

# Astronomy

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# 10 GREATEST MYSTERIES

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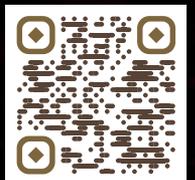
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## ON THE COVER

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JEAN-CHARLES CUILLANDRE (CFHT/CFA) & GIOVANNI ANSELMINI

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# What we know and what we don't



A Mars-sized body named Theia likely struck Earth in the early days of the solar system, resulting in the formation of the Moon. NASA

Most of what we know about the universe is recent. A thousand years ago, everyone walked around believing that the motions of heavenly bodies influenced human activities on Earth. Now we know that astrology is nonsense. (Well, many of us know it.) And the realization of the nature of galaxies and the immense size of the cosmic distance scale is only a century old.

But there is much yet to learn. My feature story this month examines 10 big subjects in astrophysics, planetary science, and cosmology that are relatively recent leaps in our knowledge. I present a few important examples where our understanding has moved strongly forward, but also underscore that we do not yet know many of the details attached to some of these critical areas.

Astronomers are hardly on the cusp of running out of things to investigate. That's a good thing for future exciting news, and also for the employment possibilities of future astronomers. For instance, we still have only a strong idea about how the Moon formed, but not yet ironclad evidence. The notion that a planet-sized body struck Earth in the solar system's youth, leading to the accretion of the Moon, is highly probable but not yet absolute. We have a pretty good idea about how Mars, our planetary neighbor, evolved from a wet to a dry world — but we don't know for certain.

Greater mysteries abound. Only very recently did we develop strong ideas about what will happen to our galaxy billions of years from now, or our concepts of the size and scope of the universe. The nature of dark matter has remained a stubborn mystery for nearly a century. We have only just begun to decipher the problem of dark energy. The behavior of black holes entices us in many ways.

And we are starting to understand the fate of the cosmos, what will ultimately happen to our universe countless ages after we are long gone. Stay tuned. There's a lot more to come on our journey.

Yours truly,

David J. Eicher  
Editor



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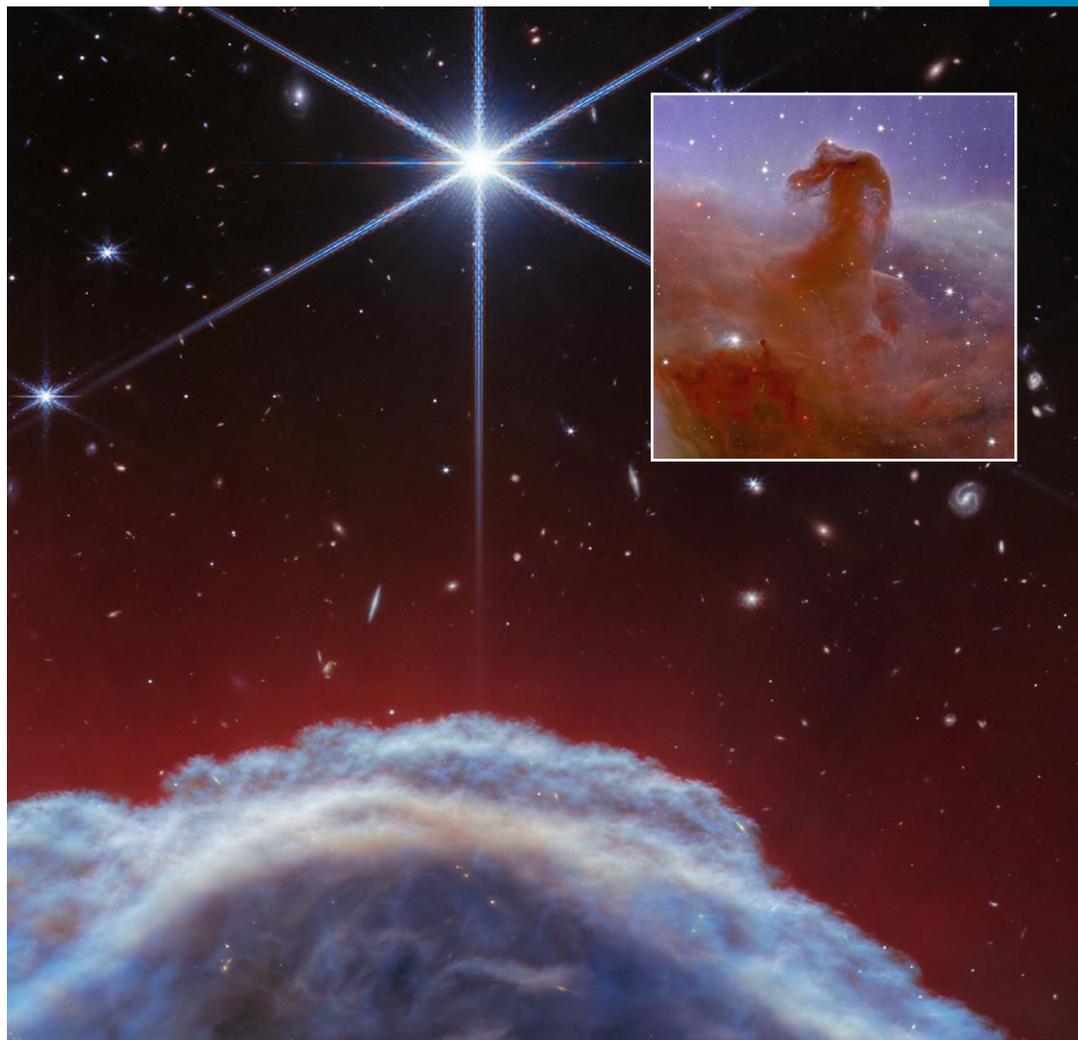
SNAPSHOT

## A HOT-HEADED STALLION

JWST gets an extreme close-up of the steaming “hair” atop the Horsehead Nebula.

The Horsehead Nebula (Barnard 33) cuts a magnificent figure amid the vast Orion molecular cloud — but its majesty is only temporary. In 5 million years, this pillar of dense gas and dust will have dissipated, ionized away by the radiation of the nearby young star Sigma ( $\sigma$ ) Orionis. In images released April 29, NASA’s James Webb Space Telescope (JWST) turned its infrared cameras to the mane of the Horsehead, which lies exposed to Sigma’s strong UV light. JWST’s resolution revealed that the evaporating gas in the main nebula is streaming away in fine, hairlike wisps of hydrogen, sweeping dust out into space along with it. It is a prime example of a so-called photo-dissociation region, allowing astronomers to study how radiation reacts with material in the interstellar medium.

—MARK ZASTROW



### HOT BYTES



#### A POLARIZING SUBJECT

Astronomers have detected a new type of behavior in magnetar XTE J1810–197. This highly magnetic, fast-spinning neutron star is emitting radio waves that are highly circularly polarized, suggesting a layer of hot plasma above the star’s magnetic pole is acting like a polarizing filter.



#### LONG-RANGE OUTLOOK

JWST has mapped the weather on exoplanet WASP-43 b, which lies 280 light-years distant in Sextans. The gas giant is tidally locked, with an overcast nightside but a clear dayside, and has equatorial winds whipping at roughly 5,000 mph (8,000 km/h).

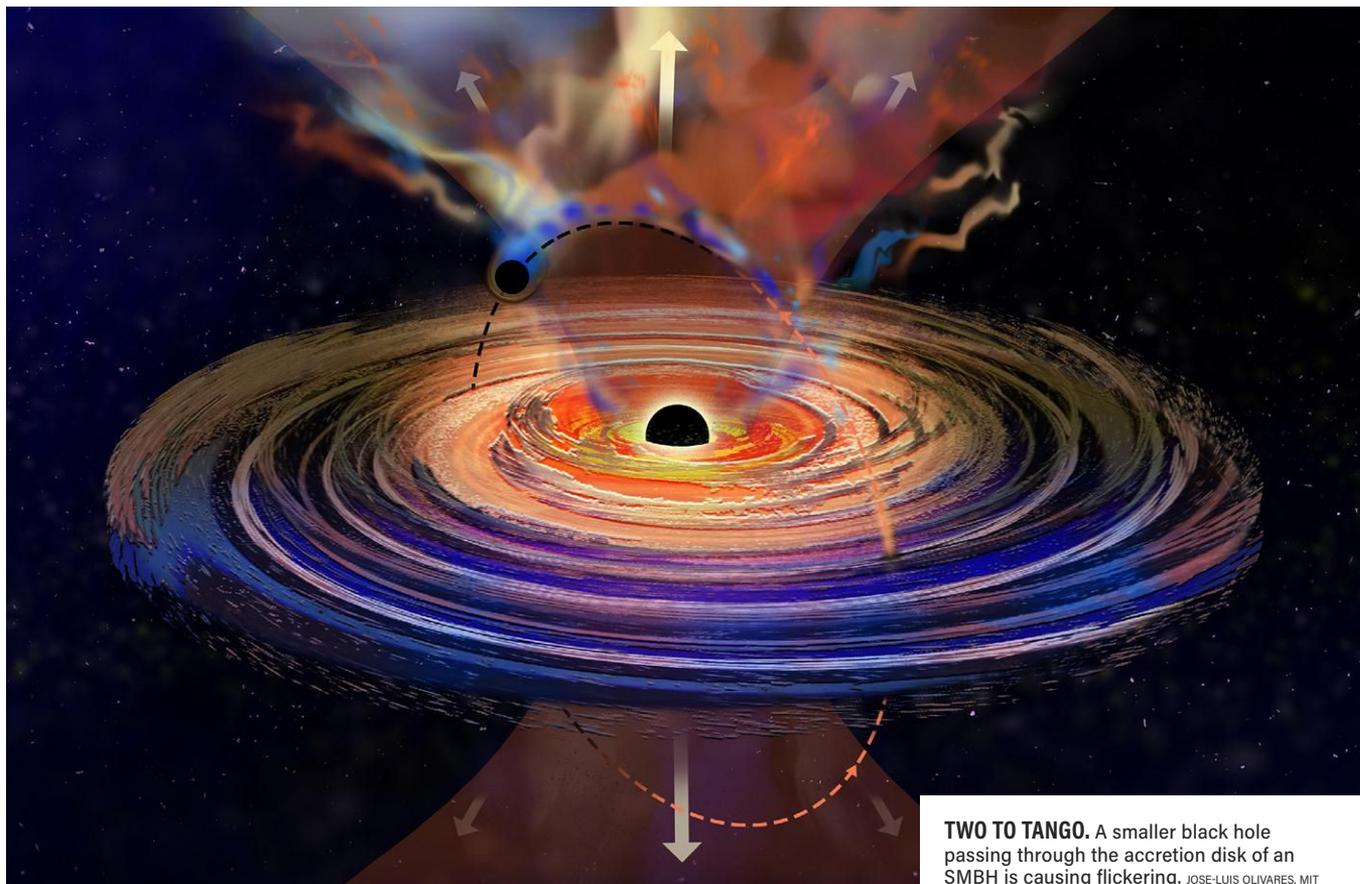


#### HEART POUNDING

Planitia, the western part of Pluto’s low-lying heart-shaped feature, may have been formed by a glancing blow from a 450-mile-wide (730 km) planetary body, a U.S.-Swiss team proposes. If true, simulations suggest the dwarf planet has no subsurface ocean.

# TWO BLACK HOLES FOUND DANCING IN THE NIGHT

Astronomers have never seen a pair of black holes quite like this one — but the universe may be filled with them.



**TWO TO TANGO.** A smaller black hole passing through the accretion disk of an SMBH is causing flickering. JOSE-LUIS OLIVARES, MIT

» Just a few years ago, astronomers witnessed something strange happening in a galaxy 848 million light-years away.

The supermassive black hole (SMBH) at the center of this galaxy was chugging along, steadily gobbling up matter. Then in December 2020, it suddenly flared up as it feasted on a wayward star and became 1,000 times brighter — only to subsequently develop an odd, steady flicker.

For four months, until the outburst eventually faded, the galaxy's center dimmed slightly every 8.3 days — a

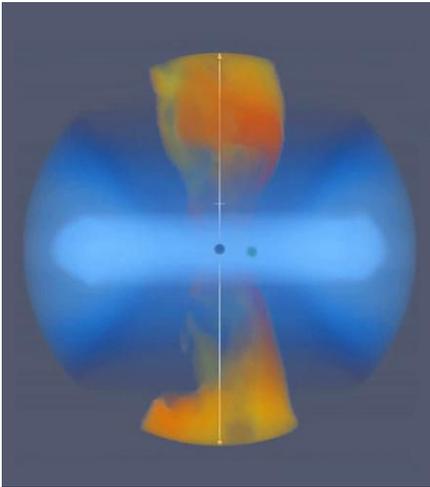
behavior never seen before in an SMBH outburst.

After some forensic investigation, astronomers think they know why: This supermassive black hole has a smaller companion black hole zipping around it that kicks up dust every time it pops through the disk of material that surrounds the SMBH. In a paper published March 27 in *Science Advances*, an MIT-led team reported on the strange sequence of events.

This binary system of black holes is the first known to contain an SMBH and an intermediate-mass black hole

(IMBH). IMBHs, which range from about 100 to 100,000 solar masses, are thought to be common in the universe but have proved difficult to find — the first direct detection of an IMBH was in 2020. Researchers now hope this flickering behavior is a signature that could lead to the discovery of many more binary systems featuring IMBHs.

The find also shakes up our thinking of what the environment at the core of a galaxy looks like. Instead of a simple disk of matter surrounding the central black hole, steadily swirling across its event horizon, the centers of galaxies



**SIMULATED DANCE.** Every time the smaller black hole (green) punches through the accretion disk (blue) surrounding its larger companion (black), it generates a plume of material (orange-yellow), seen in this frame from a computer simulation.

PETRA SUKOVA, ASTRONOMICAL INSTITUTE OF THE CAS

could host multiple black holes of different sizes, leading to more complex behavior.

### A FLASH IN THE NIGHT

The initial flare was likely caused by the SMBH tearing apart and gorging on a star that wandered too close — what astronomers call a tidal disruption event. Dubbed ASASSN-20qc, it was identified by the All-Sky Automated Survey for Supernovae (ASAS-SN), a global network of telescopes that looks for bright flashes across the sky every night. After ASASSN-20qc was first spotted in December 2020, astronomers trained a variety of space-based telescopes on the object. (Big explosions or energetic events typically shine brightest in X-rays, which can't be observed from the ground.)

At first glance, the X-ray data did not immediately appear unusual. "I was like, 'OK, cool, you know, whatever, X-ray detection,'" says Dheeraj R. Pasham, an Einstein Fellow at MIT and lead author of the paper. "But when I looked closer, what we found was, there's some interesting signal within the X-ray spectrum that appeared to be showing these regular modulations repeating every 8.3 days."

After gathering a stream of data, the team considered a number of scenarios. These included ongoing changes in how the inner accretion disk rotates, clumpy

matter falling into the black hole, or light being reflected in odd ways by material in the region.

But none of these could create the kind of flickering seen in ASASSN-20qc. That's when the team realized the likeliest culprit: a second black hole.

While the main, larger black hole is millions of times the mass of the Sun, the second black hole is mere hundreds or thousands of times the mass of the Sun. As the IMBH orbited the larger black hole, it passed through the surrounding accretion disk and kicked up dust that blocked our view, causing it to dim.

Pasham says that while looking for possible culprits, the team came across a paper from a group of Czech astronomers proposing a theoretical scenario just like this, where "there is a supermassive black hole with an accretion disk and then the secondary object that is going around," Pasham says. "Every time it punches through, you should see these kind of absorption features."

After holding several meetings and performing some simulations, Pasham's team and the Czech authors discovered that the kinds of features seen in ASASSN-20qc could only be caused by an IMBH.

### MORE TO COME

The team thinks that such systems are commonplace, and they have already found another dozen or so candidate events with similar features. Currently, they're working on observing these objects from the ground and with X-ray space telescopes.

Because these objects will continue to spiral closer to each other until they merge, they will also produce gravitational waves — ripples in the fabric of space-time caused by powerful events.

Mergers of large black holes produce gravitational waves that are too long for current technology to detect. But ESA's Laser Interferometer Space Antenna (LISA) mission should be able to detect these gravitational waves from space, Pasham says, providing astronomers with insight into what happens when huge black holes merge.

"For one of the systems, we predict that it could be detectable with the LISA in 2037," Pasham says. —JOHN WENZ

### SPACE BROTHERS

The U.S. and Japan have declared their "shared goal" for a Japanese national to be the first non-American to walk on the Moon on a future Artemis mission. As part of an agreement signed April 9, Japan will also develop and build a lunar rover with a pressurized closed cockpit.

### HIDING IN PLAIN SIGHT

Researchers have discovered the eroded remains of a 280-mile-wide (450 km) volcano on Mars amid the canyons of Noctis Labyrinthus. A buried glacier may lie below its lava flows, making it an intriguing site for human settlements and to search for life.

### SINK LIKE A STONE

Meteorites preserved on Antarctic ice fields are important sources of solar system material. But a study finds climate change is causing roughly 5,000 meteorites to sink into the ice every year; over three-quarters of all meteorites could be lost by 2100 in a high-emissions scenario.

### STELLAR OUROBOROS

A study published April 11 proposes that the 2019 mysterious gamma-ray burst GRB 191019A — originally thought to be a supernova — was a star that met a black hole and became so stretched that it wrapped fully around the black hole and collided with itself.

### VOYAGER CHECKS IN

On April 20, NASA successfully reestablished a readable download from the Voyager 1 probe after a five-month period when it was sending gibberish signals. A memory chip failed on the 46-year-old craft, requiring a software patch to store code across multiple chips instead.

### TINIEST GALAXY

A trio of observatories in Hawaii has discovered what could be the Milky Way's smallest satellite galaxy yet known. The suspected dwarf galaxy UMa3/U1 consists of 60 stars with a combined mass 16 times that of the Sun; it appears to be held together mostly by dark matter. —M.Z.

# Io's long, active life



**NO CHILL.** Io is constantly being recoated by volcanic eruptions, erasing our ability to learn much about its past by analyzing its surface. NASA/JPL/UNIVERSITY OF ARIZONA

of stable sulfur and chlorine isotopes in Io's thin, tenuous atmosphere. (Isotopes are atoms of a single element that have the same number of protons but varying numbers of neutrons in their nuclei.) Sulfur dioxide and chlorine gasses are released during volcanic activity, so their presence and concentration in the atmosphere could be telling.

What they found was that lighter isotopes seem to be depleted, while heavier isotopes dominate the current volcanic outbursts, which spew an average of about 1 ton of material per second across the world. This indicates Io has already depleted about 94 to 99 percent of its available sulfur, which in turn is evidence that "Io has been losing sulfur essentially for the entire time period of its existence," says study lead author Katherine de Kleer, a planetary scientist at Caltech.

The current study also gives insight into how Jupiter's Galilean moons — Io, Europa, Ganymede, and Callisto — formed, as their orbits indicate these moons likely formed in the places they're at now. "If Io has been volcanically active for billions of years, then that means that these three moons have been in this dynamical configuration potentially for the entire age of the solar system," as well, de Kleer says.

Assuming Io initially held some 20,000,000,000,000,000,000 (or 20 sextillion) tons of sulfur, the amount it's lost so far leaves roughly

## NASA'S SLITHERING ROVER

**A NEW SNAKELIKE ROBOT** being developed at NASA's Jet Propulsion Laboratory (JPL) could someday help scientists explore icy moons like Saturn's Enceladus and Jupiter's Europa — tantalizing places to search for alien life, thanks to liquid oceans sloshing beneath their frozen surfaces.

The 13-foot-long (4 meters) robot, named Exobiology Extant Life Surveyor (EELS), is currently in its third year of development and is designed to autonomously navigate icy surfaces and explore areas that are otherwise inaccessible to conventional four-wheeled rovers. The serpent-shaped robot has a "head" infused with cameras and sensors, including a laser-based system that creates maps of its environment, similar to an

200 quintillion to 1.2 sextillion tons of sulfur still within the moon to drive new eruptions. That may seem like a lot, but at the rate it's going, "before the end of the solar system, before the Sun expands and swallows some of the planets and changes everything, Io will run out of [its] sulfur," de Kleer says.

What happens next is an intriguing puzzle for planetary scientists. Magma can't just make its way to the surface prior to an eruption — it needs gases to push it along. "Without the sulfur dioxide, there'd have to be something else to drive the magma to the surface," de Kleer says. "It's kind of fun to think about what Io's volcanism might look like when it doesn't have that sulfur-rich gas driving it." —J.W.

» Jupiter's diminutive moon Io is an infernal hellworld that constantly spits sulfurous magma into space. And a new study, published April 18 in *Science*, suggests that it's been that way for most — or possibly all — of its 4.57 billion years of existence.

As Jupiter's innermost large moon, Io is subject to an intense gravitational tug-of-war between its massive parent planet and nearby large moons Europa and Ganymede, both of which are locked in resonant orbits.

This makes Io the most volcanic body in the solar system, and a fascinating world. But because Io is so volcanic, its surface is relatively young and can't be used to peer very far back into the moon's history. Instead, the study authors turned to radio astronomy, using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile to look for the presence

autonomous car. The bot's "body" comprises individual modules linked together that can host science instruments. It also has spiral connectors throughout the body to propel the robot forward.

This technology, described in a paper published March 13 in *Science Robotics*, allows EELS to traverse flat ground, wrap itself around an object to inch ahead, and tunnel through narrow passages by changing its shape to get in and out of spaces where a conventional rover is too big to fit. The sleek design is inspired by the desire to wiggle through narrow plume-blasting vents on Enceladus. So far, the team has tested it at JPL's Mars Yard — plus a Canadian glacier, a snowy California ski resort, and a local ice rink.

When EELS finds itself in dimly lit terrain where the robot's cameras cannot create a good map of its surroundings, it relies on a sense of touch, courtesy of sensors that measure how much it is pushing against its environment, says EELS



**SLITHERING SPEARHEAD.** JPL's EELS robot snakes across Athabasca Glacier in Alberta during field testing in September 2023. NASA/JPL-CALTECH

project manager Matt Robinson of JPL. On destinations like Enceladus or Europa, which are nearly a billion miles (1.6 billion kilometers) from Earth, the engineers can't "joystick the robot" in real time, says Robinson, because it would take up to an hour to send a command and another hour to get a response. Hence, the necessity of autonomy.

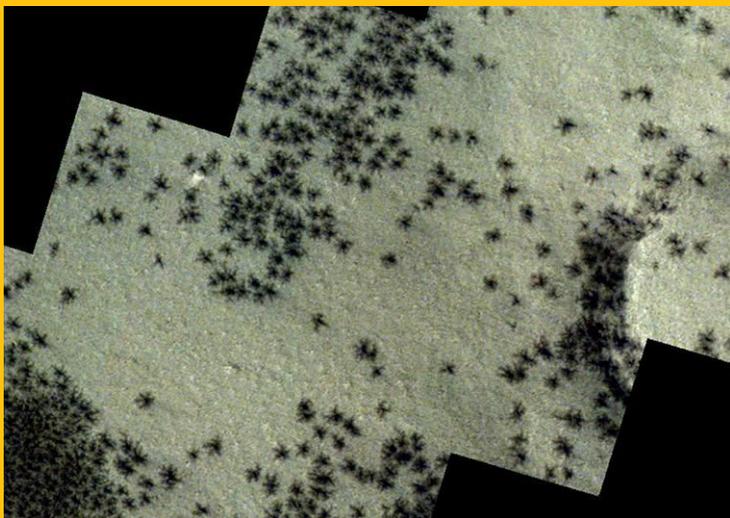
"It represents very impressive state-of-the-art engineering," says Manasvi Lingam, an astrobiologist at the Florida Institute of Technology.

The robot is still in the early stages

of development and is currently not part of any NASA mission. If it were to be sent to explore Enceladus, however, it would need to tunnel through several miles of ice to reach the moon's subsurface ocean — a challenging task, Lingam says, but "it might be able to search for biosignatures frozen in the surface ice."

EELS' engineers also envision versions of the robot that could scope out cavelike structures on the Moon where astronauts may find shelter, or explore hard-to-reach areas on Earth itself. —SHARMILA KUTHUNUR

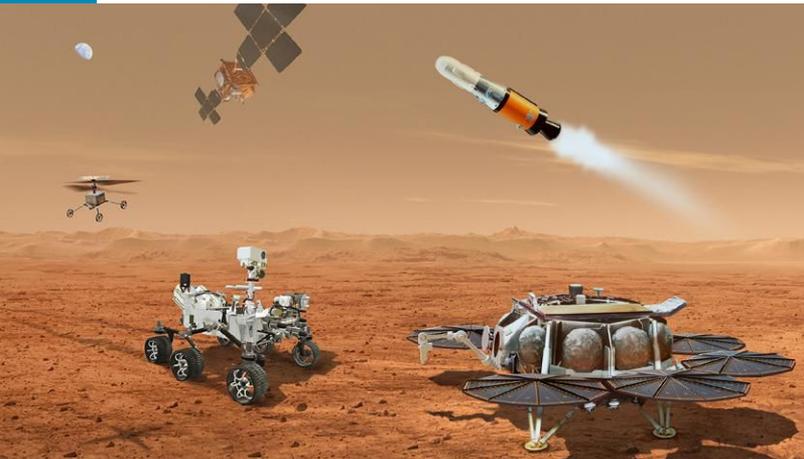
## 'SPIDERS' ON MARS



ESA/TEC/CASSIS

ESA's ExoMars Trace Gas Orbiter (TGO) normally studies the martian atmosphere — but recently, it added spiders to its research agenda. These creepy-crawly topographical features are found during spring near the southern polar region of Mars. As temperatures rise and rays of sunlight touch the carbon dioxide ice that built up during winter, the accumulated warmth at the bottom of the layer causes the carbon dioxide to turn into gas. The gas eventually escapes by cracking and bursting through the slabs of ice as a fountain or geyser, mixing with dark dust. This mixture then falls back to the surface and settles in a spindly shape. —ELIZABETH GAMILLO

# NASA reboots Mars sample return



**MARTIAN FLOTILLA.** The previously proposed Mars Sample Return mission architecture included a NASA-provided lander and ascent vehicle with a European return vehicle waiting in orbit. Perseverance, which touched down on Mars in 2021, would be expected to deliver its samples to the lander; helicopter drones could be used as a secondary recovery method.

NASA/ESA/JPL-CALTECH

**NASA IS ASKING THE SPACE INDUSTRY** for fresh ideas to complete its long-held goal of ferrying rocks back from the Red Planet.

NASA administrator Bill Nelson announced April 15 that the space agency will solicit proposals for a new plan for the Mars Sample Return (MSR) mission, which aims to send robotic craft to Mars, retrieve rock samples that have been collected and cached by the Perseverance rover, and bring them back to Earth.

The mission has faced delays and a ballooning budget. Two independent studies of the Jet Propulsion Laboratory's progress

concluded that MSR would cost anywhere from \$8 billion to \$11 billion to complete and would make it to its destination five to 10 years later than expected.

Increasingly, planetary scientists have fretted as MSR threatens to swallow NASA's planetary science budget and starve other missions of needed funds, much as the James Webb Space Telescope did for years in the agency's astrophysics division. By asking the commercial space industry to step in, NASA is hoping to halt the budgetary bleeding.

