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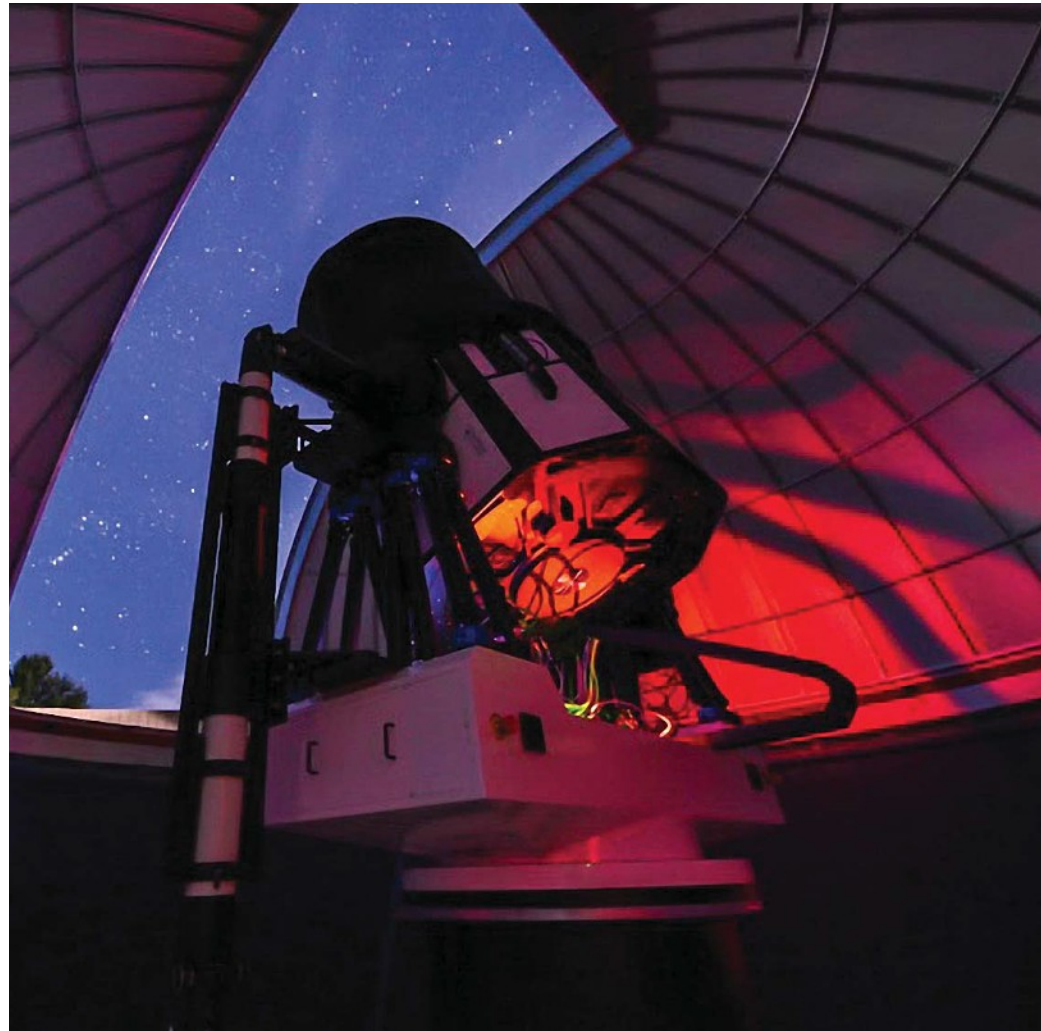


THE ARTEMIS ISSUE

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ON THE COVER

The vibrant crescent Earth sets behind the cratered limb of the Moon, captured by the Artemis 2 crew on April 6 during their lunar flyby. NASA

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JWST and Hubble observe nearly 9,000 star clusters and learn which achieve maturity first. **RICHARD TALCOTT**

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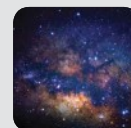
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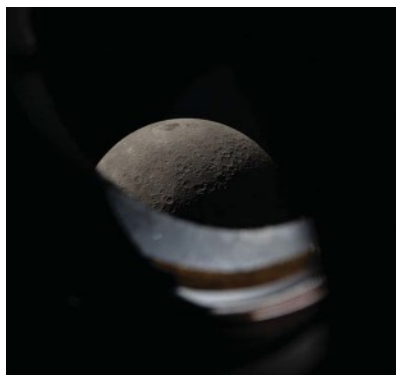
A daily digest of celestial events.



Ask Astro Archives

Answers to all your cosmic questions.

Artemis inspiration



The Moon lies above a windowsill of the Orion crew capsule during the Artemis 2 lunar flyby on April 6, 2026. NASA



The Artemis 2 mission was billed in part as a test flight, intended to gather data on the craft, from head to heat shield. In that, it was a success, marking a key milestone for the beleaguered Artemis program.

But it also had a much broader impact, inspiring generations around the world. The crew's voices radiated with the joy of scientific exploration. And when we saw the extraordinary images that they took, it was easier to understand how they must have felt as they took in deep-space vistas that humans had never before seen. You'll find all of this and more captured in Christopher Cokinos' cover story (page 14), which

anchors our coverage of Artemis in this special issue.

Since the mission, I've lost count of the people who have told me that Artemis 2 rekindled not only their interest in space exploration, but also their *optimism* for it. Spaceflight activities in low Earth orbit have leaped forward over the past decade, driven by SpaceX and its commercial competitors around the world. But for many, the ambition of Artemis 2 — sending a human crew to the Moon as part of a NASA-led international coalition — was an even more powerful reminder of what we can achieve when we come together to tackle colossal challenges.

Before the Artemis program can take the next step of returning humans to the lunar surface, it will need to solve a daunting challenge: in-orbit refueling. The long-term ambitions of the U.S. and its partners include a permanent lunar base; to build it, landers must be capable of ferrying large payloads. And no such lander currently on the drawing board can travel to the Moon without first needing to refuel in Earth orbit. On page 36, Brooks Mendenhall's story and Roen Kelly's illustrations detail why this is one of the toughest problems in spaceflight, and how the industry is seeking to solve it.

I hope you enjoy the issue.

Mark Zastrow
Editor-in-Chief



CHIEF ZENG WANG

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Aurora australis dances over the Indian Ocean in this shot taken from the International Space Station on June 12, 2025. NASA/NICHOLE AYERS

→ We welcome your comments via email to astronomyeditorial@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.

Aurora innovation

I loved the article on the history and physics of the aurora (“The science and lore of aurorae,” May 2026). One thing not mentioned, though, was aurorae’s ability to reflect radio waves, discovered in the 1930s. Around that time, amateur radio operators also noticed that signals were stronger when

everyone pointed their beam antennas north. These radio reflections were and are highly distorted for voice because of the undulating nature of the aurora, but amateur operators still use them to extend their VHF/UHF signals far beyond simple terrestrial contact. —**Bill Gerhold**, Hewitt, New Jersey

A unique existence

Two articles under the rubric “Is anyone out there?” (May 2026) discuss that subject in the context of SETI. The apparent puzzle posited by the Fermi Paradox and the Great Silence are addressed. The relevant subject of the appearance of technologically advanced life in light of

evolutionary biology and the story of such development on Planet Earth is absent, though. A careful analysis of the improbable contingencies leading to the appearance of *Homo sapiens* lends support to the likelihood of us being alone, at the very least, within our galaxy. Nevertheless, I tend to side with the continuance of SETI if for no other reason than to confirm that assumption of uniqueness. —**Pedro Lilienfeld**, Lexington, Massachusetts

From the editors: You are correct that we do somewhat gloss over this concept, called the Great Filter, in our articles in the May issue. For any readers interested in learning more, check out this article on [Astronomy.com](https://www.astronomy.com) (QR code at right), which explores the concept in further detail.



Errata

On page 20 of the May 2026 issue, Earth’s rotation should have been depicted as counterclockwise, the same direction as its orbit. Also on page 20, the year Chuck Yeager broke the sound barrier in his Bell X-1 jet for the first time was incorrect; the historic flight occurred in 1947, not 1946.

Around Here, Adventure Works The Night Shift

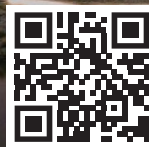


Out here, darkness isn’t empty—it’s alive.

As the last light fades, the sky fills with something bigger: stars stretching horizon to horizon, constellations sharp and clear, silence you can actually hear.

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Gaze and Be Amazed

SNAPSHOT

CAUGHT IN THE MIDDLE

A dusty, post-starburst galaxy hints at a messy past.

Look closely at this Hubble photo of NGC 1266, a lenticular galaxy whose structure appears not like a pinwheel-shaped spiral or a fuzzy elliptical, but somewhere in between. Lenticulars have a bright central nucleus but no spiral arms — although this detailed image certainly hints that such structure could be lurking in NGC 1266's disk.

More prominent, however, are the red-brown filaments of dust partially blocking our view of the galaxy's center. That region hides an actively feeding supermassive black hole, which astronomers think may be fueled by material stirred up when NGC 1266 underwent a merger half a billion years ago. Although the merger triggered a round of intense star formation, outflows from the black hole have since heated or blown away much of the material available to birth new stars, bringing star production in the outer regions of NGC 1266 to a halt. NGC 1266 is now helping scientists better understand the processes that cause large-scale changes as galaxies age.

— ALISON KLESMAN



HOT BYTES



ON AIR

Observations of (612533) 2002 XV₉₃ occulting a star indicate the small, rocky outer solar system object hosts a thin atmosphere, possibly created by outgassing or a recent cometary impact.



DISK DESTROYERS

New simulations suggest rotating galactic disks are destroyed in mergers — and that the Milky Way's current disk is not its first. Instead, it is a newer structure that formed following our galaxy's last destructive merger.

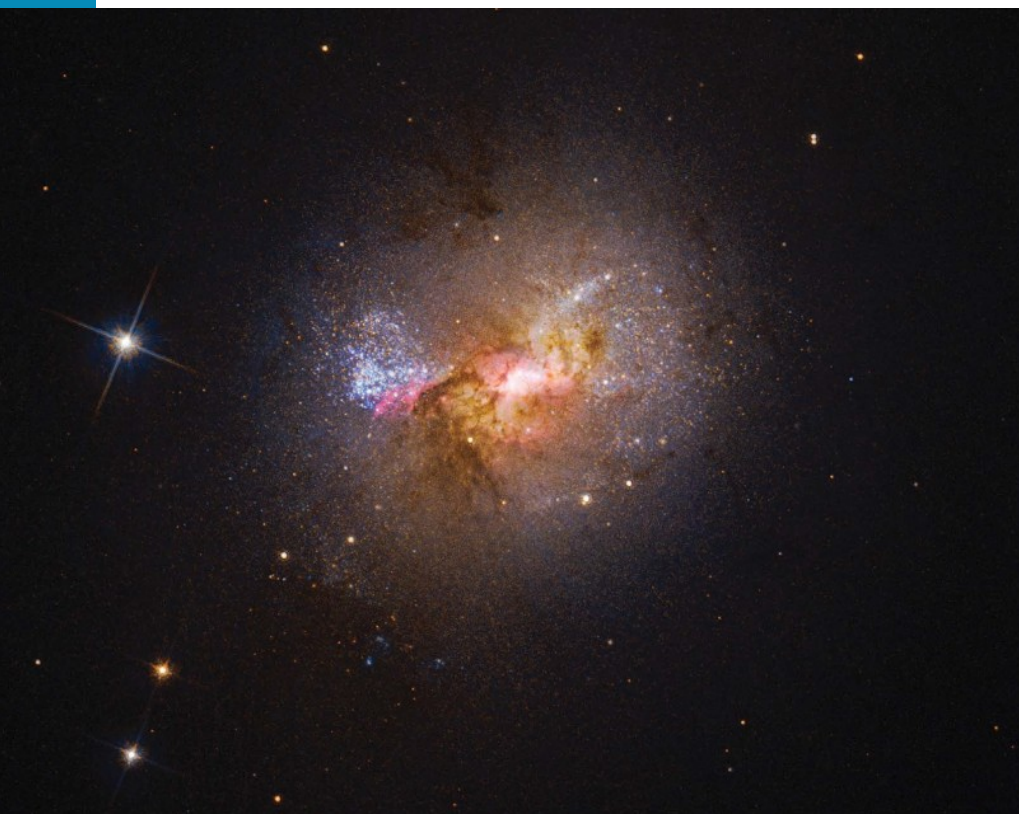


NEED A BOOST?

Just seven months after NASA contracted Katalyst Space Technologies to boost the orbit of the Neil Gehrels Swift Observatory, which is sinking into the atmosphere, its robotic craft completed all pre-launch testing May 4.

NEW CENSUS UNCOVERS UNSEEN BLACK HOLES IN DWARF GALAXIES

More feeding black holes were found in small galaxies than ever before, with an uptick in activity as galaxy mass increases.



» New methods of looking for active galactic nuclei (AGN) — galaxies powered by a feeding central black hole — have found that more dwarf galaxies host active black holes than previously thought. The work also shows that as galaxy mass increases, the number of galaxies hosting AGN rises, with a sharp upturn at intermediate-mass, Milky Way-like galaxies.

The findings were presented by study leader Mugdha Polimera, a data pipeline developer at the Harvard-Smithsonian Center for Astrophysics,

BRIGHT CENTER. Dwarf galaxy Henize 2-10 houses an active central black hole. However, the question of how many dwarf galaxies host central black holes remains unanswered. NASA, ESA, ZACHARY SCHUTTE (XGI), AMY REINES (XGI); IMAGE PROCESSING: ALYSSA PAGAN (STSCI)

Jan. 8 at the 247th meeting of the American Astronomical Society.

FINDING AGN

All large galaxies and at least some dwarf galaxies host a central super-massive black hole with millions to billions of solar masses. But spotting black hole activity amidst the glare of stars forming in the galaxy around it is a challenge, particularly in dwarf

galaxies, where rapid star formation is common. Standard searches examine a galaxy's light for strong oxygen and nitrogen emission. This is a hallmark of an AGN because high energy input — like from a feeding black hole — is required to cause these gases to shine at certain wavelengths.

But this emission depends heavily on the amount of so-called metals (elements heavier than helium) a galaxy contains. Metal-poor dwarf galaxies often show only weak nitrogen emission, so astronomers might overlook an AGN there. In 2022, Polimera, then a graduate student at the University of North Carolina at Chapel Hill (UNC), led development of a new approach to identify AGN in dwarf galaxies using emission from sulfur and neutral oxygen, which remains strong even in metal-poor dwarfs.

UPDATED COUNTS

Polimera's team analyzed 8,000 galaxies from the RESolved Spectroscopy Of a Local Volume (RESOLVE) and Environmental CONtext (ECO) surveys using the new method. They uncovered about five times more AGN in dwarf galaxies than earlier studies had seen. Their results suggest that 2% to 5% of dwarf galaxies host an AGN and 16% to 27% of "transitional" galaxies — those between dwarfs and intermediate-sized galaxies, like our own Milky Way — contain AGN. The fraction rises to 20% to 48% in giant galaxies.

The broad ranges reflect detection uncertainties: Even with improved methods, star formation and black hole activity can blur together in a galaxy's signal. Nonetheless, the increase in AGN

in Milky Way-like galaxies versus dwarfs is clear — but the reason why is not.

One possibility is that episodes of intense star formation — common in dwarf galaxies — unleash strong winds and supernova explosions that push gas out of the galaxy's center. The lack of gas leaves the black hole without fuel.

Another reason could be that as galaxies grow, they become better hosts to AGN. Study co-author Sheila Kannappan, who led the RESOLVE and ECO surveys at UNC, explains that the rise in AGN at intermediate masses coincides with a shift from dwarf galaxies, which have little structure, to well-ordered galaxies with bulges and spiral arms. In particular, the formation of bulges, which concentrate gas in the galaxy's center, may be making it easier to form or detect active black holes, "but we really don't understand the details yet," she says.

Observational biases are also a likely factor. "The diagnostics may not work in the same way in the low-mass galaxies as they do on the massive galaxies scale," notes Ragadeepika Pucha, a postdoctoral researcher at the University of Utah who

was not involved in the study. Perhaps there are different conditions at play in smaller galaxies that could affect the reliability of traditional detection methods.

Additionally, the survey's method was to observe the very center of a galaxy. That means they could be missing off-center AGN, says Kannappan.

WORKING BACKWARD

Astronomers still don't know how super-massive black holes form. One possibility is that dwarf galaxies with smaller central black holes merge over time, gradually building up into larger galaxies with the monster black holes seen today.

Understanding how many lower-mass galaxies host black holes is thus crucial for testing current formation scenarios. Using the number of galaxies with AGN as a baseline, researchers can work backward to determine which formation mechanisms are more likely. The new census thus provides a critical lower limit for models, while also deepening our understanding of the processes that dominate lower-mass galaxies.

— SHREEJAYA KARANATHA

BY THE LIGHT OF THE MOON

A decade of tracking red-necked nightjars in Spain found that the amount of moonlight governs many major aspects of the migratory birds' lives — when they hunt, migrate, and hatch — raising further alarms about the effects of light pollution on nocturnal species.

CLOSE TO HOME

Analysis of meteorites and computer models of the early solar system suggest that at least some of Earth's nitrogen and phosphorus — essential for life — likely originated nearby, not only in the outer solar system, as previously thought.

PSYCHE PASSES MARS

NASA's Psyche spacecraft successfully completed a Mars gravity assist May 15 to gain speed and redirect its flight path toward the metal-rich asteroid 16 Psyche, where it will arrive in summer 2029.

DRINK UP!

Researchers developed six drink recipes in three flavors for astronauts that deliver up to one-third of the daily recommended omega-3 intake per serving. They are designed to combat bone and muscle loss on long-duration space missions.

SWALLOWED WHOLE

Using data from Gaia, astronomers found lithium in six red dwarf stars — an element that should be absent in their atmospheres. Its presence suggests each star engulfed one or more of its rocky Earth-like planets early in their formation.

ANSWERS IN ICE

A study of ancient Antarctic ice and even older sediment samples shows that Earth is accumulating the radioactive isotope iron-60 as it travels through the Local Interstellar Cloud. The ice cores date to when we entered the cloud and explain how the material has been reaching our planet with no nearby supernovae to account for it.

— BROOKS MENDENHALL

JUNO'S COLORFUL JUPITER

THE JUNOCAM visible-light camera on NASA's Juno mission captured this enhanced-color shot of Jupiter's northern hemisphere May 12, 2024, during the spacecraft's 61st flyby of the gas giant. Data from JunoCam was processed by citizen scientist Gary Eason to bring out detail and enhance color differences.

This shot in particular shows a folded filamentary region. These occur at mid to high latitudes, where the horizontally blowing winds that dominate Jupiter's lower latitudes break down. The resulting turbulence creates rapidly changing clouds and storms. Studying these regions with Juno allows scientists to build up a three-dimensional picture of Jupiter's atmosphere and learn more about the dynamic processes that rule it. — A.K.



NASA/JPL-CALTECH/SWRI/MSSS; IMAGE PROCESSING BY GARY EASON © CC BY

Sunspots increase falling space junk



DRIFTING DEBRIS. Hundreds of space junk fragments float in orbit in this composite of 250 photographs of real debris. A new study finds that as the Sun approaches solar maximum, these objects lose altitude faster. MAX ALEXANDER/STEVE KELLY/ESA

A STUDY PUBLISHED May 6 in *Frontiers in Astronomy and Space Sciences* found that space junk falls to Earth faster when the Sun is more active — specifically, when activity hits roughly two-thirds of its peak. The work is the first to identify the specific point in the 11-year solar cycle at which orbital decay rates accelerate — and to track how much faster debris falls once that threshold is crossed.

The researchers used orbital positions from the Space-Track database — a catalog of every tracked object in orbit stretching back to the early Space Age — pulling data going back to 1986 for 17 objects launched in the 1960s and still in orbit today. A pattern emerged across all 17 objects: Orbital decay doesn't proceed at a steady rate. Near solar minimum, when there are few sunspots, debris gradually drifts downward. Once sunspot numbers climb past roughly 67% to 75% of their cycle maximum, the descent steepens, shifting into a faster decline that

persists through solar maximum before easing again as the cycle winds down. The behavior repeated over all three cycles in the data.

