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In the 1920s, Edwin Hubble found the universe of galaxies is expanding. The Sombrero Galaxy in Virgo is a classic edge-on example.
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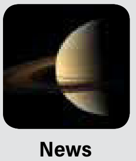

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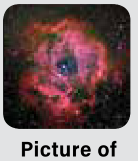

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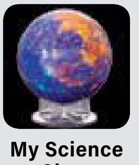

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Perfect gifts for your favorite science geeks.

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FROM THE EDITOR

The evolution of justice

Lowell Observatory astronomer Vesto M. Slipher detected the expansion of the cosmos well before Edwin Hubble did. Should he share in a renaming of the fundamental number we know as the Hubble constant? LOWELL OBSERVATORY ARCHIVES

We live in a world that often is not fair. Sometimes justice takes quite a while to arrive, and other times it never materializes at all. One such saga has been brewing in the world of astronomy for a very long time.

In the fall of 1923, a young astronomer in Pasadena, California, Edwin Hubble, made a groundbreaking image of the Andromeda "Nebula," as it was then called. This was the first key to both the nature of galaxies and the vast cosmic distance scale. Six years later, Hubble published a landmark paper that laid out how the universe is expanding, a milestone moment in the history of science.

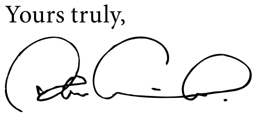
But as historical stories often turn out to be, it's not quite as simple as we read in our schoolbooks. It was actually in 1912, at Lowell Observatory in the frontiers of Arizona, that another young astronomer, Vesto M. Slipher, first recorded evidence with his spectrograph that "spiral nebulae" were receding away from us, the initial evidence of universal expansion.

Edwin Hubble is a giant in the world of astronomy, but he didn't always play well with others. Brimming with ego and anxious to push his own papers forward, he didn't always share credit where justice might have called for it.

Thus, a team of science writers now presents the lead story in our current issue (page 14). The team consists of Douglas MacDougal, Joseph Marcus, and Marcia Bartusiak.

One of the preeminent cosmological parameters is the so-called Hubble constant, which arose from Hubble's 1929 paper and which relates the velocities galaxies are moving away from us to their distances. Our present team proposes that the Hubble constant should be renamed the Hubble-Slipher constant. What do you think of this revolutionary idea?

Yours truly,



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Editor

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Astronomy
THE WORLD'S BEST-SELLING ASTRONOMY MAGAZINE /// NOVEMBER 2024
EVERYTHING WE KNOW ABOUT
THE SUN
WHAT CAUSES RAINBOWS AND MOONBOWS?
Astronomy
EVERYTHING WE KNOW ABOUT
THE SUN
PLUS:
THE STARMUS FESTIVAL ROCKS SLOVAKIA
WEBB UNLOCKS STARBIRTH IN SERPENS
BEHIND THE SCENES AT A ROCKET LAUNCH
WHAT CAUSES RAINBOWS AND MOONBOWS?

JWST could someday identify the finer details of the Andromeda Galaxy. NASA/JPL-CALTECH

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

Meet your neighbor

Klaus R. Brasch's excellent article on the Andromeda Galaxy, "The spiral galaxy next door" (September 2024), is a comprehensive article that places Andromeda's historical and astronomical importance in proper perspective. Andromeda was a door that was opened by the careful work of many astronomers and scientists and revealed the true scope of our universe. It has become a signpost in the significant discoveries that continue to open our eyes and minds. I will look forward to the research from JWST as we continue to use our neighbor, Andromeda. **— Donald Craig Jr.,** Indianapolis, IN

Globs of enjoyment

I thought the August issue of *Astronomy* magazine was fantastic, and I especially enjoyed Rod Pommier's article on how globular clusters can be used to trace the history of our galaxy. I am working on the Astronomical League's Globular Cluster Observing Program, and I found the information and the sense of wonder expressed in the article to be very inspiring. I will now be looking at globular clusters with a new appreciation. **— Jonathan Scheetz II,** Chesapeake, VA

Lights off

I very much appreciated the special report on light pollution in the July 2024 issue. I've been an off-and-on subscriber to the magazine since I was a kid in the 1990s, and I remember reading about light pollution way back then. Of course, then I could see the Milky Way and Andromeda Galaxy as naked-eye objects from my parents' home in the countryside. Now I'm lucky to see the Summer Triangle from my small-town backyard. I hope that you continue to spotlight the problems of — and solutions to — light pollution in your magazine. I'd even welcome a monthly column on the topic. As the report mentions, this goes way beyond enjoyment of the night sky and has serious, detrimental consequences for human, animal, and plant life. Please keep your (fully shielded) spotlight on this issue. **— Katie Yelinek,** Bloomsburg, PA

SNAPSHOT

JWST HUNTS FOR ROGUE WORLDS

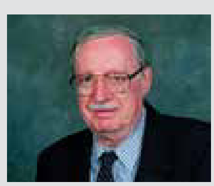
These planet-sized objects may give clues to how stars form.