"The bottom line is an \$11 billion budget is too expensive, and a 2040 return date is too far away," said Nelson.

Earlier estimates had put the cost of the mission between \$5 billion to \$7 billion and said would get to Mars and back in the 2030s. Nelson said NASA expects new proposals to be in line with those estimates.

NASA officials have also stated that the project may be streamlined. In a letter responding to the most recent independent study this past September, NASA Associate Administrator Nicky Fox wrote that this could include creating a smaller Mars Ascent Vehicle than originally planned. In the April 15 press conference she also said the mission may have to return fewer than the 30 samples that have already been collected on Mars.

This announcement comes after recent budget cuts from Congress equaling \$2 billion each year for 2024 and 2025 for all of NASA's programs, as well as almost \$1 billion from the science division specifically. Nelson referenced other projects in the planetary science division, such as DAVINCI, Dragonfly, and VERITAS (which has experienced its own roadblocks) as projects that will benefit from the change, allowing for more resources to be allocated to those missions. —SAMANTHA HILL

## BIGGEST ASTRONOMICAL CAMERA COMPLETE

### Stats

**RESOLUTION:**  
3,200 megapixels  
(189 CCD sensors of  
4,096 by 4,097 pixels)

**WEIGHT:**  
6,600 pounds  
(3,000 kilograms)

**FRONT LENS  
DIAMETER:**  
61 inches (1.57 meters)

**READY FOR RUBIN.** The Legacy Survey of Space and Time (LSST) Camera, built by the Department of Energy's SLAC National Accelerator Laboratory for the Vera C. Rubin Observatory in Chile, is the largest digital camera ever built for astronomy. After two decades of work, its construction is complete, officials announced April 3; it arrived at Rubin May 16. When Rubin starts operations in 2025, the LSST Camera will image the southern sky every three days, allowing astronomers to find changing objects with unprecedented sensitivity and probe the nature of dark matter and dark energy. —M.Z.



J. RAMSEYER ORRELL/SLAC NATIONAL ACCELERATOR LABORATORY

# WHAT TIME IS IT ON THE MOON?



If all goes to plan, by the end of this decade, the Moon will be bustling with activity from dozens of explorers — both human and robotic. But as this new space race heats up, scientists have just begun working out a key question: What time is it on the Moon?

This simple query has a complicated answer. So far, lunar missions have functioned on the time of their respective home countries. But early last year the European Space Agency (ESA) deemed this unsustainable for the upcoming swell of Moon missions.

On April 2, over a year after ESA identified the issue, the White House directed NASA to set up a new standardized lunar time by the end of 2026. This Coordinated Lunar Time (LTC) is a necessity for the “safety and accuracy” of future Moon missions, Steve Welby, the deputy director for national security at the White House Office of Science and Technology Policy, said in a statement.

Without a standard time for the Moon, “there’s a risk that something could go horribly wrong,” says Catherine Heymans, an astrophysicist at Edinburgh University in the U.K. “This clock does need to be defined.” Multiple spacecraft from different countries are expected to be on or around the Moon at the same time, underscoring the need for a common lunar time — and by extension



**SCALING UP.** The Moon is set to become a hive of activity in the next decade, as depicted in this artist's impression of NASA and ESA lunar operations. ESA-ATG

a navigation system — that would facilitate real-time communications, avoid collisions, and carry out joint operations, per ESA.

“The White House intervention is very helpful because it really puts the foot on the accelerator to get this to happen ahead of the planned Artemis landing by the end of 2026,” says Heymans.

## TIME IS RELATIVE

According to relativity, clocks placed in different gravitational fields tick at different rates. This means time moves just a tad faster on the Moon, by about one second every 50 years.

That minuscule difference wouldn't be a bother if there was only one crew working on the Moon, in which case these changes could be easily accounted for, says Heymans. Given the surge of interest from multiple nations, however, “accurate time measurement becomes even more imperative.”

NASA's proposed LTC is “a system that, while independent, maintains traceability to Earth's Coordinated Universal Time (UTC) to facilitate seamless time conversion,” says Julian Coltre, public

affairs officer in NASA's Space Operations Mission Directorate.

Space agencies also hope by 2030 to launch a small constellation of satellites to the Moon to provide position tracking and navigation — effectively a lunar equivalent to Earth's GPS. This will also require a consistent lunar time, says Welby.

## LUNAR TIMEKEEPERS

Many technical details are



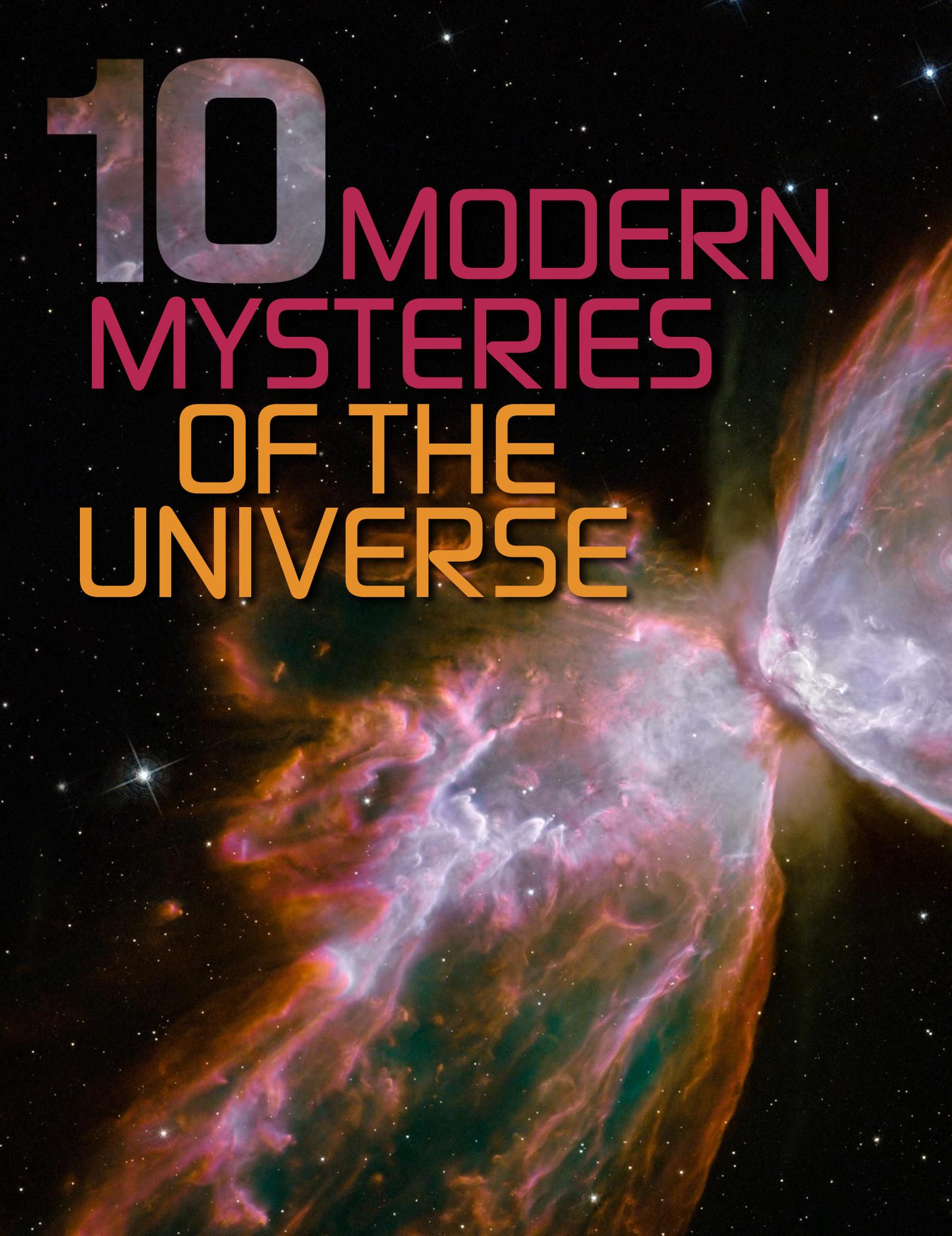
**STANDARD TIME.** Atomic clocks, like this one housed at the National Institute of Standards and Technology in Boulder, Colorado, are used to track time — one second per 9,192,631,770 energy transitions within a cesium atom.

NIST

yet to be worked out. One is whether Moon time should be maintained by atomic clocks on the Moon or stay synchronized with those on Earth, in which case a relay system would need to continuously communicate with our planet to register the time and convey that to lunar habitants.

Perhaps the most unconventional idea is to maintain time by the flashes of light from pulsars, the immensely magnetized remnants of massive stars. As they rotate, pulsars blast electromagnetic radiation from their poles; if directed toward Earth, we receive a flash like a lighthouse beacon — a predictable “pulse” that astronomers observe regularly with radio telescopes. Although pulsars offer significantly lower precision than atomic clocks, the stars wouldn't demand constant calibration like degrading clocks would, thus offering centuries-long stability.

One thing a lunar time-keeping system likely won't have is multiple time zones. A day on the Moon lasts for two Earth weeks, rendering different time zones unnecessary, says Heymans. —S.K.



# 10 MODERN MYSTERIES OF THE UNIVERSE



## What is the fate of the universe? What is dark matter? Why are we here? These are the enigmas keeping astronomers up at night — literally. BY DAVID J. EICHER

### WHETHER YOU REALIZE IT OR NOT, YOU'RE PART OF A REVOLUTION.

Let me explain. In the past, ideas to interpret the nature of things developed slowly. Before there was astronomy, there was astrology, attempting to divine mystic meaning from the motions of stars and planets. What became chemistry was originally alchemy, seeking to transform lead into gold.

It took millennia for these primitive practices to mature into the sciences. And even when they did, early science was largely about classification, whether it be bones, mineral specimens, or tree leaves.

The landscape of astronomy really changed in the 1860s, when the development of spectroscopy ushered in a new era of understanding the universe: the era of astrophysics. Finally, astronomers could begin in earnest to decipher the physical nature of objects in the cosmos in an objective and measured sense.

Big moments of realization followed. A century ago, Albert Einstein transformed physics with his theories of relativity, rewriting our basic laws of motion for the first time since Isaac Newton. Edwin Hubble revolutionized astronomy in the early 1920s by discovering the nature of galaxies and the first glimmers of the enormous cosmic distance scale.

But the most recent generation has witnessed an explosion of knowledge about the universe like nothing that preceded it. And along the way, huge surprises have completely changed many of our ideas about the universe.

We are now getting answers to some of the largest and most fundamental questions that humans have asked since time immemorial: How old is the universe? How did it begin? How large is the cosmos? Do black holes exist? How will the universe end? And why are we here on a planet orbiting a pretty ordinary star?

Truly, there has never been a better time to be someone who loves astronomy and gazing up at the heavens in awe.

The universe is a vast, spectacular place that humans have striven to understand for millennia. Now, with the help of instruments such as the Hubble Space Telescope, which snapped this image of the beautiful planetary nebula NGC 6302, we are finally able to grasp how our cosmos works. NASA, ESA AND THE HUBBLE SM4 ERO TEAM

The leading theory for the formation of Earth's Moon is that our satellite resulted from the debris flung off during a collision with a Mars-sized body named Theia early in the solar system's lifetime. NASA



# 1

## How the Moon formed

**ONE OF THE GREAT MYSTERIES** of astronomy is our nearest celestial neighbor. Presumably among the first objects in the sky that our ancient ancestors noticed and wondered over is the Moon.

For a long time, the Moon presented planetary scientists with some perplexing puzzles. The Earth-Moon system is a strange one. It has high angular momentum — that is, it has a high orbital speed, rotational speed, and mass. The Moon is also relatively massive compared to Earth and its orbit is odd, inclined by  $5.1^\circ$  to the ecliptic plane. Yet, for all that mass, the Moon has a strangely low overall density.

The first strong hints about the Moon's origin arrived when the Apollo astronauts brought back Moon rocks to study — though at first, the

samples only added to the mysteries. The rocks' chemical complexity confused scientists and led to several possibilities for the Moon's origin. Perhaps the Moon was a roaming body captured by Earth's gravity. Or maybe Earth and the Moon formed simultaneously as a sort of double planet. Perhaps our world gave birth to the Moon through an act of fission.

Maybe large planetesimals in Earth's neighborhood, early in the solar system's history, broke apart and formed the Moon. Or maybe a large impact occurred, generating debris that formed the Moon we now have.

In the 1970s, William Hartmann and Donald Davis at the University of Arizona suggested that a Mars-sized body (later called Theia)

collided with Earth in the solar system's early days, knocking out a huge cloud of material that accreted into the Moon. At first, the idea failed to catch on. But after years of study, the idea took hold, with further strong evidence provided by analysis in the 1990s by planetary scientist Robin Canup.

The so-called Giant Impact Hypothesis is now the leading idea about how the Moon formed. The strongest line of evidence is that oxygen isotopes — the particular varieties of the element, distinguished by their number of neutrons — in Moon rocks closely match those of Earth. They must have come from a common source, planetary scientists believe, and an impact would explain that.

What happened to Theia? Most of it was absorbed into Earth, under your feet.



The Apollo astronauts brought back to Earth lunar samples, whose composition provided planetary scientists with major clues about the origin of our Moon. NASA/EUGENE CERMAN

## 2 Where did the water on Mars go?

**SCIENCE FICTION DATING BACK** to the 19th century held that Mars was an Earth-like world, perhaps with all manner of creatures staring back at us. Our planetary neighbor had a complex system of canals — or so believed Percival Lowell, armed with his mighty 24-inch telescope in Arizona. The lore built around the Red Planet had us hoping that this world might hold forests, water-worn valleys, and cousins to humankind among its living beings.

Any possibility of that was shattered when the first spacecraft imaged Mars up close in the 1960s. It was obviously a barren, lifeless world.

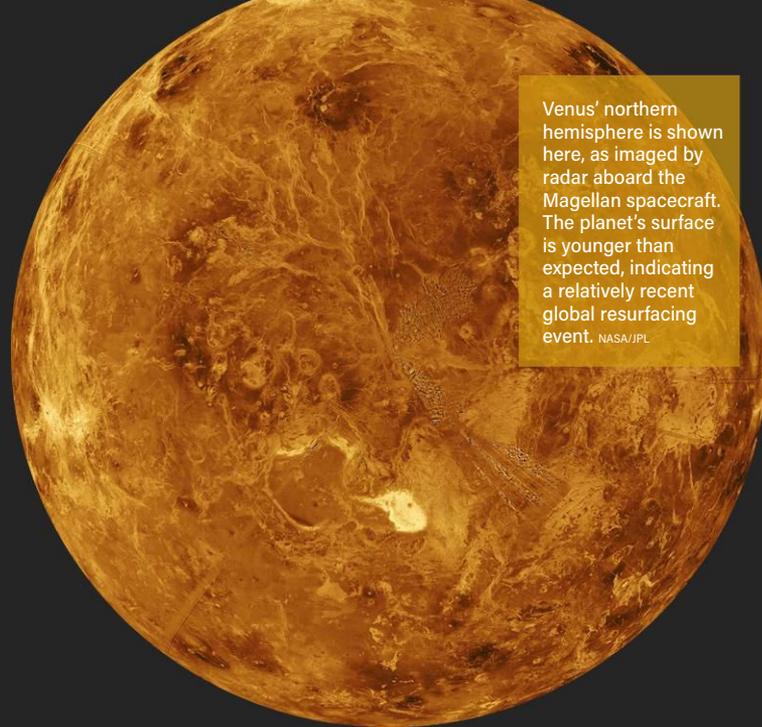
But with the arrival of orbiters and rovers at the Red Planet in the 1990s, a deeper story of Mars' evolution began to emerge. These craft, particularly the Mars Reconnaissance Orbiter, demonstrated that abundant water once had flowed on the martian surface. Substantial river channels are carved into the rocks in many places. There's plentiful evidence for subsurface aquifers on Mars, as well as water ice, including in the polar caps. But none of that water is flowing *on* the planet's surface. So what caused the planet to dry up?

The short answer is climate change. Planetary scientists believe that during its early history, Mars had a much denser atmosphere than it does now, which helped to keep water on the planet's surface. But then the atmosphere evolved and thinned. Now, water molecules on the surface of Mars would evaporate and quickly be broken apart into lighter byproducts, which are then quickly lost into space.

It will be intriguing for future astronauts on Mars to drill down into the aquifers just yards below the surface. Could they contain microbes? It might herald the first detection of life on another planet.



Images from both orbiting spacecraft and on-the-ground rovers show clear signs that water once flowed on the surface of Mars. Here, a Mars Reconnaissance Orbiter image shows ancient riverbeds that have since been filled in with gravel and turned into raised ridges. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA



Venus' northern hemisphere is shown here, as imaged by radar aboard the Magellan spacecraft. The planet's surface is younger than expected, indicating a relatively recent global resurfacing event. NASA/JPL

## 3 Why did Venus turn inside out?

**THE BRIGHTEST OBJECT** in our skies after the Sun and Moon, Venus is another planetary neighbor filled with rich lore and science fiction fun. As with Mars, we discovered with the first spacecraft forays that Venus is not exactly a place to hang around. Soviet and American landers in the 1960s quickly found that they could survive on the planet's surface for only a short time, subjected to temperatures of 800 degrees Fahrenheit (425 degrees Celsius). That Venus is like the cultural fables of hell became immediately apparent, a resemblance that only deepened with the knowledge of its toxic atmospheric gases.

Besides disappointing legions of science fiction fans, Venus also posed a substantial puzzle for planetary scientists. Researchers typically estimate the ages of planetary surfaces by counting craters. We know that the inner solar system underwent a violent epoch called the Late Heavy Bombardment, in which small bodies pelted the surfaces of planets and moons. Evidence of this still exists in a

simple glance at the Moon. But Venus, by comparison, shows very few impact craters. "What is going on with Venus?" planetary scientists wondered.

A great deal of data on Venus and its surface arrived in the early 1990s with the Magellan spacecraft, kicking off a new era of Venus studies. It became apparent that Venus is a planet with a young surface. It has been very volcanically active in the relatively recent past. And perhaps three-quarters of a billion years ago, Venus was globally resurfaced via a cataclysmic volcanic event. The older craters were obliterated. As one planetary scientist put it, "Venus is the planet that threw up on itself."

What could have caused this dramatic action? The belief is that an enormous amount of energy was trapped deep within Venus, perhaps because its crust grew so thick it smothered the world in its own internal heat. At some critical point, this energy escaped and, as Venus has no plate tectonics, the event led to the cataclysmic global resurfacing.



## 4 Here comes Milkomeda

**MYSTERIES AND STRANGE DISCOVERIES** also extend far out into the cosmos beyond our solar system. In the early 1920s, Edwin Hubble discovered the nature of galaxies when he found a Cepheid variable star in the Andromeda Galaxy, our closest big extragalactic neighbor. Because Cepheid variables pulsate at a rate that depends on their intrinsic brightness, Hubble could accurately determine its distance.

He found that the Andromeda Galaxy lies an astonishing 2.5 million light-years away. The light you see from the galaxy in your telescopic eyepiece has been traveling at the fastest possible speed for 2.5 million years, since the time our early ancestors roamed Earth.

Even before Hubble, the astronomer V.M. Slipher at Lowell Observatory had

found that most “spiral nebulae,” as they were then called, are moving away from each other.

But not all of them. The exceptions are usually within clusters and groups. We are in the same group of galaxies with Andromeda, named the Local Group by Hubble. Gravity and random motions play a large role in the behavior of galaxies in groups.

It turns out that the Andromeda Galaxy and our own Milky Way are moving toward each other at a velocity of about 70 miles per second (110 km/s). In 2008, Harvard University astronomy professor Avi Loeb and his collaborators produced a detailed study of the Andromeda Galaxy and found that eventually the Andromeda Galaxy and the Milky Way will merge into one

In another 3.75 billion years, the Andromeda Galaxy (left) will loom large in Earth's skies, as rendered in this illustration. By this time, the massive galaxy's gravity will have begun to distort the plane of our Milky Way, at right. NASA; ESA; Z. LEVAY AND R. VAN DER MAREL, STSCI; T. HALLAS; AND A. MELLINGER

supergalaxy, which they dubbed Milkomeda.

There's nothing to worry about — this will happen long after life on Earth is gone. But eventually, several billion years from now, the Andromeda Galaxy will loom larger and larger in our sky — or in the skies of surviving planets in the Milky Way. Any inhabitants will witness the galaxies' spiral arms entangle in a cosmic dance, and perhaps Milkomeda will eventually appear like one of the great elliptical galaxies we can now observe, such as Centaurus A in our southern sky.

# 5

## How large is the universe?

**THIS IS A QUESTION** that in some form must go back to when human ancestors first became capable of complex thought, staring up into the sky and contemplating why they exist. And yet the answer, in any sophisticated sense, has come pretty recently.

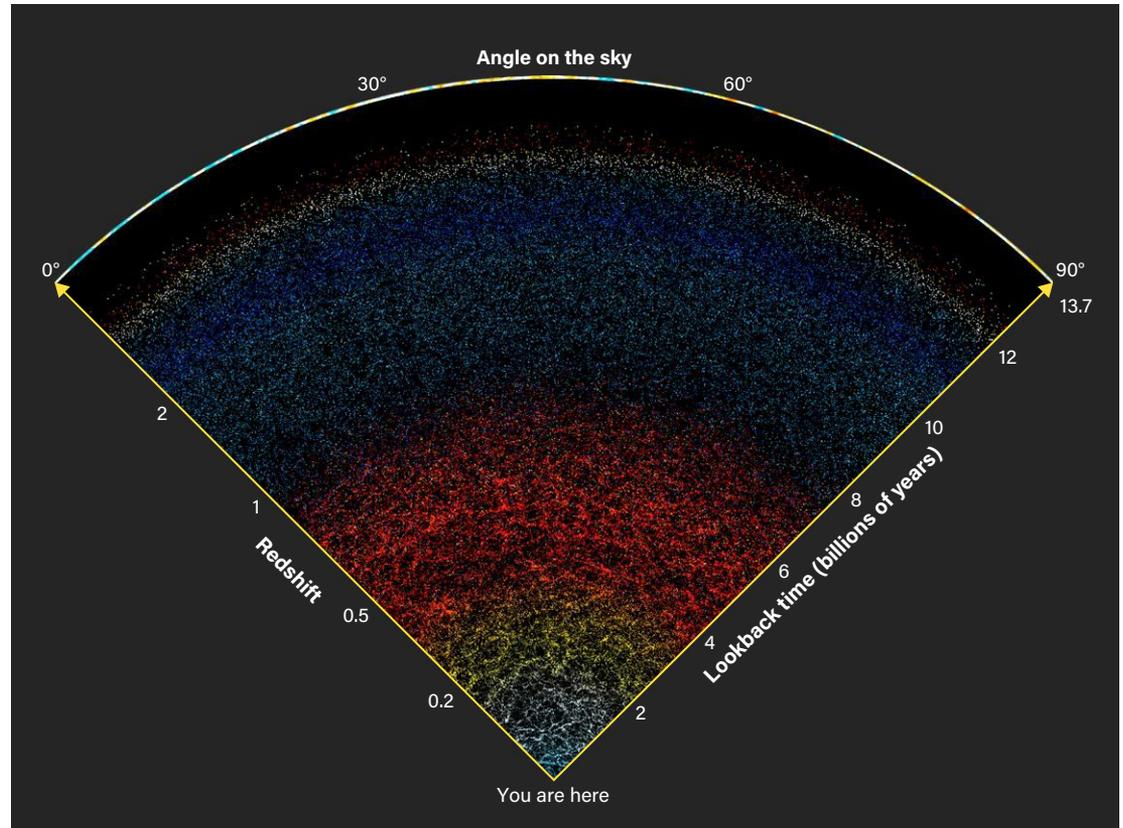
Cosmological investigations tell us that the universe is 13.8 billion years old. The most recent and accurate determination of major cosmological data comes from the European Space Agency's Planck satellite. We've known that the Big Bang marks the starting point of the universe since Arno Penzias and Bob Wilson discovered the cosmic microwave background radiation in 1964. We know the universe is expanding, which Slipher discerned in 1912. And since 1998 and the discovery of dark energy (see No. 7), we know that this expansion is accelerating over time.

The amazing fact is that we now also know the cosmos is *at least* 93 billion light-years in diameter. How can that be? Because the universe is not like a box with its contents moving outward. Space itself expands over time, interstitially. A distance of 1 inch (2.54 centimeters) in the early universe later became 2 inches (5.1 cm), and so on.

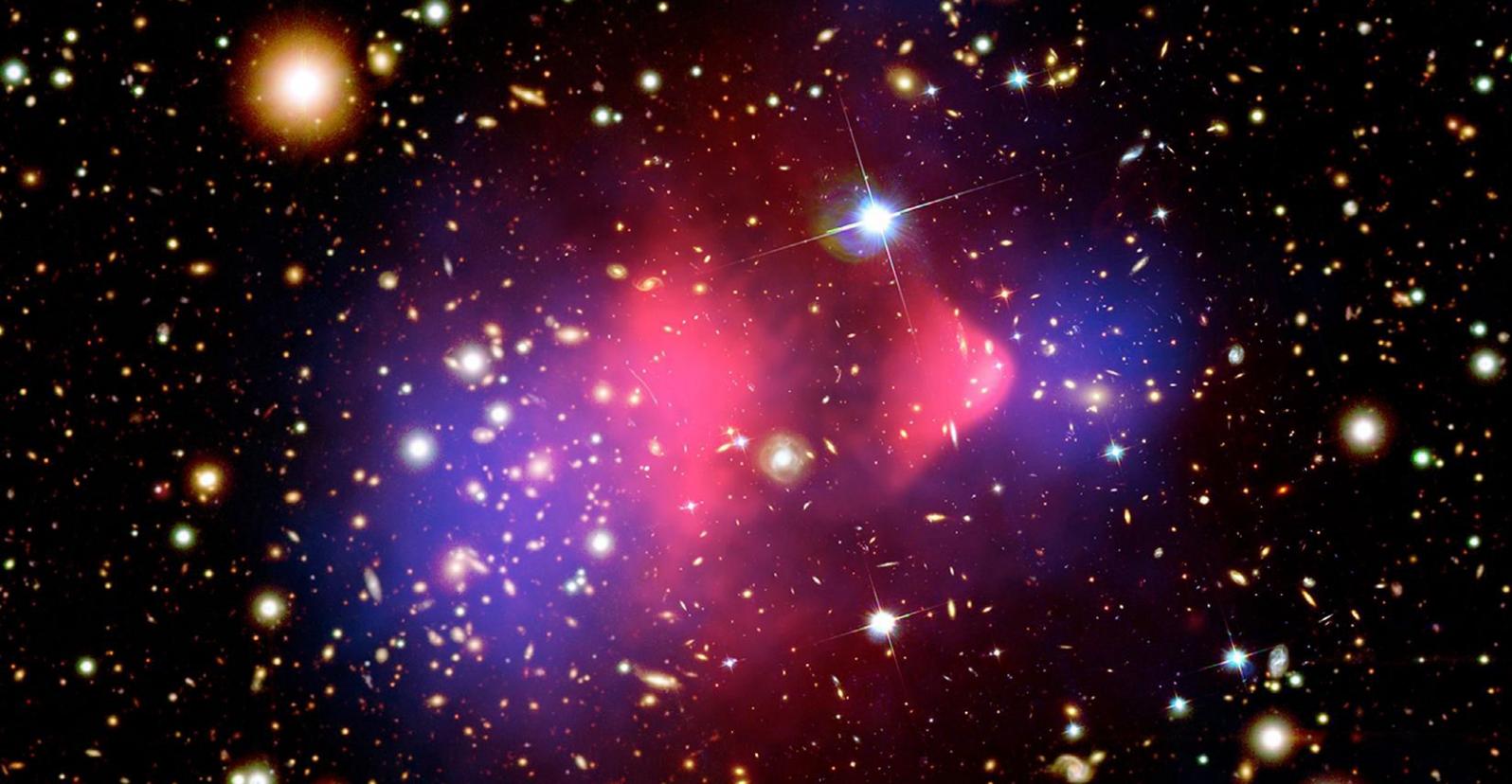
Note that I said the universe is at least 93 billion light-years across. That's because in some cosmological models, the universe could be infinite. Now *that* sounds like sci-fi — but maybe it's true.