Near solar maximum, the Sun emits intense ultraviolet radiation along with streams of charged particles. These heat Earth's thermosphere — the atmospheric layer about 62 to 620 miles (100 to 1,000 kilometers) up — and pushes denser air higher, increasing the drag on anything in low Earth orbit, where most satellites and debris reside. More drag means orbits decay faster.

The findings add another variable to the already complex problem of orbital debris removal. An object that poses a manageable risk near solar minimum may become a higher priority target as solar maximum approaches and its orbit decays faster than expected. Knowing when that acceleration kicks in — and by how much — gives both satellite operators and debris trackers a clearer picture of orbit. — B.M.

NASA REVEALS MOON BASE PLANS

DURING A MAY 26 press conference, NASA offered the most detailed look yet into Phase One of the Moon Base plan the agency first revealed in March. The long-term plan involves three phases, beginning with robotic scouts this year, semipermanent habitats by 2029, and ultimately a permanent base by 2032. It's a big lift and a tight timeline.

Phase One is chiefly reconnaissance — no permanent infrastructure, only robots and short-duration crew conducting technology tests and surveys. Excluding the crewed Artemis missions, Phase One consists of 25 missions and 21 landings, all uncrewed. Three are scheduled before the end of 2026. The first mission, Moon Base 1, targets a fall launch, with Blue Origin's Blue Moon Mark 1 Endurance lander delivering science payloads to Shackleton Connecting Ridge near the lunar south pole. Moon Base 2 follows with Astrobotic's Griffin lander headed to the south pole aboard a SpaceX Falcon Heavy. The mission will be the company's second lunar attempt after the Peregrine propellant failure in 2024. Moon Base 3 will send Intuitive Machines' Nova-C Trinity lander

to study lunar swirls and surface evolution.

During Phase One, NASA is also planning to launch two Lunar Terrain Vehicles (LTVs) by 2028. Both are next-generation Moon buggies capable of carrying crew across the south pole terrain but also of operating autonomously before astronauts arrive on Artemis 4. NASA has awarded contracts of about \$220 million each to two companies, Astrolab and Lunar Outpost. Both will adapt their previous designs to meet NASA's requirements.



A MAN, A PLAN, A MOON BASE.

NASA Administrator Jared Isaacman speaks at the May 26 press conference at NASA headquarters in Washington, D.C. NASA/AUBREY GEMIGNANI

Phase Two, beginning around 2029, introduces semipermanent habitats and infrastructure. Phase Three aims to make that presence permanent by 2032 with a fully operational base.

The roadmap is set. Now comes the hard part, said Carlos Garcia-Galan, Moon Base program executive, during the conference, "which is delivering on time and having successful missions back to back." — B.M.



GONE, BUT NOT FORGOTTEN. NASA's MAVEN spacecraft orbits Mars in this artist's depiction. Before going silent in December 2025, the orbiter spent more than 11 years studying how Mars lost its atmosphere to space. NASA/GODDARD/UNIVERSITY OF COLORADO/LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS

MAVEN MARS ORBITER DECOMMISSIONED

AT A JUNE 3 media conference, NASA officials announced the agency had ended its attempts to reconnect with the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft. NASA lost contact with the spacecraft on Dec. 6, 2025, as it passed behind Mars. An anomaly review board, assembled in February, determined in June that MAVEN cannot be recovered. As a result, NASA began

decommissioning the orbiter, closing the book on a mission that spent over a decade studying how Mars lost its atmosphere.

Although NASA never regained contact with MAVEN, a radio science experiment already running on Dec. 6 meant ground receivers had been recording MAVEN's transmissions. Jet Propulsion Laboratory engineers went back to those recordings and managed to extract bits of usable

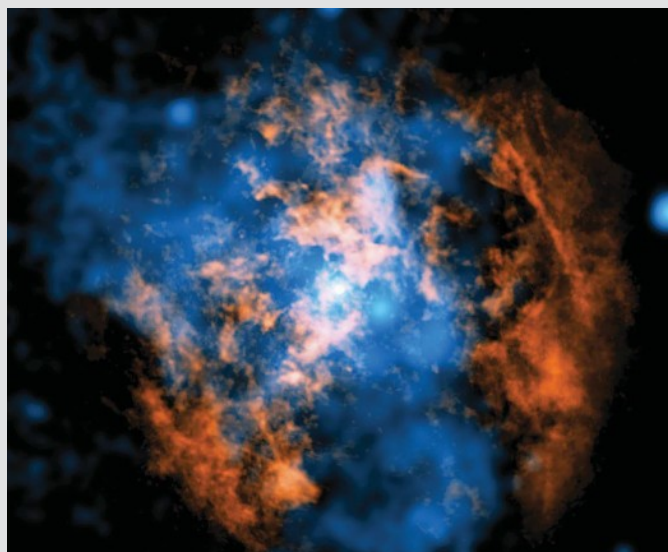
telemetry data. The data revealed that when MAVEN came back around from behind Mars, it was spinning out of control at roughly 2.7 revolutions per minute.

The board believes the uncontrolled spin kept the solar panels from charging the craft's batteries, which drained over several hours until the radio system lost power entirely. Why the spacecraft started spinning in the first place remains unknown. The board's full root-cause report is expected later this year.

Launched in November 2013 and operational since September 2014, MAVEN completed a one-year primary mission in 2015 and continued operating through five mission extensions over the following decade. MAVEN was the first NASA mission designed explicitly to study the martian atmosphere. Its central goal was to help scientists understand one of planetary science's biggest mysteries: How did Mars, once seemingly warm and wet, become the cold, dry world it is today? Throughout the mission, the science team behind MAVEN produced more than 800 publications, with more still on the way. — B.M.

ALMA uncovers black hole's missing wind

OUR MILKY WAY GALAXY contains a supermassive black hole weighing some 4 million solar masses, called Sagittarius A* (Sgr A*). Although it is not highly active, Sgr A* is still slowly consuming nearby dust and gas — and black holes are notoriously messy eaters. This process should produce a wind flowing out from Sgr A*, but evidence of it had never been seen until astronomers mapped the cold gas in the center of our galaxy using five years of data from the Atacama Large Millimeter/submillimeter Array (ALMA). Shown in orange, the ALMA data trace cold carbon monoxide in a 3-light-year-wide region around Sgr A*, whose position is marked by a white dot. The new map is some 80 times sharper and 100 times deeper than previous work. In blue is X-ray data from the Chandra X-ray Observatory, showing hot gas. The hot gas fills a cavity devoid of cold gas, which astronomers now think was carved by the wind from Sgr A*. — A.K.

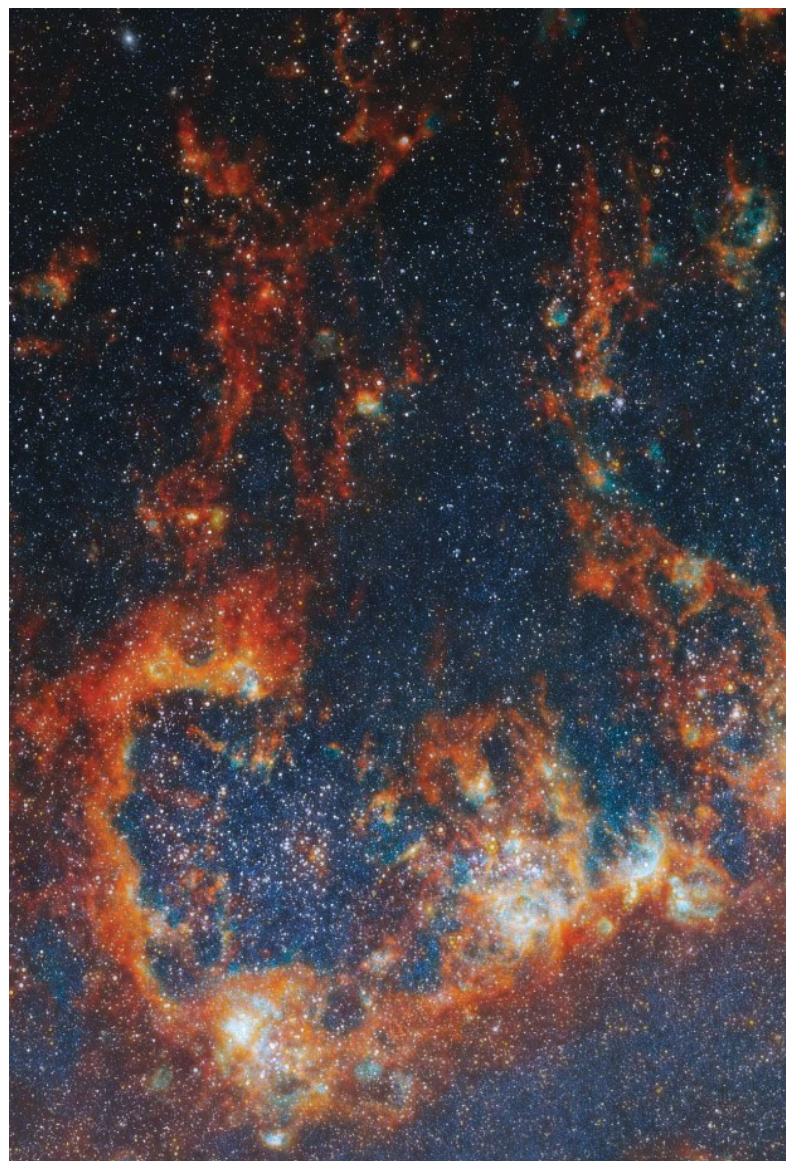


X-RAY: NASA/CXC/NORTHWESTERN UNIV./M. GORSKI; RADIO: ESO/NAOJ/NRAO/ALMA; IMAGE PROCESSING: NASA/CXC/SAO/K. ARCAD AND P. EDMONDS

MASSIVE CLUSTERS DRIVE GALAXY EVOLUTION

JWST and Hubble observe nearly 9,000 star clusters and learn which reach maturity first.

BY RICHARD TALCOTT



ASTRONOMERS understand the basics of star formation. It starts in giant molecular clouds when an event — perhaps a nearby supernova or a collision with another cloud — triggers a high-density region to collapse under the force of gravity. The region fragments into individual pockets that eventually contract into stars within a cluster.

The more massive stars emit copious amounts of high-energy ultraviolet radiation and fierce stellar winds, and they eventually explode as supernovae. These forces — collectively known as stellar feedback — disperse the cluster's remaining gas well before much of it can be incorporated into new suns. Yet how long this process takes and how it depends on a cluster's intrinsic properties have remained open questions. And

computer simulations struggle to replicate what astronomers see.

A massive survey

Researchers have now turned the powerful eye of the James Webb Space Telescope (JWST) on thousands of clusters in four nearby galaxies to answer these questions. They find that the most massive clusters emerge from their natal clouds and unleash a torrent of ultraviolet light in about 5 million years, while less massive ones take between 7 million and 8 million years. Heavyweight clusters thus have a much bigger and earlier impact on their surroundings and how their host galaxies evolve.

Despite JWST's unique abilities, scientists also needed to use archival images from the Hubble Space Telescope.

JWST's infrared vision penetrates the gas and dust surrounding the youngest clusters, allowing researchers to view those still totally cloaked in their formative material and those starting to emerge from their nurseries. Hubble, which records visible light, targets mature clusters clear of gas and dust. By studying the spectral fingerprints of the clusters, the astronomers estimated the mass and age of each.

The team focused on four galaxies — the Whirlpool Galaxy (M51), the Southern Pinwheel Galaxy (M83), the Phantom Galaxy (M74), and NGC 4449 — each of which provides a unique perspective. Although the Milky Way might seem a more promising target, Earth and most of our galaxy's young clusters reside in its disk, hindering clear views.



The chosen four are close enough to study in exquisite detail but far enough away that a multitude of clusters appear in every image.

The prominent spiral arms of the Whirlpool are chock-full of stellar nurseries and the star clusters they give birth to. It lies about 27 million light-years from Earth in the constellation Canes Venatici. The Southern Pinwheel boasts an unusually high rate of star formation and has witnessed six supernovae in the past 105 years. It resides 15 million light-years away in Hydra and is one of the closest and brightest barred spirals.

The Phantom is a spiral galaxy located 32 million light-years from Earth. It appears face-on to us and thus allows astronomers to study its entire disk. An intense burst of star formation

and totally different structure set the dwarf irregular galaxy NGC 4449 apart from the others. It lies 12 million light-years away in Canes Venatici.

All told, the team studied 8,897 clusters. The survey comes as part of Feedback in Emerging extrAGalactic Star clusTers (FEAST), a JWST program designed to investigate stellar feedback and the emergence of clusters in nearby galaxies. FEAST principal investigator Angela Adamo of Stockholm University and the Oskar Klein Centre in Sweden and her team reported their results in the May 6 issue of *Nature Astronomy*.

Planet perspective

Despite the focus on stars, the new observations also affect theories of planet formation. Planets form in the

One of the Whirlpool Galaxy's spiral arms resolves into dozens of stellar nurseries that one day will produce massive open star clusters. Each of the nascent clusters spans up to 100 light-years. This JWST infrared image, combined with Hubble observations at optical wavelengths, shows that more massive clusters emerge from their birth clouds more quickly. ESA/WEBB, NASA & CSA, A. PEDRINI, A. ADAMO (STOCKHOLM UNIVERSITY), AND THE FEAST JWST TEAM

disks of gas and dust surrounding newborn stars. Intense ultraviolet radiation from nearby suns erodes these disks, and the faster this happens, the smaller any resulting planets will be. This makes it less likely that gas giant worlds, which appear to be crucial in forging planetary systems like ours, will form in the most massive clusters. »

Contributing Editor **Richard Talcott** wrote about JWST's observations of protostar EC 53 and the formation of silicate crystals in the August issue.



ARTEMIS 2 BRINGS BACK MOON JOY

After a long road to launch, Artemis 2 was a rousing success that captivated the world for 10 days.

BY CHRISTOPHER COKINOS

Artemis 2 carried four astronauts around the farside of the Moon on April 6 — the first time humans had made the trip in more than 50 years. A photo from that flyby shows the spacecraft itself, lit by the Sun, with the Moon in the foreground and the much more distant crescent Earth floating off the lunar limb. NASA



APOLLO 17, our last crewed lunar mission, was in 1972. It ended the Apollo era. Those who witnessed it have waited decades to see humans return to the Moon. And those who were born after or were too young to recall have waited their entire lives.

The waiting ended this year. For 10 days in April, the Moon again loomed large in wider human consciousness, its intensely cratered surface and vast volcanic plains contrasting with a dazzling blue-green Earth in images and descriptions shared by the crew of Artemis 2.

The mission sent Commander Reid Wiseman, Pilot Victor Glover, Mission Specialist Christina Koch, and Mission Specialist Jeremy Hansen around the Moon on the first crewed test flight of NASA's deep-space Orion capsule and the European Space Agency's (ESA) service module. The crew included the first woman (Koch), the first Black astronaut (Glover), and the first non-U.S. national (Hansen, of the Canadian Space Agency) to leave Earth orbit.

The mission was nearly flawless. The crew checked out systems on the capsule they named *Integrity*, performed lunar observations, and even ran medical experiments. Flying farther than any humans before, Artemis 2 begins our next age of exploration, back to the Moon — “this time ... to stay,” according to NASA Administrator Jared Isaacman — and onward to Mars.

Rhyming with history

Mark Twain is apocryphally credited with saying that “history doesn’t repeat itself, but it often rhymes.” Regardless of who originated the quote, Artemis 2 embodies it, drawing uncanny parallels with humanity’s first crewed moonshot, Apollo 8. Both missions launched during

times of roiling civil unrest, political violence, global uncertainty, and an unpopular U.S. war.

In 1968, Apollo 8 sent three astronauts to the Moon for the first time, beating the Soviets there and proving the safety of the spacecraft. Apollo 8 orbited our companion world, photographed the iconic “Earthrise,” and read lines from the biblical book of Genesis to a billion people around the world on Christmas Eve. One American sent NASA a message saying the mission had “saved 1968.”

Like Apollo 8, Artemis 2 fascinated people around the world, with tens of millions of social media engagements, according to an article on the business site Fast Company, citing Muck Rack and Sprout Social. TV viewership of the launch was

TOP: A joyful crowd watches as Artemis 2 lifts off, many filming or photographing the momentous return of humanity to the Moon on their smartphones. RIGHT: Artemis 2 launches from Launch Complex 39B at NASA's Kennedy Space Center on April 1, headed for the Moon, as birds also take to the sky in the foreground. NASA/KEEGAN BARBER (2)







nearly 20 million on major networks, and polls showed that around 70% to 80% of the U.S. public was aware of the mission.

That awareness was aided by the crew members themselves. Diverse, eloquent, and open-hearted, the Artemis 2 astronauts had intensive training in lunar science (unlike Apollo 8) as well as a strong appreciation for the Moon's humanistic and cultural dimensions. That came through loud and clear: In response to Wiseman's exclamation during the flight that the Moon's beauty was "absolutely unbelievable," capsule communicator Jacki Mahaffey laughed, saying, "Copy, Moon joy."

Moon joy begins

But on April 1, the tone was much more serious.

Artemis 2 would be only the second launch of the controversial Space Launch System (SLS) rocket. SLS took years longer than expected to develop. The cost overrun is at least 20% and perhaps twice that. Each launch is more than \$4 billion a pop. While commercial companies are developing and using reusable launch vehicles, SLS has a nonreusable liquid-fuel core stage and space shuttle-era tech engines and solid rocket boosters (SRBs) that break up in the atmosphere and fall into the ocean after every launch.

The rocket had flown once before, when Artemis 1 launched after several delays in November 2022. It worked, though, and sent an uncrewed capsule to the Moon. This time, SLS had four humans on top of its 322-foot (98 meters) stack, standing higher than the Statue of Liberty and about 40 feet (12 m) shy of the height of the Apollo-era Saturn V.

Earlier launch opportunities had been marred by liquid hydrogen leaks and pressurization problems. But when the April 1 launch window opened at 6:24 P.M. EDT, NASA encountered only two small issues: one involving communications, the other a battery, both related to systems that would protect the crew and public in case the SLS malfunctioned. They were quickly resolved.

In the cool, breezy evening air, spectators waited. Nearly 350,000 people

gathered along roads, in parks, or on the beach not far from Cape Canaveral. They watched beside rows of seagrass and under palm trees. Inland, Orlando residents watched from backyards and on top of parking garages.

Along the causeway to Kennedy Space Center, nearly 100 buses had disgorged agency guests (including the author), who bided their time with books, conversation, and card games.

They were all struck with awe when Artemis 2 lifted off at 6:35 P.M. EDT.

Sudden squalls of steam clouds boiled up as the rocket's exhaust superheated water released to dampen the violent vibrations at Launch Complex 39B. Soundlessly, a gray-white thunderhead extruded from the ground, as if in fast-forward. Bubbling orange-white flames gushed out of the SRBs like waterfalls made of fire. The world's most powerful operational rocket — with nearly 9 million pounds (4.1 million kilograms) of thrust, more than the legendary Saturn V — was on its way.

The crowd erupted in collective celebration, holding up smartphones, looking through binoculars, or just staring with teary eyes. There were chants, there were embraces.

In under 10 seconds, SLS had cleared the tower — about the time it took a Saturn V to develop enough thrust to even *begin* liftoff. Lit by the setting Sun on one side, shadowed on the other, the exhaust grew like a tapered pyramid of cloud.

Audible to those on the causeway, a loudspeaker crackled with calls to and from the crew, as Artemis 2 rose into a pale blue sky of thin, scattered clouds. When sound caught up with light, a low, thrumming rumble passed quickly, like a distant earthquake, replaced by a high-up pop-pop-pop cracking like gunshots or a backfiring Apollo-era muscle car.