The James Webb Space Telescope (JWST) is scouring clouds of dust and gas for rogue worlds — objects that have masses similar to planets but do not orbit parent stars. One of JWST's hunting grounds is NGC 1333, a reflection nebula with several star clusters, located in the constellation Perseus some 960 light-years away. JWST's observations yielded six free-floating objects with masses ranging from five to 15 times that of Jupiter. (Three of them are indicated at right).

These rogue planets may have formed the way stars do — a molecular cloud of gas and dust collapsing under its own gravity. But they are far too small to begin the process of nuclear fusion, which powers stars; in fact, they are smaller than many giant exoplanets.

However, the researchers found no objects with masses below five times that of Jupiter, even though JWST's sensitivity would allow them to see such objects. This leads them to think that they have identified a threshold: Objects lighter than this must form around a star. The work is detailed in a paper submitted to the *arXiv* preprint server Aug. 22 and accepted for publication in *The Astronomical Journal*. — MICHAEL E. BAKICH

» HOT BYTES



DARK-SKY LEADER

David Crawford, an astronomer and pioneer of the modern dark-sky movement, died July 22 in Carlsbad, California, at 93. He was a founder of DarkSky International and worked tirelessly to educate local officials and the public on the importance of preserving the night sky.

EXTRAGALACTIC SETI

The Murchison Widefield Array in Western Australia has begun searching for signs of alien technology beyond the Milky Way. The array's large field of view allowed it to target some 2,800 galaxies in a single observation.

MAGMA MOON

Rock samples analyzed by India's robotic lunar rover Pragyan near the Moon's south pole are remarkably similar in composition to samples returned by Apollo 16 and Luna 20. This adds weight to the theory that the Moon's entire surface was once covered by an ocean of magma.

ESA/WEBB, NASA & CSA, A. SCHOLZ, K. MUZIC, A. LANGEVELD, R. JAYAWARDHANA. BOTTOM FROM LEFT: LISA CRAWFORD BRUHN; SETI INSTITUTE; ISRO

NASA CANCELS FULLY BUILT MOON ROVER, STUNNING SCIENTISTS

The VIPER rover was meant to be a key scouting mission ahead of NASA's Artemis program.

FOR SALE: MOON ROVER, NEVER FLOWN. The VIPER rover sits fully assembled in its clean room at NASA's Johnson Space Center. NASA

» In a shock to the lunar science community, on July 17, NASA canceled the much-anticipated Volatiles Investigating Polar Exploration Rover (VIPER) mission, which was expected to prospect for water ice on the Moon — a critical resource for future explorers. The fate of the mission now rests with outside parties, including private space companies, who are lining up to convince NASA to hand over VIPER's reins.

VIPER was one of the highest-profile missions in NASA's ongoing Commercial Lunar Payload Services (CLPS) program, which is sending robotic missions to the Moon in support of future Artemis crews. The Artemis program is targeting landing sites near the lunar south pole, where the shallow angle of the Sun means many craters lie in permanent shadow. Scientists know that these craters contain water ice, which could be used as drinking water for astronauts and to produce rocket fuel and energy. But how much ice is there and how easy it will be to extract is not known. VIPER's mission was to answer those questions; its cancellation deprives the Artemis program of answers.

Equally shocking to the science community is that $450 million has already been spent designing and building VIPER and its suite of instruments. The completed VIPER only needed to pass its environmental tests. The rover, and the Astrobiotics Griffin lunar lander that was to deposit VIPER near the south pole, were scheduled to launch in September 2025, aboard a SpaceX Falcon Heavy rocket.

THE COST OF COST CUTTING

NASA says that COVID-induced supply chain issues with both the rover and its Griffin lander escalated mission costs and have delayed its anticipated launch by two years. By canceling the project — after already spending nearly half a billion dollars — NASA says it will save $84 million. The agency will still pay Astrobiotics $323 million to complete the Griffin lander and fly it to the Moon without VIPER. As of this writing, plans call for landing a "mass simulator," or a dead weight, in its place.