### THE VAST UNIVERSE

We all love science fiction stories that carry our minds out into the cosmos to imagine what's there. But one thing we do know for sure is that the universe is very large. To start, the distances to the nearest stars in our galaxy, let alone to any of the other 100 billion or more galaxies, are already immense — so immense that it is probably silly to think of physical life-forms traveling those distances within any reasonable amount of time. Photons can travel at the fastest possible speed, the speed of light, because they are massless. But objects with mass take enormously more energy to move. — D.J.E



This 2D "slice" of the universe shows the distribution of some 200,000 galaxies — each represented by a dot — over an angle of about 90° on the sky. Each galaxy's distance, or redshift, is translated into a lookback time in billions of years, ending with the cosmic microwave background, generated some 13.7 billion years ago. VISUALIZATION BY B. MÉNARD & N. SHTARKMAN



# 6 The mystery of dark matter

**IN THE EARLY 1930s**, two astronomers independently postulated the existence of a strange, unseen form of matter. The Dutch astronomer Jan Oort (soon to be famous for studies of the solar system's cloud of comets) and Swiss astronomer Fritz Zwicky both studied the motions of stars in our galaxy. They each determined that the bright stuff we can see, the stars and the galactic disk, can't be everything that exists. Some unseen form of matter must also exist, and help the stars to orbit the galaxy's center as quickly as they do. Zwicky named it *dunkle Materie*, or dark matter.

Fast-forward 40 years to the 1970s, when American astronomer Vera Rubin and her research group at the Carnegie Institution were busily studying the rotation of galaxies. They found indeed that dark matter exists, and theorists at the time proposed it must exist in the form of unseen particles. In the decades that followed, proposed particles have included WIMPs (weakly interacting massive particles) and axions.

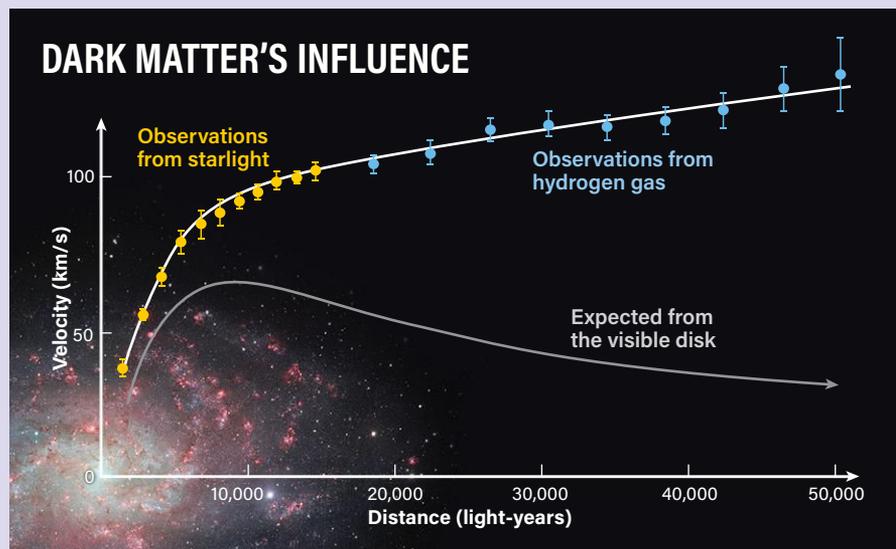
This composite image shows X-rays and visible light from the Bullet Cluster of galaxies, which is made of two separate galaxy clusters colliding. The hot gas associated with the cluster, which comprises most of the normal matter and is visible in X-rays, is colored pink. But the distribution of mass obtained through gravitational lensing is shown in blue — this is the location of the cluster's dark matter. The disconnect between the two shows that dark matter and normal matter are affected differently by the merger.

X-RAY: NASA/CXC/CFIA/M.MARKEVITCH, OPTICAL AND LENSING MAP: NASA/STSCI, MAGELLAN/U.ARIZONA/D.CLOWE, LENSING MAP: ESO WFI

Fast-forward *another* 40 years to just the last decade or so, and satellites like Planck have determined that this dark matter, whatever it is, must make up some 26 percent of the mass-energy content of the universe. All the familiar stuff in the cosmos — stars, planets, galaxies, dogs, cats, trees, etc. — must be only about 5 percent of the mass-energy.

We call that familiar stuff baryonic matter.

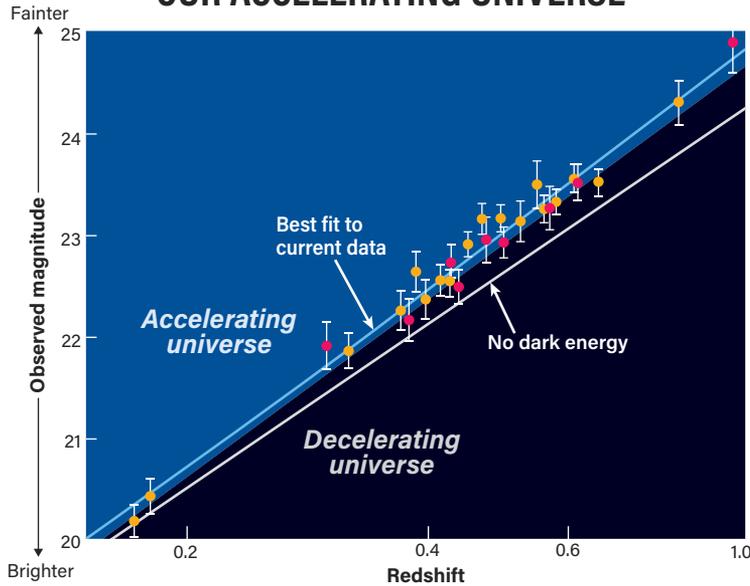
That means of all the matter in the universe, about 80 percent consists of dark matter, and we don't yet understand what it is or what it's made of. Particle accelerator experiments have not yet detected an axion or any other explanation. Stay tuned.



This rotation curve for the Triangulum Galaxy (M33) plots the velocity of stars as a function of distance from the galaxy's center. It shows the stars moving in a way that indicates the galaxy has more mass than visible matter can account for. This unseen "extra" mass is called dark matter. ASTRONOMY: ROEN KELLY, M33: ESO

# 7 The bigger mystery of dark energy

## OUR ACCELERATING UNIVERSE



Observations of distant type Ia supernovae show the universe is expanding faster today than in the past. Astronomers believe dark energy is responsible. This graph shows the brightness of supernovae plotted against their redshift, a proxy for distance. The blue line shows the best fit to the current observations, which match predictions for an accelerating universe. The white line indicates how bright these supernovae would appear in a universe with no dark energy — notably, it predicts the distant explosions should appear brighter than they actually do. *ASTRONOMY: ROEN KELLY, AFTER CARROLL, BRADLEY W. AND OSTLIE, DALE A., AN INTRODUCTION TO MODERN ASTROPHYSICS, 2ND ED., PEARSON EDUCATION, INC., 2007.*

demonstrate this by eating a sandwich and then running down the street, converting the food into energy.

The Planck satellite and others have helped us to understand the composition of the universe. But our understanding of the universe was again rocked in 1998, when astronomers discovered what is now called dark energy. Through observations of distant supernovae, astronomers found that the expansion of the universe, long believed to be constant, is accelerating over time.

This means that an unknown force — dark energy — is accelerating the expansion. What this force is composed of and its exact nature are still a mystery. But it definitely exists. So, if you are unsettled by the fact that we don't know what dark matter is, hold onto your hat. Dark energy makes up the remaining 69 percent of the mass-energy content of the cosmos.

A note to up-and-coming cosmologists: If you want to win a Nobel Prize, find out what either dark matter or dark energy is. Your prize will be a sure thing.

**WAIT A MINUTE**, you say. What is this mass-energy content you speak of? One of the things Albert Einstein's theories of relativity taught us, now more than a century ago, is that matter and energy are interconvertible forms of the same thing. That's what  $E = mc^2$  is all about. The  $c$ , which represents the speed of light, is a constant. So, the equation essentially shows that energy equals mass. The old joke, only slightly exaggerated (because the conversion doesn't happen perfectly or instantly), is that you can

# 8 Black holes are everywhere

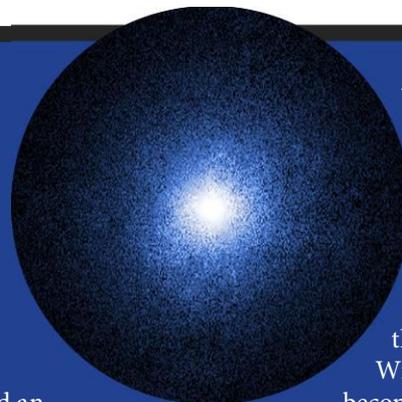
**MY STARMUS FESTIVAL** friend Kip Thorne, the world's leading expert on black holes, writes that they are "the most luminous objects in the universe, but no light!" These regions of space so gravitationally strong that nothing, not even light, can escape, are among the most bizarre objects in the cosmos. And infalling material gets so hot that it glows in X-rays, which are more energetic than the visible light our eyes are tuned to see.

The concept of black holes goes all the way back to the English philosopher and clergyman John Michell, who wrote about "dark stars" in a paper in 1783. But confirming the existence of black holes was a long time coming. They are

extremely hard to find. They are, after all, not luminous.

In the 1970s, astronomers detected an extremely strong X-ray source dubbed Cygnus X-1, seemingly a black hole candidate. Thorne and his friend Stephen Hawking made a famous bet over whether the object would be confirmed as a black hole. Finally, by 1990, it was shown to be a stellar-mass black hole — the remnant of a dead, massive star.

Soon thereafter, astronomers using the Hubble Space Telescope began finding evidence for another type of black hole — supermassive black holes — in

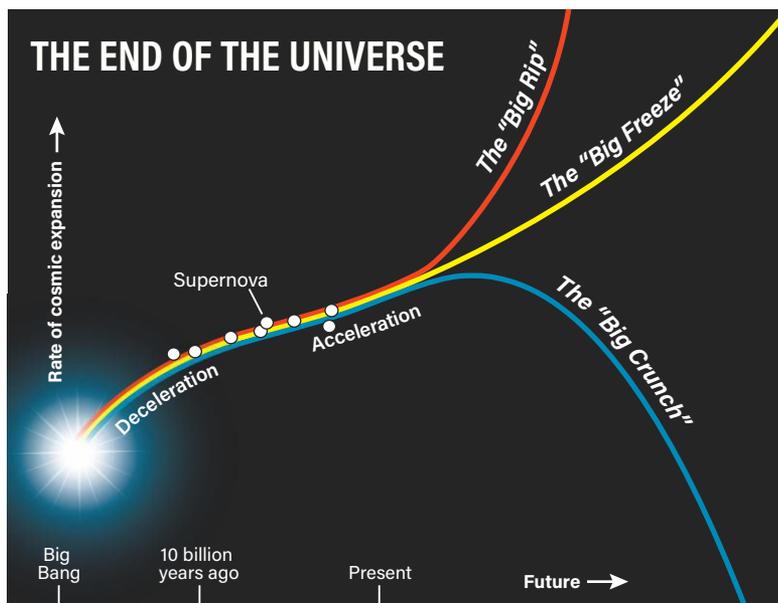


This Chandra X-ray Observatory image shows the black hole Cygnus X-1, which does not give off visible light. Instead, the accretion disk of material around the black hole, pulled from its stellar companion, glows so hot that it gives off X-rays. *NASA/CXC*

the centers of many galaxies. Within the last generation, it's become clear that massive galaxies have central supermassive black holes. (Smaller dwarf galaxies, however, do not.)

Millions of stellar-mass black holes must exist in the Milky Way, although we know of only a couple of dozen because they remain so hard to detect. The first examples of a third class, intermediate-mass black holes, have also been discovered. The catalog of known black holes will certainly swell into astronomical numbers as research carries on.

# 9 What is the universe's fate?



There are three likely scenarios for the end of the universe. In the Big Crunch, gravity dominates over the cosmos' expansion, causing it to collapse again. In the Big Freeze, the universe simply continues expanding forever. And in the Big Rip, dark energy's influence grows even stronger, tearing everything — even atoms — apart. Currently, astronomers favor the Big Freeze, though observations based on distant supernovae do not yet allow us to differentiate between the three. ASTRONOMY: ROEN KELLY

**THERE ARE BIG QUESTIONS**, and then there are *big* questions. One of the biggest has to be, “What is eventually gonna happen to this thing we call the universe?”

To begin to answer this question, astronomers need to know all about the current physical nature of the universe. This really comes down to which cosmological model we have evidence to support. For a long time, the Big Bang was just one possible model of many.

Fred Hoyle and others pushed the Steady State theory for many years, which proposed a universe that was and will be always expanding, creating matter as it goes to maintain a constant density. Others suggested an oscillating universe that expands outward before collapsing inward and starting over in a series of Big Bangs. In these models, the universe's fate was a simpler matter, either expanding forever or coming back in on itself in a so-called Big Crunch.

With the discovery of dark energy, the issue became more complex. We can still think of several possible outcomes, however. The first is the so-called Big Rip, in which billions of years from now, the expansion of the cosmos and the growing power of dark energy unbind objects currently held together by gravity. But this is a fairly unlikely scenario.

The likeliest possibility, most cosmologists believe, is the Big Freeze. This would see the universe expanding into an increasingly colder, darker, lonelier cosmos. As stars like the Sun age and die, their remnants will go cold and dark. And as billions and trillions of years pass, any remaining photons will be increasingly redshifted, stretched into wavelengths beyond visual detection. Any vantage point in the cosmos would be left with just a few unimaginably distant dwarf stars, glowing dimly like remote embers, until these, too, wink out.

The universe may have started with a bang, but the likeliest scenario at present is that it will end with a whimper.



# 10 The meaning of life in the universe

**AND THEN THERE'S PERHAPS** the most fundamental question of all: How did we get here? Some related questions: How did life on Earth originate? How common is life in the universe? Are we alone, or simply isolated from civilizations that exist in huge numbers located across vast gulfs of space, like islands in a cosmic ocean?

From the earliest microbial fossils, we know that life took a foothold on Earth quickly following the Late Heavy Bombardment, about 4 billion years ago. Life on our planet remained very simple for a long, long time. Complex life-forms like us emerged only in the past few millions of years.

The atoms in your body are many, perhaps 7 billion billion billion in the average human. They are the same atoms created in the early universe. Hydrogen and helium were made in the Big Bang, with more massive elements coming from the deaths of stars. The universe is at some level a giant recycling program, and you're part of it. As another old friend, Carl Sagan, used to say, we are literally star stuff, rearranged into self-replicating cells built into complex, thinking systems.

We know that the conditions for assembling these atoms into complex systems are pretty common

throughout the cosmos. Lots of exoplanets that could host life exist relatively near us in the Milky Way. Our galaxy contains something like 400 billion stars. (We don't know exactly because the most common stars, dwarfs, are dim and hard to see over long distances.) And the cosmos contains at least 100 billion galaxies, perhaps many more.

Conservatively, let's say that the cosmos contains 10,000 billion billion star systems. We also know, through spectroscopy, that chemistry is uniform throughout the cosmos, and that the stuff of life is plentiful. Do we really think that Earth is the only planet in the whole shooting match to have developed life? Not too likely, a master of understatement would say.

But the distances are vast, and it is almost miraculous enough that we are sentient beings. We can talk about these questions, communicate our feelings and thoughts about the night sky, and gaze up in wonder. How many mysteries of the cosmos will astronomers solve in the coming generations?

Not too many, I hope. Some of what keeps us human is to be outside on a dark night, gazing up at stars and galaxies and simply wondering. ☾



ABOVE: The question of whether Earth is the only planet with life is a big one. Although we don't yet know the answer, we suspect we are not alone — even if we may never contact other civilizations because the cosmos is so vast.

JACOB FRANK/NPS

RIGHT: Astronomers are discovering extrasolar planets such as those in this illustration at an astounding rate. With so many planets in the universe, surely others must be hospitable to life. PHL@UPR ARECIBO (PHLUPR.EDU), ESA/HUBBLE, NASA

**David J. Eicher** is editor of *Astronomy*, author of 26 books on science and history, and a member of the boards of the *Starmus Festival* and *Lowell Observatory*.

NGC 2623 is a great example of what a pair of interacting galaxies looks like, 260 million light-years distant. Galaxies need mergers or other cosmic events to perturb different regions and trigger star formation and galaxy evolution. NASA/ESA  
HUBBLE SPACE TELESCOPE

Galaxy mergers are a violent process — but these clusters lived to tell the tale. **BY ROD POMMIER**

# SURVIVORS

*FROM* THE MILKY



**OVER THE PAST EIGHT YEARS**, the European Space Agency's (ESA) Gaia space observatory has transformed our understanding of the history of our Milky Way Galaxy. From Gaia's perch at Earth's L2 Lagrange point, roughly 1 million miles (1.5 million kilometers) distant, it has produced the most comprehensive three-dimensional survey of the Milky Way ever made: a catalog

containing the precise locations, motions, and chemical compositions of nearly 2 billion objects.

For scientists, the Gaia catalog is an astonishing treasure trove that has revealed that the Milky Way had a more violent and dynamic history than we ever imagined. Researchers have identified families of stars with common origins, related by similarities in their composition and motions. Some of these

families are streams of stars flowing through and around the galaxy, flung about by gravity when the Milky Way cannibalized other, smaller galaxies.

But perhaps the most ancient relics in Gaia's catalog are globular clusters — tightly bound, stable systems composed of tens of thousands to millions of stars, commonly found throughout the

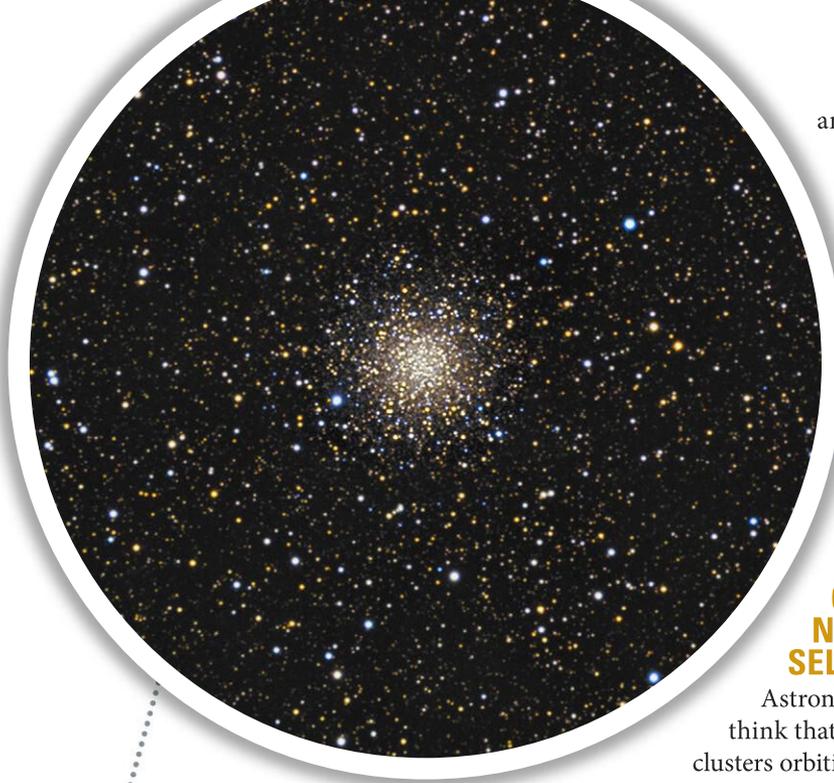


**M2  
(NGC 7089)**

M2 features dark lanes arcing and branching across its northwest quadrant (lower right of this image) that can be seen visually through a telescope.

PHOTOS BY ROD POMMIER  
UNLESS OTHERWISE NOTED

# WAY'S BIRTH



### M56 (NGC 6779)

With any telescope, viewing M56 amidst a field populated with countless colorful stars of the summer Milky Way is a real treat.

galaxy's halo and the outskirts of its disk. Some of them are immigrants to our galaxy, having originally formed billions of years ago in the dwarf galaxies that the Milky Way devoured. They are survivors from a distant past, carrying vital records of the events that formed our galaxy.

Thanks to Gaia's observations of these globular clusters — plus supercomputer simulations and machine-learning algorithms — researchers have been able to reconstruct the merger history of the Milky Way (see sidebar). They have identified dwarf galaxies and pinpointed when they made contact with our galaxy, including Gaia-Enceladus about 9 billion years ago and the Sagittarius Dwarf Elliptical Galaxy roughly 7 billion years ago.

Amazingly, you can observe many of these surviving globulars from the Milky Way's dynamic past with a telescope from your backyard: They have been hiding from us in plain sight as objects in the famous Messier Catalog. Before Gaia, I viewed them many times, simply taking note of their appearance

and some of their interesting visual features, but with no knowledge of their tremendous significance to the formation of the Milky Way. Now, I view them with a new-found sense of awe and wonder.

### GALACTIC NATURAL SELECTION

Astronomers used to think that all of the globular clusters orbiting in our galaxy's spherical halo had formed out of leftover gas on the outskirts of the nascent Milky Way. However, running the galactic clock backward with supercomputer simulations shows that the dwarf galaxy Gaia-Enceladus brought along several of its original globular clusters that managed to survive the merger. These remnants include M2, M56, M75, and M79.

M2 (NGC 7089) is a magnitude 6.5 globular in Aquarius, about 5° north of the star Sadalsuud (Beta [β] Aquarii) and lying at a distance of around 40,000 light-years. It is one of the largest and richest known globulars, measuring 16' in diameter. M2 is very dense and classified as a Class II globular. (The Shapley-Sawyer classification system ranks globulars by density on a scale in Roman

numerals from I to XII, with I being the densest.) Photometry measurements indicate that a 1' by 1' area in the center of M2 contributes 37 percent of its total light. An equal area 5' from the center contributes a mere 0.02 percent. In small telescopes, M2 appears as a large, bright, unresolved ball, but under careful scrutiny, it is slightly ellipsoidal in shape. Medium-sized scopes will resolve some of its outer stars, while larger apertures are needed to resolve stars toward the core. Some interesting visual features in M2 are dark lanes curving and branching across its northwest quadrant, which are visible through medium- and large-aperture scopes.

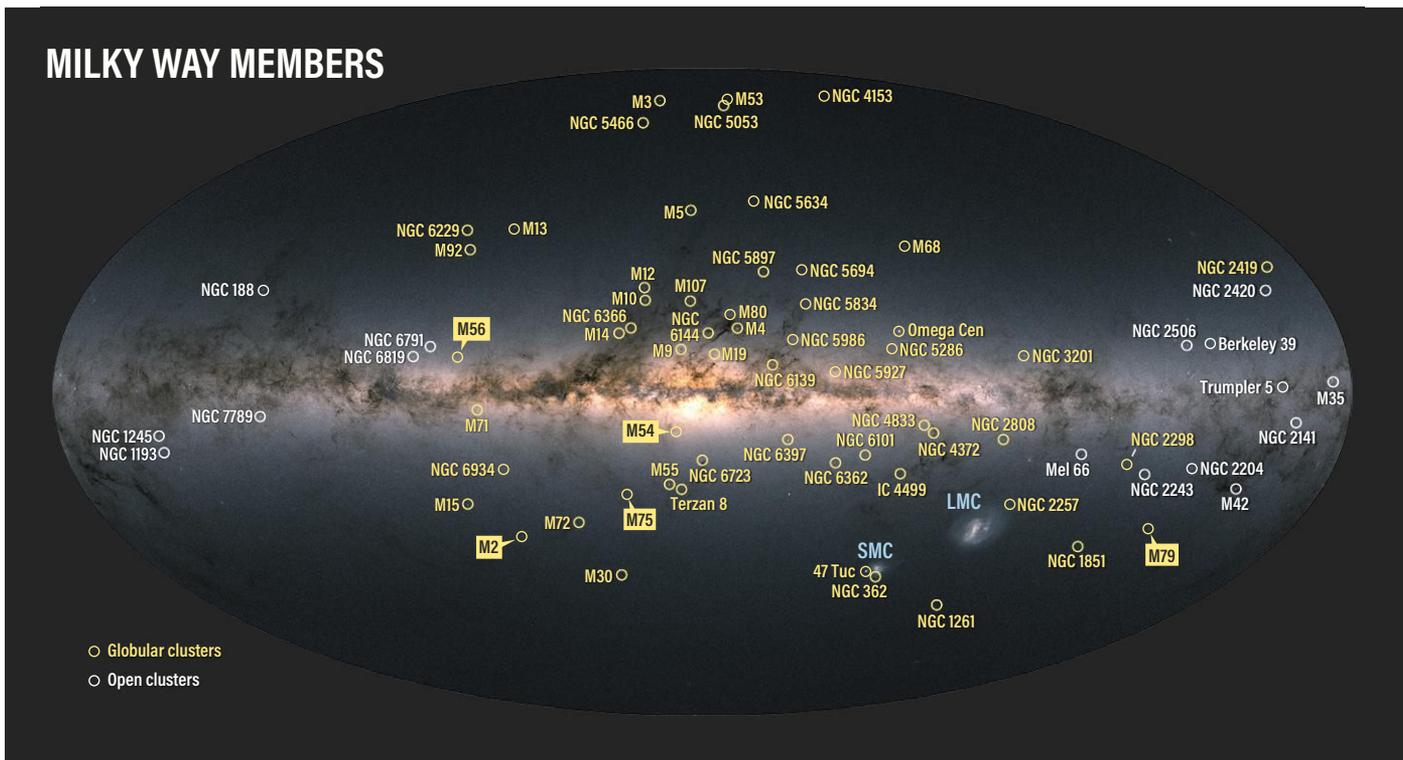
I have always felt sorry for poor M56 (NGC 6779) in Lyra because its beautiful neighbor, the Ring Nebula (M57), grabs most of the attention. Few bother to shift their telescope a short distance toward Albireo (β Cygni) to gaze upon this gem. This is a shame — while most globulars lie in sparsely populated regions outside the plane of the Milky Way, M56 dazzles at magnitude 8.3 amidst countless colorful summer Milky Way stars. M56 is one of the smallest globulars in the Messier Catalog; despite it lying closer than M2 at

### M79 (NGC 1904)

M79 is a wintertime globular in the southern constellation Lepus, south of Orion. The arc of stars above the core doubles back on itself in a V-shape on its left side, then trails off to the left.