At roughly two minutes after liftoff, the SRBs were jettisoned. They fell like two icicles away from the main stage, now powered by its four RS-25 engines. The Orion capsule fairing was next to separate, and then, like flaring fireworks, the abort rocket shot off. The rocket was traveling at more than 18,500 mph (29,000 km/h) when the core stage shut down. Wind sheared the rocket's dragon tail and, barely visible from the ground, Artemis 2 was on its way.

Artemis 2 saw the crescent Earth set along the rugged lunar limb at 6:41 P.M. EDT on April 6. The breathtaking image is reminiscent of Apollo 8's "Earthrise," captured in December 1968. NASA

Go for TLI

After launch, *Integrity* deployed solar panels on the service module and performed engine burns to lift the craft into a high Earth orbit. Glover then flew the Orion capsule manually, simulating docking procedures with a landing craft using the SLS upper-stage rocket as a proxy. He praised the performance of the craft, saying, “It flew like a dream.”

While in orbit, the crew released four CubeSats provided by international partners, each with its own science payload. And, crucially, they tested their spacecraft’s environmental systems before proceeding on their lunar journey.

There were some minor issues. A water valve issue was solved, but prompted Mission Control to direct the crew to store some water in bags to ensure they would have enough to drink in case the malfunction cropped up again. There was an unexpected burning odor from the hygiene bay. The cabin also was too chilly early on.

Briefly, the world fixated on that most humble and crucial of utilities: the toilet. Not primed properly, the toilet pump

required troubleshooting. This was successful — but then frozen urine blocked the vent line. The crew performed workarounds, like rotating the craft into sunlight to warm the line. (Wiseman’s verdict post-flight? “That was a wonderful toilet.”)

There was one tense moment, when a warning alerted the crew to a possible cabin leak. But it was a false alarm.

A day after launch, Artemis 2 was ready for the historic command: trans-lunar injection, or TLI. This maneuver, which involved lighting the Orion’s engine for nearly six minutes, would send the capsule out of Earth orbit and to the Moon. Koch said, “With this burn to the Moon, we do not leave Earth. We choose it.”

The journey to the Moon took five days, during which the crew of four got used to living in a spaceborne minivan. There were live question-and-answer sessions with earthlings, a weightless CPR test, additional manual piloting of Orion in deep space, and tests of emergency communications. The astronauts donned their space suits and evaluated

everything, from checking for leaks to determining the ease of eating in them.

Meanwhile, the TLI had been so precise that only one of three planned correction burns was needed. The Moon grew closer every day.

Yet spectacular views had already greeted them. On the second day, Wiseman captured a whole-Earth photo with green aurorae visible on the limb, along with a snow-bright crescent of zodiacal light. It’s now called “Hello, World.”

On April 4, the eve of Easter Sunday, Glover told Earth in a broadcast, “You guys are talking to us because we’re in a spaceship really far from Earth, but you’re on a spaceship called Earth. ... Whether you believe in God or not, this is an opportunity for us to remember where we are, who we are, and that we are the same thing and that we’ve got to get through this together.”

Lunar flyby

On April 6, the crew of Artemis 2 was in fact really far from Earth — they traveled farther from our planet than anyone before. Reaching a distance of 252,756 miles (406,771 kilometers), the mission beat previous-record-holder Apollo 13 by over 4,000 miles (6,400 km).

During their seven-hour Moon overflight, Wiseman, Glover, Koch, and Hansen made science observations and took photos, seeing parts of the lunar far-side no human had directly seen before.

NASA reported on its official Artemis 2 blog: “A lively stream of science observations from the crew throughout the flyby has been received with grins, nods, and lots of chatter in the Science Evaluation Room ... The crew reported color nuances, which will help enhance scientific understandings of the Moon. Shades of browns and blues that can be picked out with human eyes can help reveal the mineral composition of a feature and its age.”

More than 600,000 people watched NASA’s YouTube channel as the crew saw the Moon as it truly is: a sublime, wild, awesome place — “not just a poster in the sky,” as Koch put it. She noted that bright, small craters dot the surface like “a lampshade with tiny pinprick holes and the light shining through. They are so bright compared to the rest of the Moon.” Wiseman compared the southern gouges of the massive farside impact

Artemis 2 saw a 54-minute-long total solar eclipse during the lunar flyby April 6. The glow visible around the Moon (which itself is lit by earthshine) may be from the Sun’s corona, the zodiacal light, or both. NASA





ARTEMIS 2'S FLIGHT PATH

1 Launch from Kennedy Space Center, Florida.

2 Solid rocket boosters, fairings, and launch abort system jettisoned.

3 Core stage main-engine cutoff and separation.

4 Perigee raise burn to low Earth orbit.

5 Apogee raise burn to high Earth orbit.

6 Orion separates from rocket upper stage and performs proximity operations demo.

7 Perigee raise burn.

8 Trans-lunar injection burn.

9 Five-day trip to the Moon on a free-return trajectory.

10 Lunar flyby 4,067 miles (6,545 km) above surface.

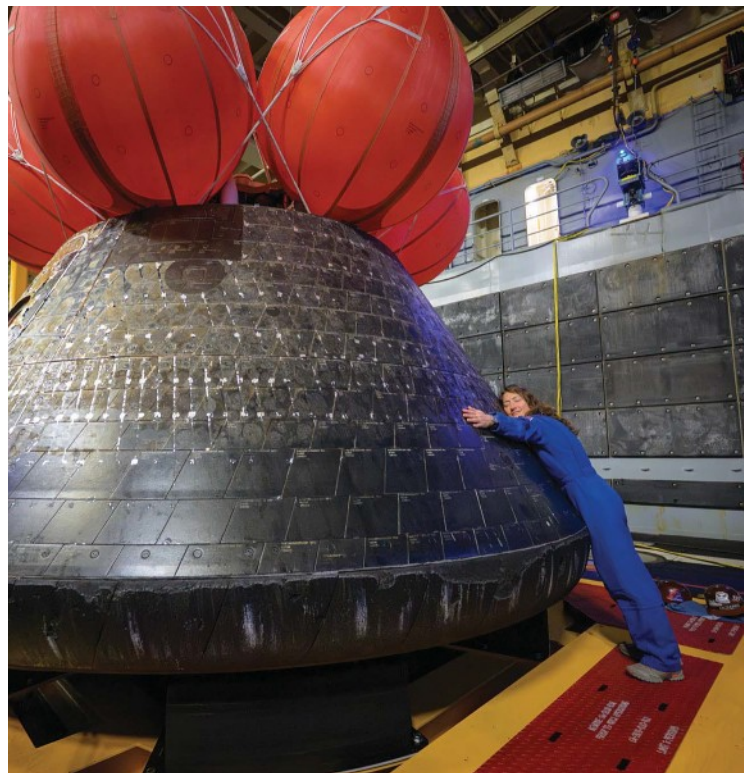
11 Four-day return trip to Earth.

12 Crew Module separates from Service Module.

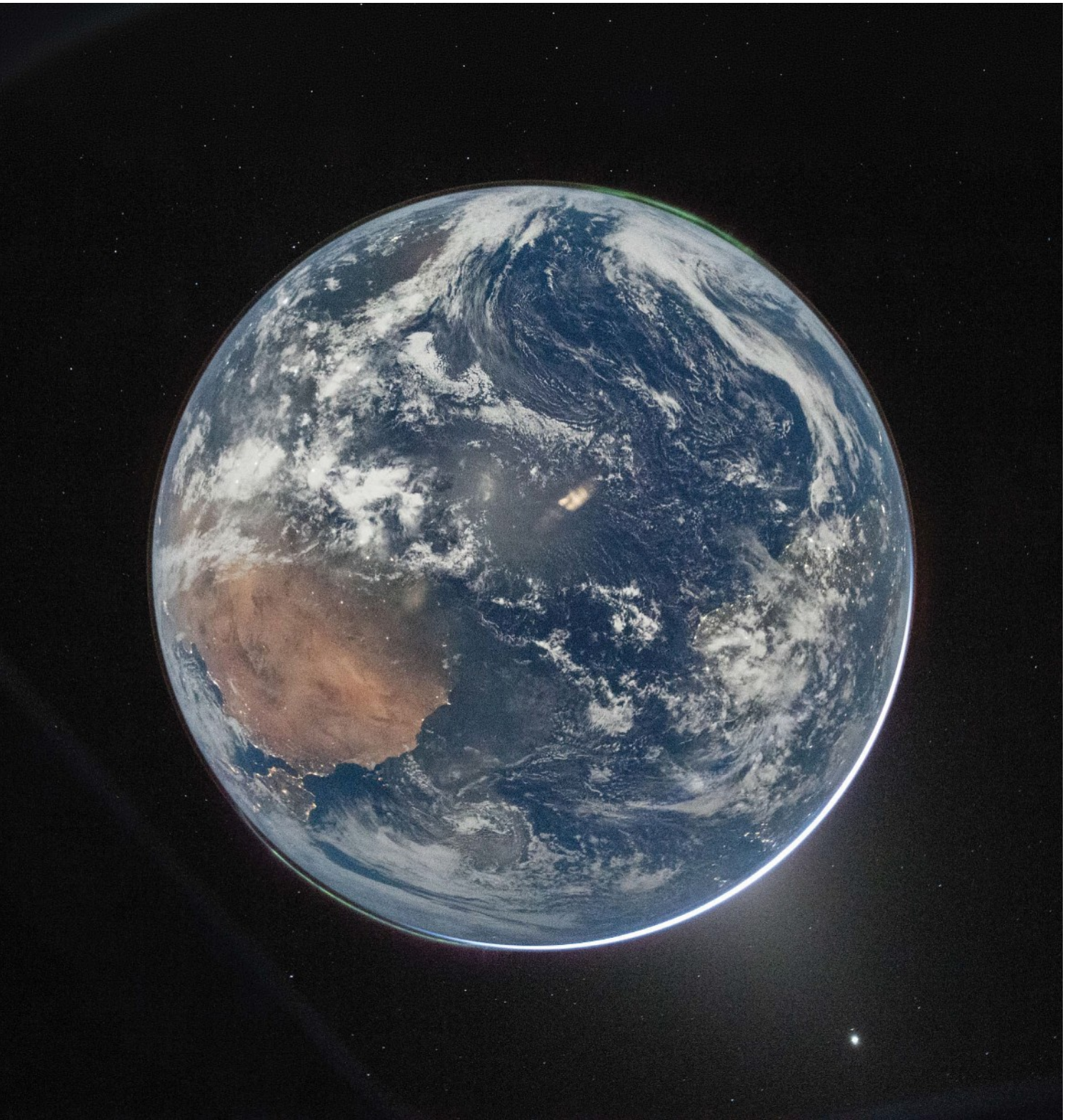
13 Crew Module reenters atmosphere.

14 Splashdown in the Pacific Ocean.

Artemis 2's 695,081-mile (1,118,624 km) journey carried it first into Earth orbit, then out beyond the Moon on a free-return trajectory that utilized the gravity of Earth and the Moon to bring the spacecraft home. At its farthest point, the spacecraft reached 252,756 miles (406,771 km) from Earth, surpassing the record for the farthest distance humans have flown from our planet, set by Apollo 13 in 1970. In total, the mission lasted 10 days, leaving Earth orbit April 2, flying around the Moon April 6, and splashing down April 10. ASTRONOMY: ROEN KELLY



TOP LEFT: On the second day of the mission, astronaut Christina Koch admires the view of Earth, still large in the spacecraft window. TOP RIGHT: After the crew's return, Koch embraces the Orion crew capsule that carried the four astronauts on their historic trip. BOTTOM LEFT: The Artemis crew embraces in zero gravity as the *Ingenuity* capsule streaks toward home on April 7. At lower right is Rise, the mission's plush zero-gravity indicator mascot. BOTTOM RIGHT: Canadian Space Agency astronaut Jeremy Hansen photographs the Moon through the spacecraft window during the April 6 lunar flyby. Throughout the seven-hour maneuver, the four astronauts took turns observing and photographing our satellite. NASA; NASA/BILL INGALLS; NASA (2)



Astronaut Reid Wiseman snapped one of the mission's most iconic photos just one day after launch. Called "Hello, World," it shows the nightside of Earth lit by moonlight; aurorae are visible at upper right and lower left, while the zodiacal light extends into space at lower right, encompassing a bright spot: Venus. NASA

basin Mare Orientale to “gorges, or almost like rain when it comes down the Grand Canyon and fingers off into the desert.” Glover saw darkness so intense he imagined falling through “to the middle of the Moon.” More domestically, Hansen compared a brown area to “a piece of pie.”

These comments offer a marked contrast to those of Apollo 8. Their lunar impressions — humanity’s first from up close and in person — held largely negative connotations. Lunar Module Pilot Bill Anders compared the Moon to “dirty beach sand.” Command Module Pilot Jim Lovell described it as “essentially gray,” with “no color.” And Commander

Frank Borman called the lunar surface he saw “a vast, lonely, forbidding type existence, great expanse of nothing ... it certainly would not appear to be a very inviting place to live or work.”

Artemis crew members took thousands of photographs, including an “Earthset” image reminiscent of Apollo 8’s well-known “Earthrise” photo. They also captured scenes of the rugged lunar surface, especially along the line between day and night, called the terminator. Along this line, terrain always features a low lighting angle and long shadows, like the conditions at the lunar south pole where future Artemis missions will land.

Also witnessed by the crew: a nearly hour-long solar eclipse, with the Moon looming much larger before the Sun than as seen from Earth. “It’s just, it’s indescribable,” Wiseman effused. “No matter how long we look at this, our brains are not processing this image in front of us. It is absolutely spectacular. Surreal. ... There’s no adjectives. I’m gonna need to invent some new ones to describe what we are looking at out this window.”

They also spied six real-time meteorite impacts on the Moon during the eclipse. These observations — rarely witnessed — will help scientists determine the frequency of such impacts on the



lunar surface. And that will have real-world implications for safety once a long-term presence is established there.

One particular set of craters, however, drew the most attention. Hansen reported that the crew wished to name one after *Integrity* and another after Wiseman's late wife, Carroll. "A number of years ago we started this journey in our close-knit astronaut family, and we lost a loved one," Hansen said. "And there's a feature in a really neat place on the Moon. It's a bright spot on the Moon, and we would like to call it Carroll." As he spoke, his voice broke with emotion. Wiseman could be seen wiping a tear from his face, and the

entire crew embraced. Viewers around the world likely shed tears alongside them.

Coming home

After the drama and emotion of flight day six, the crew kept busy on their way home. They noted lessons learned on how to efficiently stow materials and manage the cabin's limited space during exercise. They conducted health research, including checking in on organ chips gathering data on the astronauts' cellular responses to space. (See "Innovation through Artemis" on page 44 for more details.) Later, in an interview with *The New Yorker*, Wiseman recounted a tense "full-on fire emergency." It was a false alarm, but he commended the crew's response. "Everybody did exactly what we had trained to do."

All the while, the final milestone of reentry and splashdown loomed large. On everyone's minds: the heat shield. During the return of Artemis 1, the protective shielding experienced unexpected charring and cracking, sending engineers back to the drawing board to make sure no such damage to *Integrity* would take place. NASA modified the craft's reentry profile to reduce the amount of time it would spend exposed to high temperatures and ensure a safe return; still, critics questioned NASA's decision not to redesign Artemis 2's heat shield, arguing the risk of failure was unacceptably high. (Future Artemis missions will use a redesigned heat shield intended to avoid such concerns entirely.)

Ready or not, on April 10, *Integrity* plummeted toward the Pacific Ocean at nearly 25,000 mph (40,230 km/h), enduring temperatures of some 5,000 degrees Fahrenheit (2,760 degrees Celsius). Plasma seared past the windows, so bright that Hansen put down his sun visor. The plasma meant a blackout in communications, lasting roughly six minutes. Glover later compared reentry to jumping "off a skyscraper backwards."

Then — "Houston, *Integrity*, we have you loud and clear," came Wiseman's voice. The blackout ended. The crew was safely through the atmosphere. Parachutes slowed the capsule to some 20 mph (32 km/h) for splashdown.

Afterwards, on the Navy recovery ship, the crew inspected the capsule. Koch later posted a social media photo of herself embracing *Integrity*, as well as a video of her greeting her joyous pet dog Sadie when she got home to Houston.

In a post-mission press conference, Wiseman said that, while he's not particularly religious, he quickly asked to see the Navy chaplain aboard ship. When he did, Wiseman broke down in tears. "It's very hard to fully grasp what we just went through," he explained.

Passing the baton

"This is a relay race," Koch said during the mission, adding that the crew had bought literal batons with the intent of handing them to the next crew, whom NASA announced on June 9 as NASA astronauts Randy Bresnik, Andre Douglas, and Frank Rubio, along with ESA astronaut Luca Parmitano.

The Artemis 3 mission, currently planned for late 2027, will remain in low Earth orbit to rendezvous and attempt to dock with one or both of the planned Human Landing System landers, as well as test next-generation spacesuits. It will ensure not only that Orion can successfully dock with the lander, but that all flight hardware — created by different manufacturers — is compatible. Both landers are as yet unbuilt by SpaceX and Blue Origin, though. Blue Origin's New Glenn rocket, which will be used to launch its lander, exploded on the pad this spring. And the Axiom spacesuits intended for use on the lunar surface by later crews also aren't ready. All that casts doubt on the current timeline to land on the Moon not once, but twice, in 2028.

The current administration has portrayed the Artemis program as the U.S. effort in a modern race to beat China to the Moon, language that echoes the U.S./Soviet space race. But not everyone agrees with that spin.

Casey Dreier, the space policy chief at the nonpartisan Planetary Society, wrote in the March 2026 *Space Advocate Newsletter* that such rhetoric "risks undermining the very things that were intended to make Artemis different from Apollo: durable international partnerships, rich scientific returns and potential resource utilization at the south pole, and a sustained program that endures for decades."



The Moon and Earth appear together out the spacecraft window on April 6. When this photo was taken, Artemis 2 was 4,564 miles (7,344 km) from the Moon and 252,494 miles (406,348 km) from Earth. NASA

But think tanks, Senate committees, and former NASA administrator Bill Nelson have all argued that allowing China to reach the lunar south pole first would allow a country that critics say flouts international law to take advantage by potentially setting up procedures or infrastructure that could affect others' attempts to reach nearby areas.

Regardless, Artemis continues with a budget that pales in comparison to Apollo. Dreier pointed out that "the United States would ultimately spend more than \$300 billion (in 2025 dollars) on Apollo over 12 years. Artemis has cost a third of that amount."

Our reflection

After the Apollo 11 landing in 1969, the public quickly grew bored with moonshots. For now, though, support for Artemis remains high, according to the polling firm Ipsos. The crew is part of that goodwill, says space expert Deana Weibel, an anthropologist at Grand Valley State University. "The Artemis 2 mission ... was live on television screens, computer monitors, and smartphones. ... Traveling to the Moon became relatable. ... These astronauts weren't legendary heroes from our parents' time taking part in a superhuman event. Instead, it was Christina, Victor, Jeremy, and Reid taking pictures on their iPhones and chatting with ground control."

After 695,081 miles (1,118,624 km) of total travel, that crew returned to an Earth needing uplift in difficult times. And that uplift, Koch said, was "every bit as important" as the mission's engineering and science goals. As Hansen stood with his beloved crewmates after splashdown, he put it this way: "When you look up here, you're not looking at us. We are a mirror reflecting you. And if you like what you see, then just look a little deeper. This is you." »

Christopher Cokinos is the author of *Still as Bright: An Illuminating History of the Moon, from Antiquity to Tomorrow* (Pegasus Books, 2024), an audio edition of which is forthcoming.

Astronauts (from left to right) Christina Koch, Victor Glover, Jeremy Hansen, and Reid Wiseman, having just exited the Orion capsule following splashdown, offer celebratory smiles as they sit on the inflatable front porch raft alongside Navy recovery personnel.

