent field designed for immersive visual observing. Shown at the 2026 Northeast Astronomy Forum this past April, it features premium ED glass to provide high contrast and sharp images across the field, even in fast optical systems. The eyepiece is fully waterproof and purged to prevent internal fogging. It offers 18mm of eye relief and has a 2" barrel that fits a wide range of telescopes. Other focal lengths in this new series include 9mm, 20mm, and 25mm.

\$449.99 / explorescientific.com



DayStar Sol 100 Hydrogen-alpha solar refractor

Designed to reveal prominences, filaments, and surface detail not visible with white-light filters, DayStar's Sol 100 is a dedicated 3.9-inch solar telescope that shows the Sun at 656.3 nm, the Hydrogen-alpha wavelength. The optical system incorporates an integrated narrowband filter for high-contrast viewing and imaging, with electronic tuning to adjust the bandpass for best results. The telescope includes a helical focuser and is intended for use on a tracking mount, which is sold separately.

\$4,995.00 / daystarfilters.com



Explore Scientific FirstLight 100mm Mak-Cassegrain telescope with EQ3 mount

If you enjoy views of the Moon, planets, close double stars, and smaller deep-sky objects such as planetary nebulae, the Explore Scientific FirstLight 100mm Maksutov-Cassegrain delivers strong performance in a compact package. Its 3.9-inch (100mm) f/14 optical system delivers sharp, high-contrast views across a range of magnifications. The system includes an EXOS Nano EQ3 German equatorial mount with slow-motion controls, a full-size tripod, a 25mm Plössl eyepiece, a red-dot finder, and a 1¼" 90° diagonal for a complete observing setup.

\$249.99 / explorescientific.com



Explore Scientific U-mount with tripod

Holding large binoculars steady while remaining comfortable can be a challenge, especially when observing high overhead. Explore Scientific's U-mount addresses both issues with a solid fork mount and stainless steel tripod designed for binoculars with 70mm to 120mm objectives. It accommodates binoculars weighing up to 26.5 pounds (12 kg) and as wide as 11.4 inches (290 mm). Adjustable friction in both axes provides smooth tracking, while a quick-release adapter plate speeds setup and removal.

\$749.99 / explorescientific.com



Houdini 20mm Coma-Correcting Eyepiece

If you own a fast-focal-ratio Newtonian, you know that coma can seriously affect the view. The Houdini 20mm eyepiece addresses this by combining an 86° apparent field with built-in coma correction, eliminating the need for a separate corrector. It is designed to deliver sharp star images across the field in fast systems. The optical design features multicoated elements and high-transmission glass, along with blackened edges to improve contrast. With 20mm of eye relief, it offers comfortable viewing. Additional focal lengths in the series include 12mm, 9mm, and 7mm.

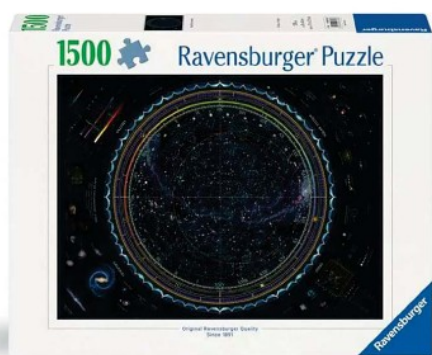
€399.00 / houdinitelescopes.com



LEGO Art The Milky Way Galaxy

It's cloudy again tonight. What can I do? LEGO offers one answer. How about building a galaxy? This 3,091-piece set creates a layered, three-dimensional wall display of the Milky Way using vividly colored bricks to convey depth and structure across the spiral arms. The model is assembled in multiple panels, turning it into a collaborative building experience if desired. Each section includes a QR code linking to a curated educational soundtrack, so you can learn more about our home galaxy while you build. LEGO® is a trademark of the LEGO Group, which does not sponsor, authorize, or endorse this article.

\$199.99 / lego.com



Ravensburger Map of the Universe jigsaw puzzle

Looking for another enjoyable way to build the universe? Ravensburger's 1,500-piece Map of the Universe jigsaw puzzle is a fun project for ages 14 and up. Images of galaxies, stars, spectra, and the solar system surround a map of the celestial sphere. When complete, it measures 31.5 by 23.6 inches (80 by 60 cm) and is presented in a horizontal layout that is suitable for framing.

\$33.99 / ravensburger.us



Sky Rover 10x42 mm Banner Cloud APO binoculars

Sky Rover is a relative newcomer to the binocular field, and its 10x42 Banner Cloud APO model emphasizes optical performance. Its roof prism design combines a double-ED apochromatic system with full broadband multi-coatings and phase- and dielectric-coated prisms to deliver bright, high-contrast views and excellent color correction. A wide 7.5° true field and flat-field design provide sharp images from center to edge. The 10x42 configuration yields a 4.2mm exit pupil, an excellent match for urban and suburban observers, balancing image brightness with contrast while maintaining useful reach on deep-sky objects.

\$509.00 / skyroveroptics.com



Sky Rover XWA 13mm 100° Ultra-Wide-Angle Eyepiece

This 13mm eyepiece is part of the new Sky Rover XWA series, which span focal lengths from 3.5mm to 20mm. Like the rest of the XWAs, the 13mm has a spacious 100° apparent field of view, producing a truly immersive experience at moderate power. The eyepiece uses a hybrid 1¼"/2" barrel design with a removable 2" collar, making it compatible with most focusers. Its optical system consists of nine elements in six groups, all fully multicoated to enhance contrast and light transmission. O-ring sealing helps protect against moisture and contamination, while the wide apparent field allows objects to remain in view longer during manual tracking.