## MILKY WAY MEMBERS



## MERGERS AND ACQUISITIONS

**IN A 2020 PAPER** in *Monthly Notices of the Royal Astronomical Society*, researchers published the most detailed account of the Milky Way's merger history to date. The project trained neural networks on globular cluster data from Gaia and galactic evolution simulations to turn back the clock and extrapolate the history of our galaxy over the past 12 billion years.

Thanks to this work, we now know that the appearance of today's Milky Way is the product of several dramatic mergers with other galaxies. The first and most significant merger occurred 11 billion years ago when a formless, barely rotating Milky Way collided with a progenitor dwarf galaxy dubbed Kraken, estimated to be about 200 million solar masses, about a quarter of the Milky Way's mass at the time. This union increased the mass of our galaxy by 100 million stars, roughly 10 percent, and gave rise to its first disklike structure surrounding its core.

The Milky Way's disk owes its thickness to the next galactic merger event: the collision with a dwarf galaxy named Gaia-Enceladus (also known as the Gaia Sausage) about 9 billion years ago. This accretion infused the Milky Way with 600 million solar masses worth of gas and stars, increasing the mass by another 10 percent. The majority of young metal-rich stars living in the Milky Way's inner halo and thick disk can be attributed to Gaia-Enceladus, either as acquired stars or stars born as the galaxies intermingled.

Much of the Milky Way's current morphology as a barred spiral galaxy is due to multiple encounters with the Sagittarius Dwarf Elliptical Galaxy. The Sagittarius dwarf galaxy began interacting with the Milky Way about 7 billion years ago, but the merger is not yet complete. It still orbits our galaxy, passing the disk at a nearly perpendicular angle every few billion years. Those passages send gravitational ripples and density waves throughout our galaxy, triggering spiral arm formation and bursts of star formation. — R.P.

Both globular clusters and open clusters are labeled in this map compiled by the Gaia space telescope. The older globular clusters (yellow) are located within the thick disk and the halo, and the younger open clusters (white) are along the edges of the Milky Way — where there is active star formation. ESA'S GAIA

33,000 light-years, it measures only 8.8' in diameter. Through medium-sized apertures, M56 is a small circular glow, brighter toward the center, and peppered with a few individual stars.

Larger apertures show an impressive compact object with many individual stars resolved toward the core, giving it a granular appearance. Interestingly, M56 has a retrograde orbit

## IN 1918, HARLOW SHAPLEY DETERMINED OUR POSITION WITHIN THE MILKY WAY BY PLOTTING THE DISTANCES TO GLOBULAR CLUSTERS. HE FOUND THAT THEY OCCUPIED A SPHERICAL DISTRIBUTION.

relative to the direction of our galaxy's rotation and that of other globulars in its halo, indicating that it must have arrived from outside our galaxy.

M79 (NGC 1904) is a rare

wintertime globular in the southern constellation Lepus. M79 has always held a special place in my heart because of its historical significance. In 1918, Harlow Shapley determined our



### M75 (NGC 6864)

M75's core is so densely packed as to be visually unresolvable in even large amateur telescopes. However, this image, taken with a 17-inch CDK telescope, shows splendid photographic resolution of its core.

position within the Milky Way by plotting the distances to globular clusters. He found that they occupied a spherical distribution with many in the general direction of Sagittarius, some of which lay at tremendous distances. In contrast, there were only three in the opposite direction lying at moderate distances, one of which was M79. By correctly assuming that the center of the sphere was also the center of the Milky Way, he concluded our solar system must be located about halfway from the center toward the outer edge, giving us our biggest demotion of position in the universe since Copernicus put the Sun at the center of the solar system.

At 40,000 light-years distant, M79 is brighter and larger than M56, shining at magnitude 7.7 and measuring 9.6' in diameter. Through a medium-sized telescope, it's an impressive globular that resembles a bull's eye with a small bright circular center surrounded by a larger but dimmer circle of light, all of which is dotted with numerous resolved stars. An interesting visual feature is a beautiful arc of stars on the east side of the cluster. Follow the arc southwest where

it abruptly doubles back in a sharp V-shape, leading to a string of stars that trail off to the south.

Speaking of globular clusters lying at tremendous distances in the direction of Sagittarius, our next target from the Gaia-Enceladus event is M75

(NGC 6864). I sometimes lament that our views of the Milky Way's myriad deep-sky treasures are largely restricted to our immediate region of the galaxy. But here is an opportunity to break out of these confines.

When you gaze upon M75, you are peering past the southern edge of our galaxy's central hub and viewing a globular lying at a distance of 68,000 light-years, hovering over the outskirts of the far side of our galaxy's disk!

M75 occupies an area of only 6.8' in a region devoid of bright stars and is the only Shapley-Sawyer Class I globular in the Messier Catalog. Indeed, M75's core refuses to be resolved even in the largest amateur telescopes. However, the extremely dense core enables it to shine like a beacon from the other side of the galaxy, with a magnitude of 8.5.

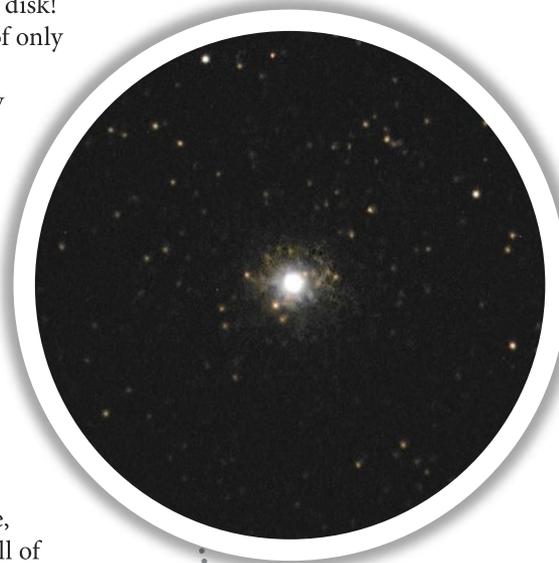
Through any size scope, M75 appears as a small ball of light with a dim edge that fades rapidly into the background sky. When viewed through my 17-inch Corrected Dall-Kirkham (CDK) telescope, it gives no hint whatsoever of resolution nor granular texture in its core. However, my CDK does resolve the core spectacularly well in photographs. While most globulars have circular orbits around the Milky Way, M75's orbit is

elliptical, which, like M56's retrograde orbit, is a strong indication of its extragalactic origin.

### YOU CAN RUN BUT YOU CAN'T HIDE

Oriented nearly perpendicular to our galaxy's disk and arching far above the Milky Way's north and south galactic poles are the Sagittarius streams. A large concentration of stars in these streams lie within an elongated ellipse south of the far side of the Milky Way's disk. These are the strewn remains of the Sagittarius Dwarf Elliptical Galaxy, which continues to orbit and pass through the Milky Way's disk 7 billion years after it first collided with our galaxy.

At the center of the concentrated ellipse, we find globular cluster M54 (NGC 6715). Charles Messier first discovered M54 in 1778, but it wasn't until 1994 that astronomers found it



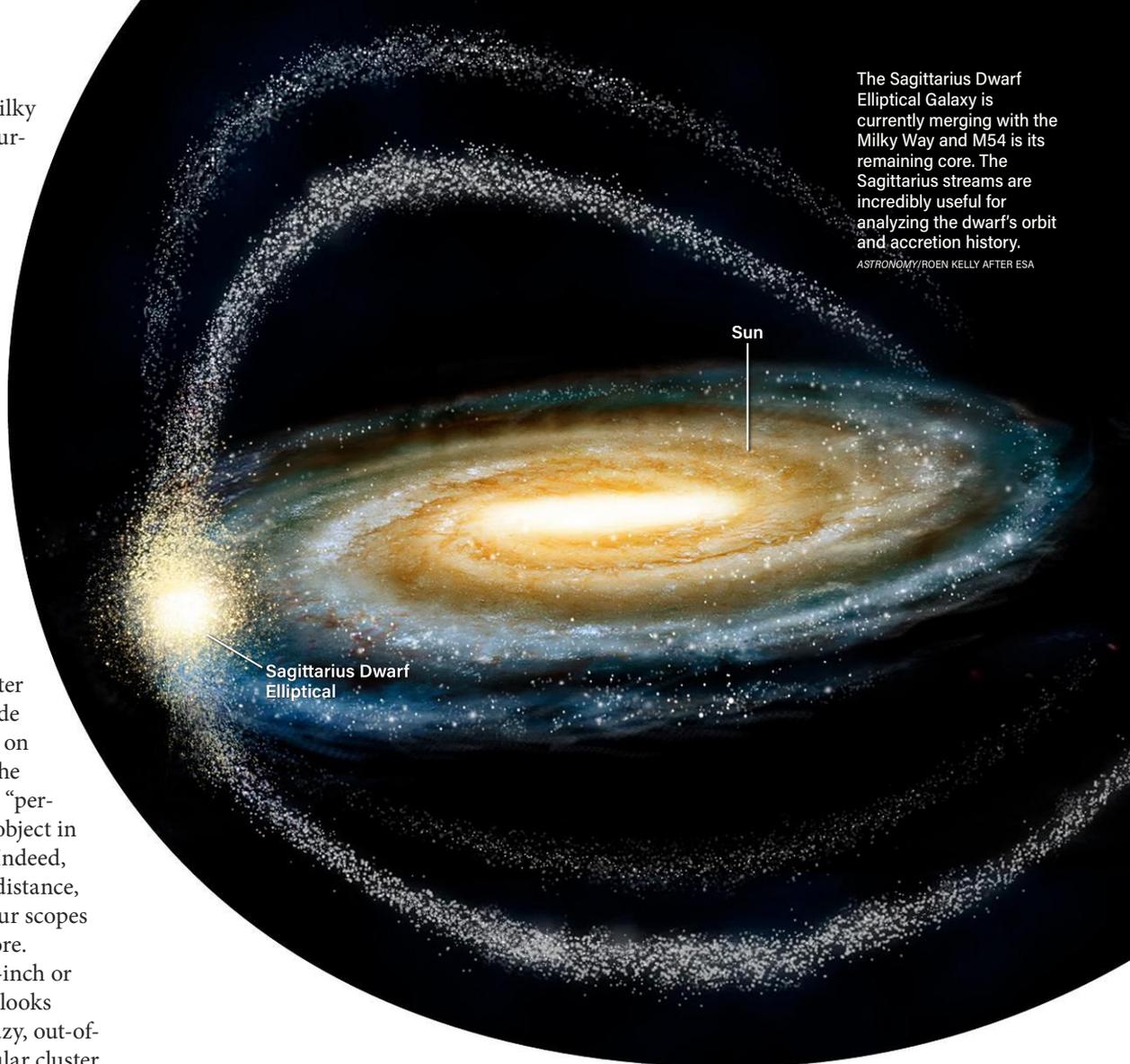
### M54 (NGC 6715)

M54 may not look like much, but its initial passage through the disk likely triggered the birth of our Sun, and by extension, the existence of life on Earth.

didn't belong to the Milky Way. Rather, it is the surviving core of the Sagittarius dwarf galaxy. These findings have been robustly confirmed with Gaia data. M54 lies at the immense distance of 87,000 light-years and is currently plummeting toward its fourth encounter with our galaxy's disk.

M54 can be found a short distance southwest of the bright star Ascella (Zeta [ $\zeta$ ] Sagittarii). It measures 12' in diameter and shines at magnitude 7.6. My personal notes on Messier objects from the 1980s describe M54 as "perhaps the most boring object in the Messier Catalog." Indeed, at such a tremendous distance, even the largest amateur scopes fail to resolve M54's core. Through either my 14-inch or 17-inch scope, its core looks more like a bloated, hazy, out-of-focus star than a globular cluster with a few faint stars resolved around its rim.

However, M54 should not be dismissed so lightly. Gaia simulations indicate the first passage of the Sagittarius dwarf galaxy through the Milky Way's disk sent gravitational ripples throughout our galaxy, triggering a burst of star formation and generating spiral arms that almost certainly included the birth of our Sun. It appears the Sagittarius dwarf is responsible for more than just the current spiral morphology of our galaxy. Our solar system and all life within it may owe their very existence to that first passage. Accordingly, I now consider M54 one of the most fascinating Messier objects, deserving to be sought out, gazed upon with awe, and even revered.



The Sagittarius Dwarf Elliptical Galaxy is currently merging with the Milky Way and M54 is its remaining core. The Sagittarius streams are incredibly useful for analyzing the dwarf's orbit and accretion history.  
ASTRONOMY/ROEN KELLY AFTER ESA

## I NOW CONSIDER M54 ONE OF THE MOST FASCINATING MESSIER OBJECTS, DESERVING TO BE SOUGHT OUT, GAZED UPON WITH AWE, AND EVEN REVERED.

### TIME TO TAKE OUT YOUR TELESCOPE

We live in a universe where the rule among galaxies is "Eat or be eaten." This cosmic drama will continue billions of years into the future as the Milky Way absorbs the Sagittarius Dwarf Elliptical Galaxy and the Magellanic Clouds, and eventually collides and merges with the Andromeda Galaxy to form a giant elliptical galaxy. I hope you will seek out each of these objects (or their remains) and view them with a

new sense of awe and wonder as you contemplate their dramatic roles in the building of our home galaxy.

We observers are among the privileged few who can still view remnants of the Milky Way's dynamic mergers with our own eyes. Don't let this opportunity pass you by. ☾

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**Rod Pommier** is a surgical oncologist, a professor of surgery at Oregon Health & Science University, an astroimager, and a regular contributor to Astronomy.

# 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 late-summer stars wheel in the sky above Jumbo Rocks Campground at Joshua Tree National Park. NPS/

ALESSANDRA PUIG-SANTANA

**Saturn** is next to rise in the evening, appearing over the eastern horizon at about 10 P.M. local daylight time on Aug. 1. It is up two hours earlier by the end of August. The ringed planet is a month from opposition and is a fine object. Starting the month at magnitude 0.7, it's easy to spot among the much fainter stars of Aquarius. The planet stands  $1.5^\circ$  south of 4th-magnitude Phi ( $\phi$ ) Aquarii, a star familiar to recent followers of Neptune.

As its distance from Earth slowly diminishes, the angular size of Saturn's disk in a telescope grows imperceptibly from 18.7" to 19.2". The polar diameter is 17", showing more than 10 percent flattening of the disk, obvious now that the ring system is close to edge-on.

The rings widen slightly as their tilt grows from  $2.5^\circ$  to  $3.5^\circ$ ,

» Venus is a bright evening star for a short period after sunset, beckoning skywatchers to view the oncoming string of planets. Saturn puts on a great show when it rises in the late evening. You can also grab a pair of binoculars to spy Uranus and Neptune — we provide guides below. The real spectacle of the month is the conjunction of Jupiter and Mars in Taurus on the 14th, visible in the early-morning hours. It's one sight you won't want to miss.

**Venus** is striking once the Sun sets in the west. Standing  $3^\circ$  high 30 minutes after sunset, it shines at magnitude  $-3.9$ . It's an easy object if you have a clear horizon, though its visibility only slightly improves throughout the month. On the 4th, Venus stands  $1^\circ$  north of Regulus, a 1st-magnitude star in Leo that will require binoculars or a small telescope to spot in the bright evening twilight. On Aug. 5, a crescent Moon joins

the scene, with Venus  $1^\circ$  west of our satellite — again a challenging view, since the two set an hour after sunset.

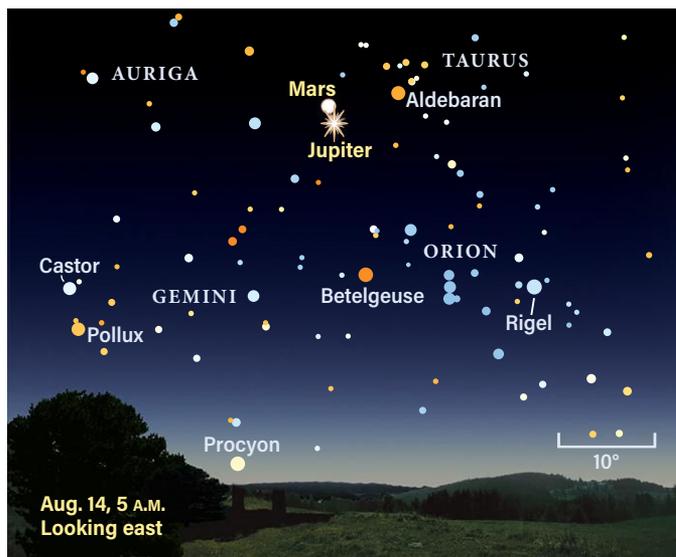
By Aug. 31, while the elongation of Venus has grown to  $24^\circ$  east of the Sun, the angle of the ecliptic to the western horizon hasn't improved, so Venus remains only  $5^\circ$  high 30 minutes after sunset. Venus is on the far side of the solar system with respect to Earth and presents an almost full disk (92 percent lit) in a telescope, spanning  $11''$ .

You might spot **Mercury** on Aug. 1 standing  $8.7^\circ$  to the left of Venus in the sky for mid-northern latitudes. It shines at magnitude 0.9 and may be easily mistaken for Regulus (magnitude 1.4), which lies about midway along and above a line joining the two planets.

Mercury quickly sinks out of view and reaches inferior conjunction with the Sun Aug. 18. After that it reappears in the morning sky, reaching

magnitude 1 on the 30th. Look for it on the 31st, when it hangs  $13^\circ$  below the waning crescent Moon as the planet rises some 80 minutes before the Sun.

## A close meeting in Taurus 👁️ 🔭 📡



Jupiter and Mars meet in a close conjunction the morning of Aug. 14. Uranus, visible with binoculars, is not shown but lies slightly higher in the sky, near the Pleiades. ALL ILLUSTRATIONS: ASTRONOMY; ROEN KELLY

## RISING MOON | An enduring favorite

### OBSERVING HIGHLIGHT

**MARS** and **JUPITER** close to within  $0.3^\circ$  of each other in a conjunction Aug. 14.



as our orbital path carries us slightly above the plane of the rings. This will continue through November, when they reach a peak of  $5.2^\circ$  and then head toward the next ring-plane crossing in March 2025.

The satellites of Saturn cross in front of or behind the planet, although only Titan is easily visible through small telescopes. Others may be captured with high-speed video and image refinement.

Titan shines at magnitude 8.4 and orbits every 16 days. On July 31/Aug. 1, Titan transits the southern pole of Saturn starting around 1:15 A.M. EDT

— Continued on page 34

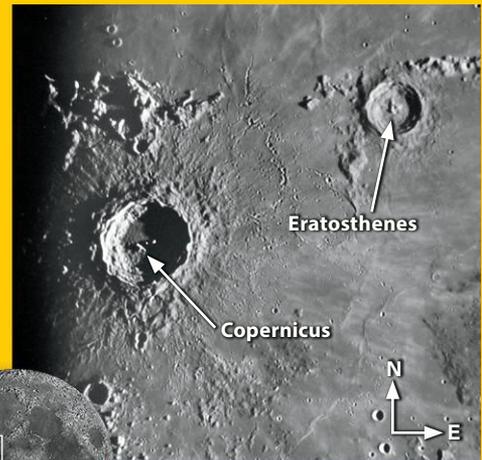
**TERRACED WALLS**, complex central peaks, a rough ejecta blanket, and a ray system at Full Moon — it's no surprise that Copernicus is visited again and again by lunar observers! The Sun rises first over the tall, modestly sharp rim on the 13th, a night after First Quarter.

Under a low Sun, the lunar topography casts long shadows, accentuating the visibility of peaks and bumps as well as holes and mild depressions. Note the jagged black teeth and spike projected onto the sandpaper-like floor. The entire crater is surrounded by an apron of fantastic texture, the result of the contents splattering outwards in all directions shortly after impact. Lunar geologists call that an ejecta blanket.

The terraces are a delight at high power. Dig a hole in a wet sandy beach and within seconds, the steep walls collapse inward to form giant staircases down to the floor. Sharp-eyed observers have noted that the terraces here are tilted down on the outside based on how the higher inner edge casts a shadow rimward. On the night of the 14th, the eastern terraces become visible. In case you get clouded out, the sequence almost repeats on Sept. 11, but with an even lower Sun angle than the image shown here.

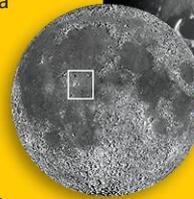
For a few days on either side of Full, the nearly overhead Sun beats down on the 60-mile-wide impact crater. Thread in a filter to reduce the glare, pump up the power, and take in the scenery. The rough terrain and differences in elevation

### Copernicus 🔭



Copernicus Crater is much loved by observers. Its nearest neighbor is Eratosthenes. CONSOLIDATED LUNAR ATLAS/UJ/LPL.

INSET: NASA/GSFC/ASU

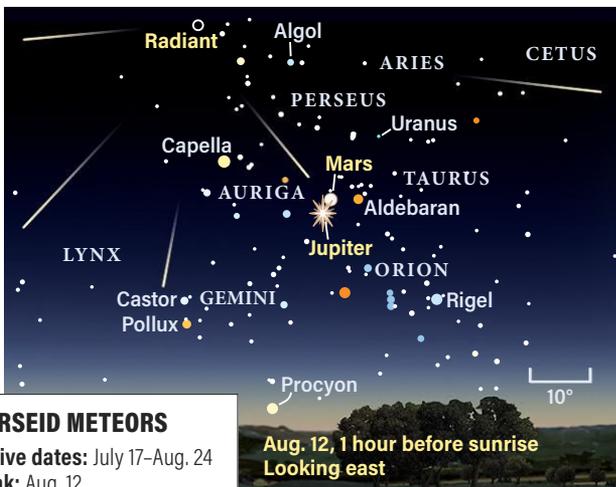


and texture have completely disappeared, replaced by a land of light rays and darker mottled mare showing through from underneath. These brightness (albedo) variations help astronomers piece together the history of the lunar surface. The impacting asteroid may have landed in a dark lava field, but the blast excavated down to the lighter-hued rocks below and hurled them outward in a fantastic system of rays.

After a good look at Copernicus under different phases, you too will keep coming back for more.

## METEOR WATCH | The Perseids return

### Perseid meteor shower 👁



### PERSEID METEORS

**Active dates:** July 17–Aug. 24  
**Peak:** Aug. 12  
**Moon at peak:** First Quarter  
**Maximum rate at peak:** 100 meteors/hour

Aug. 12, 1 hour before sunrise  
 Looking east

The Perseids' peak Aug. 12 is best viewed in the early morning. Note that Mars and Jupiter are days from a conjunction.

### THE PERSEID METEOR

**SHOWER** is favorable this year. The First Quarter Moon sets around midnight, offering hours of viewing in a dark sky when we are on the leading hemisphere of Earth as we orbit the Sun. As we plow into the stream, we'll see higher-velocity — and therefore brighter — meteors.

The shower, a result of Comet 109P/Swift-Tuttle, is active from July 17 to Aug. 24 and peaks Aug. 12. Both the mornings of Aug. 11 and 12 should provide good rates; if poor weather is around, try Aug. 10 and 13 as well.

The zenithal hourly rate (ZHR; when the radiant is at  $90^\circ$  altitude) may reach 100 meteors per hour.

The radiant in Perseus rises above  $60^\circ$  in the hour before dawn. This attenuates the listed ZHR rate by about 15 percent, which converts to an average of more than one meteor per minute in the pre-dawn hours if you have a clear dark sky away from streetlights. From a city this value will drop by more than 50 percent, since you will only see the brightest members.

Center your view  $40^\circ$  to  $60^\circ$  from the radiant by sitting in a comfortable chair or lounger. Perseid meteors can appear anywhere in the sky, but the longer streaks lie some distance from the radiant. Many bright Perseids leave a fluorescent trail called a persistent train.

# 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:

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

Planets are shown at midmonth

## MAP SYMBOLS

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

## STAR MAGNITUDES

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

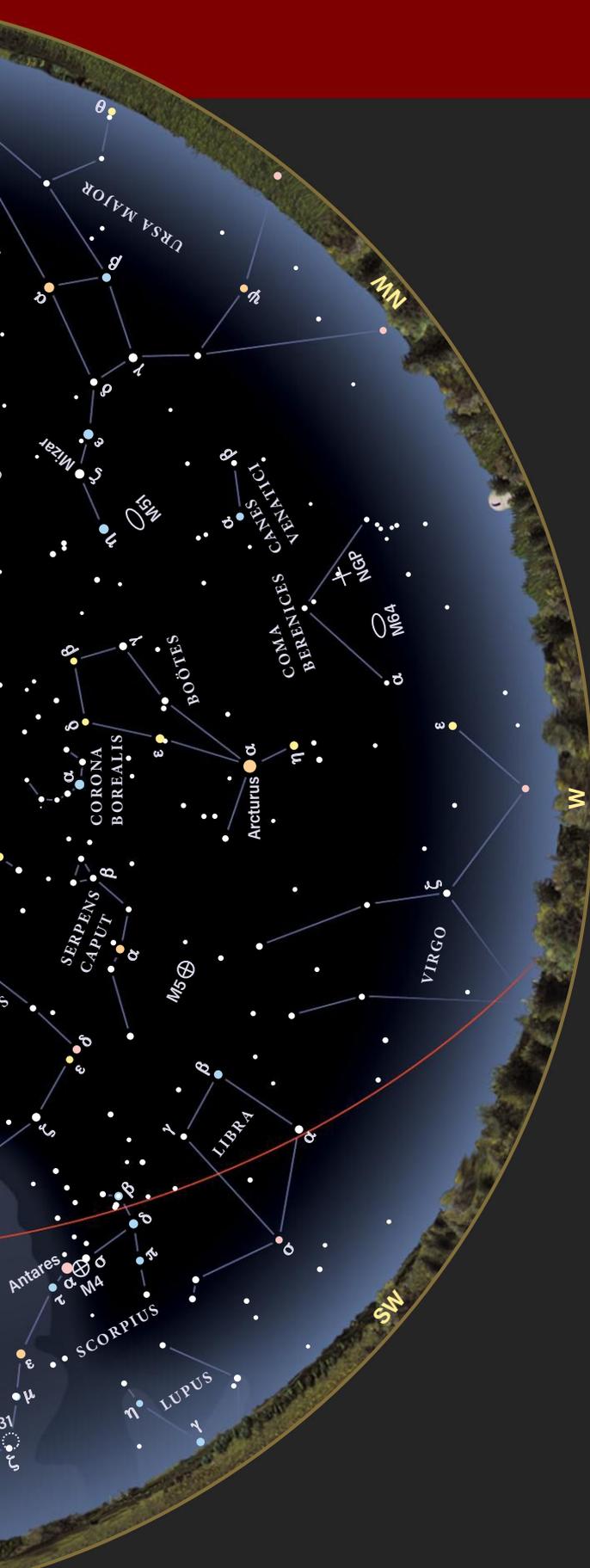
## STAR COLORS

A star's color depends on its surface temperature.

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



BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT [www.Astronomy.com/starchart](http://www.Astronomy.com/starchart).