U.S. NAVY PHOTO BY MASS COMMUNICATION SPECIALIST DAVID ROWE



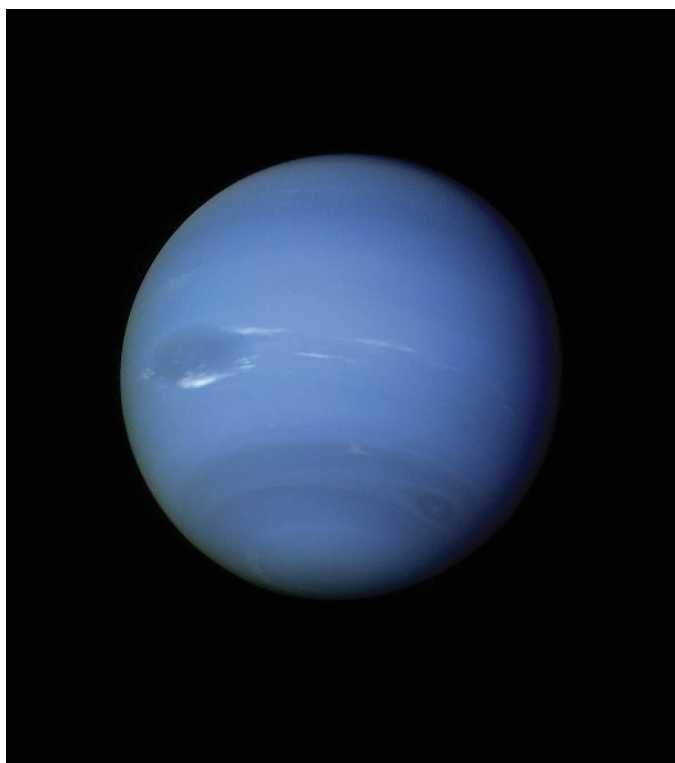


SKY THIS MONTH

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



The solar system's most distant planet, Neptune, was imaged by Voyager 2 in August 1989. This month, the ice giant reaches opposition in our sky. NASA/JPL

magnitude -0.6 . Your observing window is only five to 10 minutes, as the pair sets shortly before 8 P.M. local daylight time from 40° north. From a spot with a clear western horizon, look 20 minutes after sunset. You'll see Venus first, 18° east of the Moon and 8° high. The Moon is only 2° high and setting. Those in the desert southwest with a flat horizon and a dry, transparent sky may be the only ones to catch the view.

Mercury begins to spring up out of the solar glow at the end of the month, although the low angle of the ecliptic still favors Southern Hemisphere observers.

Venus dominates the evening sky and is best seen early in the month. On the 1st it stands 10° high in the west 30 minutes after sunset. As the sky darkens, you'll spot Spica 1.5° above it. Venus sets by 9 P.M. local daylight time.

If you look west at the same time each evening, you'll see Venus drop in altitude. For example, at 8:30 P.M., Venus stands 5° high on the 1st and is only 2° high by the 7th. A crescent Moon joins Venus Sept. 13 and 14, lying 6° west of the planet on the 13th and nearly 7° east of it on the 14th.

Venus reaches its greatest illuminated extent, now a dazzling magnitude -4.8 , on the 18th. Setting earlier each evening, it is gone within about an hour of sunset. Through a telescope, Venus exhibits a 26%-lit disk spanning $39''$. By the 21st, Venus stands 38° east of the Sun but its declination of -19° places it very low in the sky during Northern Hemisphere twilight.

On the last day of the month, try spotting both Venus and Mercury just 1° and 2° above the western horizon, respectively, 30 minutes after sunset. You'll need a flat western horizon and very transparent skies to see them both. Mercury stands 9° from Venus.

Neptune rises in the east as

SEPTEMBER 2026

A distant planet now at its best

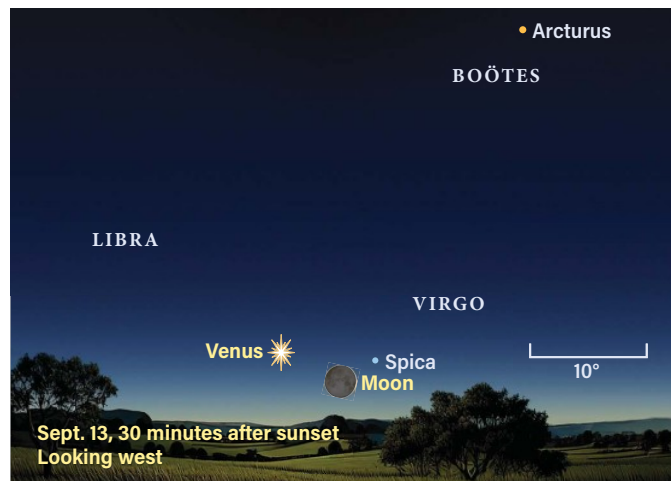


Venus is the brightest object in the west after sunset, reaching its greatest illuminated extent this month. Neptune reaches opposition, with Saturn in the same region of sky. Uranus could be visible from dark skies without optical aid; we'll tell you where to look. Mars is slowly brightening, while Jupiter

is ready for observing in the morning sky.

There's limited viewing of Mercury this month due to its unfavorable location on the ecliptic, which is inclined at a low angle relative to the western horizon. Look for it near the Moon on Sept. 12, when they stand some 11° apart and at the same altitude. Mercury shines at

Brief pairing



Venus and the crescent Moon sit briefly above the horizon after the Sun sets in mid-September. Spica, although shown, will likely require binoculars to spot this soon after sunset. ALL ILLUSTRATIONS: ASTRONOMY: ROEN KELLY

OBSERVING HIGHLIGHT

NEPTUNE reaches opposition in Pisces the evening of Sept. 25.



the Sun sets in the west, marking the time the distant planet reaches opposition, which occurs Sept. 25. At magnitude 7.7, it's within reach of binoculars.

Neptune lies in southern Pisces, with no bright stars nearby. Saturn is 9.5° to its east, and an imaginary line drawn down the eastern side of the Square of Pegasus points right at Neptune's location.

As you scan this region, you'll come across a large parallelogram of 4th- and 5th-magnitude stars consisting of 27, 29, 30, and 33 Piscium. Neptune lies about 4° northeast of 29 Psc, the northeasternmost star in the parallelogram. Try on Sept. 3, when Neptune stands within $1'$ of a magnitude 8.6 field star (HIP 1127). The bluish glow of Neptune contrasts well with the yellowish main sequence star. Neptune has a similar encounter on the 24th, standing $1.5'$ from another yellow main sequence star (HIP 968), which shines at magnitude 8.7. Neptune looks distinctly nonstellar in comparison, its disk spanning $2''$.

On the night of Neptune's opposition, a Full Moon stands to the lower right of **Saturn**, with Neptune 9° southwest of the ringed planet. Saturn dominates Pisces, starting the month at magnitude 0.4 and brightening by 0.1 magnitude as it approaches next month's opposition. Both Saturn and Neptune

— Continued on page 34

RIISING MOON | No glory for Galileo

WE HAVE DRESSED the Moon's face with the honor roll of great scientists and philosophers of human history. The bigger the name, the more impressive its feature, generally, with the best craters reserved for the pre-telescopic thinkers.

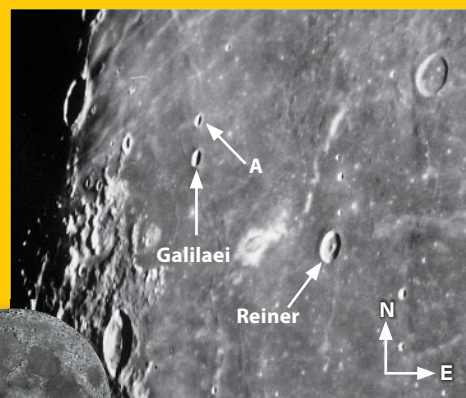
Galileo must have rubbed the lunar cartographers the wrong way, then, because his crater is half the size of and less prominent than the one named for his friend and student, Reiner. Appropriately though, they appear near each other as isolated islands in the large western "sea" named Oceanus Procellarum. Look for them due west of Copernicus, the dominating large crater with prominent rays near the middle of the Moon's disk.

Spanning nearly 10 miles in diameter, Galilaei is a classic sharp-rimmed crater, young in that it formed well after the huge lava upwellings that characterized the earlier parts of the Moon's existence.

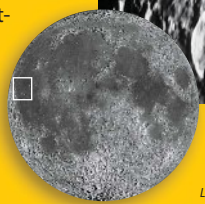
On the 23rd, look for the gorgeous hills, rilles, and ridges. Note the super-long, sinuous wrinkle ridge snaking through Galilaei and its junior, A. The craters break up the ridge, solid evidence that the impacts came after the lava of Procellarum solidified. Just to the northeast lies a fantastic field of volcanic domes called the Marius Hills. Can you see the thin rille Rima Galilaei wriggling along the hills' western flank?

The weird stuff becomes visible on the 24th,

Galilaei and Reiner 🔭



Galilaei (and smaller Galilaei A) are separated from Reiner by the strange white feature Reiner Gamma. CONSOLIDATED LUNAR ATLAS/JA/LPL. INSET: NASA/GSFC/ASU



the Sun now high enough in the lunar sky that albedo (brightness) features catch the eye more than shadowed topographic ones. Use a filter to reduce the intensity of light coming through the eyepiece. A most curious splotchy white feature, Reiner Gamma, lies between Galilaei and Reiner. Apollo missions confirmed this is not topographic in origin, but like other white splotches on the farside, is quite magnetic. To date, there is no widespread agreement as to what it is or how it formed — a lasting lunar mystery!

METEOR WATCH | Many lights

Caught by chance 👁



A bright sporadic meteor briefly lights the sky, captured in a single frame of a time-lapse composite. ALAN DYER

NO MAJOR meteor showers occur in September. There is, however, an elusive glow from the meteoritic debris that fills the inner solar system. It is visible in the east before dawn when there's no Moon. This is the zodiacal light, a cone-shaped glow aligned with the ecliptic. Look for it at least an hour before dawn, reaching up through Leo toward where Jupiter sits.

With a New Moon Sept. 10, the following seven to 10 days are a good time to view this glow, with the Moon limited to the evening sky. Travel well away from any city; higher altitude also aids viewing this light. Avoid street-light glow from cities to your east.

While observing the planets in the morning sky, also keep an eye on the sky for sporadic meteors, and possibly a fireball. Random meteors add to the splendor of a night under the stars. There's always something special happening in the sky.

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. September 1
9 P.M. September 15
8 P.M. September 30

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.



SEPTEMBER 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			

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

- 2 Venus passes 1.7° south of Spica, 11 P.M. EDT
- 3 The Moon passes 5° north of Uranus, 7 P.M. EDT
- 4  Last Quarter Moon occurs at 3:51 A.M. EDT
- 6 The Moon passes 3° north of Mars, 2 P.M. EDT
The Moon is at perigee (228,825 miles from Earth), 4:43 P.M. EDT
- 8 The Moon passes 0.8° north of Jupiter, 2 P.M. EDT
- 9 The Moon passes 0.6° south of Regulus, 4 P.M. EDT
- 10 Uranus is stationary, 2 P.M. EDT
 New Moon occurs at 11:27 P.M. EDT
- 14 Asteroid Juno is stationary, 1 A.M. EDT
The Moon passes 0.5° north of Venus, 7 A.M. EDT
- 17 The Moon passes 0.6° south of Antares, 9 A.M. EDT
- 18  First Quarter Moon occurs at 4:44 P.M. EDT
Venus is at greatest brilliancy (magnitude -4.8) 9 P.M. EDT
The Moon is at apogee (251,171 miles from Earth), 11:00 P.M. EDT
Mars passes 6° south of Pollux, midnight EDT
- 22 Autumnal equinox occurs at 8:05 P.M. EDT
- 25 Mercury passes 1.0° north of Spica, 9 P.M. EDT
Neptune is at opposition, 10 P.M. EDT
- 26  Full Moon occurs at 12:49 P.M. EDT
The Moon passes 5° north of Neptune, 3 P.M. EDT
- 27 The Moon passes 7° north of Saturn, 8 A.M. EDT
- 30 Asteroid Nausikaa is at opposition, 6 P.M. EDT
The Moon passes 5° north of Uranus, midnight EDT

THE PLANETS IN THEIR ORBITS

Jupiter

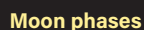
Ceres

Mars

Mercury

Venus

Earth
Autumnal equinox
is September 22



Dawn

Midnight



Asteroid Nausikaa reaches opposition September 30

Neptune appears at its best for the year in September

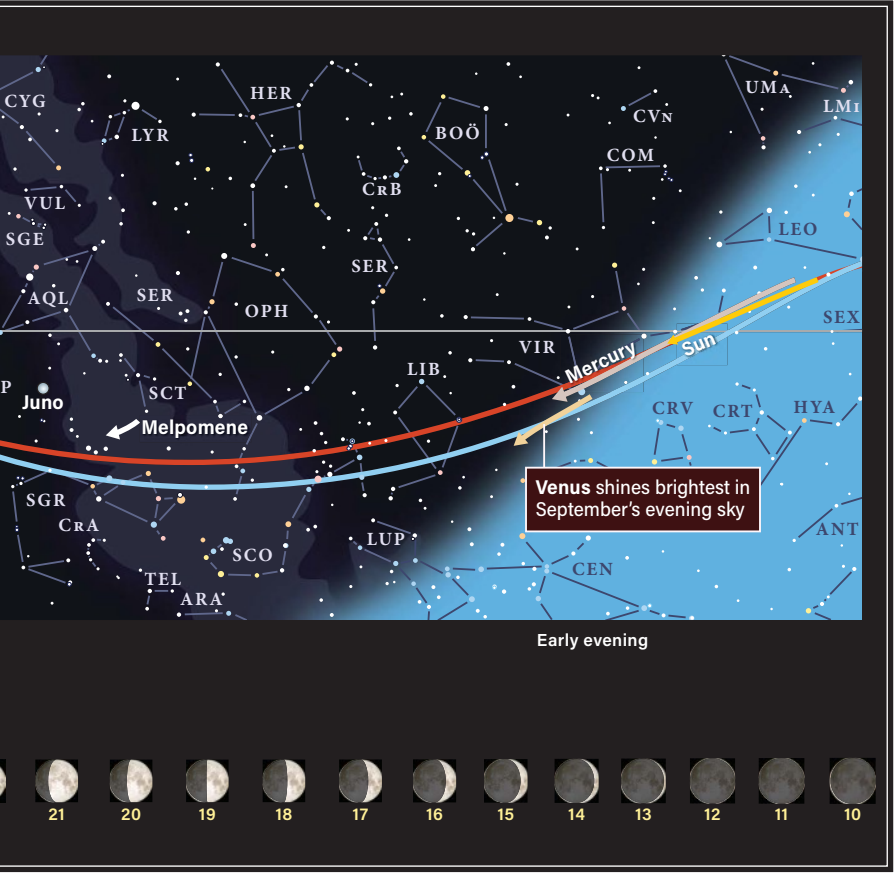
Neptune
Opposition is
September 25

Earth
Autumnal equinox
is September 22

32 ASTRONOMY • SEPTEMBER 2026

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.

SEPTEMBER 2026



Callisto



Europa



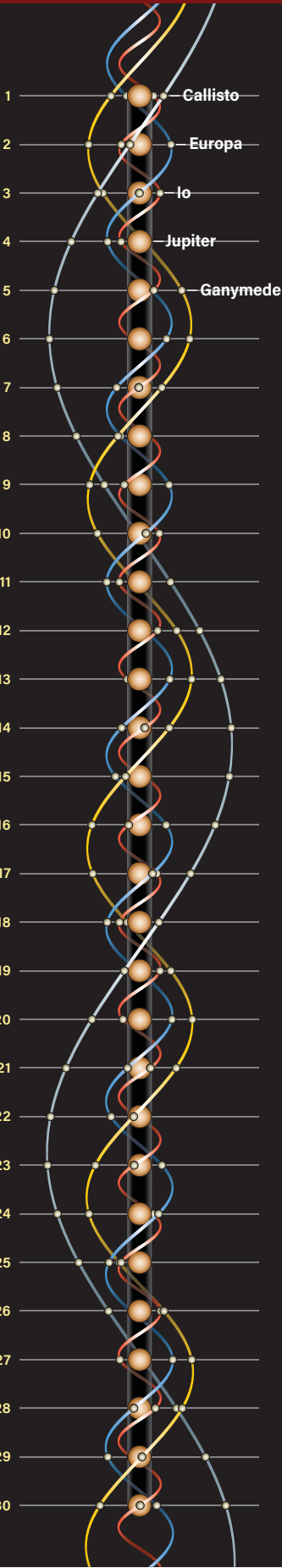
Io



Ganymede

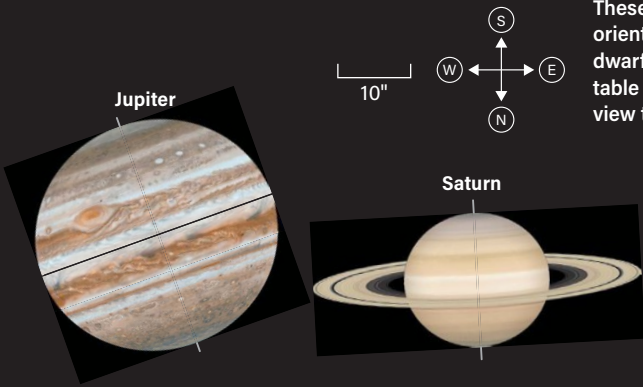
JUPITER'S MOONS

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.



Uranus

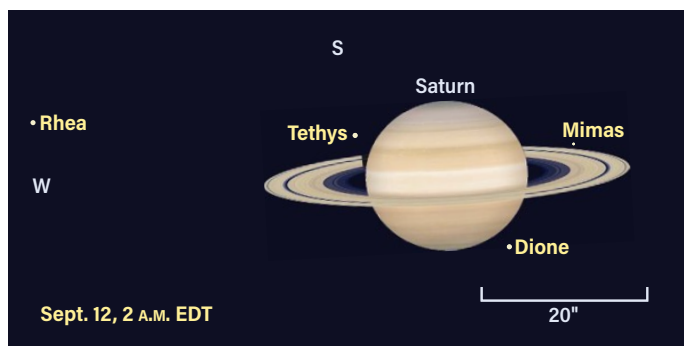
Neptune

Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15
1.2	8.8	-1.8	0.4	5.7	7.7	15.1
5.3"	0.5"	32.4"	19.6"	3.7"	2.4"	0.1"
91%	97%	100%	100%	100%	100%	100%
1.769	2.844	6.087	8.492	19.135	28.891	34.932
1.538	2.686	5.302	9.440	19.444	29.878	35.599
7h34.5m	6h48.2m	9h15.3m	0h49.8m	4h13.7m	0h13.0m	20h25.1m
22°25'	23°00'	16°31'	2°25'	21°02'	-0°08'	-23°41'

SKY THIS MONTH — Continued from page 29

Busy morning ☞



Early on Sept. 12, Dione is preparing to skim Saturn's north pole as Tethys is about to disappear into the planet's shadow. Mimas, although shown, is 13th magnitude and too faint for many scopes. Note that Iapetus is some 2' north of Saturn at this time, outside this field of view.

are best observed around midnight, when they are high in the southeastern sky.

In early September Saturn rises around 9 P.M. local daylight time, and by 7 P.M. on the 30th, when it is well up by 8 P.M. and visible all night. Saturn's rings are opening, tilted by more than 8° early in September, although they narrow slightly throughout the month.

Titan, Saturn's brightest moon, wings around the planet every 16 days. You'll find it close to Saturn on the 5th and 6th, when it lies northeast and northwest of the planet, respectively. On the 13th and 14th, Titan lies southwest and southeast of Saturn, respectively.

On Sept. 21/22, Titan again stands northeast of Saturn and is very close to a magnitude 10.6 field star. Titan passes some 2" south of the star at 1:17 A.M. EDT on the 22nd (still late on the 21st for the western half of the U.S.). Titan returns south of the planet Sept. 29 and 30.