VIPER was built with an array of features for exploring frosty, shaded polar craters. Standing a boxy 5 feet (1.5 meters) square and 8 feet (2.4 m) high, the vehicle would have been the first on the Moon equipped with headlights for operating during the long lunar night. VIPER also features an innovative wheel design with independent steering and active suspension for all four wheels, enabling the rover to traverse a variety of soil conditions on the Moon and slopes of up to 30°.

Mission planning called for VIPER to operate for 100 days on the lunar surface, controlled by a driver on Earth. VIPER would have used a suite of spectrometers and a drill capable of penetrating the surface to a depth of 40 inches (1.0 m) to extract subsurface samples for analysis.

NOCTURNAL EXPLORER. VIPER is equipped with headlights — a first for lunar rovers — to enable operations during nighttime on the Moon, which lasts nearly 15 Earth days. NASA

VIPER'S PLAN B

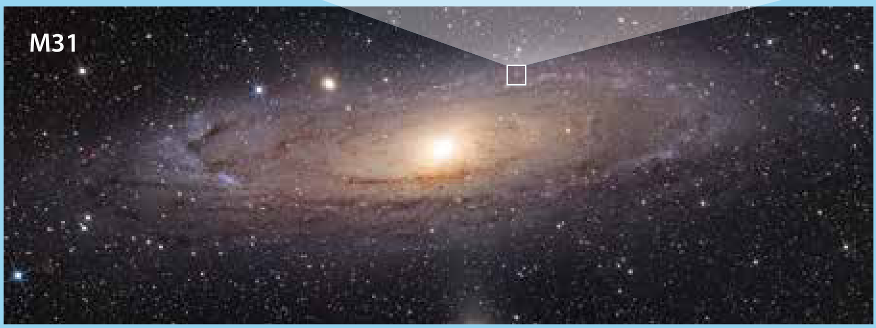
NASA is open to handing the vehicle over to another organization to fly it to the Moon and carry out its scientific mission — if it comes at no additional cost to NASA. As of this writing, NASA is evaluating proposals it received from a variety of organizations and companies.

The interested parties include Intuitive Machines, another commercial partner in NASA's CLPS program. In February, the firm's Odysseus lander carried out the first successful soft lunar landing by a private company.

Intuitive Machines' next-generation lander will be capable of delivering 3,300 pounds (1,500 kilograms) to the Moon. VIPER would occupy one-third of that payload capacity; selling the rest to other parties could help offset the cost. — ROBERT REEVES

HUBBLE SEES HYDROGEN

LIKE THE MILKY WAY, the Andromeda Galaxy (M31) is a spiral marked by winding arms. These are regions where star birth and death run rampant, from glowing stellar nurseries to exploding supernovae. Together, these factors create the glowing red clouds of hydrogen gas recently revealed by the Hubble Space Telescope, whose Advanced Camera for Surveys and Wide Field Camera 3 combined to offer researchers a glimpse at what's going on in our near neighbor. By using the powerful space telescope to peer into M31's arms, researchers can not only learn more about its stellar population and life cycle, but also use the galaxy as an analogue for more distant galaxies, whose stars we cannot resolve. — ALISON KLESMAN



TOP: NASA, ESA, M. BOYER (SPACE TELESCOPE SCIENCE INSTITUTE), J. DALCANTON (UNIVERSITY OF WASHINGTON). BOTTOM: KPNO/NOIRLAB/NSF/AURA/ADAM BLOCK

QUICK TAKES

CHINA'S STARLINK

The first batch of 18 satellites for the Qianfan ("thousand sails") communications megaconstellation launched Aug. 6 from Taiyuan Satellite Launch Center in northern China. Plans call for an eventual total of more than 14,000 satellites.

CAUGHT SPEEDING

Citizen scientists and a team of astronomers have found a star just 0.08 times the mass of the Sun traveling at 1 million mph (1.6 million km/h) — fast enough to escape the Milky Way. The object, 400 light-years distant, is the smallest such galactic runaway yet known.

O_2 SANS SUNLIGHT

Rare-metal seafloor rocks called polymetallic nodules may be producing oxygen from seawater through electrolysis, says a July 22 report in *Nature Geoscience*. If confirmed, this "dark oxygen" has implications for life on worlds with subsurface oceans like Enceladus and Europa.

SLINGSHOT ENGAGED

On Aug. 19–20, the European Space Agency's Jupiter Icy Moons Explorer (JUICE) became the first spacecraft to perform a double flyby of Earth and the Moon, getting gravity assists from both bodies en route to a 2031 arrival at Jupiter.

TERRAFORMING MARS

Glitter-sized metallic nanorods, if released into Mars' atmosphere, could warm the planet 5,000 times more efficiently than greenhouse gases, an Aug. 7 *Science Advances* study finds. Releasing 8 gallons (30 liters) of nanorods per second would warm Mars by an estimated 54 F (30 C) or more.