# AUGUST 2024

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

ILLUSTRATIONS BY ASTRONOMY ROSEN 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

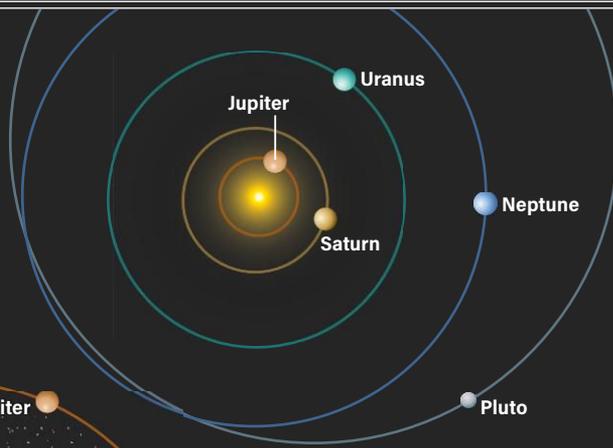
- 4 Mercury is stationary, 4 A.M. EDT  
 New Moon occurs at 7:13 A.M. EDT  
 Venus passes 1.1° north of Regulus, 6 P.M. EDT
- 5 Mars passes 5° north of Aldebaran, 3 P.M. EDT  
 The Moon passes 1.7° north of Venus, 6 P.M. EDT  
 The Moon passes 7° north of Mercury, 8 P.M. EDT
- 6 Asteroid Psyche is at opposition, 2 A.M. EDT  
 Mercury passes 6° south of Venus, 11 A.M. EDT  
 Asteroid Iris is at opposition, 4 P.M. EDT
- 8 The Moon is at apogee (251,840 miles from Earth), 9:31 P.M. EDT
- 10 The Moon passes 0.7° north of Spica, 6 A.M. EDT
- 11 Mercury passes 6° south of Regulus, 6 P.M. EDT
- 12 Perseid meteor shower peaks  
 First Quarter Moon occurs at 11:19 A.M. EDT
- 14 The Moon passes 0.004° south of Antares, 1 A.M. EDT  
 Mars passes 0.3° north of Jupiter, 1 P.M. EDT
- 18 Mercury is in inferior conjunction, 10 P.M. EDT
- 19 Full Moon occurs at 2:26 P.M. EDT
- 20 Asteroid Vesta is in conjunction with the Sun, 5 A.M. EDT  
 The Moon passes 0.5° north of Saturn, 11 P.M. EDT
- 21 The Moon is at perigee (223,815 miles from Earth), 1:02 A.M. EDT  
 The Moon passes 0.7° north of Neptune, 6 P.M. EDT
- 25 The Moon passes 4° north of Uranus, 8 P.M. EDT
- 26 Dwarf planet Ceres is stationary, 4 A.M. EDT  
 Last Quarter Moon occurs at 5:26 A.M. EDT
- 27 The Moon passes 6° north of Jupiter, 9 A.M. EDT  
 The Moon passes 5° north of Mars, 8 P.M. EDT  
 Mercury is stationary, 11 P.M. EDT

# PATHS OF THE PLANETS



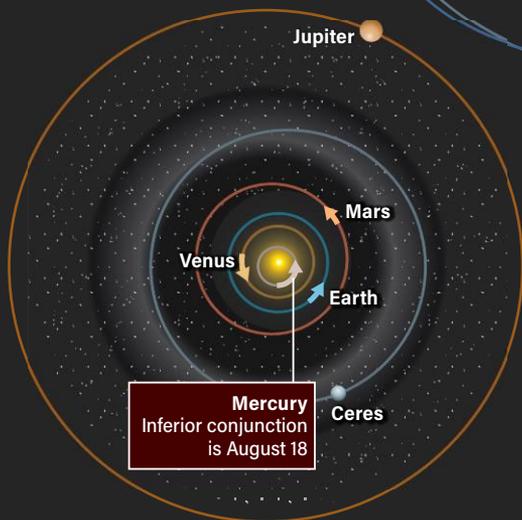
## THE PLANETS IN THEIR ORBITS

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



## THE PLANETS IN THE SKY

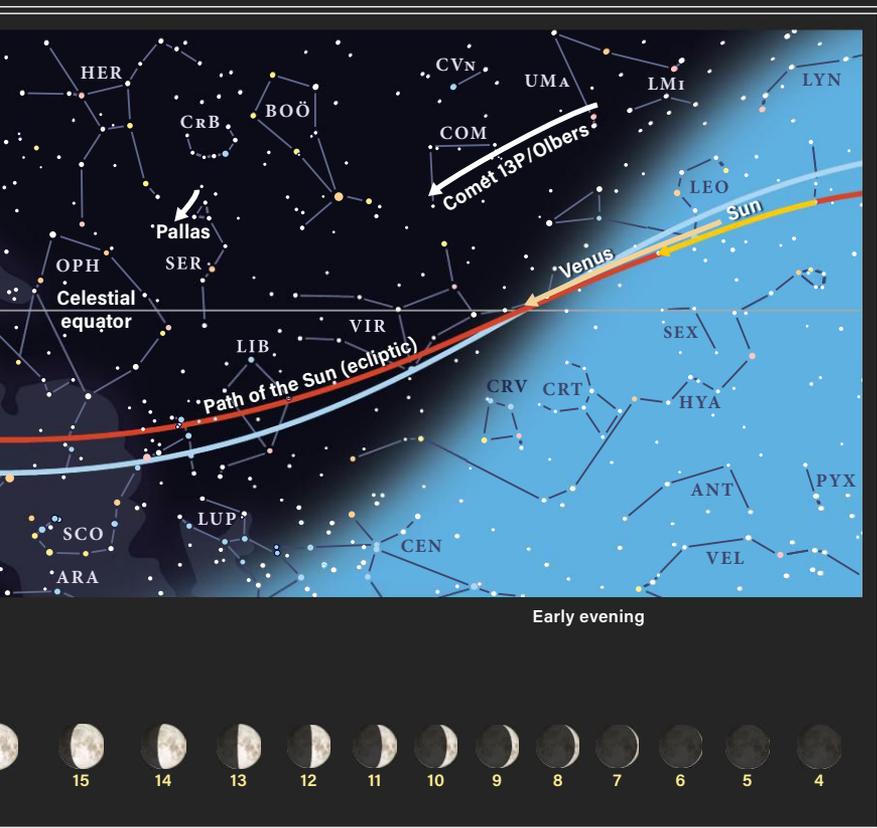
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Aug. 31	Aug. 15
Magnitude	0.7	-3.9
Angular size	8.5"	10.5"
Illumination	24%	94%
Distance (AU) from Earth	0.795	1.591
Distance (AU) from Sun	0.334	0.721
Right ascension (2000.0)	9h33.2m	10h55.1m
Declination (2000.0)	13°03'	8°26'

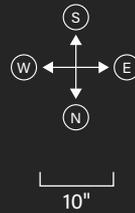
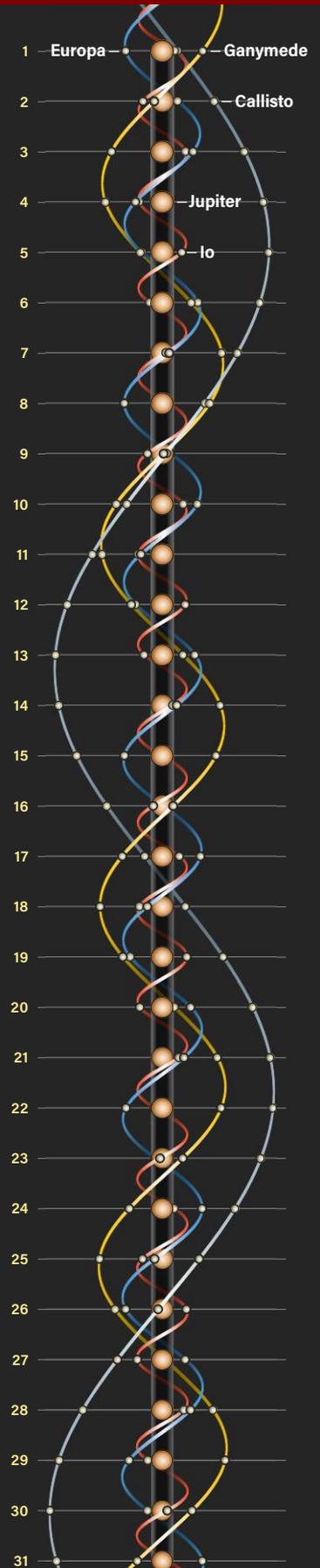
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

# AUGUST 2024



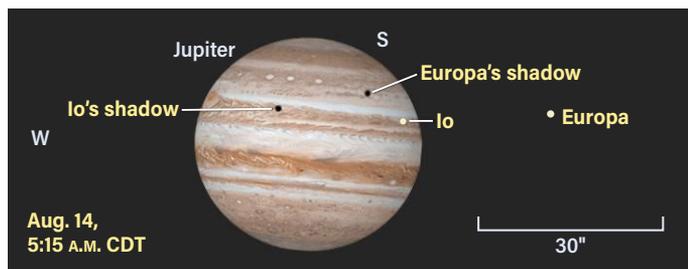
## JUPITER'S MOONS

Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15	Aug. 15
0.8	8.2	-2.2	0.7	5.8	7.7	15.1
6.1"	0.6"	36.7"	19.0"	3.6"	2.3"	0.1"
88%	98%	99%	100%	100%	100%	100%
1.526	2.121	5.367	8.746	19.629	29.081	34.139
1.444	2.923	5.040	9.672	19.577	29.898	35.074
5h01.8m	18h34.8m	5h01.2m	23h17.2m	3h38.2m	23h58.8m	20h11.7m
22°23'	-30°54'	22°03'	-6°56'	19°11'	-1°34'	-23°19'

## Triple play



While you're trained on Jupiter for its conjunction with Mars, watch a triple event as the shadows of Io and Europa, as well as Io itself, cross the planet's disk. Not shown are Ganymede to Jupiter's east and Callisto to the west.

(11:15 P.M. MDT on July 31), although Saturn is at an elevation of only 20°. This transit lasts just over two hours, with latter parts visible from the western U.S. Eagle-eyed observers with large scopes under optimal seeing conditions may spot Dione transiting Saturn starting an hour later.

Titan undergoes a brief occultation behind the northern limb of Saturn between about 12:05 A.M. and 2:05 A.M. EDT Aug. 8/9 (note the event starts late on the 8th for time zones west of Eastern). These are the last events involving Titan for a while, since later in August the moon misses Saturn as the angle of the plane of its orbit increases from our perspective.

Fainter moons (such as 10th-magnitude Tethys, Dione, and Rhea) skim the edge of the rings as seen from Earth and sometimes transit or enter an occultation, although they are very difficult to observe. Iapetus reaches superior conjunction Aug. 15 and stands about 1' due south of Saturn. It shines near 11th magnitude and in the second half of August moves east of the planet, fading as its darker hemisphere turns earthward.

**Neptune** stands 12° east of Phi Aqr, across the border in Pisces the Fish. It rises 20 minutes after Saturn. At magnitude 7.7 it is reachable with binoculars; mounting them on

a tripod will improve the ease of detection. Southeast of Pisces' Circlet asterism is a parallelogram of four stars shining at 4th and 5th magnitude. Neptune stands just north of this group, 1.6° north of the northwestern star in the parallelogram asterism on the 1st.

A telescope reveals the small, 2"-wide disk if your seeing conditions are calm. The planet is

one month from opposition and will soon be visible all night.

It's well worth observing in the morning, as Taurus the Bull houses three major planets.

**Uranus** is first to rise, shortly before 1 A.M. local daylight time on Aug. 1. It stands just over 5° south-southwest of M45, the Pleiades star cluster. Shining at magnitude 5.8, the planet can be spotted in a pair of binoculars. You'll notice it wandering east each night. There's a pair of 6th-magnitude stars, 13 and 14 Tauri, similar in brightness to Uranus and 1.5° northeast of the planet's location. This gap closes to 1° during the month.

Through a telescope, Uranus shows a 4"-wide disk. This distant world is four times wider than Earth and is home to many storms whisking through its atmosphere, though they can't be seen with amateur scopes.

# WHEN TO VIEW THE PLANETS

## EVENING SKY

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

## MIDNIGHT

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

## MORNING SKY

Mercury (east)  
Mars (east)  
Jupiter (east)  
Saturn (southwest)  
Uranus (southeast)  
Neptune (southwest)

**Mars** is now a stunning object north of Aldebaran, the brightest star in Taurus. The Red Planet starts August at magnitude 0.8, just 0.1 magnitude brighter than Aldebaran. Suddenly the Bull has not just one eye but a pair of them. On

# COMET SEARCH | Tangled in stars

## PREPARE FOR OCTOBER'S

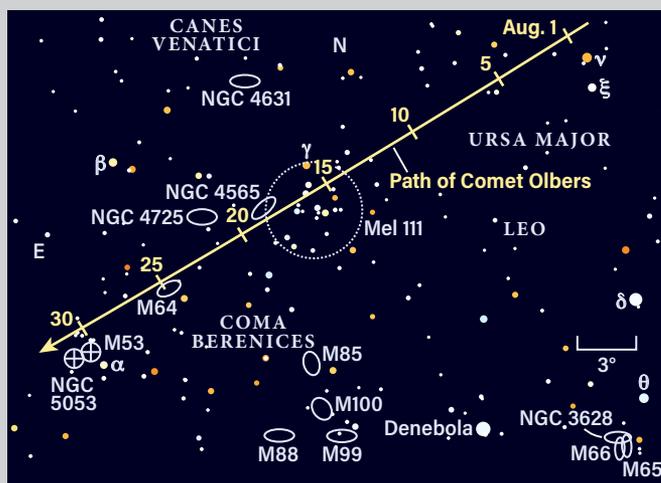
bright comet by studying departing 13P/Olbers. Glowing at 8th to 9th magnitude and below 25° in altitude in the evening twilight, Olbers will be tough for binoculars. Without computer pointing, arm yourself with a finder chart to get you from Alkaid at the end of the Big Dipper's handle, down 13° to galaxy M94 (a good reference at magnitude 8.1), then down another 16° to land southeast of Nu (ν) and Xi (ξ) Ursae Majoris.

Look for a well-defined southern flank where the solar wind pushes the dust northward into a stubby tail that diffuses away. The comet likely sports a concentrated false nucleus, outshining the inner coma. Compare that form to the symmetrical one of the galaxy.

Moonlight interferes after the 10th, but imagers will want to capture the comet's green glow lying in the sparkling strands of Berenice's Hair with the cluster Melotte 111 for a few days starting on the 15th.

Celebrate the reopening of the moonless window on the 24th when Olbers — fading past 9th magnitude — shares a low-power field with the famous Blackeye Galaxy (M64). Push the power past 120x, be patient, and take the time to compare and contrast the two. Repeat on the 25th to hone your skills.

## Comet 13P/Olbers

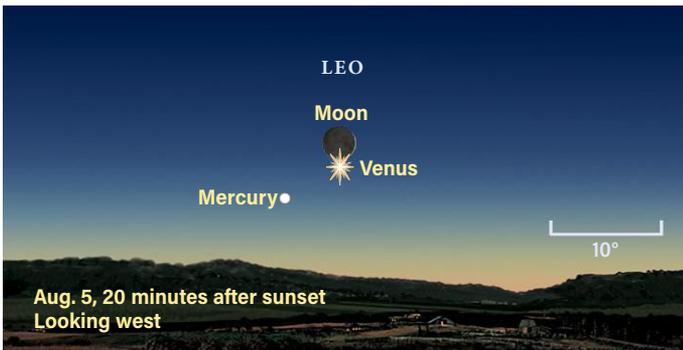


Comet Olbers is fading but still presents a great target amid the stars of Melotte 111 midmonth.

# LOCATING ASTEROIDS |

Time for tea

Bright beacon   



Venus is a bright evening star this month. On the 5th, use its light to help you find the crescent Moon and Mercury in bright twilight.

the 5th, Mars is  $5^\circ$  north of the star. And the gap between Mars and Jupiter is now under  $5^\circ$ .

Watch the two planets over the following nine days, as the easterly motion of Mars carries it closer to Jupiter. On Aug. 14, they stand less than  $20'$  apart. Jupiter shines at magnitude  $-2.2$  and Mars is about 16 times fainter. Aldebaran stands  $8^\circ$  southwest of the pair.

Through a telescope Mars remains tiny, as its distance from Earth is nearly 140 million miles. It spans  $6''$ . Jupiter, nearly four times farther, spans  $37''$ , a reflection of its gargantuan size. Features on Mars are difficult to discern. At the end of the month, the main dark feature, Syrtis Major, comes into view for observers across the U.S.

Mars continues east across Taurus, standing  $1.1^\circ$  north of the Crab Nebula (M1) on the 26th and ending the month  $3^\circ$  northeast of Zeta ( $\zeta$ ) Tauri.

**Jupiter** dominates the morning sky, rising just before 2 A.M. local daylight time on Aug. 1 and at local midnight on the 31st. An hour before dawn on Aug. 31, Jupiter is nearly  $60^\circ$  high, a great target for visual observing and high-speed video capture.

A waning Moon just one day past Last Quarter stands  $5.3^\circ$  north of Jupiter on the 27th. Jupiter, like Mars, wanders east across central Taurus but at a slower pace than the Red Planet, owing to the gas giant's greater distance from Earth.

The Galilean moons Io, Europa, Ganymede, and Callisto undergo a variety of events visible in small telescopes. On Aug. 14, there are two shadow transits — of Io and Europa — plus Io itself in transit, making it a triple event. With Io and Europa well to the east of Jupiter, their shadows fall on the cloud tops beginning with Io's at 4:41 A.M. EDT. It takes 2 hours 9 minutes to cross Jupiter. Europa's shadow is next, shortly after 5:30 A.M. EDT, followed soon after by Io, which starts its transit around 5:55 A.M. EDT. For nearly an hour the three features — two shadows and one moon — cross the disk. Notice how Io catches up to Europa's shadow because Io is orbiting faster and in a smaller orbit than Europa.

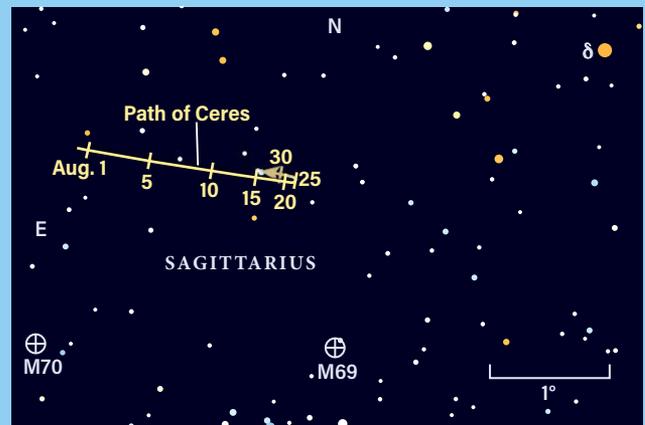
Ganymede, Jupiter's largest moon, undergoes a few events this month. On the 9th, the large moon begins a transit across the south polar region at

**FLOATING IN THE MIDDLE** of Sagittarius' Teapot asterism, 1 Ceres steeps in the space front of the Milky Way's central bulge. Fading slowly through 8th magnitude following last month's opposition, the dwarf planet may be ruler of the main belt, but it could take image-stabilized 10x binoculars to spot it from the suburbs. The Moon will join the view from Aug. 14 to 16.

Print yourself a  $4^\circ$ -wide finder chart with stars to 9th magnitude, anchored at the west end by Delta ( $\delta$ ) Sagittarii, the bright star at the crook of the Teapot's spout. Hop your way over to Ceres' location and add a dot. During the last half of the month, the 600-mile-wide asteroid slows down, stops, then returns eastward, a result of relative movement between it and Earth.

Since Ceres stays within the same  $30'$  field during the latter half of the month, note which field stars are brighter, similar, and slightly fainter than the dwarf planet on the 11th or 12th, then repeat at month's end. If you find the half-magnitude drop easy to spot, check out some of the American Association of Variable Star Observer's (AAVSO) beginner variable stars for astrophysics in action.

Steeping time  



Ceres stays within the body of Sagittarius' Teapot asterism all month.

3:38 A.M. EDT. (Jupiter hasn't risen for western states yet.) With the transit underway, it's also fascinating to watch Callisto below Jupiter a short distance away, missing the planet due to the inclination of the plane of the jovian moons' orbits as seen from Earth. Ganymede's transit ends at 5:36 A.M. EDT, this time largely visible across the country.

On Aug. 23, Ganymede's shadow transits in twilight for those in the Mountain and Pacific time zones. Its huge shadow appears on the southeastern limb beginning around 4:46 A.M. MDT; it takes several minutes until the full dark

shadow is visible. The transit lasts nearly two hours.

Ganymede itself reappears from behind Jupiter on the 27th beginning around 3:46 A.M. EDT, and again takes many minutes to appear at the northeastern limb. How soon do you notice it come back into view?

Enjoy your summertime viewing of the planets! ☿

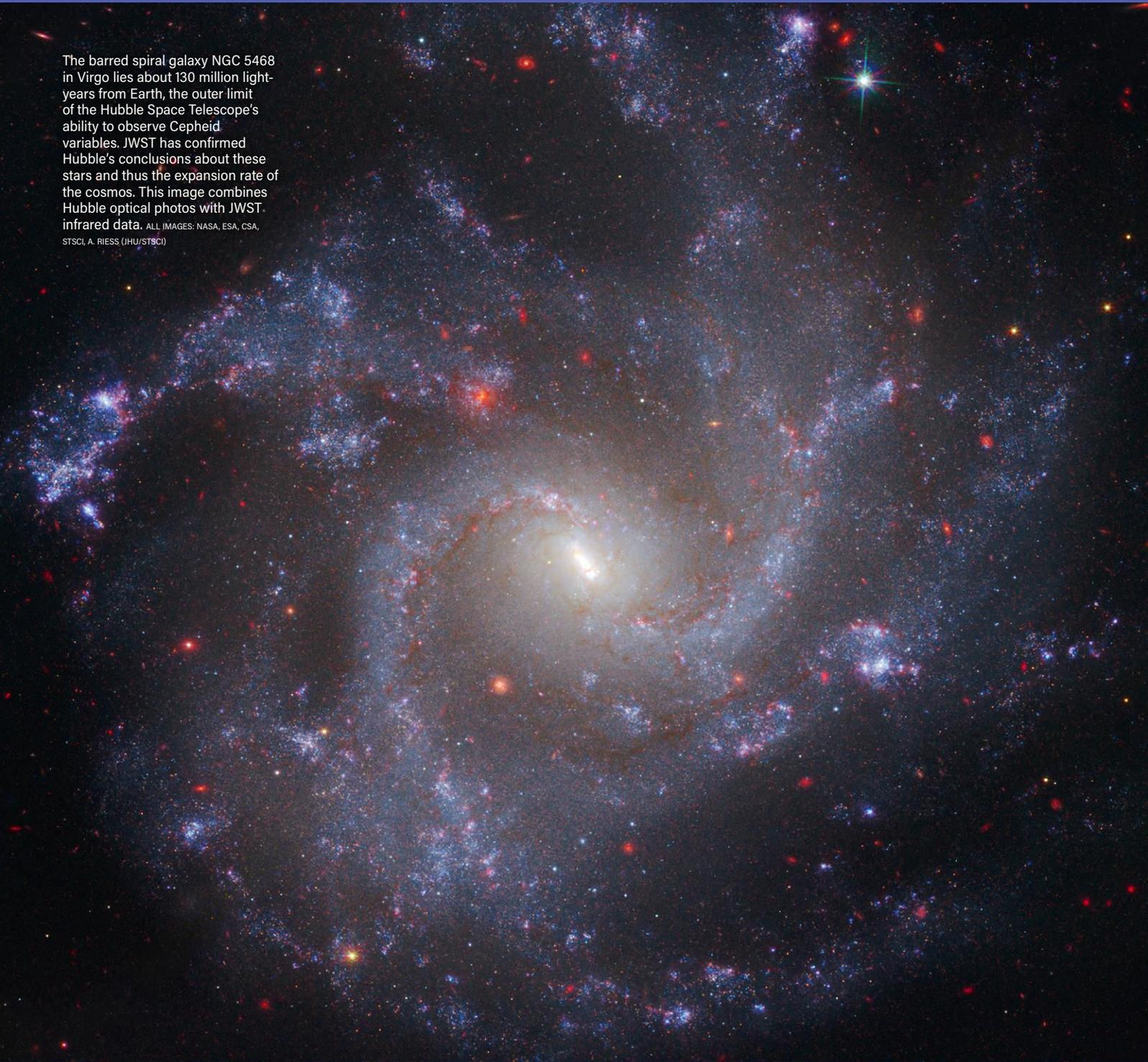
**Martin Ratcliffe** is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City. **Alister Ling**, who lives in Edmonton, Alberta, is a longtime watcher of the skies.



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[www.Astronomy.com/skythisweek](http://www.Astronomy.com/skythisweek).

# TROUBLE AT THE HEART OF

The barred spiral galaxy NGC 5468 in Virgo lies about 130 million light-years from Earth, the outer limit of the Hubble Space Telescope's ability to observe Cepheid variables. JWST has confirmed Hubble's conclusions about these stars and thus the expansion rate of the cosmos. This image combines Hubble optical photos with JWST infrared data. ALL IMAGES: NASA, ESA, CSA, STSCI, A. RIESS (JHU/STSCI)



JWST and Hubble agree: The universe is expanding faster than theorists predict. BY RICHARD TALCOTT

# COSMOLOGY

**NUMBERS TURN UP EVERYWHERE** in astronomy, though none plays a bigger role than the Hubble constant ( $H_0$ , pronounced “H-naught”) — the current expansion rate of the universe. The speed at which the cosmos expands plays a fundamental role in revealing the universe’s size, age, history, evolution, and ultimate fate.

In the past decade, researchers studying the motions of distant galaxies with both the Hubble Space Telescope and ground-based instruments have found  $H_0$  equals 73.0 kilometers per second per megaparsec (km/s/Mpc; 1 megaparsec equals 3.26 million light-years) with an error of no more than 1.0 km/s/Mpc.

But cosmologists also can predict what the current expansion rate of the universe should be based on the standard model of cosmology. Applying the model to measurements of the cosmic microwave background yields an  $H_0$  of 67.4 km/s/Mpc accurate to within 0.5 km/s/Mpc — two precise yet mutually incompatible values.

## ENTER JWST

Scientists keenly waited for the James Webb Space Telescope (JWST) to weigh in on this so-called “Hubble tension.” The powerful infrared instrument has confirmed Hubble’s

findings and removed any doubt that the problem might lie with observations.

To measure the universe’s expansion rate, astronomers construct a “distance ladder.” Cepheids form the ladder’s first rung. These highly luminous stars vary predictably: Intrinsically brighter stars take longer to complete a cycle. Scientists calibrate this period-luminosity relation in the Milky Way with independent distance measurements, and then extend it to more distant galaxies. Researchers can monitor Cepheids accurately out to spiral galaxy NGC 5468, some 130 million light-years from Earth.

A specific type of supernova creates the ladder’s second rung. Type Ia supernovae occur when a white dwarf siphons too much material from a companion and explodes. All such white dwarfs weigh about 1.4 solar masses, so the explosions

peak at a similar luminosity, some 100,000 times greater than a typical Cepheid. If you observe Cepheids and supernovae in the same galaxies, you can calibrate the exploding stars to extend the distance ladder hundreds of times farther away.