\$229.00 / skyroveroptics.com



Sky-Watcher HAC125DX Minigraph

The HAC125DX is a 5-inch (125mm) f/2 astrograph that uses Sky-Watcher's Honders Advanced Catadioptric (HAC) optical design to deliver fast, wide-field imaging in a compact package. With a 250mm focal length, a 16mm image circle, and a rear focusing system, it is designed for small-format cameras. Measuring just 15.7 inches (40 cm) long and weighing 8.4 pounds (3.8 kg), it is highly portable. Included are clamshell rings, a Vixen-style dovetail, camera adapters, and a dew shield.

\$899.00 / skywatcherusa.com



Sky-Watcher Heliostar 100mm/WAVE 100i Pro Mount Kit

The Sun may look tranquil through a white-light filter, but it comes alive in hydrogen-alpha, with prominences, filaments, and other surface detail. Sky-Watcher's Heliostar 100 can bring those details to you. This dedicated 3.9-inch (100mm) f/7.6 hydrogen-alpha refractor uses a built-in Solis Etalon system to produce a 0.55-angstrom bandpass. Its Trifid Tuner allows fine adjustment for solar detail. Paired with the WAVE 100i strain-wave go-to mount, the kit includes mounting rings, Vixen-style dovetail, solar finder, sunshade, 22mm eyepiece, 20mm blocking-filter diagonal, hard case, mount, and tripod.

\$7,995.00 / skywatcherusa.com



Spectrum Optics DS8 8-inch Dobsonian reflector

An 8-inch reflector, such as Spectrum Optics' DS8, is often considered the sweet spot between performance and portability. The DS8 features a curved spider vane assembly (the supporting legs that hold a telescope's secondary mirror) to reduce diffraction spikes around bright stars and a dual-speed 2" Crayford-style focuser with a 1¼" adapter for precise focusing. The rocker box rides on Teflon pads with adjustable altitude tension controls for smooth manual motion. Standard equipment includes 23mm and 10mm 1.25" Plössl eyepieces, a

2x Barlow lens, and an 8x50 finderscope.

\$649.00 / spectrumoi.com



Spectrum Optics MirroSky SPi53 Smart Telescope

The MirroSky SPi53 is a portable go-to smart telescope built around a 53mm ED refractor and a Sony IMX662 color imaging sensor. The camera slips directly into the scope's helical focuser. Since it is separate, the camera can be easily changed or upgraded in the future, if desired. Controlled through the MirroSky app for iOS and Android, the SPi53 uses plate-solving technology to determine its position automatically without manual star alignment. Its wide field suits large targets such as the Pleiades (M45), the Andromeda Galaxy (M31), and the Orion Nebula (M42). The system includes a mount, mini tripod, carrying case, AC adapter, and USB-C cables.

\$599.00 / spectrumoi.com



Starfield Optics GEAR 80 Triplet APO refractor

The GEAR 80 is a compact 3.1-inch f/6 apochromatic triplet refractor engineered for wide-field imaging and high-contrast visual observing. Its multicoated optical system uses one lens element of extra-low-dispersion Ohara FPL53 glass for improved color correction and contrast. It features a retractable dew shield and a rotatable 2.5" dual-speed rack-and-pinion focuser with a self-centering rotational lock to maintain alignment. Included are tube rings, a Vixen-style dovetail, finder mount, handle, hard case, and optical test report.

\$1,300.00 / starfieldoptics.com



NGC 602 nebula T-shirt

STARtorialist's NGC 602 T-shirt transforms astronomical imagery into wearable art through an all-over print inspired by this colorful star-forming region in the Small Magellanic Cloud. The design combines imagery from the Hubble Space Telescope, Spitzer Space Telescope, and Chandra X-ray Observatory, wrapping the scene across both front and back. The print-on-demand shirt is available in straight-cut and fitted styles and is offered in a range of adult sizes. STARtorialist also offers many other astronomy- and space-themed products.

\$49.00 / startorialist.com



SVBONY SV233 telescope accessory kit

If you have a new telescope and are looking to expand your accessory collection on a budget, SVBONY's SV233 1¼" telescope accessory kit adds eyepieces, filters, and storage in one package. The 8-piece set includes 25mm and 32mm Plössl eyepieces, a 3.2mm planetary eyepiece, a 7–21mm zoom eyepiece, a 2x Barlow lens, a Moon filter, a color filter set, a variable polarizing filter, and an accessory box. Fully multicoated optics and multiple focal lengths give observers flexibility for lunar, planetary, and deep-sky viewing.

\$119.99 / svbony.com



Tele Vue 24mm Delos eyepiece

Tele Vue eyepieces are considered among the best available, and the Delos line is among the best that Tele Vue offers. The latest addition, the 24mm Delos, extends the series into a 2" format while preserving its emphasis on comfort and high-quality observing. Its optical design produces a 72° apparent field of view and 22mm of eye relief, delivering sharp, high-contrast images across the field. The Delos 24 has a listed weight of 19.2 ounces (0.54 kg) and is compatible with Tele Vue's DioptRx astigmatism corrector.

\$551.00 / televue.com



The Space Store Space Launch System scale model

NASA's Artemis program has put lunar exploration back in the spotlight, and the Space Launch System (SLS) is central to that effort. The Space Store's model accurately scales NASA's 322-foot-tall (98 meters) heavy-lift launch vehicle down to an 18-inch (45.7 cm) display piece. The model includes the Orion spacecraft and launch abort system at the top, along with a sturdy display base suitable for desks, shelves, classrooms, or display cases, making it a timely choice for spaceflight buffs.