Tethys continues a series of transits and shadow transits. These are a challenge for advanced observers. One occurs the morning of Sept. 11, between about 4 A.M. EDT and 5 A.M. CDT (note the time zone change: The event ends only half an hour before sunrise on

the East Coast). A second occurs overnight on Sept. 12/13, from around 1 A.M. to 3:30 A.M. EDT on the 13th (still late on the 12th in other time zones). A third event occurs Sept. 14, starting shortly after 10 P.M. EDT and lasting about 2.5 hours.

Dione skims the northern pole of Saturn Sept. 12 between about 2:55 A.M. and 3:35 A.M. EDT (note this event begins just before midnight PDT on the 11th). Its shadow precedes the moon by about 50 minutes, appearing shortly after 2 A.M. EDT. As Dione approaches the northeastern limb, Tethys is lining up to enter the planet's extended shadow to its southwest. Tethys begins to dim about 2:10 A.M. EDT.

Iapetus passes through inferior conjunction Sept. 12. You'll find it located 1.9' due north of the planet on the night of Sept. 12/13. It's heading toward western elongation early next month, when its brighter hemisphere faces Earth. As it does so, Iapetus brightens from 11th magnitude in mid-September to 10th magnitude by the end of the month. Follow Iapetus as it

WHEN TO VIEW THE PLANETS

EVENING SKY

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

MIDNIGHT

Saturn (southeast)
Uranus (east)
Neptune (southeast)

MORNING SKY

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

moves west. On the 30th, it stands 9.5' west of Saturn.

Uranus is midway between the Pleiades and Hyades star clusters. It spends the month between 5th-magnitude Omega (ω) Tauri and 4th-magnitude 37 Tauri, which stand 3.3° apart

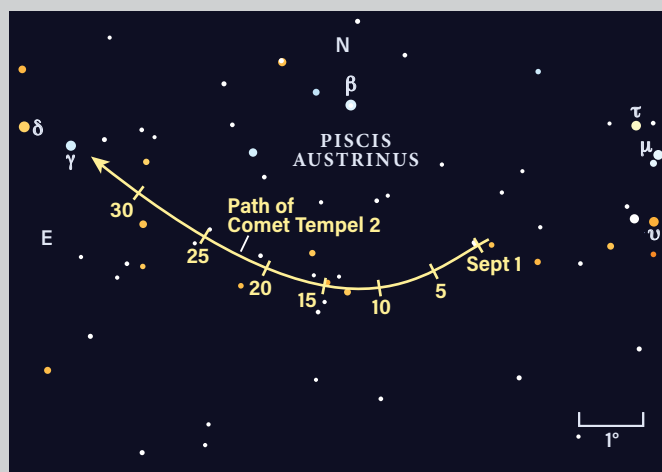
COMET SEARCH | Gone fishin'

GETTING UPSTAGED by a surprise visitor is pretty common for comets like 10P/Tempel (also called Tempel 2). We'll take one, but Tempel 2's respectable 8th magnitude will keep us well entertained as autumn begins. The classic green diatomic carbon glow might just be seen in larger scopes.

Look low in the south beginning around midnight to find Fomalhaut in Piscis Austrinus swimming near the horizon, then shift another binocular field to the southwest. After a quick peek in binoculars and under low power in a scope, bump up the magnification to 150x if the night allows, revealing a bizarre galaxylike shape. The glow from the outflow of dust should be flattened and better defined with an off-center false nucleus.

Discovered in 1873 by Wilhelm Tempel, this is a short-period comet, circling the Sun in 5.36 years. It never gets closer than Mars, nor as far as Jupiter, tracing out a moderately asteroidlike path. The extra time past the decimal means we only get reasonable apparitions every 16 years, and the next won't be as good as this one.

Comet 10P/Tempel ☞

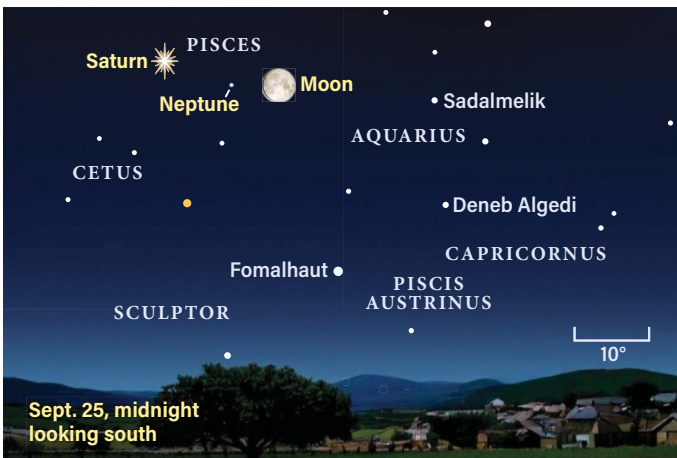


Comet Tempel 2 remains a great late-night target after reaching perihelion last month. Fomalhaut lies just northeast of this field of view.

LOCATING ASTEROIDS |

Studious search

Opposition time   



Neptune reaches opposition late Sept. 25 and is best viewed around local midnight. Note that the ice giant requires binoculars or a telescope to spot, and viewing it may be challenging with the Full Moon nearby. For more detailed charts showing Neptune's position, see the online version of this story.

and are easily spotted with your eyes or in binoculars. Uranus is 1° northwest of fainter Omega on Sept. 1. The ice giant ends its prograde (eastward) path on the 10th, when it halts and resumes a retrograde (westward) track.

Uranus shines at magnitude 5.7, potentially visible to the unaided eye from a dark location with a moonless sky. It's a perfect month to try this feat: The pair of guide stars mentioned above makes it easy to locate the position of the planet.

This distant world is so far away — 1.78 billion miles — that even though it spans about 4 Earth diameters, through a telescope it appears as a tiny, 4"-wide disk.

Mars is located in central Gemini as September begins. The Red Planet rises shortly before 2 A.M. local daylight time on the 1st, and by 1:30 A.M. on the 30th. A waning crescent Moon joins Mars the morning of Sept. 6, some 6° away.

Mars moves eastward against the background stars and crosses into Cancer Sept. 25. It

brightens from magnitude 1.2 to 1.1 during the month, similar in brilliance to Pollux. Mars passes 6° due south of this star at midnight on the 18th.

Mars remains a tiny 5" across, too small for easy visual observation. Experienced imagers will be targeting the world, however, already searching for potential dust storms hiding its features. It reaches opposition in February.

Jupiter is in Cancer as September begins, glowing at magnitude -1.8. It rises shortly after 4 A.M. local daylight time on Sept. 1, not long before twilight breaks. A beautiful waning crescent Moon stands 5° from Jupiter the morning of Sept. 8.

Jupiter crosses into Leo Sept. 24 and ends the month standing nearly 11° northwest of Regulus, Leo's brightest star. By this time Jupiter has brightened to magnitude -1.9. It's a good time for observing the gas giant, as it is nearly 30° high in the east by 5:30 A.M. local daylight time around the start of twilight.

In a telescope, Jupiter reveals

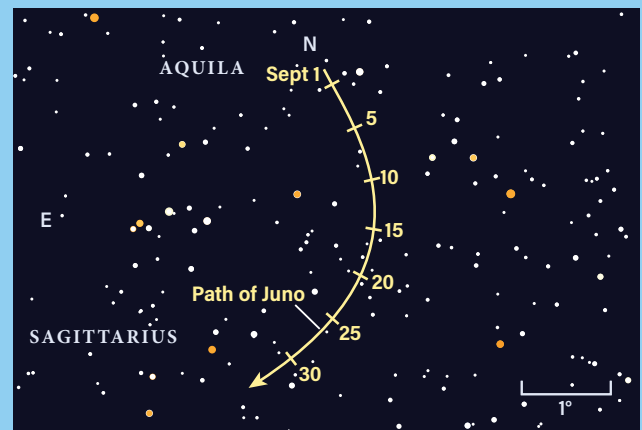
THE MAGNITUDE of an asteroid follows the same rules as that of Mars: Not only does it have to be close to Earth to shine brightly, it also needs to be close to the light source: the Sun. This month we've got a bit of both, adding up such that asteroid 3 Juno starts the month at magnitude 9.4, then slowly drops off as Earth pulls ahead on the solar system race track. In 2031, Juno will be two magnitudes brighter as these parameters fully combine.

Whether you are star-hopping or go-to-ing, you'll need a methodical search technique to home in on a point about halfway between the Scutum Star Cloud and the marvelous golden double star Alpha (α) Capricorni. Sept. 18 to 21 is the best time to catch 145-mile-wide Juno as it passes through a random collection of 9th- to 10th-magnitude stars. A view at 80x will net you eight to 10 dots, one of which will be Juno. Come back in a night or two to see which one moved. That's how Karl Harding found it in 1804.

Other nights, Juno may be the only dot in the field. That's when you should deliberately slew the scope toward bright stars on the chart or in a planetarium app to confirm that they enter the field as expected.

Also check out Juno's Little Gem of a neighbor: NGC 6818 is a planetary nebula of similar magnitude to Juno, about 3° to the south. An OIII filter will make it pop out of a suburban sky.

Connect the dots  



Juno is skimming through a relatively sparse star field, but there are some nearby background stars to help you find it midmonth.

its banded atmospheric structure: two dark equatorial belts, with more subtle features north and south of those belts.

The four Galilean moons occasionally transit the disk. The window of observability for these events is currently narrow. Notably, Ganymede — the largest moon — transits on Sept. 29. The transit takes more than three hours and is visible across the U.S. Observers in the eastern half of

the country see the event begin at 5:24 A.M. EDT. The western U.S. sees Ganymede leave at 6:02 A.M. PDT.

Earth reaches its autumnal equinox Sept. 22 at 8:05 P.M.

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.



FUELING OUR LUNAR RETURN

NASA is aiming to have boots on the Moon by 2028. But that landing hinges on in-orbit refueling — a feat never before done.

BY BROOKS MENDENHALL



LEFT: The Orion crew capsule *Integrity* splashes down in the Pacific Ocean on April 10, 2026, returning the Artemis 2 crew to Earth after a successful mission. ABOVE: SpaceX's Starship Human Landing System (HLS) stands tall on the lunar surface in this artist's rendering. HLS is one of two commercial landers NASA will test on the agency's upcoming Artemis 3 low Earth orbit mission. The HLS is currently under contract to land crew on the Moon for the Artemis 4 mission in 2028. NASA/JOSH VALCARCEL; SPACEX



The Artemis 2 crew poses in front of *Integrity* below the deck of the USS *John P. Murtha* on April 11, 2026. Left to right are Commander Reid Wiseman, Mission Specialist Christina Koch, Mission Specialist and Canadian Space Agency astronaut Jeremy Hansen, and Pilot Victor Glover. NASA/BILL INGALLS

WHEN THE ARTEMIS 2 crew splashed down in the Pacific Ocean on April 10, the excitement was palpable — Reid Wiseman, Victor Glover, Christina Koch, and Jeremy Hansen had swung around the Moon, broken a human spaceflight distance record, and come home safely. But for the Artemis program, it was just the beginning.

Between April's historic splashdown and boots on the lunar south pole lies a series of technical challenges more complex than anything Artemis 2 was asked to solve, including newly revised mission architecture and numerous so-far unproven technologies. But perhaps the most critical item on the to-do list is to accomplish something that has never been done in the history of spaceflight: refueling a rocket in orbit. And the clock is ticking.

The rocket equation

When Neil Armstrong and Buzz Aldrin landed in the Sea of Tranquility in 1969, they arrived aboard a spacecraft that had launched as a single stack from Kennedy Space Center. The Saturn V carried everything — the Command Module,

the Service Module, and the Lunar Module — all at once, on one rocket. The Saturn V could deliver roughly 47 tons to translunar injection, cost the equivalent of billions of dollars per flight, and was entirely expendable. That same approach won't work for the cadence and payloads required for building a permanent base.

The Artemis program is built around the Space Launch System (SLS) — a core stage supplemented with solid rocket boosters that combine to deliver the most liftoff thrust of any rocket in history. But despite its lifting power, SLS is actually less capable than the Saturn V when it comes to sending mass to the Moon: In its current configuration, known as Block 1, SLS can deliver around 27 tons to lunar orbit. A variant with more powerful upper stages — which would have

delivered the Lunar Gateway — was cancelled as part of the Artemis restructure led by NASA Administrator Jared Isaacman.

More critically, SLS was never designed to carry a lunar lander. The entire Artemis architecture is built around a separately launched lander meeting the crew in space and delivering them to the lunar surface.

NASA has contracted two companies to build those landers: SpaceX, with its Starship Human Landing System (HLS), and Blue Origin, with its Blue Moon. And getting either vehicle to the Moon requires something Apollo never needed: refueling in orbit.

The need for orbital refueling comes down to a hard constraint of physics. A Starship or Blue Moon loaded with enough propellant to fly to the Moon and land would be too heavy to launch. The fuel required to lift that fuel requires yet more fuel, a compounding problem that engineers call the tyranny of the rocket equation. The solution is to launch the lander with its tank of propellant nearly empty and fill it once it reaches low Earth orbit (LEO), before it sets off for the Moon.

Aircraft have been refueling in flight since the 1920s. A tanker, flying in close formation with a receiver, connects the two through a flexible hose or a rigid boom, transfers fuel, and the aircraft flies on. Rockets are different.

SpaceX's Starship runs on liquid oxygen (LOX) and liquid methane; Blue Origin's New Glenn, which will launch Blue Moon, runs on LOX and liquid hydrogen. These are cryogenic propellants — fuels that exist as liquids only at extremely low temperatures. Transferring them between two vehicles the size of skyscrapers, in the microgravity of LEO, introduces a set of problems that aerial refueling has never had to solve: keeping the fuel cold enough that it doesn't boil off, and managing the fact that in microgravity, liquid and gas don't behave the way they do on Earth.

A history of attempts

Transferring cryogenic propellants between two independent spacecraft has never been done before. But engineers have been chipping away at pieces of this problem for decades.

The first precedents date to as early as 1986, from the Soviet and Russian space programs. Both the Mir space station and then later the International Space Station (ISS) were serviced by Progress cargo vehicles that transferred propellant to keep the stations in orbit. But those transfers used propellants that remain liquid at room temperature.

A more direct precursor came in 2007, when DARPA's Orbital Express mission successfully demonstrated autonomous rendezvous, docking, and fluid transfer between two spacecraft. But again, the propellant was storable hydrazine fuel, not cryogenic.

NASA's Robotic Refueling Mission 3 (RRM3) came close to the cryogenic challenge. Launched to the ISS in December 2018, RRM3 was designed to demonstrate both long-duration cryogenic storage and an actual tank-to-tank transfer of liquid methane — the first anyone had attempted in orbit. It achieved the first goal: Special cryocoolers kept the methane stable for four months. Then on April 8, 2019, the coolers stopped responding and could not be revived. The methane was safely vented, and the transfer demonstration never ran.

Several years later, SpaceX was able to succeed where RRM3 had failed. In March 2024, SpaceX's Starship Flight Test 3 became the first vehicle in history to transfer cryogenic propellant in space, moving at least 10 metric tons of LOX between two internal tanks. This demo took place inside one vehicle, not two, with no docking interface to negotiate. But it was a necessary first step, and an important proof that cryogenic transfer in space is physically possible.

The boil-off problem

One of the biggest challenges is keeping cryogenic fuel in its liquid state. LOX boils at -297.3 degrees Fahrenheit (-183 degrees Celsius); liquid methane at -258.7 F (-162 C). Liquid hydrogen is even more extreme, boiling at -423.2 F (-253 C) — just 20 degrees above absolute zero. No matter how insulated a fuel tank's walls are, heat from sunlight and radiation will constantly leak through. This causes liquid propellant to boil into vapor, which collects in the space around the liquid — a region called the ullage.

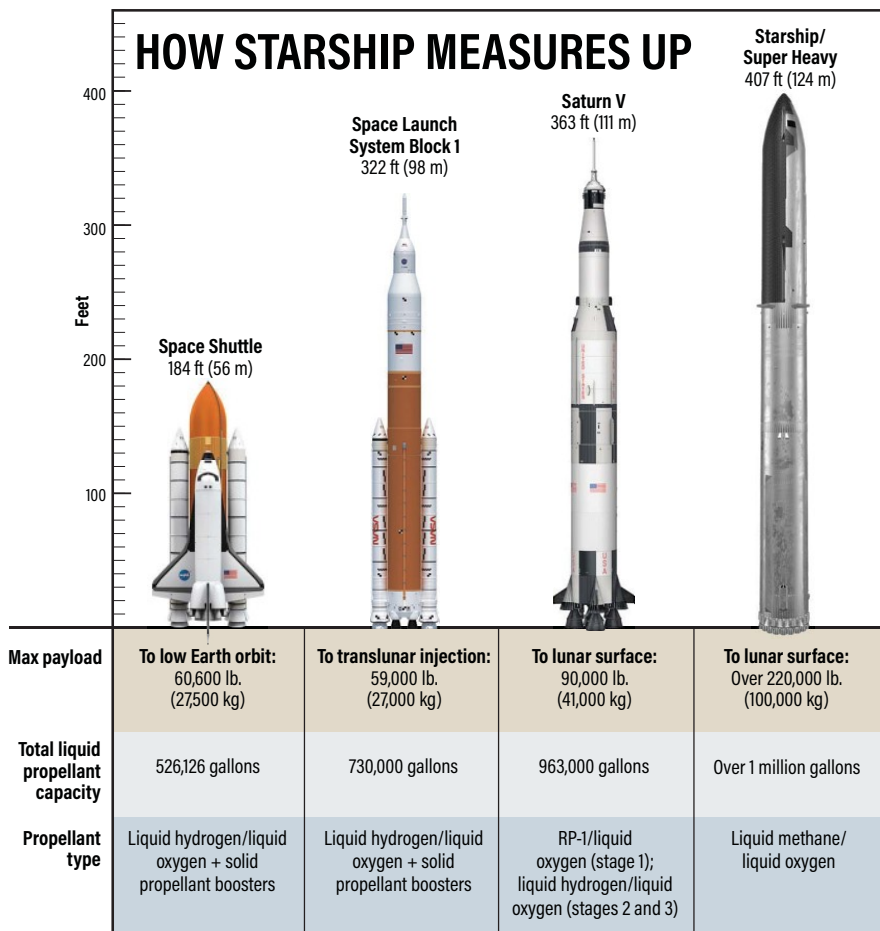
As more vapor accumulates, pressure in the sealed tank climbs. For a fuel depot sitting in orbit for months, it's a fundamental problem. "The most underappreciated challenge is not a single cryogenic transfer event, but long-duration cryogenic storage in orbit," says Qiyun Cheng, an engineer and postdoctoral associate at MIT. "Over weeks or months, even very small heat leaks can accumulate." The passive solution — venting the vapor through a relief valve — throws away propellant the mission needs. A NASA analysis for a hypothetical Mars mission found that passive boil-off losses for a large liquid hydrogen tank carrying 38 tons of fuel would run roughly 16 tons per year, meaning the propellant would boil-off long before the mission arrived at Mars.

Keeping propellants cold requires active cooling through what engineers call zero boil-off (ZBO) storage (like what was used during RRM3). Two main mechanisms have been developed. The

first is jet mixing: A stream of cold liquid is pumped through the tank, cooling and condensing vapor before pressure can build. The second is droplet injection: Cold droplets are sprayed directly into the ullage, where they absorb heat from the vapor and reduce pressure without venting.

NASA has been testing ZBO storage in microgravity aboard the ISS since 2017 through a project called the Zero Boil-Off Tank experiments. The results confirmed the basic approach works. On that same hypothetical Mars mission, the analysis found ZBO storage could cut boil-off losses by 42 percent, making the mission viable. However, questions about how the technology performs at operational scale remain unresolved.