The best views of Cepheids come in the near-infrared because those wavelengths pass untouched through intervening dust. Unfortunately, Hubble’s resolution in the near-infrared is only decent. When it observes distant galaxies, the light of an individual Cepheid often blends with those of its neighbors. JWST’s superior resolution nearly eliminates this problem.

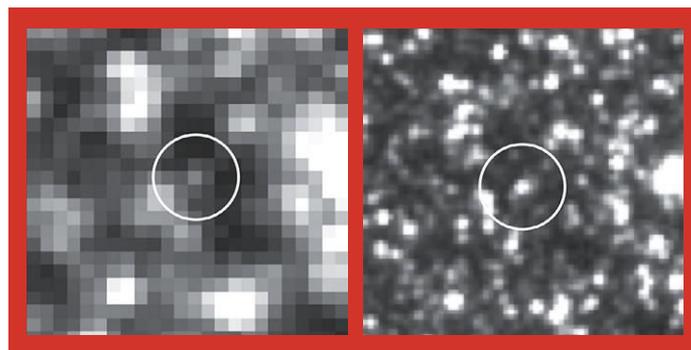
Nobel laureate Adam Riess of Johns Hopkins University and the Space Telescope Science Institute led a team of researchers that studied more than 1,000 Cepheids in five galaxies that have hosted eight Type Ia supernovae. “We’ve

now spanned the whole range of what Hubble observed, and we can rule out a measurement error as the cause of the Hubble tension with very high confidence,” said Riess in a press release. The team published its results in the Feb. 10 issue of *The Astrophysical Journal Letters*.

## TENSION MOUNTS

The results focus attention back on the standard model of cosmology, known as Lambda Cold Dark Matter. The lambda refers to the cosmological constant in Einstein’s general theory of relativity; it is the dark energy that exerts a repulsive force on space. Cold dark matter means that the universe’s mass consists mostly of slow-moving dark matter particles.

“With measurement errors negated, what remains is the real and exciting possibility that we have misunderstood the universe,” said Riess. This could mean that dark energy’s strength changes with time, yet-to-be-discovered particles influence cosmic expansion in unknown ways, or that general relativity needs revision. The quest for an answer will keep observers and theorists busy for a long time. ◀



Hubble’s modest resolution in the near-infrared means that the light from a Cepheid variable blends with those of nearby stars (left). A sharper JWST image of the same field (right) shows an uncorrupted view of this Cepheid.

Contributing Editor **Richard Talcott** wrote in the July issue about JWST’s discovery that dwarf galaxies likely reionized the early universe.

# Build a MENTAL MAP

Don't just stare at faint fuzzies — with a bit of knowledge, you can begin to get a true sense for the enormous scale of the universe.

When amateur astronomers participate in star parties for the general public, the subject of distances in space always comes up. The immensity of our universe never fails to fascinate curious minds. But when it comes to truly grasping it — let alone explaining it — words and numbers often fall short.

It might be good, then, to have on hand a ready list of relatively bright objects outside the boundaries of the Milky Way — in other words, galaxies.

So, here I'm highlighting sets of three galaxies within five different distance ranges: up to 10 million light-years, between 10 million and 50 million light-years, between 50 million and 100 million light-years, between 100 million and 200 million light-years, and between 200 million and 500 million light-years. With these objects in mind, the next time you're at a star party, not only will you be able to tell visitors how big the cosmos is, but you'll be able to show them.

 The Andromeda Galaxy (M31) is the nearest major galaxy, and spans a width equivalent to more than six Full Moons. RON BRECHER

## Nearby glory

Because most of our readers live north of the equator, my targets will have a northern bias. If, however, you're in the Southern Hemisphere, you cannot do better for nearby galaxies than aim your scope at either of the Magellanic Clouds, the two standout satellite galaxies of the Milky Way.

From positive latitudes, first aim for the **Andromeda Galaxy** (M31). It lies 2.5 million light-years away and will

BY MICHAEL E. BAKICH

# OF THE COSMOS

show details through a scope of any size. You can use low power for an overall view. You'll see M31's nucleus, dust lanes, and its two large companion galaxies, M32 and NGC 205. See how much of the galaxy's full length you can trace; that length equals six Full Moons side by side, and its width is two Full Moons ( $3^\circ$  by  $1^\circ$ ). Alternatively, you can try high power through a large scope — 300x or more, if your sky allows it. Concentrate on M31's spiral arms and look for bright clumps, which indicate star-forming regions.

The second target is the **Southern Cigar Galaxy** (NGC 55) in Sculptor, another close one you can point out. It lies some 6.5 million light-years away. Its common name comes from its core being offset to the west, which gives it a tapered, cigarlike appearance at low power. Look closely for the faint dark lanes that divide the arms. Through an 11-inch scope, try using an Oxygen-III filter. Because NGC 55 is big and bright, the filter will dim its stars and better reveal the star-forming regions of ionized hydrogen along the galaxy's arms. Few other galaxies benefit from this trick.

Our third nearby galaxy is **NGC 2403**, which you'll find in the faint northern constellation Camelopardalis the Giraffe. It lies just within our first distance limit, 9.7 million light-years away. Although its magnitude is 8.2, that brightness is spread over an area 23' by 12' (36 percent as large as that of the Full Moon), so its surface brightness is low. Small telescopes show this object as an indistinct haze roughly twice as long as it is wide, with a bright central region. Look for loose open star clusters in NGC 2403's spiral arms, which confirm that stars are still forming in this galaxy.

## A bit farther out

Although no northern galaxy can compete with M31, there are some standouts

as we move out to the 10-million- to 50-million-light-year range. Our first target is the wonderful pair of **Bode's Galaxy** (M81) and the **Cigar Galaxy** (M82) in Ursa Major. Both lie some 12 million light-years away. At magnitude 6.9, most observers can spot M81 through binoculars. Its details, however, really emerge through medium-size and larger telescopes. An 8-inch will let you see a small bright core surrounded by a larger, less bright region. M82 offers a great contrast to its neighbor. While M81 is a classic spiral, the Cigar Galaxy is one of the best examples of a starburst galaxy — one where a higher-than-normal amount of star formation is happening. Its higher surface brightness makes it appear about as bright as M81, even though it shines 1.5 magnitudes fainter.

Doubling our distance to 24 million light-years brings us to the magnificent **Whirlpool Galaxy** (M51) in Canes Venatici. This is actually a double object, combining the larger NGC 5194 with the smaller NGC 5195. An 8-inch scope will show the spiral arms, a few dust lanes, and the much brighter core of NGC 5195.

Our third object in this range is the **Southern Pinwheel Galaxy** (M83), the third galaxy ever discovered (after the

Andromeda Galaxy and its companion M32). M83 is a barred spiral some 15 million light-years away in Hydra. The bar is easy to spot, and through 11-inch and larger scopes you'll see star-forming clumps within the galaxy's arms.

## Midrange wonders

If you look out into space some 55 million light-years, you'll encounter the **Mirror Galaxy** (M100) in Coma Berenices. View it through a medium-size scope at low power and you'll see a hazy glow measuring 6' by 5'. To identify the spiral arms, however, you have to crank the power past 200x. Astronomers classify M100 as a starburst galaxy.

Our next target, **NGC 1300**, lies some 60 million light-years away in Eridanus. This is a classic barred spiral that observers never tire of showing to others. Its arms originate at the ends of the bar and tightly curve back around the galaxy's center. Use high magnification for best results.

The third object in this range is the barred spiral **NGC 1365** in Fornax, lying less than  $20^\circ$  from NGC 1300. It's 75 million light-years away and makes a great target for medium-size scopes. Even a 4-inch will reveal the bar and bright core, but you'll need at least an



🔍 M81 is a classic spiral galaxy, while M82 is seen from edge-on. GEORGH KONKOV



🌀 NGC 1365 is such a perfect example of a barred spiral that it has earned the nickname the Great Barred Spiral Galaxy. DAN CROWSON

8-inch to see the arms. If you move up to a 16-inch scope at high power, you'll see the small inner bar, which is tilted about 45° from the main bar.

### Ever farther

Our first target in the fourth distance range sits right at its lower limit, 100 million light-years away. It's the flocculent spiral **NGC 5676** in Boötes. Flocculent galaxies have a soft or fluffy appearance and no bar. Because of its high surface brightness, NGC 5676

is visible through a 6-inch scope as a grayish rectangle.

A bit farther out — around 125 million light-years away — is **NGC 2906**, a spiral in Leo. NGC 2906's coolest attribute is that it's tilted roughly 75° to our line of sight. To see its arms circling a brighter core requires an 8-inch scope; 11-inch and larger instruments will help you spot a few of the clumps along the arms, which mark regions of star formation.

My third pick in this range is the face-on spiral **NGC 1376**, which lies around 195 million light-years away in Eridanus. And, full disclosure, we're getting to objects at distances that require large telescopes to reveal details in them. German-born English astronomer William Herschel discovered this one in 1785 through his 18.7-inch reflector. On a night with great seeing (atmospheric stability), use at least an 11-inch scope and magnifications of 300x and above to see the faint arms encircling the slightly brighter nucleus. And don't forget to mention that the light from this galaxy started on its journey toward Earth around the beginning of the Jurassic Period.

### The edge of space ...

... OK, not really. But now we've reached distances where it's difficult for amateurs

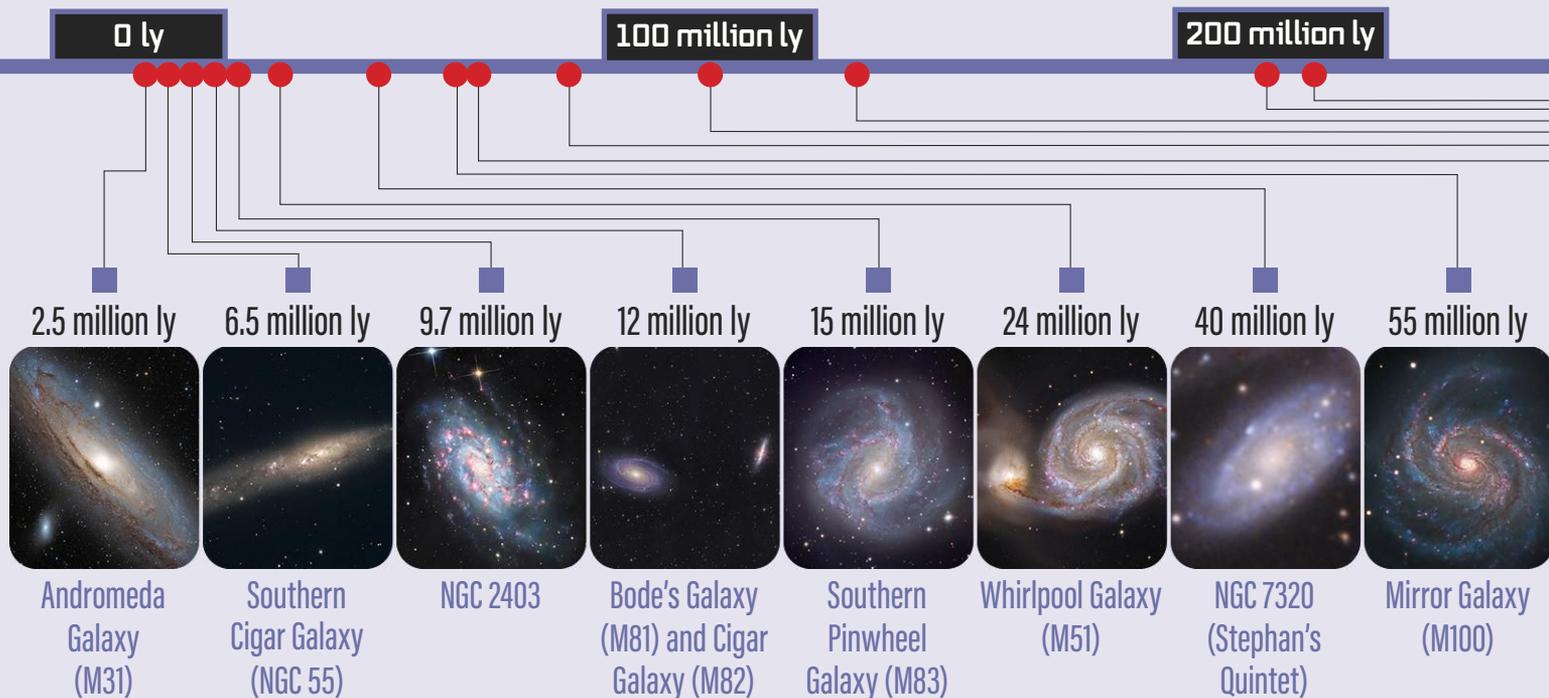
to see details in individual galaxies. That said, it's worth taking a look at the irregular galaxy **NGC 6745** in Lyra. It lies 210 million light-years away and is the result of a collision of three galaxies. Because of its high surface brightness, amateurs routinely spot it through medium-size scopes. One detail you can see through large instruments is its odd shape: a normal eastern edge but a straight western one, due to the ongoing collision.

Much farther out is a grouping of five galaxies that make up **Stephan's Quintet** — kind of. Four of the galaxies — NGC 7317, 7318A, 7318B, and 7319 (comprising Hickson Compact Group 92) lie some 290 million



🌀 The flaky, patchy appearance of the arms of NGC 5676 gives it the designation of a flocculent spiral galaxy. DIGITIZED SKY SURVEY

## OUR UNIVERSE AT A GLANCE \*ly= light-years

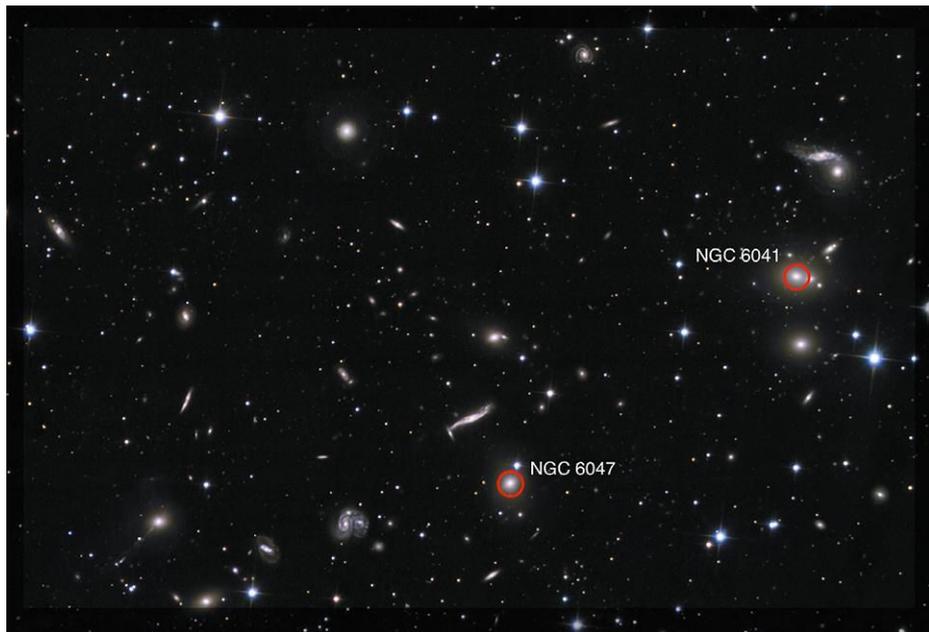


light-years away. The fifth, NGC 7320, lies “only” 40 million light-years distant. But all five are lined up from our point of view, so observers usually refer to them as a quintet. Although you can see Stephan’s Quintet through a 6-inch scope, a magnification of 50x will show you only a faint, clumpy glow 3' across. An 11-inch telescope, on the other hand, lets you identify the individual members.

Our final target, the **Hercules Galaxy Cluster** (Abell 2151), takes deep-sky observing to a whole new level. This cluster of some 200 members lies at the limit of our final distance range, 500 million light-years away. No amateur telescope could hope to reveal all the galaxies, but a few of the brightest — namely NGC 6041, NGC 6047, and NGC 6061 — are visible on the best nights through 16-inch and larger scopes.

### A parting thought

Distances in our universe correspond directly to time. How far an object is from us in light-years tells us how long its light — traveling at 186,282 miles (299,792,458 meters) per second — has taken to reach us. That means the photons from the farthest galaxy on this list have been traveling for roughly 4 percent of the universe’s current age.



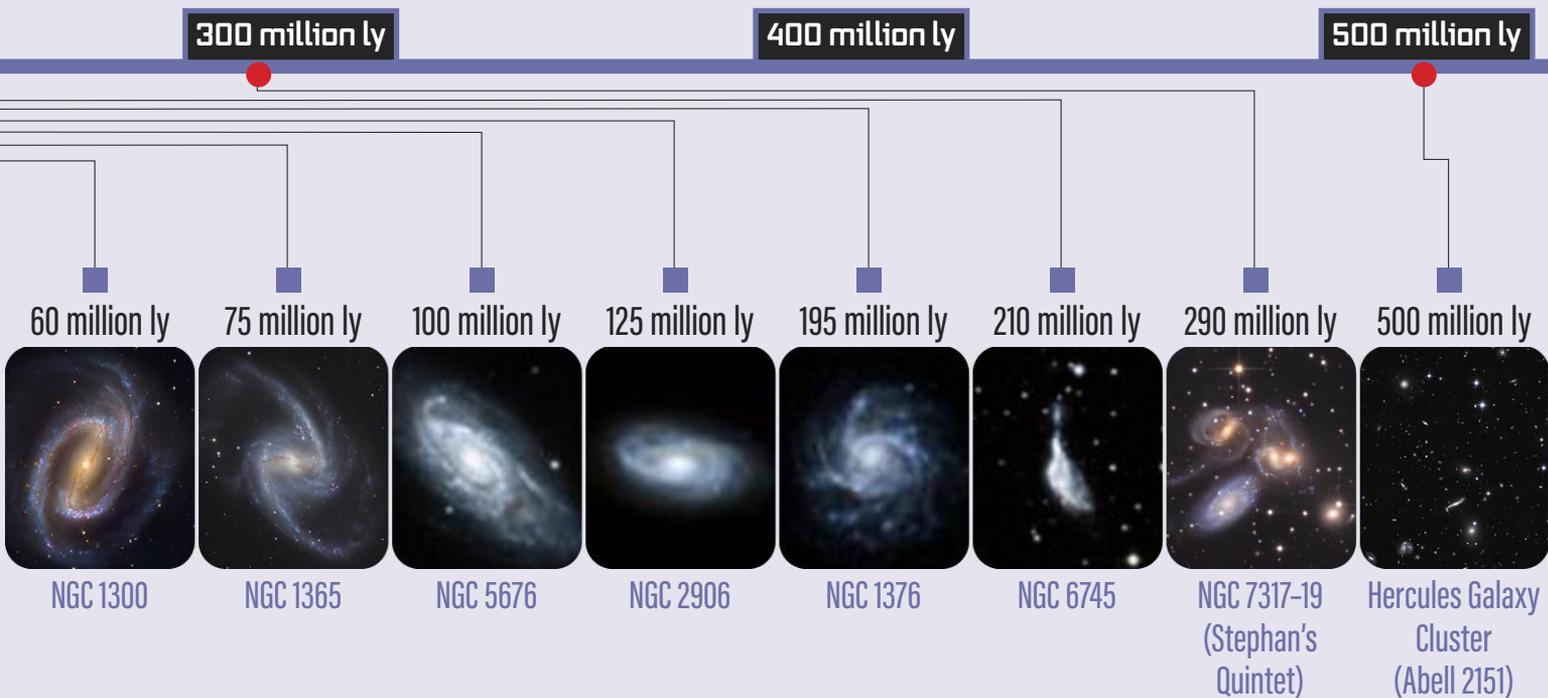
🔍 Large amateur telescopes are capable of revealing a few of the brightest members of the Hercules Galaxy Cluster, including NGC 6041 and NGC 6047. NGC 6061 is outside this field of view. KEN CRAWFORD

Humans think the Moon is far away and, compared to distances on Earth, it is. Galaxies lie at vastly greater distances. But as you can see by this list, there are different levels of “vast.” It’s mind-blowing to think that the final object on our list, the Hercules Galaxy Cluster, lies 200 times as far as target No. 1, the Andromeda Galaxy, which itself lies

more than 61 trillion times as far as the Moon.

Yes, we live in a big universe. Go out sometime soon and get somebody excited about it. 🌌

**Michael E. Bakich** is a contributing editor of *Astronomy* who feels like he’s been observing galaxies since the Jurassic Period.





The constellation Orion the Hunter hosts two of the 10 brightest stars in the sky, Betelgeuse and Rigel. At magnitude 0.5 and 0.2, respectively, Betelgeuse (orange star at upper left) and Rigel (blue-white star at lower right) stand in stark contrast to many of the surrounding stars.

ALAN DYER

# Measuring magnitudes

The brightness scale that astronomers use has been around since ancient times. Here's how to understand it. **BY MICHAEL E. BAKICH**

**IF SOMEONE ASKS YOU**, “How bright is that star?” and your answer is “Pretty bright,” that isn’t very useful. And, of course, it’s worthless for any type of comparative research. So for centuries, astronomers have used and refined a method of determining the brightness of stars and every other celestial object called the magnitude system.

## Development

The first person known to catalog differences in star brightness was Greek astronomer Hipparchus, who lived in the second century B.C.E. He divided his listing of approximately 850 visible stars

into six brightness ranges, calling the brightest stars “first magnitude.”

About 200 years later, the Egyptian polymath and author of the famous astronomy book *Almagest*, Claudius Ptolemy, refined the order of stars within these six levels. His catalog made clear that even within each magnitude range, some stars are brighter and some are dimmer. This system was used, almost unchanged, for more than 1,500 years.

In the 17th century, after the invention (and subsequent upgrading) of the telescope, Ptolemy’s system needed to be expanded. Using a telescope, people

could see more stars than ever before. In fact, after Italian astronomer Galileo Galilei had constructed several telescopes, he added 7th-magnitude objects to his list of discoveries.

As time went on, astronomers not only discovered multitudes of faint stars, but they also needed a more precise way to compare brightnesses. By the end of the 18th century, another loose system had come into play. In it, the brightness difference of stars a single magnitude apart was roughly a ratio of 2.5.

In 1856, British astronomer Norman R. Pogson suggested that all observations be calibrated by using the constant

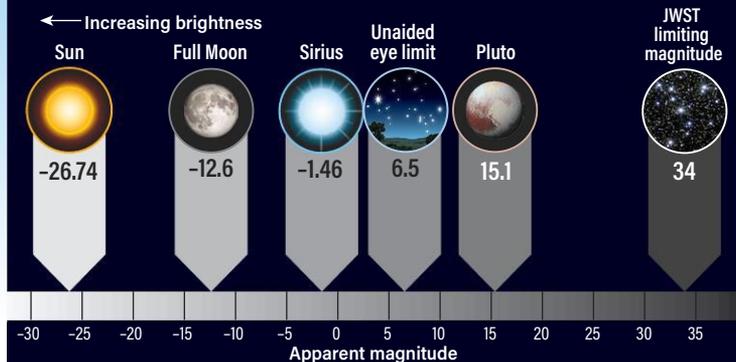
## ESTIMATING LIMITING MAGNITUDE

DURING AN OBSERVING SESSION, it is always a good idea to make an estimate of limiting visual magnitude (also called faintest star detection). Not only will this help you determine how good (or bad) the sky is at that particular time, but it will also allow you to judge the quality of your recorded observations months or years from that session.

You can estimate limiting magnitude by eye or through a telescope. Generally, telescopic limiting magnitudes are for observing faint objects. If you do use a scope, note in your log its aperture and the eyepiece (magnification) through which the estimate was made.

Most observers estimate limiting magnitude near the zenith, where the sky is usually the best. This is almost always true when estimating limiting visual magnitude by eye. If you're studying a particular object far from the zenith, you may want to make your estimate near the object. —M.E.B.

## APPARENT MAGNITUDE



Apparent magnitude is a measure of visible brightness of an astronomical object, with negative numbers representing the brightest targets in the sky.

ASTRONOMY: ROEN KELLY. PLUTO: NASA/JHU APL/SWRI/ALEX PARKER. M91: NASA, ESA, CSA, ALYSSA PAGAN (STSC)

$10^{2/5}$ . This defined the ratio between objects differing by one magnitude as 2.512, approximately, setting a mathematical standard that preserved Hipparchus' original catalog system.

At this time, the concept of using magnitudes equal to and less than zero also appeared. The rationale was to keep one of the basics of the original system, where the limiting magnitude of the human eye is approximately 6th magnitude. With this limitation, and Pogson's mathematical formula, it was evident that the three brightest stars, Sirius (Alpha [ $\alpha$ ] Canis Majoris), Canopus (Alpha Carinae), and Rigil Kentaurus (Alpha Centauri), were much brighter than 1st magnitude. And even brighter were the brightest planets, the Moon, and, of course, the Sun.

The number 2.512 is the fifth root of 100. This means that a difference of five magnitudes equals a 100-fold difference in brightness. As an example, Sirius, at magnitude  $-1.46$ , is roughly 100 times brighter than Wasat (Delta [ $\Delta$ ] Geminorum), which glows at magnitude 3.53.

### How much brighter?

Observers often want to know how much brighter star A is than star B. For example, let's find the brightness difference between Regulus [Alpha Leonis] at magnitude 1.4 and Delta Aurigae at magnitude 3.7. The formula to calculate this is simple: It is 2.512 raised to the power of the magnitude difference between the two stars. So, using this formula, we just need to calculate.  $2.512^{(3.7 - 1.4)}$ . The

difference between 3.7 and 1.4 is 2.3, so the formula becomes  $2.512^{2.3} = 8.3$ . This tells us that Regulus is 8.3 times as bright as Delta Aurigae.

### Adding magnitudes

There are times when you'd like to know the total magnitude of a double star. Pull out your calculator and use this formula to find the combined magnitude, which equals  $m_2 - 2.5\log(10^x + 1)$ , where  $x = 0.4(m_2 - m_1)$  and  $m_1$  and  $m_2$  are the magnitudes of the stars. Our example here will be the popular double star Albireo (Beta [ $\beta$ ] Cygni). The two stars have magnitudes of 3.2 and 5.1. So,  $x = 0.4(5.1 - 3.2) = 0.76$  and the formula becomes:

$$5.1 - 2.5\log(10^{0.76} + 1)$$

$$5.1 - 2.5\log(6.754)$$

$$5.1 - 2.5(0.83)$$

which equals 3.026. Albireo's total magnitude, then, is approximately 3.0.

### Other systems

What I have described so far is just the visual apparent magnitude system. Apparent magnitude is how bright a star appears from Earth. The more scientific measurement, however, is absolute magnitude. Astronomers created this scale so they could compare the actual luminosities of stars to one another. The absolute magnitude of a star, then, is how bright it would be from a standardized distance of 10 parsecs (32.6 light-years).

In this system, the apparent magnitudes of stars nearer than 10 parsecs would be greater than their absolute magnitudes. For the vast majorities of

stars, however, this is reversed. The Sun's apparent magnitude is  $-26.7$ . Move it to a distance of 10 parsecs, and its absolute magnitude drops to 4.8. That is a brightness difference of 3.98 trillion!