THE HOMEBODY PROBLEM

Philosopher Wolfhart Totschnig argues in October's *Acta Astronautica* that intelligent life chooses not to expand across the galaxy to avoid conflict over resources. This could explain the Fermi paradox, which asks why, if life is widespread, alien civilizations haven't been found. — MARK ZASTROW

Scientists identify dinosaur-killer asteroid

DEEP IMPACT. The asteroid that created the Chicxulub crater crashed into the Yucatán Peninsula in southeast Mexico, as depicted in this artist's impression. The collision wiped out roughly 60 percent of all species on Earth. SWRI/DON DAVIS

SOME 66 MILLION YEARS AGO, an asteroid struck Earth in the Gulf of Mexico near the present-day community of Chicxulub Pueblo. Now known as the Chicxulub impactor, it wiped out around 60 percent of all species, most famously the dinosaurs.

To nail down what the Chicxulub impactor was and where it came from, a team led by cosmochemist Mario Fischer-Gödde of the Institute of Geology and Mineralogy at the University of Cologne, Germany, analyzed ruthenium isotopes from samples taken from the Cretaceous–Paleogene (K-Pg) boundary. They then compared them to other samples from asteroid impacts and meteorites. Their analysis, published Aug. 15 in *Science*, found that the material in the K-Pg samples most closely matched carbonaceous chondrites, a type of meteorite that contains, among other things, water and organic compounds like amino acids.

The researchers concluded that the Chicxulub impactor likely was a C-type (carbonaceous) asteroid that originated in the outer solar system beyond Jupiter. Their reasoning is that C-type asteroids, which are the most common and comprise 75 percent of those in our solar system's asteroid belt, are mainly found at the outer edge of the belt, nearer to Jupiter than to Mars. Also, Jupiter shares its orbit with two groups of asteroids (the Trojans and the Greeks), some of which are C-types. – M.E.B.

Weighing a middling-mass black hole

» Black holes come in three weight classes. And while astronomers have identified objects in the lightest and heaviest classes, the middleweight intermediate-mass black holes, or IMBHs, have remained elusive.

But evidence is piling up for their existence, including new results from the Hubble Space Telescope (HST), published July 10 in *Nature*. After following the motions of seven fast-moving stars in the innermost region of the Milky Way's most massive globular cluster, Omega Centauri, researchers believe their motions reveal the presence of an IMBH.

The velocities of some 1.4 million of Omega Cen's stars have been observed by HST for 20 years. Within that data, the study's first author Maximilian Häberle of the Max Planck Institute for Astronomy in Germany and his team discovered seven stars "that should not be there," he said in a press release. "They are moving so fast that they would escape the cluster and never come back." But they are orbiting the cluster's center, not flinging themselves out of it.

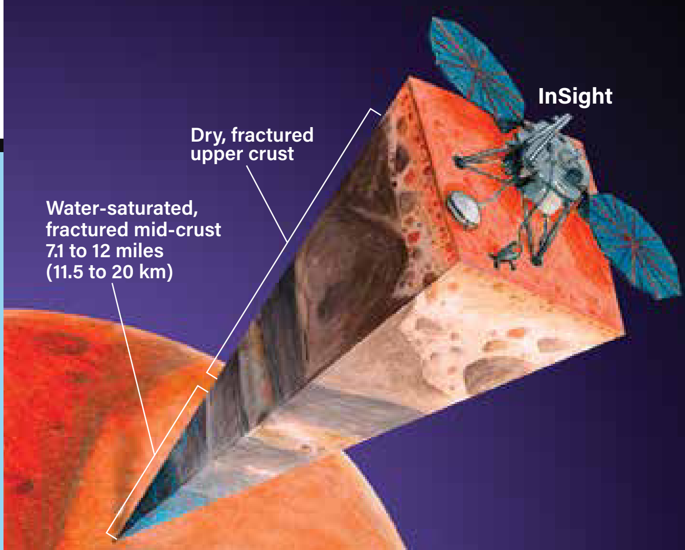
MIDDLEWEIGHT CHAMPION. The central regions of the globular cluster Omega Centauri, imaged here with Hubble, likely contain a black hole weighing more than 8,200 solar masses. NASA/ESA/THE HUBBLE HERITAGE TEAM (STSCI/AURA)

The most likely reason for that "is that a very massive object is gravitationally pulling on these stars and keeping them close to the center," Häberle said. How massive? At least 8,200 solar masses. The only known object that can be is an IMBH.