\$70.65 / thespacestore.com



Track the Stars TTS-160 Panther Pro alt-azimuth mount

The TTS-160 Panther Pro accommodates side-mounted telescopes on either side, top-mounted configurations, and multi-telescope setups. It combines manual movement with motorized go-to tracking. Move the telescope by hand, and tracking resumes when released. Depending on tube length and diameter, the 22-pound (10 kg) mount can carry one side-mounted telescope up to 55 pounds (25 kg), two side-mounted telescopes up to 44 pounds (20 kg) each, or one top-mounted telescope up to 44 pounds (20 kg). Integrated Wi-Fi permits control through SkySafari and similar apps, while adjustable clutches allow smooth manual operation without power.

€5,295.00 / trackthestars.com



William Optics Ultra-Cat 108 astrograph

The William Optics Ultra-Cat 108 excels at wide-field deep-sky astrophotography. This 4.25-inch f/4.8 astrograph uses a five-element Petzval objective that promises a flat, well-corrected field without a separate flattener. With a 518mm focal length and 60mm image circle, it supports formats up to medium frame. A rack-and-pinion focuser is built into the telescope body. The Ultra-Cat comes with a Bahtinov focusing cap; M48, M54, and M68 camera adapters; a Vixen-style plate; mounting rings with a handlebar; and a soft carrying case. ☿

\$3,998.00 / williamoptics.com

Phil Harrington is a contributing editor of Astronomy and long-time equipment guru.

Understanding celestial coordinates

Astronomers have a useful system for finding objects in the sky.



Stars wheel around the North Celestial Pole, as seen from Calhoun County Park, West Virginia.

MOLLY WAKELING



Just as we use latitude and longitude to know the precise position of something on Earth's surface, it's useful to have a system for knowing the position of objects in the heavens. The widely used system of right ascension and declination does the job — and dates back at least to the time of Hipparchus (circa 190–120 B.C.E.).

But one of the hardest parts of getting started in astronomy is comprehending that celestial coordinate system. Rather than looking down at a globe with fixed landmarks, beginners are looking outward to an unfamiliar, ever-shifting sky. So to get an understanding of the celestial sphere, let's compare to Earth.

On Earth, latitude describes the distance north and south of the equator, in degrees of a circle, from 0 to 90. Longitude describes the distance east and west of the prime meridian, which runs through the Royal Observatory in Greenwich, U.K., and extends 180° in either direction. The equator marks 0° latitude, while the North and South poles are situated at 90° north and 90° south. Columbus, Ohio, sits on the 40° north latitude

line; 115° west longitude runs right through Las Vegas, while 140° east crosses Tokyo.

Declination (or Dec. for short) is similar to latitude, but projected onto the sky, with $\pm 90^\circ$ being the North and South celestial poles, respectively, and 0° at the celestial equator. Mintaka, the westernmost star of Orion's Belt, sits very close to 0° declination, while the Andromeda Galaxy (M31) lies at 41° . From midnorthern latitudes (around 40° north), objects with a declination of -50° will just peek their noses above the southern horizon, while objects at 50° or higher are circumpolar, or visible above the horizon all night. Declination values are subdivided into arcminutes (') and arcseconds ("), where there are 60 arcminutes in 1 degree, and 60 arcseconds in 1 arcminute.

Right ascension (R.A. for short) is similar in concept to longitude, with lines that originate at the celestial poles, but is instead measured in hours, minutes, and seconds. Imagine the sky as a clock, where it takes 24 hours for a particular point to make one complete revolution; since each day is approximately 24 hours, one hour of right ascension is $\frac{1}{24}$ of a 360° circle, or 15° . The "prime meridian" of right ascension is the location of the Sun on the vernal equinox, which is currently located in Pisces. The Andromeda Galaxy is near this 0h line; on the opposite side, the Sombrero Galaxy (M104) lies near 12h.

In astronomy, the *meridian* refers specifically to the imaginary line that connects the North and South celestial poles through the zenith, the point directly overhead from your location. A helpful reference to know is the time an object crosses the meridian, also known as its transit time. In the Northern Hemisphere, objects with right ascensions between 04h and 09h cross at midnight in winter (December through February), 10h to 15h cross at mid-

night in springtime (March through May), 16h through 21h transit in summertime (June to August), and 22h to 03h transit in autumn (September through November).

Now, unlike Earth coordinates, celestial coordinates slowly change position over time due to precession, or the wobble of Earth's axis. In 2000, the Orion Nebula (M42) was located at R.A. 05h35m17s, Dec. $-05^\circ 23' 28''$, but in 2050, it will have shifted slightly to R.A. 05h37m44s, Dec. $-05^\circ 21' 40''$. Object locations are referred to by epoch; J2000 is the currently used reference, but will eventually be updated to the J2050 system.

As you observe more, you will start to get a feel for where the different coordinates are on the sky, and you will soon be able to estimate where to find a given galaxy or comet based on its coordinates. Then you can amaze your friends with your celestial navigational skills! ☾

One of the hardest parts of getting started in astronomy is comprehending the celestial coordinate system.



MOLLY WAKELING

BY MOLLY WAKELING

Molly is an avid astrophotographer active in STEM outreach. She has a Ph.D. in nuclear engineering.