Other systems use filters so astronomers can compare the light output of a single star in different wavelengths. One of the most useful is the UBV, also known as the Johnson-Morgan system, which provides a way to gauge the temperatures of stars. Three magnitudes are measured — through calibrated ultraviolet (U), blue (B), and visual (V) filters — and then compared. The visual filter is the measurement most often used when researchers talk about magnitude. The lower the number, the hotter the star, and vice versa.

Researchers even developed a system that considers all radiation a star emits, not just its light. Recording such a measurement finds a star's bolometric magnitude, which helps determine the energy output from stars. For example, the Sun has a bolometric magnitude of 4.74, similar to its absolute magnitude.

### The future is bright

Astronomers can now measure stellar brightness to a thousandth of a magnitude. We, as observers, don't need that kind of precision. However, it's nice to know that when you are plagued with the question, "How bright is it?," you'll actually know the answer. ☾

**Michael E. Bakich** is a contributing editor of *Astronomy* who can still recite the brightest 25 stars and their magnitudes.

REVIEWED

# DwarfLab's lightweight smart scope



DwarfLab's DWARF II smart telescope contains dual apochromatic lenses: telephoto and wide-angle. DWARFLAB

Don't underestimate the DWARF II — its dual apochromatic lenses and real-time stacking abilities impress.

BY PHIL HARRINGTON

**WE HAVE SMARTPHONES**, smart cars, smart appliances, and even smart lightbulbs. What about smart telescopes?

You could say that smart scopes have been around since the first go-to models were introduced decades ago. But over the past few years, a new breed of even-smarter telescopes has become increasingly popular. These next-generation smarties are not for visual observation, however. They don't even have an

eyepiece to look through. Instead, they include integrated cameras that connect to smartphones and tablets and allow the user to see and photograph celestial objects on a screen. And for the cherry on top, they come in small packages, making them easily portable inside a tote bag.

One of the newest kids on the block is DwarfLab's initial offering, the DWARF II smart telescope. This strange-looking device resembles the two-eyed mast-mounted cameras on the Mars Curiosity and Perseverance rovers, rather than a conventional telescope.

## What's in the box?

The DWARF II's clever optical design includes two apochromatic objective lenses: one for wide-field imaging and a second for telephoto shots with an aperture of 24mm. Light passes through an internal series of prisms and lenses spaced across the width of the housing to focus images onto a Sony IMX415 STARVIS sensor. The four-element f/4.2 telephoto lens has a folded focal length of 100 mm; accounting for the sensor crop factor, the equivalent focal length is 675mm. The wide-angle lens has a 48mm equivalent focal length at f/2.4.

The DWARF II is available in two versions: Classic and Deluxe. The Classic Edition comes with a replaceable battery, a 64 GB microSD card, and a 5.1- to 6.7-inch-tall (13 to 17 centimeters) tripod. The Deluxe version adds a second battery, two neutral density (ND) 1¼" solar filters, a 1¼" Ultra High Contrast (UHC) filter, and a filter adapter. Both options include a soft case to hold it all. The case measures only 9½ inches by 7 inches by 6 inches (24 cm by 18 cm by 15 cm) and weighs just 4¼ pounds (2 kilograms) when carrying the filters, tripod, and second battery.

Last winter, I had a chance to put the Deluxe DWARF II through its paces to see just how smart this compact scope really is. Quite honestly, I was skeptical due to such a small aperture, but I left my first session as a DwarfLab believer.

After unpacking the box, I downloaded and installed DwarfLab's app onto my phone. The app, available for both iOS and Android systems, controls all telescope functions and pairs with the DWARF II effortlessly. It allows you to operate the telescope in several modes, since it can be used for both terrestrial and astronomical imaging. For this review, I'll focus on the app's "Astro" mode.

While I was in the process of writing this review, DwarfLab rolled out a much-anticipated update to the app. The newest version includes several welcome improvements, most notably an autofocus feature. Digital cameras often do not autofocus well at night, but I was pleasantly surprised that DwarfLab has



Our neighboring galaxy Andromeda (M31) can be photographed exceedingly well with the small but mighty DWARF II smart telescope. PHIL HARRINGTON

conquered that hurdle successfully. Simply pressing the app's "Autofocus" command produced sharp images.

## It's showtime

Before capturing any nighttime images, I had the DWARF II take a series of dark frames that would be used later to ferret out hot pixels and other defects that would otherwise degrade subsequent astroimages. Fortunately, this only needs to be done once per session during the initial setup.

I headed outside on the next clear night and set up the DWARF II. Although a capable tabletop tripod is included, I used my own full-size tripod instead, since I didn't have any sturdy tables available.

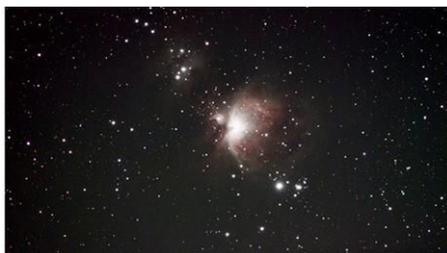
Calibrating the telescope's go-to function couldn't be any simpler. After I aimed the dual lenses toward a wide swath of unobstructed sky and selected "Calibrate" from the app's menu, the telescope quickly and quietly slewed back and forth — first left, then center, and finally to the right, to sync with the current sky. All of it took less than a minute. Next, I selected a "Star Target" from its extensive list of objects. The little telescope aimed itself quickly and was spot-on every time.

Before I could start imaging, I needed to make a few choices. Did I want the images to be saved as FITS or TIFF files? Did I want to use the telephoto or wide-field lens? How about the exposure length? The shutter speed can be set to automatic or adjusted manually from 1/10,000th of a second to 15 seconds. I usually went with my preference: eight to 10 seconds.

I then selected a gain value from 0 to 240. This is akin to the ISO setting with conventional cameras. The higher the value, the brighter the signal recorded — however, also the greater the noise. I stuck with 50 to 80 in most cases.

There is also a built-in infrared (IR) filter that can be toggled on or off. Leaving it off (labeled "Pass" in the app) allows IR light to reach the sensor and is best used for emission nebulae. Turning the IR cut filter on blocks IR light, perfect for other objects and normal daytime photography.

Finally, I chose the number of images to take. I typically went with 50 to 200,



The DWARF II automatically stacks all photos of your target for easy processing. These images show the direct output from the DWARF II (top) and the same image after processing with an iPhone stock photo app (above). PHIL HARRINGTON

## PRODUCT INFORMATION

### DWARF II smart telescope

**Field of view:** 3° (Telephoto), 50° (Wide-Angle)

**Focal length:** 675 mm (T), 48 mm (WA)

**F-number:** 4.2 (T), 2.4 (WA)

**Dimensions:** 204 mm by 62 mm by 130 mm

**Weight:** 2.4 pounds (1 kg)

**Price:** \$595.00

**Contact:** support@dwarflab.com

but the DWARF II is able to capture up to 999 images.

When all was configured, I pressed the shutter button on the app and watched the image on my smartphone's screen blossom before my eyes. Best of all, after the initial setup, I did all that from the comfort of my warm home. The DWARF II has a connection range of about 33 feet (10 meters), although it can be less if something blocks the line of sight.

## Small but mighty

Afterward, the images can be downloaded to your phone or tablet for easy sharing with friends and family. Or, if you prefer, you can remove the memory card from the telescope and process the images further on a computer. The DWARF II stacks and processes all images automatically, but also saves each

image individually for post-processing using third-party software.

Each battery that came with my DWARF II had a life of about 1.5 hours in freezing weather — in warmer weather, it should last longer. If a prolonged session is planned, an external power source can be plugged into the charger built into the telescope's base using a USB-C cable.

I was astonished by the results delivered by the little DWARF II. On the first night out, I was able to set up the telescope, calibrate it to the sky, choose exposure parameters, and be ready to go after a short five to six minutes. Before I knew it, I was getting images of several targets.

To capture the Orion Nebula (M42), I set the DWARF II to take 100 individual images with an 8-second exposure each. I subdued the light pollution in my suburban backyard by using the supplied UHC filter. The nearby Horsehead Nebula was caught nicely using 200 ten-second exposures.

I then aimed at the Pleiades (M45), which easily fit into the field of the telephoto system. The brighter stars appeared a little bloated, which could have been caused by either the optics or high-level clouds. But what really struck me was that I also captured the faintest hint of the 16th-magnitude galaxy UGC 2838, which lies 16' west of Electra (17 Tauri). That's amazing for a 24mm aperture.

I continued to fill my onboard album with great images — including the Sun and Moon. Planets are not the DWARF II's forte due to the short focal length, although Jupiter's moons are resolvable. But for deep-sky objects, its power is amazing and shouldn't be underestimated.

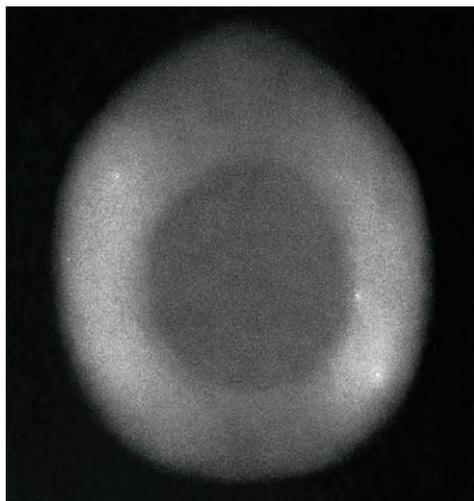
I came away extremely impressed with the DWARF II. While the images should not be expected to compete with high-end imaging gear, the ease of use and remarkable results will undoubtedly get many people interested in astroimaging who might otherwise be turned off by the difficulty or expense. DwarfLab's DWARF II is just plain fun. And I expect it will revolutionize our hobby. ☽

---

**Phil Harrington** received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

# The Ring Nebula's twilight zone

M57's central star exists in a dimension not only of sight but of mind.



The Ring Nebula (M57) in Lyra is one of the most adored planetary nebulae in the night sky. Yet its bright annulus, which is most observers' target, can steal attention away from what lies inside it.

This includes its central star, which lies at the limit of vision and is a rewarding challenge to spot. So let's take a plunge into this nebulous doughnut hole, the twilight zone of deep-sky observing. As Rod Serling intoned, inside the Ring lies "a won-

drous land whose boundaries are that of the imagination."

## Your next stop: the Ring Nebula

As with many discoveries, the Ring's subtle features were detected in stages over time. When Charles Messier discovered the object Jan. 31, 1779, he observed it as a "small patch of light." A few days later, his contemporary Antoine Darquier detected hints of an annulus: Its center, he said, appeared "a bit less pale than the remaining part of its surface." In 1785, William Herschel discerned that region as a "regular, concentric, dark spot in the middle." But it wasn't until decades later that Herschel's son John noted the empty space was filled "with a feeble but very evident nebulous light ... like a gauze stretched over a hoop."

When Messier discovered the object, it was thought that all nebulae might be unresolved star clusters. Thus, early attention was focused on the Ring's annulus to see if it could be resolved into stars, not on the core.

But then a most mysterious discovery occurred in that hazy twilight zone. Around 1795, German astronomer Friedrich von Hahn began observing the Ring. Five years later, he announced he had discovered a central star. Strangely, some observers using large apertures failed to see it, while those using smaller telescopes had success. What's even more surprising is that Hahn

made his visual discovery using a 12-inch Herschelien reflector with a speculum-metal mirror that was likely only about 65 percent reflective (compared to today's silver coatings of some 98 percent).

Adding to the mystery, during the five-year gap between starting his observations of the Ring and publishing them, Hahn himself lost sight of the central star — though he gives us a clue as to why: "A few years ago the interior of the ring was so clear that I could distinguish in its centre a telescopic star with my [12-inch] reflector. Now this telescope shows only faint fine clouds and the small star is no longer visible."

It's unfortunate that, to my knowledge, Hahn documented no magnifications for these observations. If he had, he may have answered his own question. In short, if you can see the feeble light within the annulus, your chances of sighting the central star are low. And this correlation is directly related to magnification. High magnification lowers the contrast between the Ring's hole and the background sky, making the central star more accessible. You'll want a power of around 600x, and a telescope with excellent optics that can handle it.

One more tip: Your mental focus needs to be solely on the central star and not the Ring. The smallest telescope through which I have seen the central star was the 9-inch *f*/12 Alvan Clark refractor at the Harvard College Observatory, using 650x with my favorite eyepiece (a 1/8-inch Fecker) that gave a field of view of only 10'.

The same rule applies to the other extreme of aperture size. Using the 1-meter *f*/17 Cassegrain reflector at the Pic du Midi Observatory in France, astronomical historian William Sheehan and I viewed the Ring

Nebula at 1,200x. The view was solely of the Ring's twilight zone; the ring itself was outside our tiny field of view. We saw only two objects: the magnitude 14.5 central star (our estimate; other reports place it at 15.8) and its similarly bright neighbor to the northwest. In comparison, the view through the 1-meter *f*/17 Cassegrain reflector at Lick Observatory in California was completely different because we were limited to a moderately low

power. The Ring's empty inner region was filled with bright striated cirruslike clouds. After some time, I could, on occasion, glimpse the central star, but it was quite a struggle.

The bottom line is: If you want to see the central star of the Ring Nebula, increase the power to the limit and use eyepieces with small fields of view. Prepare to dedicate a night's session to the challenge. Be patient. Breathe. And as always, tell me what you see or don't see at [sjomeara31@gmail.com](mailto:sjomeara31@gmail.com).

**Your mental focus needs to be solely on the central star.**

This 1874 lithograph was created by Étienne Léopold Trouvelot with the 15-inch refractor at the Harvard College Observatory, for the purpose of measuring the nebula's extent. A glass plate with dark black lines was placed on the focus of the telescope for marking placement. No wonder it shows no central star.

ANNALS OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE (VOL. 8)/NASA ADS

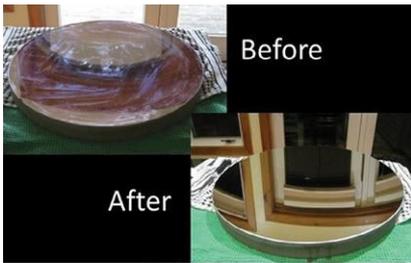


**BY STEPHEN JAMES O'MEARA**

*Stephen is a globe-trotting observer who is always looking for the next great celestial event.*



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# Framing the shot

To perfectly frame objects in your field of view, you'll need to know your telescope's focal length — and a bit of math.



ABOVE: My first image of the Lagoon Nebula (M8) was effectively zoomed in so far that the object looked nothing like a lagoon. It was taken with a Nikon D3100 on my Celestron 8-inch SCT, with an exposure time of 30 seconds at ISO 3200. MOLLY WAKELING



On the first night out with my brand-new Celestron NexStar 8SE back in July 2015, I

knew little about the relative sizes of astronomical objects. I was bowled over by my first view of Saturn — an impressive sight through an 8-inch Schmidt-Cassegrain telescope (SCT) — and I was eager to see more.

I knew the view through the scope would not be like images I had seen online, but when I slewed to the Lagoon Nebula (M8), all I could see were stars, with no hint of nebulosity. On my third night out, with a newly acquired T-adaptor to connect my DSLR to the telescope, I took a 30-second exposure, and could finally see the colorful nebula! But it filled the entire frame and didn't look anything like pictures I'd seen. "Why?" I wondered.

## Focal length and field of view

One important number associated with every telescope is its focal length, or the distance the light travels after passing through the objective to your eyepiece or camera. This figure is commonly given in millimeters (mm). For example, my 8-inch SCT has a focal length of 2,032 mm. Imagine it like an enormous 2,000mm camera lens!

This number can also be expressed via focal ratio, or f-number. Unlike camera lenses, telescopes have no iris to reduce the effective aperture, so the focal ratio is simply the focal length divided by the aperture. For my 8-inch, whose aperture in metric units is 203 mm, the focal ratio is f/10. Another example is my 106mm f/5 refractor, whose focal length is  $106 \times 5 = 530$  mm.

People at stargazing events often ask me what my magnification is. But when framing a particular object in your eyepiece or image, the more useful value is the field of view (FOV), or how large an area of sky can be seen with your telescope and a given camera or eyepiece.

The quick and dirty calculation for a camera is  $FOV = 3,436 \times (\text{sensor dimension}) \div (\text{focal length})$ , where the sensor dimension is the length or width of your camera sensor in millimeters, and the focal length is also in millimeters. The result is the FOV in arcminutes; divide by 60 to get degrees. For a Nikon DSLR with an APS-C (crop) sensor, with dimensions of 23.6 mm by 15.7 mm, the FOV of my 8-inch SCT is then 39.9' by 26.5', or 0.67° by 0.44°. For an eyepiece,  $FOV = (\text{eyepiece apparent FOV}) \times (\text{eyepiece focal length}) \div (\text{telescope focal length})$ .

There are also online calculators; my favorite is [https://astronomy.tools/calculators/field\\_of\\_view](https://astronomy.tools/calculators/field_of_view).

## Choosing your target

Now that you have calculated your FOV, you can find out which targets will be too big, too small, or fit just right. You can find the sizes of objects in apps like SkySafari or online; the Lagoon Nebula, for instance, is 90' by 40'. With an FOV of 39.9' by 26.5', no wonder I couldn't see much of it in my image — the FOV is far too small! It would be a much better target for my 530mm-focal-length refractor.

**When I slewed to the Lagoon Nebula, all I could see were stars, with no hint of nebulosity.**

On the other hand, there are many galaxies and planetary nebulae that appear tiny in my refractor but are perfect for my Schmidt-Cassegrain; for example, the peculiar galaxy Arp 273 is a mere 1.4' by 0.3' in size, but shows up nicely in my Celestron 9.25 Edge HD with a focal length of 2,345 mm.

Now that you are more aware of the effects of different focal lengths, you can plan out images for your combination of telescope and camera or eyepiece. A great resource for finding targets of a certain size (among many other criteria) is the Imm Compendium, an impressive and detailed spreadsheet from astrophotographer Gary Imm, which can be found at <https://tinyurl.com/imm-compedium>.

Happy hunting! ☺

Arp 273 sits nicely in the field of view of my 9.25-inch Celestron and ZWO ASI2600MC Pro. This shot is cropped by only 9 percent, and consists of four hours of data taken at the Okie-Tex Star Party. 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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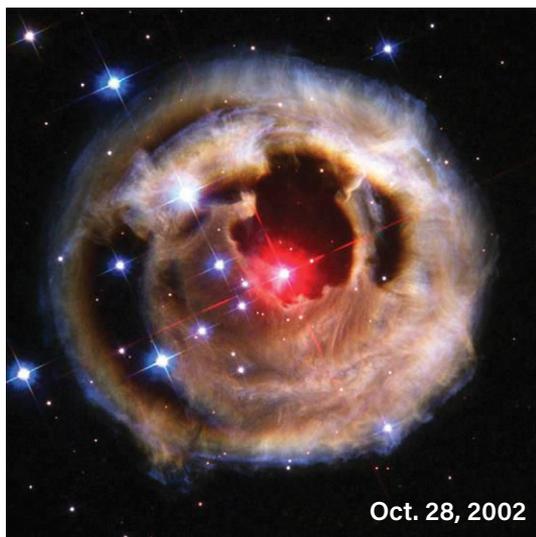
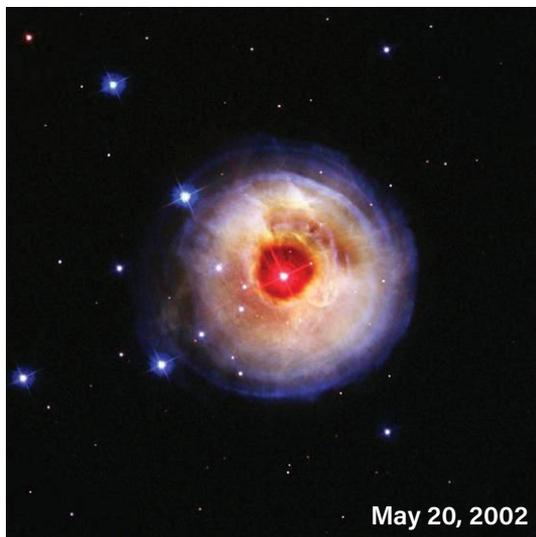
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MARKETPLACE

# Light echoes

This sequence of Hubble Space Telescope images, taken from May to December 2002, shows a light echo moving outward through the star system V838 Monocerotis. Although the dust around the star appears to grow several light-years between the first and last images, this faster-than-light growth is an illusion.

NASA, ESA AND H.E. BOND (STSCI)



**Q** | IN HUBBLE PICTURES TAKEN JUST MONTHS APART OF V838 MONOCEROTIS, THE DUST RING AROUND THIS STAR GROWS BY SEVERAL LIGHT-YEARS DURING THAT TIME, CALLED A "LIGHT ECHO." HOW CAN SOMETHING GROW BY 5 LIGHT-YEARS IN FIVE MONTHS?

*Ronald VanAtta  
Ann Arbor, Michigan*

**A** | Congratulations on noticing an effect called superluminal expansion, a phenomenon we see in a light echo. The echo appears to us to expand at many times the speed of light, seemingly violating the fundamental speed limit in the universe.

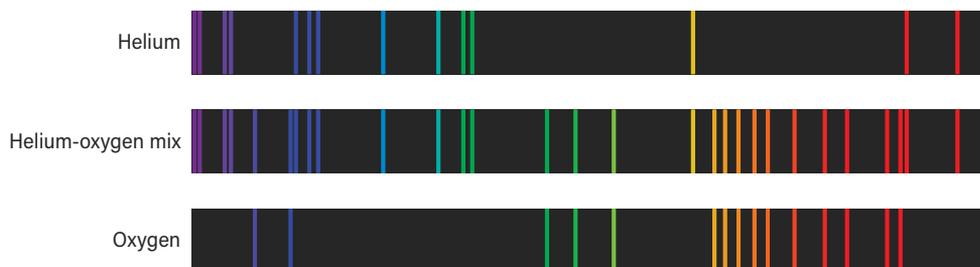
A light echo occurs when a star experiences an eruption or an object explodes in a region surrounded by interstellar dust. Light from the eruption travels straight to Earth, so that is what we see first. But the light also travels to the side, reflects off the dust, and then heads toward us. Because of the extra distance traveled, the reflected light arrives at Earth later on — like the voice



Each element emits light at specific wavelengths when it glows. By cataloging the pattern of light from a given element, scientists can disentangle the composition of unknown substances, such as in this simplified example, which shows the combined spectra of hydrogen and oxygen.

ASTRONOMY: ROEN KELLY

## FINGERPRINTING ELEMENTS



**Q** | HOW DO SCIENTISTS KNOW WHAT SPECTRAL LINES BELONG TO WHICH COMPOUND?

*Zbigniew Komala  
Chrzanów, Poland*

**A** | Each atom and molecule has its own fingerprint that, like yours, is unique. But unlike yours, this fingerprint is made of light. Elements and compounds emit identifying sets of “colors,” or wavelengths, of light. (“Colors” is in quotes here because the light is not always visible, extending to infrared and radio bands on one side and ultraviolet and gamma rays on the other.) No two color combinations are the same, allowing astronomers to accuse specific chemicals of being in stars, gas clouds, or planetary atmospheres.

But how did astronomers get these chemicals’ fingerprints in the first place? Just like in a crime drama, they brought the atoms downtown to the station. And by “station,” I mean laboratory. Chemists put the atoms through all kinds of trials, where they vary the temperature, collect the light that results, and precisely determine the different wavelengths that make up that light. Once the fingerprints are “in the system,” astronomers can go look for matching sets in space.

It may sound simple but consider this: Few things in the universe are made of one pure substance. Astrochemists, as those who work in this field are called, have to separate the signature of hydrogen from the signature of helium from the signature of ethylmethylamine, which is like trying to determine what a person’s fingerprint looks like when 10 other suspects’ prints are on top of it.

*Sarah Scoles  
Science Journalist*

**Q** | HOW IS TESS ABLE TO SPOT MORE PLANETS IN THE SKY THAN KEPLER COULD?

*Doug Kaupa  
Council Bluffs, Iowa*

**A** | The Transiting Exoplanet Survey Satellite (TESS) has outpaced the now-retired Kepler mission in discovering planets and planet candidates primarily because of the former’s significantly larger survey area. It covers almost the entire sky compared to the small patch of sky observed by Kepler. In order to maximize coverage across the sky, TESS observes roughly 1 million stars amenable to planet detection for roughly 27 days before moving on to another set of targets. Tens of millions of such stars have been observed since the start of the mission. Meanwhile, Kepler observed a smaller number of stars but for a much longer, sustained amount of time, watching about 150,000 Sun-like stars for four consecutive years.

Essentially, TESS has access to a significantly larger pool of stars in which it can find planets. The TESS mission has also operated for longer than Kepler, spanning nearly six years (and counting) compared to Kepler’s four.

The different observing strategies adopted by Kepler and TESS were chosen to support their specific scientific goals, and both missions have advanced our understanding of exoplanetary systems in unique ways. Kepler’s focused observations provided crucial insights into the demographics of small exoplanets with orbital periods up to several years, as well as the architectures of multiplanet systems around Sun-like stars. Kepler also provided the

**THE DIFFERENT OBSERVING STRATEGIES ADOPTED BY KEPLER AND TESS WERE CHOSEN TO SUPPORT THEIR SPECIFIC SCIENTIFIC GOALS.**

best dataset we have for understanding the prevalence of Earth-like exoplanets in our galaxy.

TESS complements Kepler by identifying exoplanets around a more diverse array of stars and their environments. Furthermore, by focusing on detecting planets around bright stars across the entire sky, TESS is finding targets that are perfect for follow-up observations to

measure planet masses and atmospheric compositions. Together, Kepler and TESS have been significant contributors to the discovery and understanding of exoplanets.