For one, active cooling systems for cryogenic fuel demand significant power. "It takes a lot of electrical work to move a small amount of heat out of the tank," Álvaro Romero-Calvo, an aerospace engineer at Georgia Tech who directs the



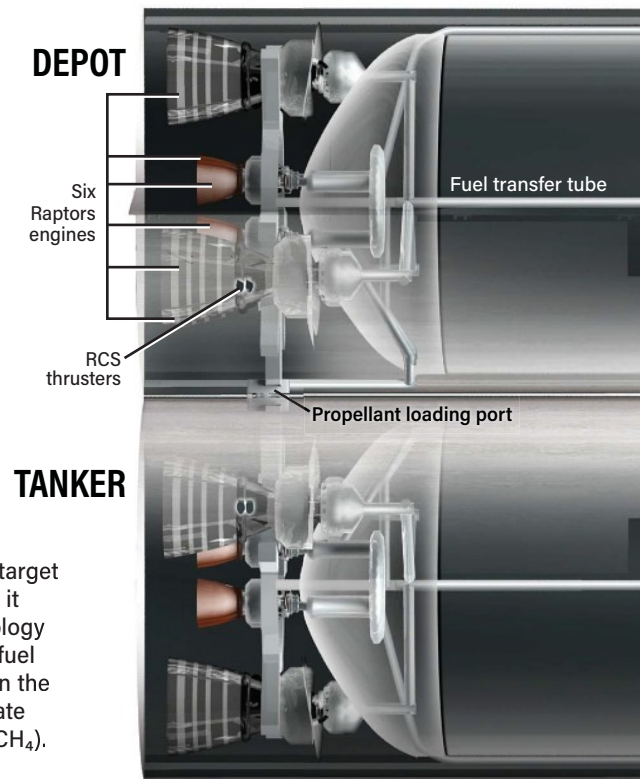
SpaceX's Starship and Super Heavy booster form the world's tallest, most powerful rocket. This fully reusable system is designed to transport humans and cargo to the Moon and beyond. ASTRONOMY: ROEN KELLY
AFTER (LEFT TO RIGHT) NERTHUZ/DREAMSTIME; NASA; NERTHUZ/DREAMSTIME; CLARENCE365, VIA SKETCHFAB, CC BY 4.0

HOW TO FILL A ROCKET IN SPACE

Before SpaceX's Starship can carry astronauts to the Moon, its tanks must be full — and filling them requires something that has never been done before: transferring cryogenic propellant between two independent spacecraft in orbit. SpaceX must first complete an uncrewed demonstration flight before NASA will certify Starship for a crewed lunar mission. The four panels below explain how that demonstration, scheduled to take place before the end of 2026, might unfold, from the docking to the physics that moves the fuel.

THE DOCKING

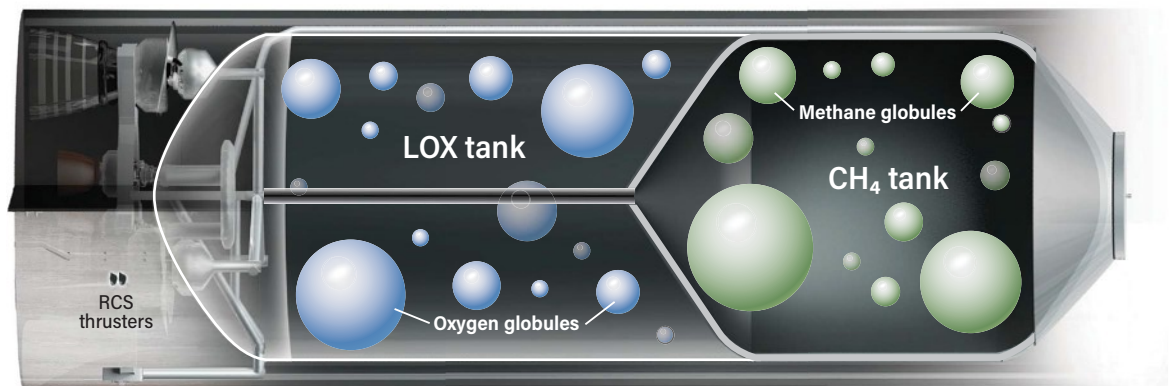
Two Starships meet in low Earth orbit and dock belly-to-belly. One — the depot, or target vehicle — launches first and waits in orbit; the second, acting as the tanker, chases it down and docks autonomously, using rendezvous and proximity operations technology SpaceX has refined across years of Dragon missions. The connection point for the fuel transfer is a propellant loading port — the same hardware used to fuel the rocket on the ground. Cross-sections reveal each vehicle's internal tank arrangement: two separate propellant tanks per ship, one for liquid oxygen (LOX) and one for liquid methane (CH₄).



THE MICROGRAVITY PROBLEM

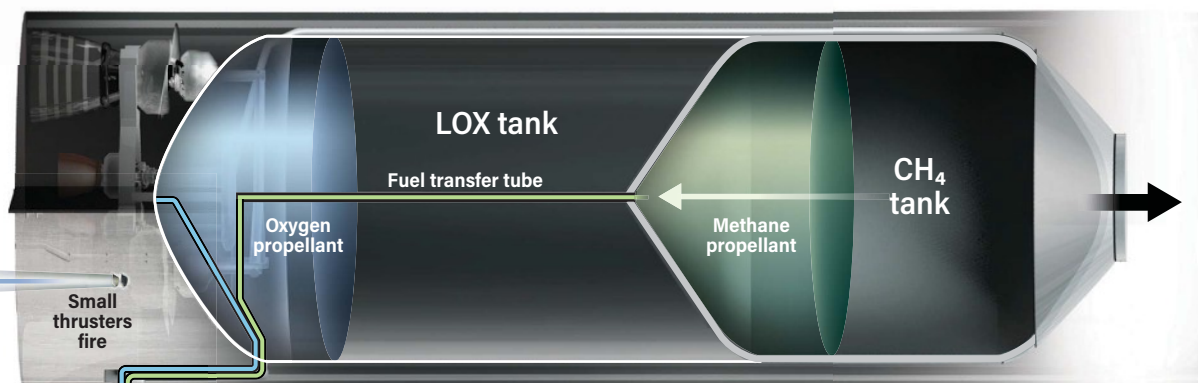
THE PROBLEM:

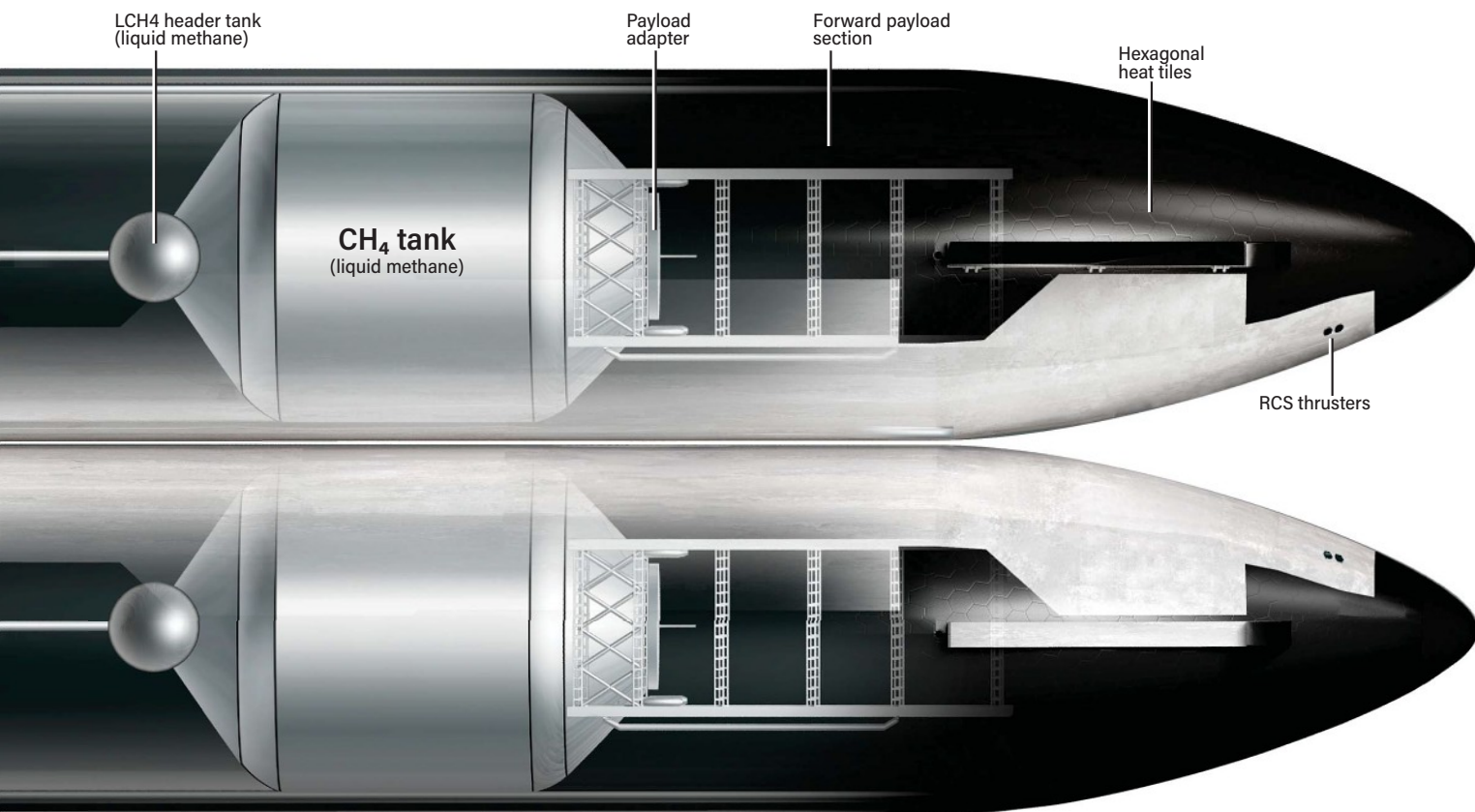
Without gravity, propellant floats freely in dispersed globules. It can't be pumped. The vapor-filled space around the floating propellant is the ullage.



THE SOLUTION:

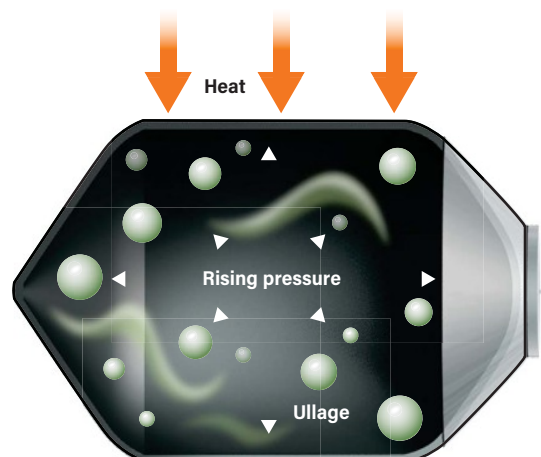
Reaction control system (RCS) thrusters — used for attitude control and maneuvering — fire, pushing the spacecraft forward and mimicking gravity. Propellant pools at the outlet. SpaceX has not confirmed which RCS thrusters will perform the settling burn.





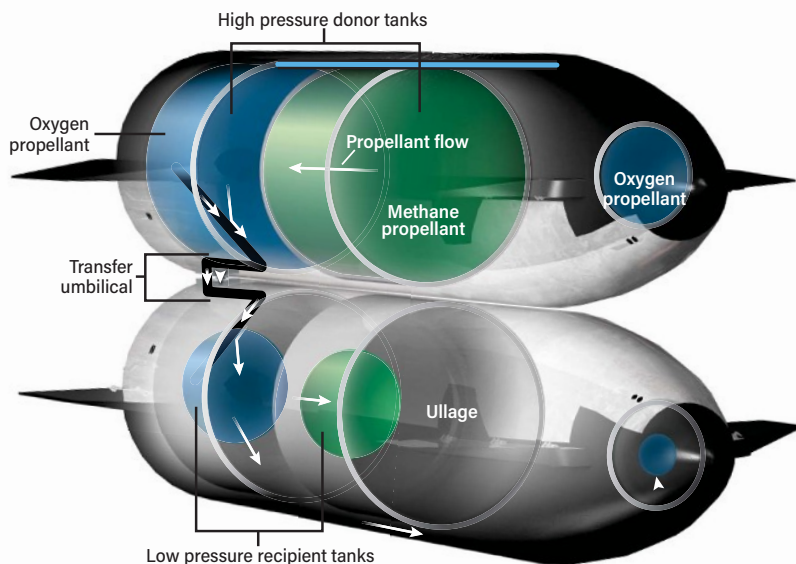
ULLAGE, BOIL-OFF, AND PRESSURE

Heat from sunlight and radiation causes cryogenic propellant — kept liquid only at extremely cold temperatures — to slowly boil. The vapor collects in the ullage, and as it accumulates, pressure inside the sealed tank steadily climbs. This is a manageable problem for a rocket that fires hours after launch, but more complex for a depot sitting in orbit for months. SpaceX will use active cooling systems — called zero boil-off (ZBO) storage — to keep propellant below its boiling point across the depot's months-long stay in low Earth orbit.



THE PRESSURE DELTA

The same pressure built by boil-off while the donor tank waits in orbit becomes the engine of transfer. When the donor tank's pressure exceeds the recipient's, propellant flows across the umbilical — no pumps required. As the donor empties, its liquid level drops and its ullage expands; the recipient's liquid level rises as it fills. SpaceX plans to allow some boil-off deliberately to build the pressure needed to drive flow — though exactly how the company will control pressure, sequencing, and transfer rates during the operation remains in development. For a crewed Artemis mission, this process will repeat across more than 10 tanker flights over roughly 200 days before the crew departs.



university's Low-Gravity Science and Technology Laboratory, tells *Astronomy*. "On Earth, we have virtually infinite energy, but in space, power is limited by what your solar panels and batteries can provide, and mass costs money." More power means more mass at launch — more insulation could reduce the needed power but carries its own mass penalty.

SpaceX will need to find a sweet spot in a tangle of trade-offs: Every kilogram devoted to insulation and cooling is a kilogram of propellant that doesn't make it to orbit. How many tanker flights it takes to top off the lander depends on how well the company navigates that balance.

Blue Origin faces the same challenge, compounded by hydrogen's more extreme boiling point. In July 2025, the company announced that ground testing of its ZBO technology had met all NASA objectives, demonstrating performance at what the company called "two times the performance of the current state of the art."

The NASA Office of Inspector General (OIG), however, found in a report released March 10, 2026, that cryogenic fluid management remains one of both Blue Origin and SpaceX's most significant technical challenges.

No gravity, no flow

On Earth, buoyancy does the work of separating liquid from gas — less dense vapor rises, denser liquid settles. "In

space, they just float around, creating froth layers or complex liquid/gas mixtures that are very hard to separate," says Romero-Calvo.

SpaceX's approach to the gravity problem combines two techniques. First, small thrusters fire briefly to push the spacecraft forward, creating a faint artificial gravity that settles propellant toward the back of the tank. The technique has been used for decades within single rockets before engine ignition, but applying it during a cryogenic transfer between two docked vehicles is unprecedented. Once the propellant is settled, flow is driven by pressure rather than pumps — controlled boil-off raises pressure in the donor tank, and that differential pushes propellant across the umbilical fuel line into the receiving vehicle. "The fundamental flow mechanism is because of the pressure delta across the umbilical," Amit Kshatriya, NASA's associate administrator, told the NASA Advisory Council's Human Exploration and Operations Committee in April 2024, according to reporting at the time from *Ars Technica*.

The full details of how SpaceX will manage pressures, sequencing, and transfer remain in development. Kshatriya told the committee that SpaceX still had work ahead, as reported by *SpaceNews*. "The point of their flight test program before we do this is to make sure they fully understand the slosh dynamics, fully understand how the ullage is being maintained, what the

settling thrust needs to be," he said. "We've gone through it with them in terms of their plan for this. It's a good plan."

It is worth noting that even on the ground, with gravity doing its job and experienced crews managing established infrastructure, cryogenic propellant tanking caused repeated delays during Artemis 2 launch preparations. In orbit, those advantages disappear entirely.

From demo to depot

If the engineering challenges can be solved, the Starship architecture works like this: SpaceX launches a dedicated propellant depot — a modified Starship, essentially a large, insulated tank with docking ports — into LEO. Then, over a period beginning more than 200 days before the crew launches, a series of Starship tanker flights lift off from the ground, rendezvous with the depot, and transfer their propellant. NASA is targeting more than 10 such tanker flights, at a cadence of roughly one every six days. Whether it takes 10 or closer to 20 depends on boil-off losses and transfer efficiency. Once full, the Starship HLS then launches separately, docks with the now full depot, tops off its tanks, and departs for the Moon.

Before that happens, SpaceX will demonstrate the propellant transfer with a test flight. Two Starships will launch from Boca Chica, Texas, several weeks apart. The first, the target vehicle, will reach

A NEW ROADMAP

On Feb. 27, 2026 — a month before Artemis 2 even left the pad — NASA Administrator Jared Isaacman announced a sweeping overhaul, restructuring the Artemis program into a more incremental series of missions modeled on Apollo's approach.

Under the new architecture, Artemis 3, currently scheduled for mid-2027, will not land on the Moon as originally planned. Instead, the four-person crew — commander Randy Bresnik, pilot Luca Parmitano of the European Space Agency, and mission specialists Frank Rubio and Andre Douglas — will launch aboard an Orion crew capsule and rendezvous in low Earth orbit with one or both of NASA's contracted commercial landers — SpaceX's Starship Human Landing System (HLS) and Blue Origin's Blue Moon. While there, they will also test the program's new spacesuits and life-support systems. The mission has drawn comparisons to Apollo 9 — the 1969 Earth orbit shakedown of the Lunar Module that cleared the way for Apollo 11 four months later.

Artemis 4, targeting early 2028, is now the first landing mission. NASA has said they will choose whichever commercial lander is ready and certified. If SpaceX is selected, a four-person crew will launch aboard Orion, travel to Earth orbit, and dock with Starship HLS for the journey to lunar orbit. If Blue Origin is selected, Blue Moon's path to lunar orbit is less clear. Once in lunar orbit, two astronauts will descend to the lunar

south pole, where they will become the first humans to stand on the Moon since Apollo 17 in December 1972. Over roughly a week on the surface, they will conduct moonwalks, collecting samples and performing experiments, before ascending back to lunar orbit and rejoining their crewmates aboard Orion for the journey home. The mission is expected to last around 30 days in total.

Artemis 5, currently targeting late 2028, will see two astronauts descending to the south pole, and the beginning of NASA's construction on the surface infrastructure for a permanent base.

Beyond Artemis, NASA's formal Moon base plan calls for \$20 billion to \$30 billion in investment over the next decade, unfolding in three phases toward a nuclear-powered permanent outpost by 2032. A planned space station in lunar orbit called the Lunar Gateway has been scrapped. In the words of Carlos Garcia-Galan, the former Gateway program deputy manager who now heads the space agency's Moon base effort, every resource is now "focused on one thing, and that is to build the Moon base."

While intended to be a simpler architecture, the timeline remains ambitious. From Isaacman's announcement to the first lunar landing is less than two years. And before either lander flies, both companies must solve the refueling problem. — B.M.



orbit and wait. The second, the tanker, will chase down the first, and dock autonomously. Next, the tanker will transfer its cryogenic propellant to the target. Both vehicles will then deorbit and return to Earth. If it works, it will be the first time cryogenic propellant has been transferred between two independent spacecraft.

The demonstration has slipped twice. It was originally planned for March 2025, then delayed 12 months to March 2026, according to a NASA OIG report. SpaceX then missed the March 2026 date as well, with the demo now expected at some point in 2026 but with no confirmed launch date announced. The OIG report explicitly flagged the delay as a risk to the overall Artemis schedule.

A successful Starship propellant transfer demonstration will clear the path for an uncrewed Starship HLS lunar landing demo. Success there clears the path for Artemis 4's crewed lunar landing in 2028.

Blue Origin's steeper climb
Blue Origin faces a less certain path.

Unlike SpaceX, which has a defined architecture and a pending demo flight, Blue Origin does not have a published plan for how refueling will work. Its original architecture depended on docking with the Lunar Gateway, which has since been canceled. How that changes Blue Origin's refueling approach has not been announced.