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INDEX of ADVERTISERS

AP Grzegorz Poplawski/Arch Paths.....	2
Analog Sky.....	13
Astro Devices.....	13
Astro-Physics.....	6
Bob's Knobs.....	51
Celestron.....	60
Chroma Technology.....	13
DayStar Filters.....	11
Mason Capital Partners.....	51
Metamorphosis Jewelry Design.....	51
Oberwerk.....	51
Rainbow Symphony.....	51
Sky-Watcher USA.....	5
Snow King Observatory & Planetarium.....	59
Scope Buggy.....	13
Subscribe to Astronomy.....	57
Telescope Live Ltd.....	51
The Space Store.....	55
ToupTek Astro.....	13

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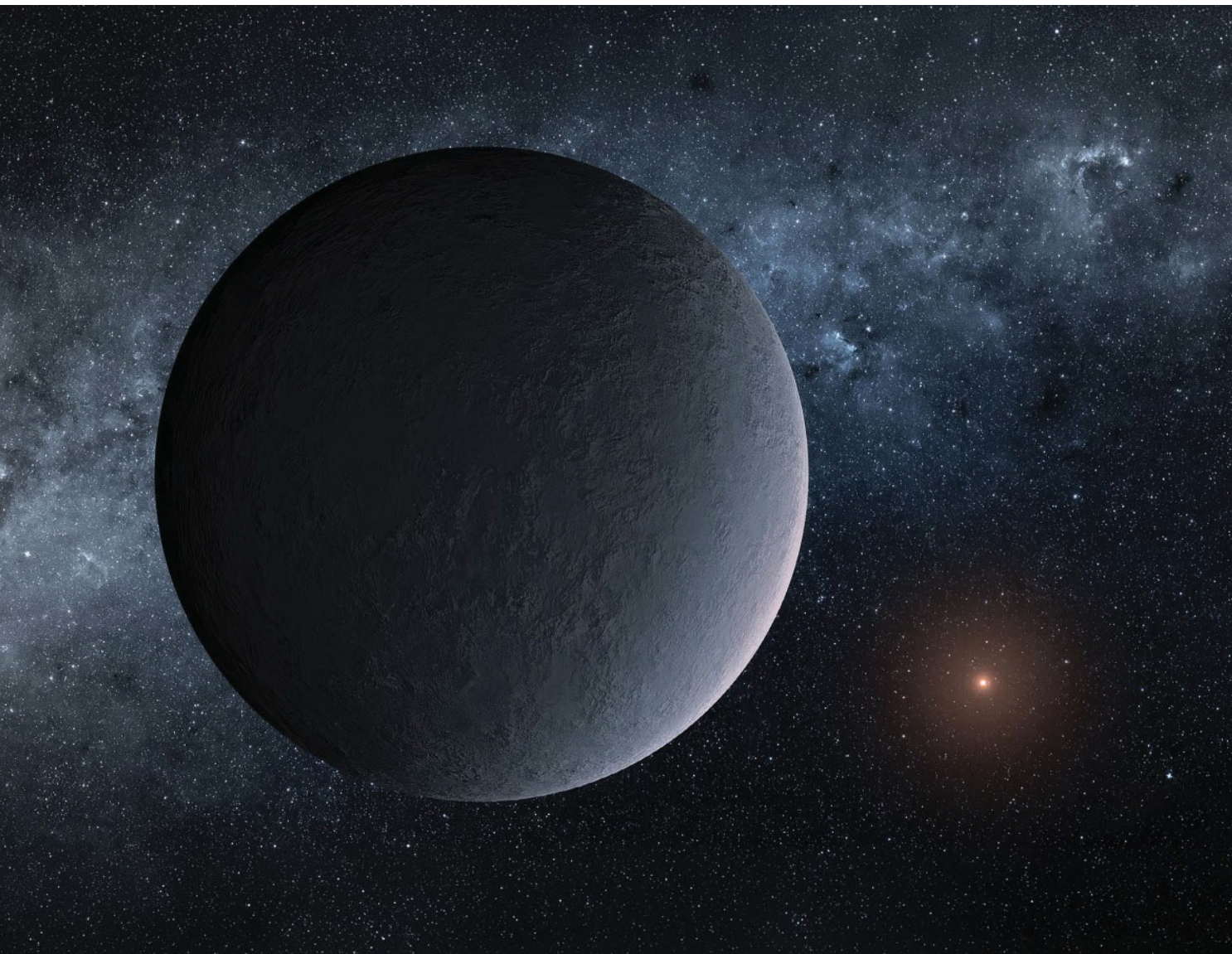
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MARKETPLACE



While gravitational lensing supplies astronomers with a variety of details about massive objects such as galaxies and clusters, microlensing allows them to discover much smaller objects — like planets. Nearly 13,000 light-years away, icy OGLE-2016-BLG-1195L b was the lowest-mass planet discovered through microlensing when the Spitzer Space Telescope sighted it in 2017. NASA/JPL-CALTECH

Q | HOW DO PROFESSIONAL ASTRONOMERS BOOK TIME ON JWST OR HUBBLE?

Frank Coulter
Tauranga, New Zealand

A | The opportunity to use either the Hubble Space Telescope (HST) or James Webb Space Telescope (JWST) as what NASA calls a general observer is available to scientists all over the world each year. The science program for both telescopes is led by the Space Telescope Science Institute (STScI) in Baltimore, and proposals are submitted annually by scientists anxiously awaiting new discoveries with these facilities across all areas of astrophysics and planetary science. Every proposal specifies how much observing time it requires, measured in hours for JWST

and orbits for HST. (HST orbits Earth roughly every 95 minutes.) The proposals are then reviewed by an international team of scientists, known as a Telescope Allocation Committee (TAC). This group evaluates and ranks the possibilities using a well-defined set of criteria that includes in-field impact, out-of-field impact, suitability, and feasibility. This is done in a dual-anonymous manner in which proposers and TAC members are not revealed to each other. The ranked programs are then provided to the STScI director, who makes the final decision on the programs selected for a given observing cycle.