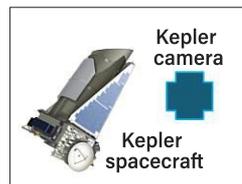
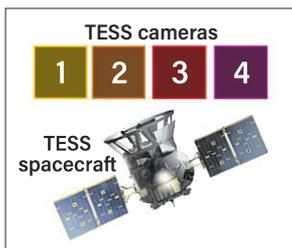
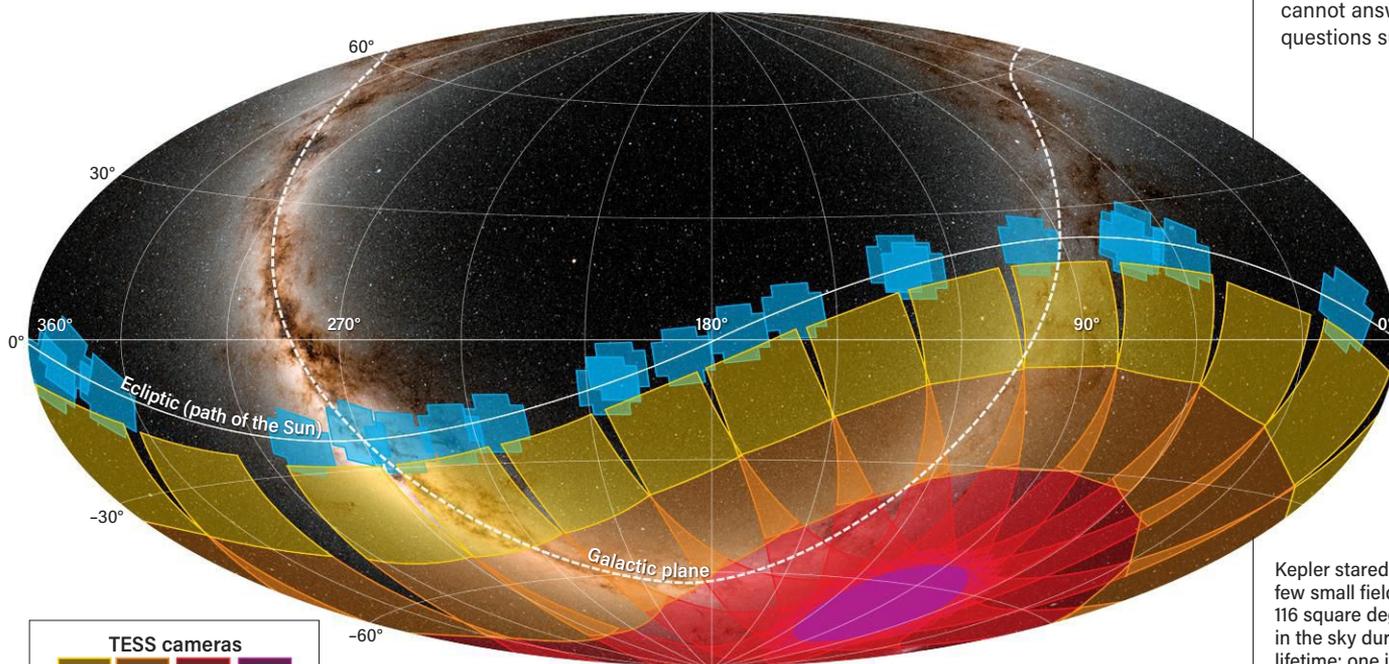
**Michelle Kunimoto**

*Torres Postdoctoral Fellow, MIT Kavli Institute for Astrophysics and Space Research, Cambridge, Massachusetts*

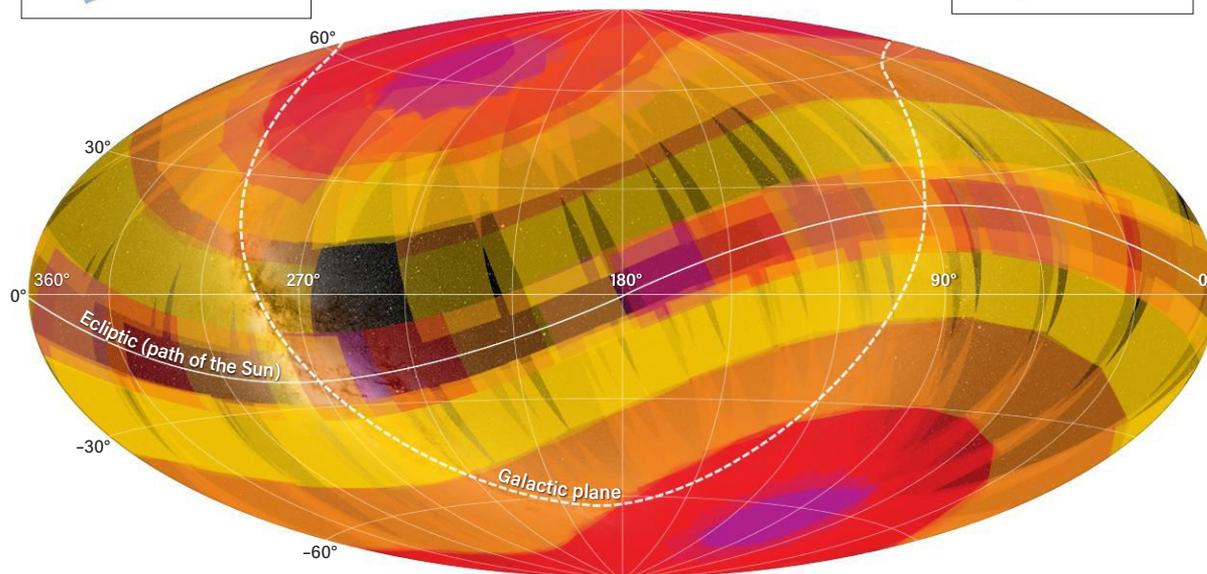
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Send your astronomy questions via email to [askastr@astronomy.com](mailto:askastr@astronomy.com). Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

## KEPLER MISSION VERSUS TESS' FIRST YEAR



## SEVEN YEARS OF TESS



Kepler stared at only a few small fields of about 116 square degrees each in the sky during its lifetime: one in Cygnus and several along the ecliptic plane. TESS is designed to cover nearly the entire sky every two years. The newer telescope observes each of 13 sectors, measuring 24° by 96° apiece, for 27.4 days before moving on to the next. The top map shows all four years of Kepler fields (blue) alongside the coverage achieved by TESS' four cameras during only its first year (yellow, orange, red, and purple). The bottom map shows how much of the sky TESS will cover once it has completed seven years of observations in September 2025.

SPACECRAFT: NASA. MAPS: ASTRONOMY: ROEN KELLY, AFTER [HTTPS://TESS.MIT.EDU](https://tess.mit.edu). MILKY WAY MAP: NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO. GAIA DR2: ESA/GAIA/DPAC. PROJECTION: G.PROJECTOR 3 — MAP PROJECTION EXPLORER.



1

**1. AN ACTIVE SUN**

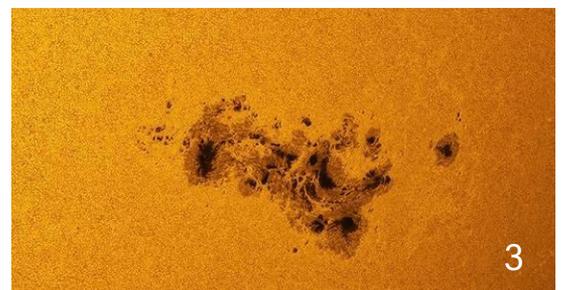
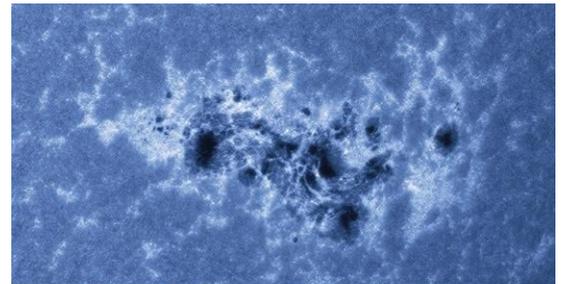
On May 8, the active sunspot region AR 3664 — captured on that date, just below and right of center, with a 2.4-inch refractor — began unleashing a series of X-class flares and coronal mass ejections (CMEs) that resulted two days later in the strongest geomagnetic storm in 21 years.  
 - *Rob Lyons*

**2. STORM'S A-BREWING**

The enormity of AR 3664 — at the bottom of the Sun's disk in this image — is apparent in this composite shot taken May 9 with a Nikon Z9 mirrorless camera and a 400mm lens at ISO 32. The solar disk exposure was 1/32,000 of a second at f/32 and the landscape was shot at 1/4,000 of a second at f/9.  
 - *Marco Meniero*



2



3



**3. SUNSPOT CLOSE-UP**  
AR 3664 was captured in this image on May 10 with a 5-inch refractor in Calcium-K (top) and white light (bottom). The sunspot complex was roughly 125,000 miles across (200,000 km), or 16 times the diameter of Earth.  
• *Salvo Lauricella*

**4. VANCOUVER LIGHTS**  
The series of CMEs struck Earth May 10, resulting in a G5-level geomagnetic storm — the strongest on the scale, and the first of that magnitude since October 2003. This image is a still from a timelapse video shot with a Sony A7R mirrorless camera and a Sigma 14mm f/1.4 lens.  
• *Rob Lyons*



**5. COLLINGWOOD LIGHTS**  
The last remnants of twilight are visible on the horizon at 9:03 P.M. local time on May 10 in this image taken from Collingwood, Ontario, but the show had already started overhead. The photographer used a Sony a7 III mirrorless camera and zoom lens at 28mm and f/4 to capture an eight-second exposure at ISO 400.  
• *Tania Wood*

**6. ELGINFIELD LIGHTS**  
The last G5 geomagnetic storm occurred more than three years before the iPhone was released, meaning this was the first time in human history we could capture and share the aurora in real time with cameras that we carry in our pockets. This photo at Elginfield Observatory, north of London, Ontario, was taken on an iPhone 13.  
• *Katelyn Beecroft*



**7. JINSHANLING LIGHTS**  
The aurora shimmers over the Jinshanling section of the Great Wall of China in this image taken May 11 at 10:20 P.M. local time. The photographer used a Nikon D850 and wide-angle zoom lens at 24mm and f/2.8 to take a five-second sky exposure at ISO 4000.  
• *Cao Yifan*

**8. LAURENTIDES LIGHTS**

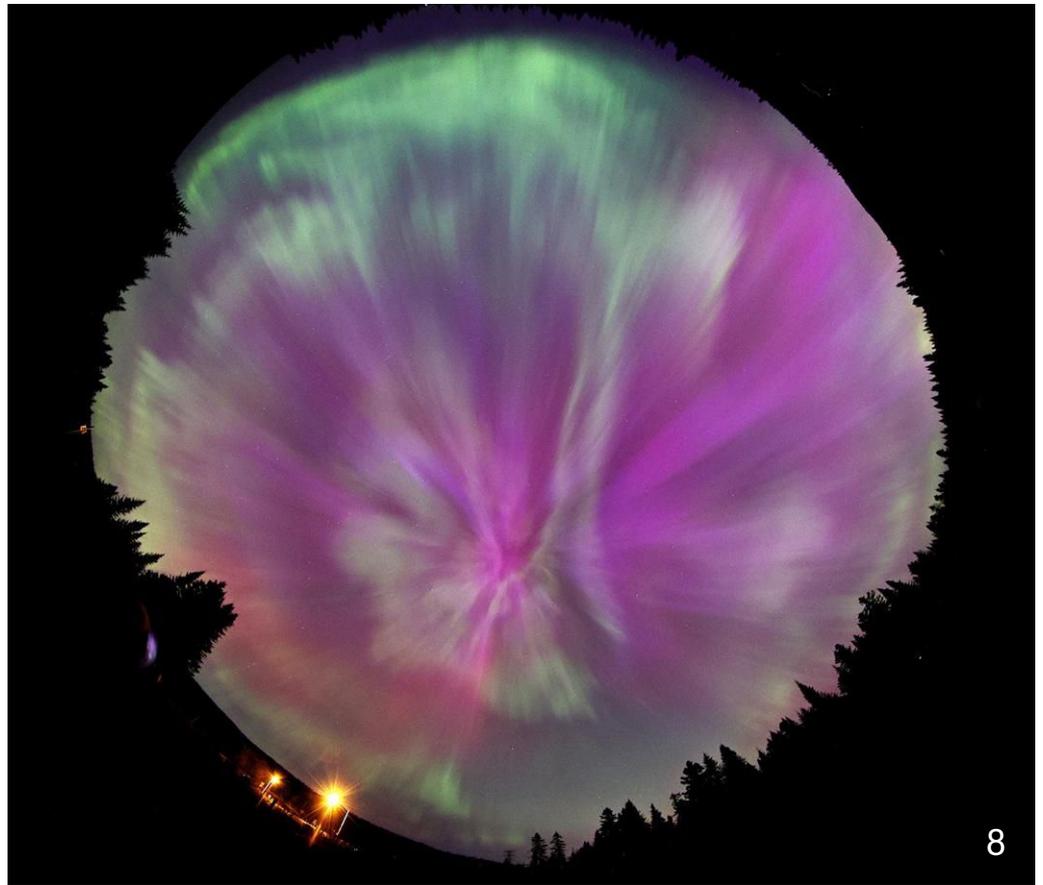
The auroral storm pushed sufficiently south for many people to witness a coronal aurora, in which the viewer is directly underneath the aurora; it appears to radiate from a single point as charged particles from space rain down on Earth's atmosphere. This four-second exposure was taken from the Laurentides Wildlife Reserve in Quebec, with a Canon EOS R3 mirrorless camera at ISO 1600 and an 8-15mm fisheye lens at f/4. • *Philippe Moussette*

**9. DEATH VALLEY LIGHTS**

Aurorae fill the sky over California's Death Valley around 1 A.M. on May 11. The imager used an astromodified Nikon Z 6II mirrorless camera and 14-24mm lens at 14mm and f/2.8 (with a UV/IR-cut and H $\alpha$ -pass filter) to take a 10-second sky exposure at ISO 2000 and 30-second foreground exposure at ISO 3200. • *Abhijit Patil*

**10. JOSHUA TREE LIGHTS**

The Milky Way is the backdrop for the aurora over Joshua Tree National Park in this 20-second exposure taken with a Pentax K-1 DSLR and 14mm f/2.8 lens at ISO 1600. • *Mirko Maher*





10



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



11



12



13

#### 11. MAZATLÁN LIGHTS

The northern lights ventured as far south as Mexico, as seen in this shot taken from Chirimoyos (23.4° north latitude), near Mazatlán, on May 11, 2 A.M. local time. The photographer used a Sony a7S II mirrorless camera and Sigma 35mm lens at f/1.4 and ISO 3200 to make this panorama of three panels of five 8-second exposures. •

**René Saade**

#### 12. ASHOKAN LIGHTS

The aurora reflects off the waters of Ashokan Reservoir in New York, captured by an astromodified Sony a7 III mirrorless camera and wide-angle zoom lens at 12mm and f/4. The exposure was 15 seconds at ISO 1000. •

**Chirag Upreti**

#### 13. REDROCK LIGHTS

In addition to the aurora filling the frame, meteor streaks appear (at right) in this image from Redrock, New Mexico. This 10-second shot was taken with a Sony a7R III mirrorless camera at ISO 1600 and a Sigma 24mm lens at f/1.4. •

**Stephen Dorn**



## A HEROIC CELEBRATION

The Little Dumbbell Nebula (M76) in Perseus the Hero ranks among the faintest objects in Charles Messier's catalog, but it more than makes up for this indignity with its visual splendor. The planetary nebula formed when a Sun-like star reached the end of its life. Having swollen into a red giant, the dying star ejected a thick ring of gas and dust that we see as an edge-on disk. Twin lobes of hot gas started escaping perpendicular to this disk soon thereafter. Meanwhile, the stellar remnant is collapsing into a white dwarf. With a surface temperature of 215,000 degrees Fahrenheit (120,000 degrees Celsius), it emits copious amounts of ultraviolet light that excites the surrounding gases to incandescence. Scientists released this Hubble Space Telescope portrait on the 34th anniversary of the observatory's launch. NASA, ESA, STSCI, A. PAGAN (STSCI)

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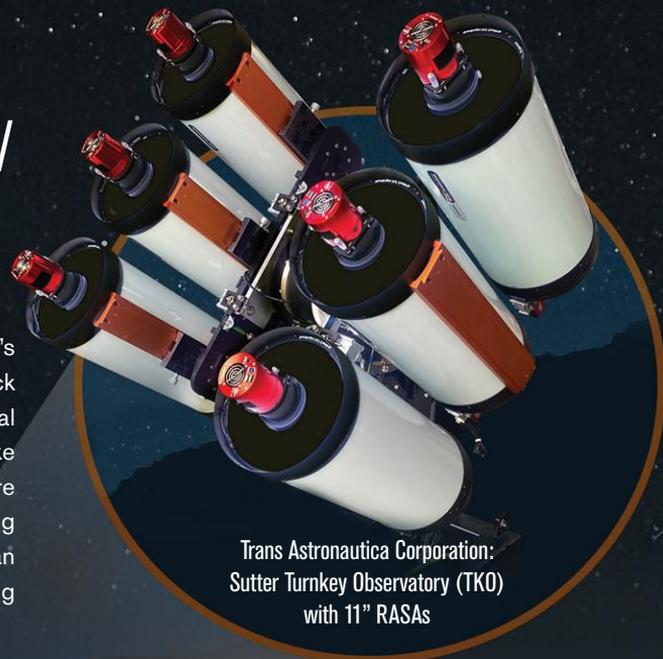
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## October 2024

# Saturn's evening show

» You can't miss **Venus** this month. The brilliant planet shines at magnitude  $-3.9$  and dominates the western sky after sunset. Venus begins October among the background stars of western Libra, spends a week crossing the narrow northern section of Scorpius after midmonth, and enters Ophiuchus in the month's final week. On October 25, the inner planet passes  $3^\circ$  north (lower right) of 1st-magnitude Antares, Scorpius' brightest star.

With Venus now pulling away from the Sun, take a few moments to view it through a telescope. The planet's disk spans  $13''$  and appears 82 percent lit in mid-October.

**Mercury** climbs into view below Venus in late October. On the 31st, the innermost planet stands  $8^\circ$  high in the west-southwest 45 minutes after sundown. It glows at magnitude  $-0.3$  and stands out nicely as twilight deepens. Mercury's gibbous disk spans  $5''$  and doesn't look impressive through a telescope, though better views await in November.

Although **Saturn** came to opposition in early September, it now appears better positioned in our evening sky. The ringed planet reaches its peak altitude in midevening and remains high until well past midnight. Saturn shines at magnitude  $0.7$  and easily overshadows the background stars of eastern Aquarius.

Saturn's famous rings open up a bit during October, making them easier to observe. They tilt  $5^\circ$  to our line of sight at midmonth, when they span  $43''$ . And keep an eye out for 8th-magnitude Titan, the planet's biggest and brightest moon. As you look at the giant satellite, remember that it is actually larger than Mercury.

A waxing gibbous Moon occults Saturn on October 14 for people in Madagascar as well as southern and eastern Africa. From Antananarivo, Saturn disappears behind the Moon's dark limb at 17h13m UT and reappears from behind the bright limb at 18h09m UT.

Before the clock strikes midnight, the magnificent vistas in Orion and Taurus rise in the east. Tucked between the Bull's long horns you'll find dazzling **Jupiter**. The magnitude  $-2.6$  planet shines three times brighter than the sky's brightest star, Sirius, which resides some  $45^\circ$  to Jupiter's right.

Because the giant planet lies well north of the celestial equator, it doesn't climb high in our sky. Still, it's worth turning your telescope on the planet when it reaches peak altitude before dawn. You'll see a world that spans  $44''$  and shows a significant amount of atmospheric detail. Also watch the dance of Jupiter's four bright moons. Being passionate about astronomical history, I often think of the wonderful records of their motions that Galileo made more than 400 years ago.

Head one constellation east of Taurus and you'll land in Gemini, the current home of **Mars**. The Red Planet shines at magnitude  $0.3$  in mid-October, easily outpacing the stars of its host constellation.

As Earth's orbital motion carries it closer to Mars, the outer planet grows larger in a telescope. By October's close, Mars' disk measures  $9''$  across. In steady moments in the hour or two before dawn, look for dark surface markings and the white north polar cap.

The Moon passes directly between the Sun and Earth on October 2, bringing an annular solar eclipse to people along the path in Chile and Argentina. After crossing Easter Island, the eclipse track hits mainland Chile near the southern edge of Laguna San Rafael National Park. On the center line there, annularity lasts 6 minutes 25 seconds. Visitors to Santa Cruz Province in southern Argentina will lose five to 10 seconds of annularity compared with Chile.

### The starry sky

Few constellations attract more attention than Crux the Cross. Yet despite its fame, Crux ranks as the smallest of the 88 official IAU constellations with an area of just  $68.4$  square degrees. The second smallest constellation lies due north in the early evening hours of October. But Equuleus the Little Horse has little of the charm of its diminutive cousin.

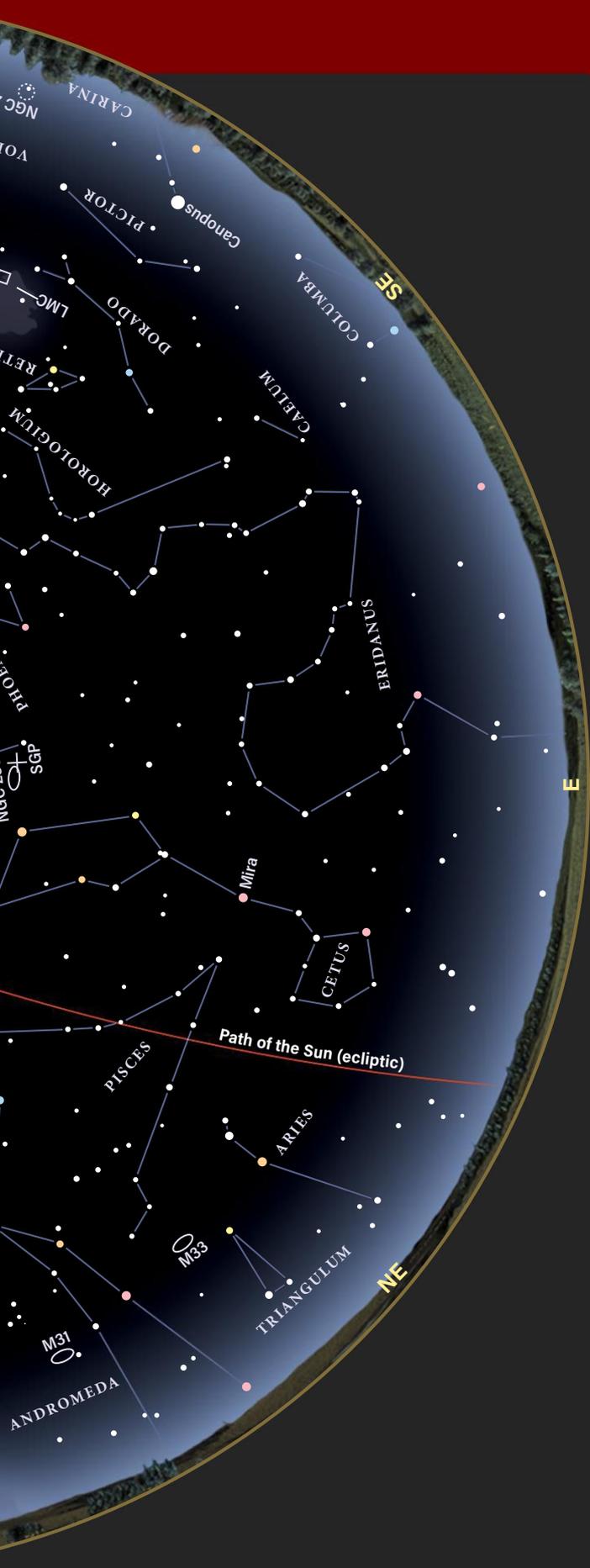
To find Equuleus, first locate the Great Square of Pegasus. The tiny constellation — just  $71.6$  square degrees in area — appears to the upper left of this conspicuous asterism. Although Equuleus lies entirely within the northern celestial hemisphere, it climbs halfway to the zenith at its peak from mid-southern latitudes.

Equuleus doesn't stand out even from a dark-sky site. Its brightest star, Kitalpha (Alpha [ $\alpha$ ] Equulei), glows at magnitude  $3.9$ . It gets its proper name from the Arabic Qit'at al-Faras, which means "part of the horse." It is the only officially named star in the constellation.

Equuleus is the 18th of the 48 constellations Ptolemy listed in his famous *Almagest*. He called it "Hippou Protome" — the forepart of a horse. (The Latin name Equuleus came later.) In fact, if you look at classic renditions of constellations, artists depicted Equuleus only as a horse's head. It appears that Ptolemy did not invent this constellation, however. That honor goes to Hipparchus centuries earlier.

Unlike Crux, which holds a surplus of objects worth exploring through binoculars and telescopes, Equuleus has little to offer. My favorite deep-sky object in the Little Horse is the double star 2 Equ, which lies  $3.6^\circ$  southwest of Gamma ( $\gamma$ ) Equ. Its two 7th-magnitude stars are separated by  $2.8''$ , making them a great target for small high-quality refractors. ☛





# OCTOBER 2024

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

ILLUSTRATIONS BY ASTRONOMY: FROENIKELLY

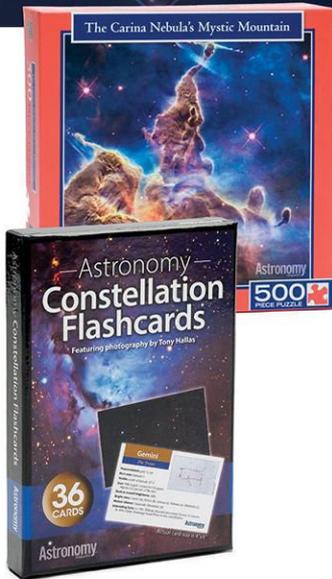
Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

## CALENDAR OF EVENTS

- 2 New Moon occurs at 18h49m UT; annular solar eclipse  
The Moon is at apogee (406,516 kilometers from Earth), 19h39m UT
- 5 The Moon passes 3° south of Venus, 20h UT
- 7 Asteroid Laetitia is at opposition, 18h UT  
The Moon passes 0.2° south of Antares, 19h UT
- 9 Jupiter is stationary, 7h UT
- 10 First Quarter Moon occurs at 18h55m UT
- 12 Pluto is stationary, 2h UT
- 14 The Moon passes 0.1° north of Saturn, 18h UT
- 15 The Moon passes 0.6° north of Neptune, 18h UT
- 16 Asteroid Juno is in conjunction with the Sun, 15h UT
- 17 The Moon is at perigee (357,175 kilometers from Earth), 0h51m UT  
 Full Moon occurs at 11h26m UT
- 19 The Moon passes 4° north of Uranus, 16h UT
- 21 Orionid meteor shower peaks  
Mars passes 6° south of Pollux, 6h UT  
The Moon passes 6° north of Jupiter, 8h UT
- 23 The Moon passes 4° north of Mars, 20h UT
- 24 Last Quarter Moon occurs at 8h03m UT
- 25 Venus passes 3° north of Antares, 19h UT
- 29 The Moon is at apogee (406,161 kilometers from Earth), 22h50m UT

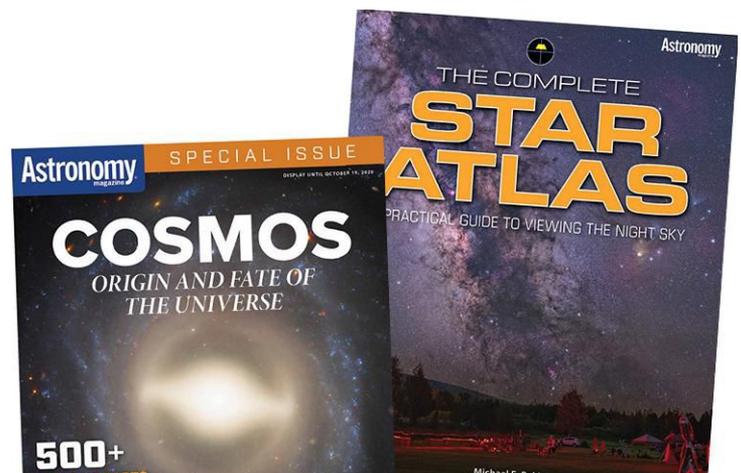
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