Blue Origin must also fly an uncrewed demonstration mission before NASA will certify its lander to carry crew. That demo will be flown by Endurance, the Mark 1 variant of Blue Moon — a smaller, uncrewed cargo and science lander designed to demonstrate precision landing, cryogenic propulsion, and zero boil-off storage at the lunar south pole. Only after Endurance succeeds can the crewed Mark 2 fly on Artemis 5.

Endurance completed thermal vacuum testing at NASA's Johnson Space Center in early May — but that milestone has been overshadowed. On May 28, the New Glenn rocket Blue Origin



LEFT: SpaceX HLS Raptor engines fire during lunar descent in this rendering. ABOVE: An astronaut works outside Blue Origin's Blue Moon lander in this artist's concept. SPACEX; BLUE ORIGIN

was preparing for an Endurance launch exploded on its pad during a static fire test, destroying the vehicle and severely damaging the company's only New Glenn pad. At a June 9 press conference, Blue Origin's vice president of lunar permanence John Couluris said the company's factories are running around-the-clock and that Mark 1 will be ready for launch this year, adding: "We will measure ourselves not only by our successes, but how we respond to setbacks." Whether Blue Origin can return New Glenn to flight, resolve its refueling architecture, and land Endurance on the Moon in time to certify Blue Moon for Artemis 5 remains to be seen.

What comes next

"Crack large-scale orbital propellant transfer, and propellant becomes a commodity you launch cheaply and aggregate in LEO, which decouples deep-space capability from single-launch mass," Romero-Calvo says. In short, the Moon, Mars, the outer planets — none are reachable without propellant transfer.

"This is a relay race," Artemis 2's Christina Koch said from space the day before splashdown. Artemis 2 ran its leg. When humanity will finally land on the Moon to stay, and Mars after that, hinges on the next legs — legs that are longer, more complex, and depend on as-of-yet unproven technology. ☛

Brooks Mendenhall is a staff writer for *Astronomy* and is based in Chattanooga, Tennessee.

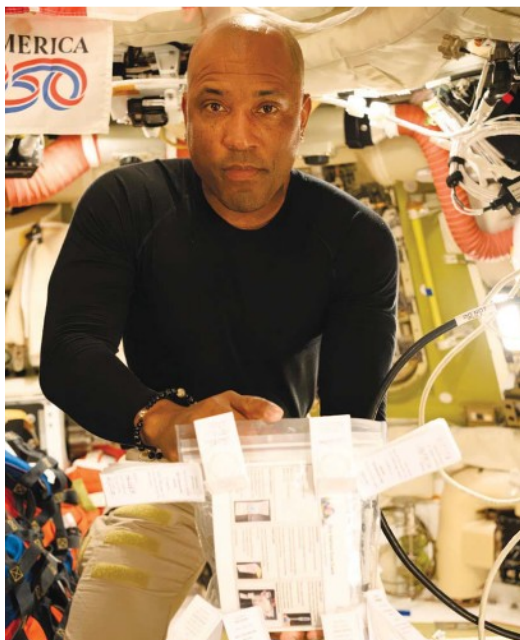
INNOVATION THROUGH ARTEMIS

Integrity served as a deep-space testbed for technology that could aid cancer patients, serve remote clinics, and supercharge the internet.

BY SARA NOVAK

A laser carrying data such as images, telemetry, and voice communications streaks from the Artemis 2 spacecraft toward Earth in an artist's rendering. (In reality, this laser would be invisible to the human eye.) The mission tested laser communications technology that is useful not only in deep space, but also on Earth and in orbit. NASA®





IN THE PURSUIT of space exploration, NASA has developed a number of innovations that today we depend on in our daily lives. Memory foam — the cushy, shock-absorbing material used in everything from furniture to medical equipment — was first invented in 1966 by NASA for use in test pilots’ cushions. In the 1990s, NASA’s Jet Propulsion Laboratory developed a new generation of digital image sensors so space missions could use smaller cameras; today, those sensors are integral to cameras and cellphones. And many other nifty innovations born out of space travel, like scratch-resistant lenses, CAT scanners, ear thermometers, and portable computers, are now ubiquitous technologies.

This space-to-ground pipeline will also be true of the Artemis program and NASA’s return to the Moon. Already, several technologies used and tested on the Artemis 2 mission are set to improve personalized medicine and clinical care, as well as provide faster communications around the globe.

Vital organs

Artemis 2 employed organ-on-a-chip technology to track the health of each astronaut before, during, and after the mission. In a project named AVATAR (A Virtual Astronaut Tissue Analog Response), bone marrow organ chips allowed researchers to look at the effects of radiation and microgravity on each

astronaut’s cells and determine how they were impacted by space travel.

First developed by the Wyss Institute at Harvard University, organ chips are small devices about the size of a USB thumb drive that contain tiny channels (less than a millimeter wide) housing human cells. Small amounts of fluids are pumped through these channels to mimic the body’s circulation system. As a result, “organ chips behave and respond to stimuli very much like human organs,” says Donald E. Ingber, director of the Wyss Institute. This allows researchers to study how living tissues and organs react to external conditions, without invasive procedures.

One of the biggest concerns about

astronauts’ health during long-term space travel is their exposure to radiation in space. Bone marrow cells are an obvious choice for evaluating this because radiation affects blood cell production early on, says Ingber. Bone marrow is responsible for producing blood cells. It’s ideal for study because radiation exposure causes a decrease in bone marrow populations that impacts the formation of new blood cells; even sublethal amounts of radiation can cause cell damage to bone marrow tissue.

Researchers created two sets of chips containing bone marrow cells cultivated from blood drawn from each Artemis astronaut. One set flew aboard the Orion crew capsule, while a second set remained on Earth. This allowed scientists to see

TOP LEFT: Inside the *Integriy* capsule, astronaut Victor Glover holds the bag containing the dry saliva sheets used by the crew during flight for later analysis on Earth. TOP RIGHT: Artemis 2 commander Reid Wiseman collects a sample of saliva during the spaceflight, to be examined after the mission for biomarkers indicating the astronauts’ health and metabolic function while in space. NASA (2)

how space travel impacted the cells from each of the four astronauts differently. While blood draws from the astronauts can provide a snapshot before and after the mission, the organ chips provide a log of how the effects of deep-space radiation and microgravity progressed during the mission, down to the cellular level.

Such data could help researchers develop medical countermeasures like treatments for cellular damage. That will become essential as astronauts attempt to establish a sustainable human presence on the Moon and undertake even longer missions to Mars.

Developing these treatments could also benefit patients on Earth — cancer patients receiving lifesaving radiation treatments, for instance, or victims of a nuclear disaster. “AVATAR is the first of its kind to be able to draw an individual-level conclusion tied to radiation exposure, and it’s a powerful tool for helping us to build out personalized medicine here on Earth,” says Lisa Carnell, division director for NASA’s Biological and Physical Sciences Division.

Saliva samples

In space, taking blood samples isn’t always an option — they need cold storage, and the Orion crew capsule used on Artemis missions doesn’t have a refrigerator. So NASA often turns to an alternative: astronauts’ spit. “Most of the things that you would look at in blood can be looked at in saliva, which is just a purified distillate of blood plasma,” says Brian Crucian, an immunologist for NASA.

The crew of Artemis 2 made use of dry saliva books, a simple yet innovative tool developed by NASA. Astronauts simply smear their saliva on strips and leave them to dry. Back on Earth, the strips are checked for various biomarkers — signs that point to specific conditions or events in the body. The strips previously have been used on the International Space Station (ISS) to record cortisol levels and evaluate stress and circadian rhythms in astronauts. For Artemis 2, scientists were able to add detection for biomarkers that would help them better understand the effects of microgravity on bone health, as well as markers for inflammation.

Saliva biomarkers are helping

scientists understand how to maintain astronaut health in deep space over long periods of time. Such samples have already shown that space travel suppresses astronauts’ immune systems, allowing dormant viruses like shingles to reemerge. Understanding these and other changes is crucial to keeping astronauts healthy on longer missions.

There are also a lot of potential applications on Earth for saliva books, says Crucian. The technology could be used in any situation where doctors don’t have the ability to collect, process, and store liquid samples. In developing countries or in field situations where refrigeration or taking blood samples might not be an option, there’s a need for this practical yet cutting-edge technology.

Laser communication

While maintaining astronaut health aboard long space flights is paramount,



The AVATAR experiment carried several USB drive-sized organ chips, containing bone marrow cells derived from each astronaut’s blood, along for the 10-day spaceflight. Once on the ground, the chips were transferred to laboratories for analysis of the effects of space travel on the cells. EMULATE/NASA

sending pictures home to keep the citizens of Earth engaged is also crucial. During Artemis 2, NASA’s Space Communications and Navigation (SCaN) Program, which operates all communication between Earth and NASA space missions, used lasers to transmit high volumes of data at broadband speeds. Laser-based communication has already been tested on satellites, robotic spacecraft, and the ISS, but Artemis 2 was its first test on a crewed deep-space mission.

Optical light is just one small portion of the larger electromagnetic spectrum,

which runs from radio waves at the lowest frequencies to gamma rays at the highest. In the past, most communication aboard crewed spacecraft used microwave radio frequency (RF) communications, a technology proliferated by Western Union in 1945. This is the same way cellphones work, using radio waves and microwaves to transmit data and voice without wires.

Artemis 2 carried two communication systems: a traditional RF system and a laser system, called the Orion Artemis II Optical Communications System (O2O). Lasers transmit data in the optical portion of the spectrum. While microwaves have wavelengths of centimeters, the wavelengths of optical light are measured in hundreds of nanometers. Optical light’s shorter wavelength (and thus, higher frequency) means more waves can fit between the sender and the receiver, ultimately increasing data transmission speed. Essentially, higher-frequency light means more megabits per second (Mbps) of data can be sent. Using O2O, Artemis 2 was able to send communications from the Moon back to Earth at a whopping 260 Mbps, compared with the RF system’s single-digit Mbps capabilities.

“This new communication allows you to push a lot more data through a system of similar size and power,” says Greg Heckler, deputy program manager for capability development for NASA’s Space Communications and Navigation Program.

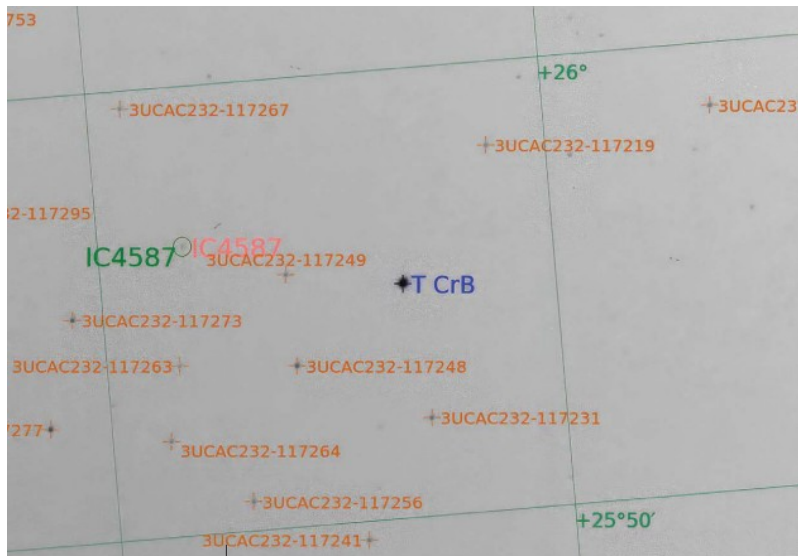
Laser communication is also used by SpaceX’s Starlink internet satellites, allowing them to communicate with each other at speeds of up to 200 gigabits per second (Gbps). And while cellphones currently use RF communications, they’re starting to utilize laser communications as well for future high-speed data transmission, says Heckler.

Such communications advances, like the medical technologies and many other innovations developed for or integrated into Artemis 2, weren’t just about making the mission more successful — their impact will be felt on Earth, too. 🌌

Sara Novak is a science journalist based in South Carolina whose work is regularly published in *The New York Times*, *Scientific American*, *National Geographic*, *Discover*, and many others.

Become a scientific observer

You can be part of ongoing research through the AAVSO.



T Coronae Borealis (T CrB) appears at the center of an inverted image used for measuring its magnitude. MOLLY WAKELING



As an astrophotographer, you might feel that you will eventually run out of targets. I disagree — amateurs are discovering new targets all the time, and old targets can look brand new with better skills and different gear — but if you are looking for a fresh astronomical challenge, look no further than the American Association of Variable Star Observers (AAVSO). With equipment you already have, you can become a scientific observer, submitting data on variable stars, exoplanet transits, and even sunspots.

Despite the name, the AAVSO unites professional and amateur astronomers on an international level. While major observatories receive more proposals than they can possibly cover, amateur observers have many eyes on the sky all over the world at every hour. Through the AAVSO, thousands of observers around the globe contribute millions of observations to a database that is more than a century old, augmenting professional efforts with critical data for scientific research. For example, a citizen science observation campaign facilitated by the AAVSO gathered extensive data during the most recent eclipse of the star Epsilon (ε) Aurigae from 2009 to 2011 to better understand this strange multiple-star system.

Monitoring variable stars lets us delve into the physics behind these universal building blocks. Stars change

brightness for many reasons: Some are eruptive recurring novae, while others pulsate regularly over periods of seconds to years. By observing these changes, we can learn about the interiors of stars and how they evolve, how galaxies and black holes form, and more. And because many stars are in multistar systems, like Epsilon Aur, studying these offers further clues about star birth and evolution.

I observe more than a dozen variable stars on a regular basis, including the much-anticipated recurring nova T Coronae Borealis (T CrB); the mysterious Tabby's Star (KIC 8462852), which attracted attention in 2017 with unusual dimming behavior; and the erratic symbiotic binary CH Cygni. The AAVSO also runs observing campaigns, usually at the request of professional astronomers, on particular stars or classes of stars of interest. Observations are often done in concert with Hubble Space Telescope, the James Webb Space Telescope, and the Chandra X-ray Observatory. You can also learn to observe exoplanet transits, following up on the thousands of candidates from the Transiting Exoplanet Survey Satellite and Kepler space telescope.

Anyone can contribute

You don't need a giant telescope or an exquisite camera to participate. Pretty much any telescope and camera you already have will work, even color cameras and DSLRs. I use a modest 8-inch f/5 Newtonian telescope with an old KAF-8300-chip CCD camera from my light-polluted backyard to monitor dozens of variable stars.

To do so, I take frames with 1- to 5-minute exposure times (depending on the star's magnitude), calibrate them with flats and darks, and align them. Then I use the AAVSO's online software VPhot, which is free for members, to perform the photometry (brightness) calculations. It spits out a text file that I upload and quality check against other observations using the submission tool. That's it! You don't need perfect focus, ideal seeing, flawless tracking, or the lowest-noise camera to contribute meaningful data. I use a monochrome camera with photometric filters, but the green channel from one-shot color cameras also provides useful information to researchers. You can even use smart scopes like the ZWO Seestar and Unistellar eVscope. The AAVSO is working with several smart telescope companies to

make the process of variable star observing even easier.

Ready to get involved? Check out the AAVSO's website, www.aavso.org, to learn how to observe. There are manuals, videos, online courses, and a mentorship program.

Turn your astrophotography into impactful science! ☞

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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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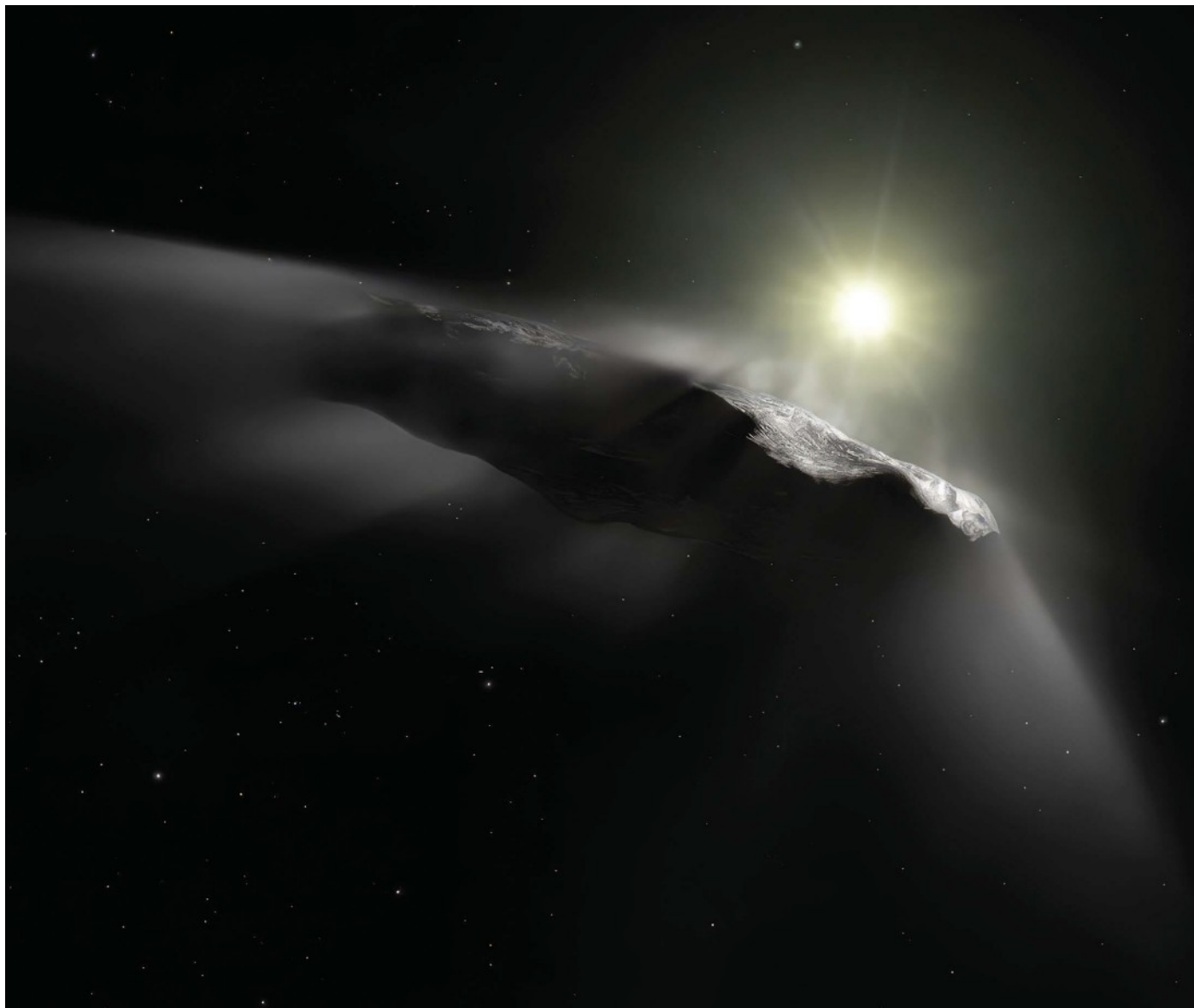
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Interstellar object 'Oumuamua sped up as it approached the Sun, shooting past at 196,000 mph (315,431 km/h) and then slowing down as it moved away ESA/HUBBLE, NASA, ESO, M. KORNMESSER

Q | WOULDN'T A FREE-FLOATING PLANET EVENTUALLY CROSS PATHS WITH A STAR OR EVEN A BLACK HOLE AND START REVOLVING AROUND IT?

*Yin
Toronto, Ontario*

A Free-floating planets (FFPs) or rogue planets are bodies that move through space by themselves, not locked into an orbit around a star. While some may have begun as typical planets flung out of their star's orbit by interactions with other objects, other FFPs may have formed by themselves, like stars. Some scientists argue that FFPs that formed like stars

should be classified as brown dwarfs, or even as a new type of object somewhere in between stars and planets.