The call for proposals is made annually to ensure the science conducted with these telescopes remains state of the art and provides the opportunity for new discoveries to be followed up as well as new users to advance the field. But, on occasion, there is an urgent need to use

one of these observatories for observations that could not have been requested in the annual proposal cycle and cannot wait for the next. An example of this would be to observe an unexpected phenomenon, such as a supernova, in a timely manner. These types of programs are proposed at any time under the STScI Director's Discretionary Time, and include small programs proposed by community members and larger initiatives deemed essential by the director.

Finally, anyone in the world can access HST or JWST data that has been archived, which typically happens one year from the date of the observation. This public archive is known as the Barbara A. Mikulski Archive for Space Telescopes (MAST), and includes all HST and JWST data.

Stefanie Milam

*JWST Project Scientist for Policy and Science Community,
NASA Goddard Space Flight Center, Greenbelt, Maryland*

Q | WHAT INFORMATION IS OBTAINABLE THROUGH GRAVITATIONAL LENSING AND HOW?

Patrick A. Clough
Wichita, Kansas

A | Gravitational lensing is the effect by which comparatively nearby objects, such as clusters of galaxies, can bend and focus the light of other objects that are more distant. Lensing is only possible because highly massive, and therefore gravitationally powerful, objects distort the space-time continuum around them.

Astronomers can glean various types of information from this distortion. For instance, since lensing focuses and therefore intensifies the brightness of galaxies from the early universe, it enables astronomers to study them in greater detail. Another application involves measuring the amount of distortion caused by the lensing in order to estimate the mass of the celestial objects responsible for it: the greater the distortion, the higher the mass. And by comparing the degree of lensing caused by foreground objects with the amount of lensing that the visible matter present in the same region would cause, astronomers can also map the distribution of dark matter within these objects.

Microlensing, which is caused by considerably smaller celestial objects such as stars and planets, enables astronomers to find exoplanets that are in orbit around

**ANYONE CAN
ACCESS HST
OR JWST DATA
ARCHIVED IN
THE MIKULSKI
ARCHIVE
FOR SPACE
TELESCOPES.**

remote stars, such as those around the galactic center. If a star appears precisely behind another star from our perspective, the light from this background star will pass along all sides of the intermediate, or "lensing," star; the lensed star will appear to suddenly brighten to hundreds of times its original brightness. If a planet is in orbit around the lensing star, it will produce another spike in brightness through its own lensing effect, and the planet's presence will be revealed.

Microlensing can also enable astronomers to find rogue planets, or planets that are not gravitationally bound to a star. A rogue planet can be detected if it moves directly in front of a distant star and distorts its light. Its size can be estimated by the duration of the lensing event: the



When the James Webb Space Telescope — seen here as it separated from its rocket — launched in December 2021, it joined the Hubble Space Telescope as a space-based resource for scientists all over the world. A Telescope Allocation Committee reviews proposals for the two telescopes' use each year, choosing programs based on impact and feasibility.
ARIANESPACE, ESA, NASA, CSA, CNES

**LENSING IS
ONLY POSSIBLE
BECAUSE
HIGHLY MASSIVE
OBJECTS DISTORT
THE SPACE-TIME
CONTINUUM
AROUND THEM.**

larger the planet, the longer the distortion.

An exhaustive list of gravitational lensing applications would exceed the space available here, but the above are examples of the common ways in which astronomers can use the space-time-bending properties of matter to both analyze highly massive structures such as galaxy clusters and discover micro-objects that could not be discovered by any other known means.

Edward Herrick-Gleason
*Astronomy Educator, St. John's,
Newfoundland and Labrador*

SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

1. SUNSPOTS BESIDE THE SPIRE

Active region AR 4475, a cluster of sunspots that emerged June 22, 2026, drifts beside the broadcast mast of the Empire State Building. The imager shot a single 1/400-second exposure at f/14 and ISO 640 with a Sony mirrorless camera and zoom lens at 600mm, plus a 2x teleconverter for an effective 1200mm focal length. • *Chirag Upreti*



1

2. BLOWING BUBBLES

The emission nebula Sharpless 2-284 lies roughly 15,000 light-years away in Monoceros, where hot young stars are carving a cavity in the surrounding gas and sculpting dense pillars of dust. The imager collected 23.6 hours of Hubble-palette data with an 11-inch f/2 RASA astrograph. • *Dave Doctor*



2



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3. COSMIC CLIFFS

The Milky Way's bright star fields and dense dust lanes arch above the chalk cliffs of Beachy Head and the English Channel in this wide-field nightscape. The photographer used a Canon DSLR and a 28mm f/1.4 lens to take a tracked vertical panorama of five panels of stacked sky exposures totaling over 24 minutes, about half of it with an H α filter. The foreground comprises a separate five-panel panorama taken with a 14mm f/2.8 lens; this was blended with the sky for the final image. • **Marco Wong**

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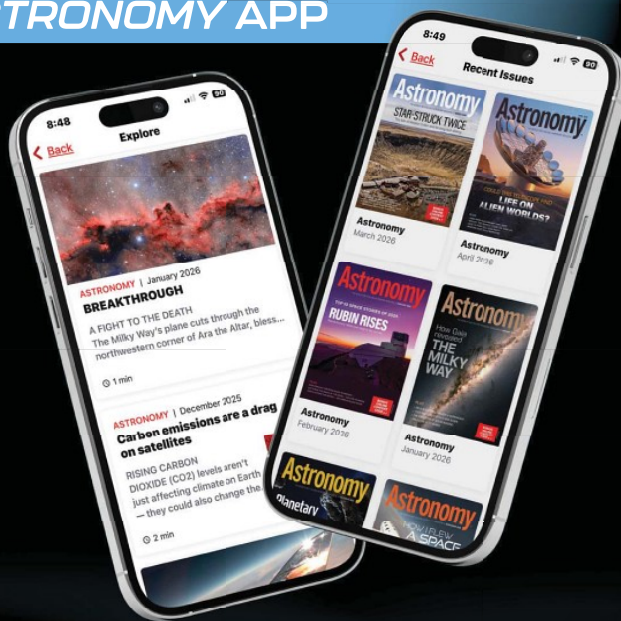
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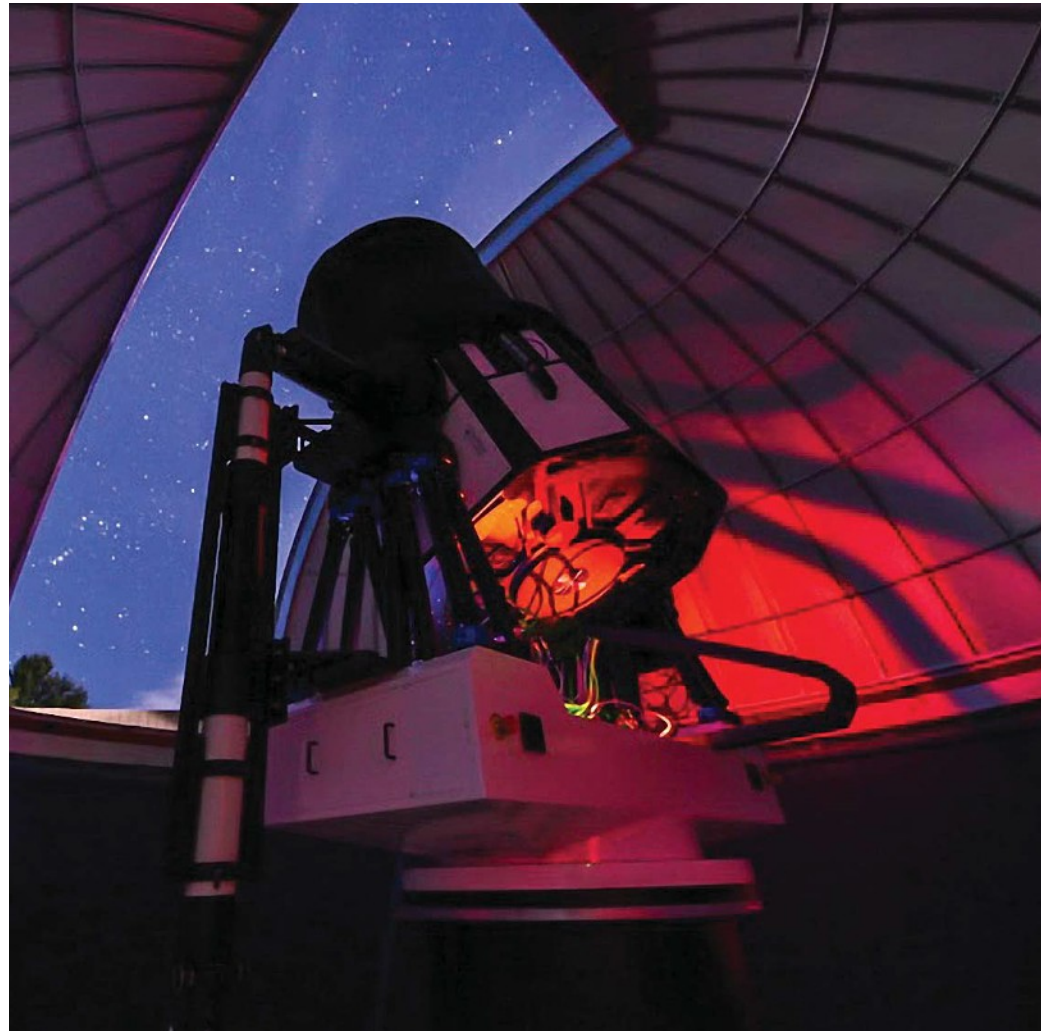


THE UNIVERSE COMES INTO FOCUS

After more than 20 years of planning, construction, and testing, astronomers have officially started the Legacy Survey of Space and Time (LSST). The survey will snap about 1,000 images per night with a 3.2-gigapixel camera — the largest digital camera in the world — attached to the 8.4-meter telescope at the Vera C. Rubin Observatory in Chile. The LSST will observe the entire southern sky every three to four nights, on average, across its 10-year lifetime. The goal: build a high-definition, time-lapse record of the cosmos from the solar system to distant galaxies. This part of the initial image covers about 1.7° by 1.7° centered in northeastern Centaurus, though the left side bleeds into Lupus. The wispy swirls are tenuous clouds of gas and dust known as galactic cirrus, illuminated by the diffuse glow of the Milky Way. NSF-DOE VERA C. RUBIN OBSERVATORY/NOIRLAB/SLAC/AURA

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December 2026

Saturn rules the evening sky

» The early evening sky looks dull at this time of year. Although the tail of Scorpius is disappearing in the west and Orion is just starting to climb in the east, there's not a lot going on in between.