However they formed, wandering FFPs may indeed encounter stars or black holes, but they're not likely to be captured by them because of conservation of energy. The only way they could be captured is if they happen to lose some energy through an additional gravitational interaction with a planet in that system: As it passes through a star system, the FFP might happen to pass close enough to another planet to transfer energy to it through gravity. If it loses enough energy, then it could not escape the system and it would go into orbit around the star. (Usually this would be an elongated or elliptical orbit that would not be in the same plane as any other planets. However, the orbit could become circular over

time due to weak interactions with other planets.)

The situation is much like the three interstellar objects that have been spotted passing through our solar system in recent years. Their paths through space are deflected by the gravity of the Sun, but they would not usually become captured into an orbit because they have enough energy to escape the solar system. They move faster as they fall in closer to the Sun and then slow down as they move away, finally leaving at the same speed that they started with.

For the Sun to capture them, they would have needed to have a gravitational encounter with a planet that robs them of some of their energy.

Philip Lucas

*Professor of Astrophysics, Centre for Astrophysics Research,
University of Hertfordshire, England*

**HOWEVER
THEY FORMED,
FREE-FLOATING
PLANETS MAY
ENCOUNTER
STARS OR BLACK
HOLES AS
THEY WANDER.**

night. The smallest delay happens at the waxing gibbous phase on the 25th, which comes up 22 minutes later than it did the previous day.

A number of other variables play into the time difference. The Moon's orbital speed is not constant, so its motion relative to the stars can be up to 12% faster or slower than the average during the month. Latitude also changes the numbers significantly because it alters the angle at which the lunar orbit meets the eastern horizon. In September 2026, the moonrise delay ranges from 29 to

70 minutes at 30° north and from 13 to 87 minutes at 50° north. In general, the closer you live to the equator, the less variation you will see.

Richard Talcott

Contributing Editor

Because the Moon's orbital speed is not constant, the time it rises each evening can vary by up to an hour. This lunar analemma over the pyramids in Cairo, Egypt, illustrates the variation: The Moon moves around the sky over the course of a month, even though the shot was taken at the same time each night. WAEL OMAR

**Q | WHY DOES THE
DAILY MOONRISE
TIME CHANGE BY AS
MUCH AS 60 MINUTES
FROM THE PREVIOUS
DAY, AND AS LITTLE AS
30 MINUTES, DURING THE
SAME MONTH?**

Jim Wakefield
Bend, Oregon

A | It depends on how far the Moon dips below the horizon from one day to the next. Our satellite moves, on average, 13.2° per day relative to the background stars. But the angle at which the Moon's orbit (tilted 5° to Earth's orbit around the Sun) intercepts the eastern horizon varies considerably during any given month. When the angle is steep, the Moon will lie well below the horizon at the same time the following night and Earth must rotate more to bring it into view. When the angle is shallow, Luna dips only a few degrees below the horizon from one night to the next and rises with much less lag time.

Take September 2026 as an example. From 40° north latitude, the biggest lag in moonrise occurs with the waning crescent Moon on the 8th, which rises 76 minutes later than it did the previous



Q | WHY DO BARS FORM IN SOME SPIRAL GALAXIES, BUT NOT IN OTHERS?

Joe Rusz
Herndon, VA

A | We believe that stellar bars can form in any galaxy that displays ordered rotation. This includes galaxies with disks of spiral arms, but also many lenticular galaxies, which feature disks with no spiral arms. When disk galaxies are perturbed — for instance, by the gravitational wake of a nearby passing companion — ripples run through the plane of the galaxy. These waves elongate the orbits of stars in the center of the disk. As stars in those elongated orbits pull on one another, their orbits align and form a resonance — a relationship between the periods of different orbits that can help stabilize them. We observe the effect as the boxy shape of a bar.

Around two-thirds of spiral galaxies today have a bar, including our own Milky Way. In fact, the instability that leads to a bar forming is so natural that decades ago it was difficult to explain why so many disk galaxies *didn't* have bars. Scientists working on simulations just couldn't come up with a way to stop them from forming in every galaxy they modeled.

Thanks to extensive work on the subject, we now know that significant turbulence in a galaxy's gas content or a particularly high dark matter content can prevent a bar from forming. This is also why disk galaxies in the early universe did not tend to develop bars: Early galaxies were much too turbulent. In the present day, now that galactic disks have become more settled, it is primarily the quantity of dark matter that controls whether a stellar bar is present.

Daniel Ivanov,
Graduate Student, Department of Physics & Astronomy,
University of Pittsburgh

The bar of this barred spiral galaxy blushes a pinkish red in infrared, while its dust lanes and star-forming regions appear in blue. NGC 1398 is about 65 million light-years away in the constellation Fornax.

VIKAS CHANDER





Q | USING THE SAME PLANET-HUNTING TECHNIQUES AS EARTH ASTRONOMERS, WOULD INHABITANTS OF A PLANET HUNDREDS OF LIGHT-YEARS AWAY BE ABLE TO DETECT EARTH? OR WOULD THE GAS GIANTS OVERPOWER THEIR OBSERVATIONS?

Michael O'Mara
Melbourne, Australia

A | The answer is no, our current planet-hunting techniques are unable to detect an Earth — specifically, an Earth-size and Earth-mass planet in an Earth-like orbit around a Sun-like star.

We are close, though. NASA's retired Kepler space telescope was built to find transits of another Earth. In principle, it had the photometric precision to do so — that is, the sensitivity to measure the tiny drop in a star's brightness as an orbiting Earth-size planet passed in front of it. In practice, Sun-like stars turned out to be more variable in brightness than previously recognized. This proved to be a limiting factor, preventing a clean detection of true Earth analogues.

A different technique, radial velocity — the ground-based telescope method of measuring how a star “wobbles” as an orbiting planet tugs it this way and that — now has instruments with the sensitivity required to

detect an Earth. However, stellar variability from spots, granulation, and other surface effects produces noise at levels that cannot yet be fully removed. The Earth signal is simply too small.

A near-future mission, NASA's Nancy Grace Roman Space Telescope (launch target Aug. 30, 2026), will use yet another technique: gravitational microlensing. This occurs when a nearby star with a planet passes in front of a more distant background star. The foreground system acts as a lens, temporarily magnifying the light from the background star. Both the lens star and its planet have an effect, allowing us to spot the planet around the nearer star. Roman will conduct a planetary census of stars roughly halfway between us and the center of the Milky Way. Microlensing is so sensitive that it can detect Earth-mass planets at Earth-like orbital distances, provided the lensing geometry is favorable.

Giant exoplanets do not “overpower” the observations in the sense of hiding Earth. Rather, the issue is that Earth's signal is intrinsically tiny — small mass, small size, and extremely faint compared to its adjacent Sun-like host star.

Sara Seager
Professor of Planetary Science,
Professor of Physics, and
Professor of Aerospace Engineering, MIT

The Nancy Grace Roman Space Telescope, currently expected to launch in late summer 2026, will use gravitational microlensing to spot exoplanets. This search should include planets with mass, size, and orbits similar to Earth's — a category that previous surveys have not been equipped to spot. NASA GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO

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. A WANDERING PAIR

Across 2025 and early 2026, Saturn and Neptune traced near-synchronous retrograde loops in Pisces and Aquarius, their oppositions falling just two days apart (Sept. 21 and 23, respectively). This composite captures their motion, combining dozens of short exposures taken roughly weekly from May 9, 2025, to Feb. 25, 2026, with a Canon DSLR and 135mm lens. These images were aligned to a master panorama taken with a 100–400mm lens. • **Tunç Tezel**

1



2. AN ANCIENT SHOCKWAVE

SNR G206.9+2.3 is what remains of a star that exploded in Monoceros about 7,000 light-years away. The supernova left behind delicate, nested shells of emission formed as the blast wave plows through surrounding gas and dust. The image comprises nearly 45 hours of exposure with 2- and 4-inch refractors in a combination of narrowband H α /OIII and one-shot color data. • **Gavin Bent/Kaleb Jordan**

2





3

3. SOUTHERN LIGHTS

The aurora australis shimmers above mountains near El Chaltén in Argentine Patagonia as the Milky Way and the Magellanic Clouds wheel overhead. The photographer used a Sony mirrorless digital camera and 16mm f/1.8 lens to take a 25-second exposure at ISO 1600.

• **Benjamin Starkel**

4. A JUNE EPSILON CYGNID

A meteor slices across the Summer Triangle, glowing hot blue as it reaches peak brightness in the center of its trail, as captured in the early morning of June 10 from Sainte-Catherine-de-la-Jacques-Cartier, Quebec. The photographer traced the meteor to the June Epsilon Cygnids, a weak meteor shower with a relatively high entry velocity. The image combines 21 minutes of total exposure taken with a Canon astrophotography DSLR and 20mm lens at f/3.2 (one meteor frame and 20 additional 60-second subexposures with a fog filter). • **Gaetan Thibault**



4



FIELD OF BEAMS

The Milky Way and the Magellanic Clouds stand above Uluru in Australia's Northern Territory; in the foreground lies "Field of Light," an installation created by the artist Bruce Munro. The photographer used a Sony astromodified mirrorless camera to take 12 sky exposures of 300 seconds at f/2.8 and ISO 800; separate ground exposures were blended to create this composite. • **Vikas Chander**

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THE LOCAL GROUP AT A DISTANCE

Glittering star clusters and ruby-colored emission nebulae pepper the star-studded spiral arms of NGC 3137. The galaxy, which spans nearly 140,000 light-years, spills out of this Hubble image's frame. The nebulae are stellar nurseries, glowing with emission from hydrogen atoms excited by the massive stars forming inside. The bluish star clusters represent the next stage in the galaxy's evolution, after radiation from these young stars blows the surrounding gas away. The galaxy harbors a supermassive black hole of about 60 million solar masses in its core. Astronomers suspect NGC 3137 and its large spiral neighbor, NGC 3175, mimic the Milky Way and Andromeda galaxies in our Local Group. Dozens of smaller dwarf galaxies in both groups enhance their similarities. NGC 3137 lies some 53 million light-years from Earth in the constellation Antlia the Air Pump. ESA/HUBBLE & NASA, D. THILKER AND THE PHANGS-HST TEAM

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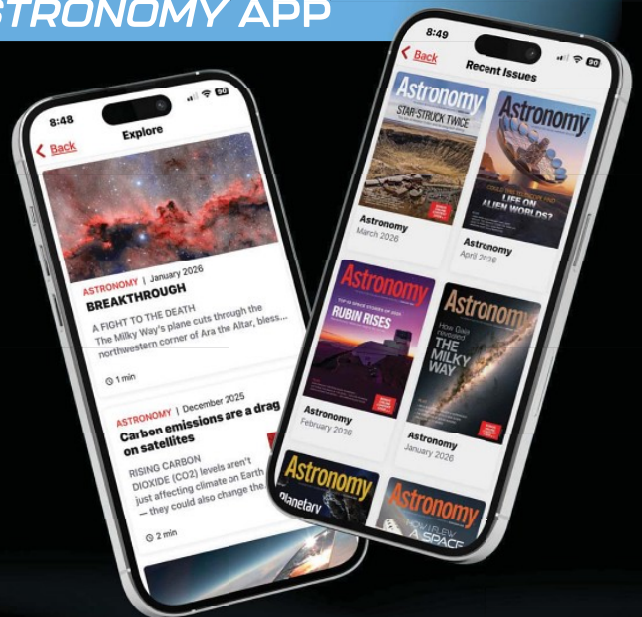
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November 2026

Venus blazes before dawn

» Although Venus has dominated the evening sky since last summer, its long apparition came to an end at inferior conjunction in late October. That leaves **Saturn** as the only naked-eye planet visible as the sky darkens this month. The ringed planet glows at magnitude 0.5 as it edges westward relative to the background stars of northwestern Cetus the Whale.

Saturn reached opposition and peak visibility in early October, but the distant world's appearance changes so slowly that you'll find it nearly as impressive through a telescope as it was last month. In mid-November, the planet measures 19" across its equator while the ring system spans 43" and tilts 6° to our line of sight. Any telescope reveals Saturn's brightest moon, 8th-magnitude Titan, and a 10-centimeter instrument brings in Tethys, Dione, and Rhea, which all glow at 10th magnitude.

November's morning sky offers a bevy of treats. A few hours after midnight, you'll see two planets forming an attractive trio with 1st-magnitude Regulus, the brightest star in the constellation Leo the Lion.

During the month's first half, **Mars** rises first with Jupiter following close behind. The Red Planet moves eastward against the backdrop of western Leo, passing both Jupiter and Regulus during November. The ruddy world slides 1.2° north of Jupiter on the 15th and 1.8°

north of Regulus on the 24th. Mars glows at magnitude 0.7 at midmonth, slightly but noticeably brighter than Regulus. Compare the orange-red color of the planet with the star's blue-white hue.

Mars' appearance through a telescope grows a bit more interesting during November. The planet spans 7" at midmonth, large enough to show some subtle surface detail during moments of good seeing.

Jupiter steals the show in this part of the sky, however. Shining at magnitude -2.1 and with a disk measuring 37" across, it easily bests its planetary companion in both brightness and telescopic splendor. The gas giant features a series of alternating atmospheric bands, with bright zones and darker belts running parallel to one another. Even under mediocre seeing conditions, the central Equatorial Zone and its neighboring belts stand out.

The approach of dawn brings the final two naked-eye planets into view. **Venus** appears first. It rises less than an hour before sunrise in early November but more than two hours before the Sun at month's end. You won't mistake the brilliant planet for any other object. It brightens from magnitude -4.2 on the 1st to magnitude -4.9 at month's end.

A telescope reveals impressive changes to Venus during November, though its large crescent remains a treat all

month. On the 1st, you'll see a disk that measures a whopping 1' across but is only 3 percent lit. By the 30th, the planet spans 40" while the Sun illuminates 27 percent of its Earth-facing hemisphere.

Mercury passes between the Sun and Earth on Nov. 4 and slowly climbs into view after midmonth. The shallow angle of the ecliptic — the apparent path of the Sun and planets across the sky — to the eastern horizon before dawn at this time of year means the planet never gains a lot of altitude. On the 30th, it stands 5° high 30 minutes before sunrise.

Still, the innermost planet shines brightly at magnitude -0.7 and should be visible in the twilight. Point you telescope at Mercury that morning and you'll see a disk 6" in diameter and 83 percent lit.

A waning gibbous Moon occults Regulus on Nov. 30 Universal Time. Residents in New Zealand can watch the event in the early morning hours of Dec. 1 local time. From Auckland, the star disappears behind the Moon's bright limb at 13h24m UT and reappears from behind the dark limb at 14h23m UT.

The starry sky

Look high in the south on any November evening and the relatively dim constellation Tucana the Toucan comes into view. Tucana's brightest star, Alpha (α) Tucanae, glows at 3rd magnitude. The easiest way to

find the constellation is to look just southwest of magnitude 0.5 Achernar, the brightest star in Eridanus the River. Tucana does possess two deep-sky treasures, however: the Small Magellanic Cloud and the stunning globular star cluster 47 Tucanae.

The origin of the constellation's name remains a source of confusion. Sixteenth-century Dutch navigators Pieter Dirkszoon Keyser and Frederick de Houtman devised the constellation in the late 16th century. Flemish astronomer Petrus Plancius first placed Tucana on a celestial globe in 1598.

Yet Keyser and de Houtman observed the sky from what we now know as the East Indies after visiting Madagascar, and the toucan is not native to that part of the world. The brightly colored bird resides in Central and South America, which lies about 180° in longitude from the East Indies.

In 1603, De Houtman published *Malay and Madagascan Vocabulary*, which included a star catalog. He headed his entry for the constellation Tucana "The Indian Magpie, named by the Indians Lang." On the line below, he included the subhead "Tucana."

This is where Keyser comes back into the story. He once visited South America and likely had observed toucans. It seems plausible that the confusion arose because the toucan bears some similarity to the oriental pied hornbill of the East Indies. ☛

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. November 1
10 P.M. November 15
9 P.M. November 30

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



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NOVEMBER 2026

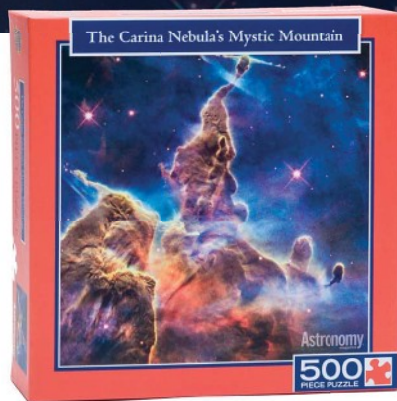
SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
 1	 2	 3	 4	 5	 6	 7
 8	 9	 10	 11	 12	 13	 14
 15	 16	 17	 18	 19	 20	 21
 22	 23	 24	 25	 26	 27	 28
 29	 30	Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.				

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

CALENDAR OF EVENTS

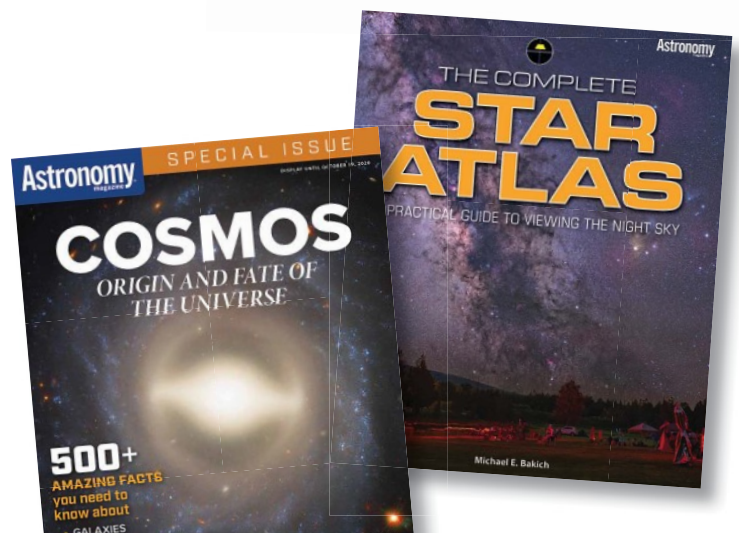
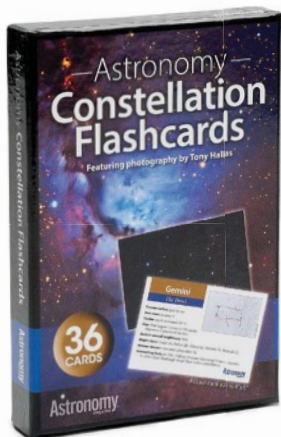
-  Last Quarter Moon occurs at 20h28m UT
- The Moon passes 1.1° south of Mars, 14h UT
The Moon passes 0.5° south of Jupiter, 23h UT
- The Moon passes 0.8° south of Regulus, 9h UT
Venus passes 2° south of Spica, 13h UT
- Mercury is in inferior conjunction, 14h UT
- The Moon passes 1.1° south of Venus, 12h UT
-  New Moon occurs at 7h02m UT
- The Moon passes 0.3° south of Antares, 5h UT
Venus is stationary, 15h UT
- Mercury is stationary, 9h UT
The Moon is at apogee (405,619 kilometers from Earth), 17h50m UT
- Mars passes 1.2° north of Jupiter, 3h UT
-  First Quarter Moon occurs at 11h48m UT
Leonid meteor shower peaks
- Venus passes 1.8° north of Spica, 23h UT
- The Moon passes 5° north of Neptune, 13h UT
- Mercury is at greatest western elongation (20°), 0h UT
The Moon passes 7° north of Saturn, 1h UT
- Dwarf planet Ceres is stationary, 9h UT
 Full Moon occurs at 14h54m UT
The Moon passes 5° north of Uranus, 19h UT
Mars passes 1.8° north of Regulus, 22h UT
- The Moon is at perigee (359,347 kilometers from Earth), 21h01m UT
Uranus is at opposition, 23h UT
- Venus is at greatest brilliancy (magnitude -4.9), 19h UT
- The Moon passes 1.2° south of Jupiter, 9h UT
The Moon passes 1.1° south of Regulus, 15h UT
The Moon passes 3° south of Mars, 20h UT

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