Fortunately, one prominent point of light pierces this relative blandness. It's not a star, though, but a planet: **Saturn**. The ringed world shines at magnitude 0.6 against the backdrop of northwestern Cetus. The planet's westward motion relative to the stars ends Dec. 11 when it resumes its normal eastward motion.

Now two months past opposition, Saturn rides high in the north as darkness falls. It's a great time to observe this stunning world through a telescope. The planet's disk appears 18" across at midmonth while the rings span 41" and incline 6° to our line of sight. Although this is the smallest angle since April, the trend bottoms out in December and the tilt will increase noticeably next year.

After you enjoy the ring system, take a few minutes to look for Saturn's moons. The planet's brightest, 8th-magnitude Titan, appears through any telescope. A trio of 10th-magnitude satellites — Tethys, Dione, and Rhea — show up in 10-centimeter and larger instruments.

If you have clear skies in the hours before dawn Dec. 1, you'll see a tightly packed group of three solar system objects joined by a stellar interloper. The 1st-magnitude star

Regulus in Leo appears dimmest, while Jupiter and Mars lie west and east of the star, respectively, and a waning gibbous Moon stands between the planets. All four appear within 5° of one another.

The gathering's brightest point of light is **Jupiter**. It shines at magnitude -2.2 and stands at the western (leftmost) end of the group.

The giant planet offers a wealth of detail when viewed through a telescope, though you should wait until it climbs well clear of the horizon around the onset of twilight. Jupiter's disk spans 39" and displays a bright equatorial zone sandwiched between two darker belts. Also watch for the planet's four bright Galilean moons, which show up through any scope.

You should have no trouble identifying **Mars**. The magnitude 0.5 world has a distinctive reddish color and contrasts nicely with blue-white Regulus and yellow-white Jupiter.

The Red Planet's disk grows noticeably during December, swelling from 8" to 10" in diameter. That's large enough to reveal some surface markings through a telescope, especially during moments of steady seeing once Mars climbs higher before dawn. A red or orange filter enhances these markings. And because the planet's north pole tilts 23° toward us, you also should see the white north polar cap.

The brightest planet, **Venus**, rises a couple of hours before

the Sun. Although it dims slightly this month, from magnitude -4.9 to magnitude -4.6, it still outshines Jupiter by about 10 times.

Be sure to point your telescope toward Venus to view its large crescent-shaped disk. On Dec. 1, the inner planet appears 39" across and 28 percent lit. By the 31st, it spans 26" and looks nearly half-lit.

You can probably forget about spotting **Mercury** this month. Although it shines brightly on the 1st, at magnitude -0.7, it stands just 4° high a half hour before sunrise. And it only gets closer to the Sun as December progresses.

The starry sky

The late evening sky presents several prominent constellations at this time of the year. Although Crux the Cross is scraping the southern horizon, plenty of well-known star patterns help compensate. Canis Major the Big Dog, Taurus the Bull, and Orion the Hunter spread out nicely above the northeastern horizon. All three are among the 48 original constellations named in Ptolemy's epic treatise, the *Almagest*.

Another of those 48 is Eridanus the River. This long, meandering constellation begins near Orion's Rigel and ends near magnitude 0.5 Achernar, the River's brightest star. Eridanus features the greatest north-south extent of any constellation. Its northern limit lies just north of the

celestial equator while its southern limit extends a degree or so south of Achernar's declination of -57°.

Some early astronomers claimed that Eridanus represented the Nile River, but later researchers have disputed this. The constellation's name comes from *Eridanos*, a Greek word for a mythological river, although Ptolemy called it *Potamos*.

Italy's Po River is a strong contender for Eridanus' inspiration. British author Robert Brown claimed as much in his 1883 work *Eridanus: River and Constellation*. But he also acknowledged others who disagreed.

The ancient Greek scholar Eratosthenes — the man who first calculated Earth's circumference — considered the Nile as the source of Eridanus, and commented that the Nile is the only major river that runs south to north. Yet most astronomers accept the idea that Eridanus runs from north to south in the sky.

Regardless of what inspired the constellation, there's no denying that it makes a lovely sight on a moonless December night far from the lights of the city. As Richard Hinkley Allen wrote in *Star Names: Their Lore and Meaning*, the constellation divides into two streams, the northern one runs from near Rigel to the paws of Cetus, and the southern one extends to just past Achernar. See if you can trace the River's entire extent on the next clear night. ♀

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south 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:

11 P.M. December 1
10 P.M. December 15
9 P.M. December 31

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

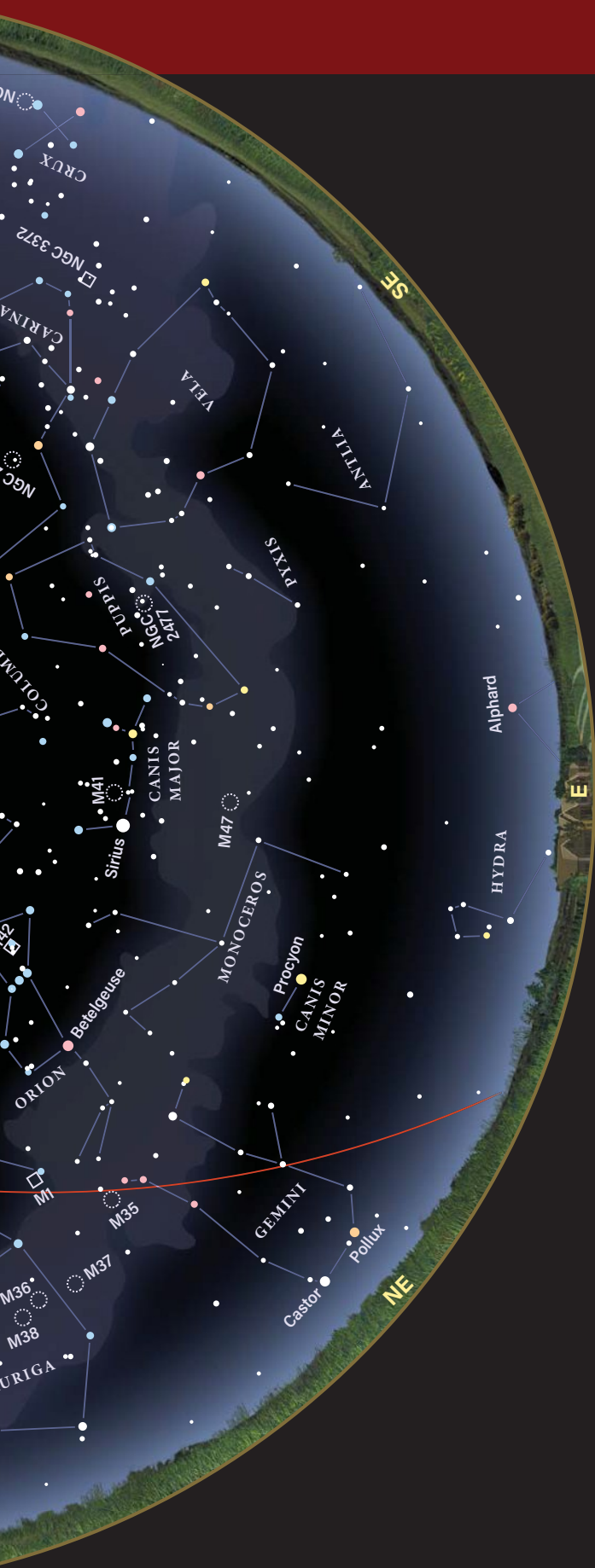
STAR COLORS

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.



DECEMBER 2026

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	 30	 31		

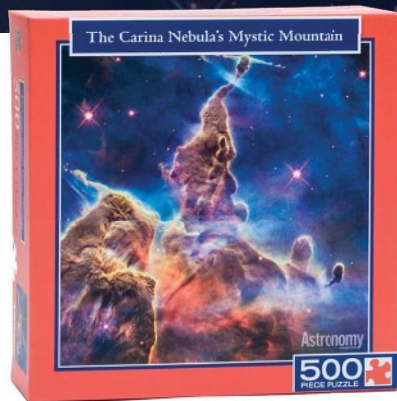
ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

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

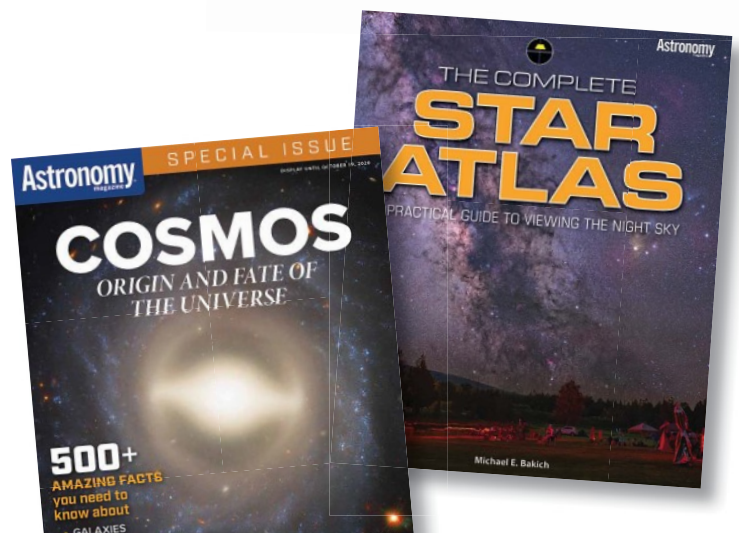
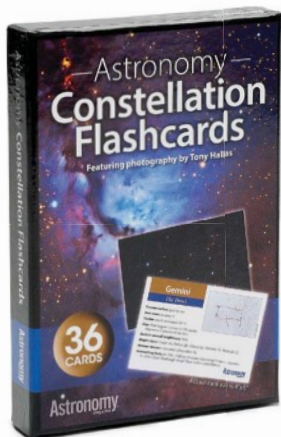
- Last Quarter Moon occurs at 6h09m UT
Asteroid Pallas is stationary, 12h UT
- Asteroid Vesta is stationary, 16h UT
- The Moon passes 7° south of Venus, 11h UT
-  New Moon occurs at 0h52m UT
- The Moon is at apogee (406,419 kilometers from Earth), 6h45m UT
Saturn is stationary, 23h UT
- Mercury passes 5° north of Antares, 13h UT
- Neptune is stationary, 11h UT
Jupiter is stationary, 12h UT
- Geminid meteor shower peaks
-  First Quarter Moon occurs at 5h43m UT
The Moon passes 5° north of Neptune, 21h UT
- The Moon passes 7° north of Saturn, 10h UT
- Summer solstice occurs at 20h50m UT
- The Moon passes 5° north of Uranus, 4h UT
-  Full Moon occurs at 1h28m UT
The Moon is at perigee (356,650 kilometers from Earth), 8h31m UT
- The Moon passes 1.5° south of Jupiter, 18h UT
The Moon passes 1.4° south of Regulus, 23h UT
- The Moon passes 5° south of Mars, 18h UT
-  Last Quarter Moon occurs at 18h59m UT

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