Although previous studies hinted that Omega Cen might host an IMBH, "this discovery is the most direct evidence so far of an IMBH in Omega Centauri," said coauthor Nadine Neumayer, also at the Max Planck Institute.

IMBHs may help bridge the gap between stellar-mass black holes, born from single stars, and supermassive black holes, millions to billions of times the Sun's mass. Astronomers don't know how supermassive black holes form; IMBHs could be the missing link.

Omega Cen remains one of only a few IMBH candidates to date. And at a distance of 17,710 light-years, "the black hole in Omega Centauri may be the best example of an IMBH in our cosmic neighborhood," Neumayer said. – A.K.



HIDDEN WATER. InSight data suggest Mars' mid-crust hosts a region of fractured rock saturated with liquid water far beneath the surface, as shown in this illustration. JAMES TUTTLE KEANE AND AARON RODRIQUEZ, COURTESY OF SCRIPPS INSTITUTION OF OCEANOGRAPHY

MARS MAY HOST OCEANS' WORTH OF BURIED WATER

DEEP BENEATH MARS' SURFACE lies a reservoir of liquid water sufficient to cover the planet globally to a depth of over a mile (1.6 kilometers), according to a study published Aug. 12 in *Proceedings of the National Academy of Sciences*.

The water lies in minuscule cracks and pores in rock deep within the Red Planet's crust, some 7.1 to 12 miles (11.5 to 20 km) beneath the surface. This is the best evidence to date that vast amounts of martian water — most of which scientists believed had evaporated into space billions of years ago — instead may have gone to ground, raising hopes in the search for life.

Capable of detecting vibrations as soft as a breeze, the Seismic Experiment for Interior Structure (SEIS) on NASA's InSight lander gathered data from December 2018 until the mission's end in December 2022. The study's findings rest on Insight's measurements, specifically of the density of the rock beneath the craft and the speed of seismic waves (produced by marsquakes and impacts) as they travel through that rock. Researchers incorporated these into a mathematical model of rock physics identical to methodologies used on Earth to map underground aquifers and oilfields; their results suggest the seismic data is best explained by a layer of fractured igneous rock saturated with liquid water, embedded in the middle of the planet's crust.

"From what data we have elsewhere on Mars, there is no clear reason to think the mid-crust elsewhere is much different from beneath InSight," said lead author Vashan Wright, of the University of San Diego's Scripps Institution of Oceanography, in a press release. "If there is groundwater below InSight, we would expect groundwater elsewhere too." Assuming that, there should be more than enough water in this reservoir to fill the Red Planet's ancient oceans, the authors argue.

How the water found its way so deep underground remains unclear, but its presence is another line of evidence for a warmer, wetter Mars in the past. It also raises the possibility that the porous, saturated rock teems with microbes. "On Earth, deep, deep mines host life, the bottom of the ocean hosts life," said co-author Michael Manga of the University of California, Berkeley. "We haven't found any evidence for life on Mars, but at least we have identified a place that should, in principle, be able to sustain life." – BEN EVANS

A celestial transference phenomenon

Explore the power of conjunctions.

The conjunction of Venus and the Beehive was a beautiful, if not dazzling, sight as seen from the author's home in Maun, Botswana — a sight that appeared to enhance the visibility of the dim naked-eye cluster.
STEPHEN JAMES O'MEARA

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

Beginning in late November during the waning phases of the Moon, and then again in late December, you can investigate the possibility of a curious optical phenomenon. It involves a bright planet passing by a large and diffuse star cluster visible with the naked eye.

On the evening of June 13, 2023, I went out as twilight faded to observe the conjunction of Venus with the Beehive open star cluster (M44). Shining brilliantly at magnitude –4.2, Venus sailed within 1° of the cluster. Under a dark sky, the Beehive appears to the unaided eye as a diffuse, 4th-magnitude glow spanning 95' of sky.

When darkness fell, I could see both Venus and the Beehive with direct vision. Unsurprisingly, when I looked at them with averted vision, the Beehive appeared to swell in brightness (as its light fell onto the night-sensitive rod cells in my eyes), while that of Venus diminished slightly (as its bright light no longer stimulated the day-sensitive cone cells). The feeling was one of transference, as if Venus had lent the Beehive some of its light. The view made Venus appear like a comic-book superhero — a bright gleaming superstar with a diffuse cape blowing in the wind.

Then, I noticed a most curious phenomenon: If I extended a finger at arm's length and blocked the light of Venus, the Beehive appeared to dim! It didn't matter if I was using averted vision or direct vision. The result remained constant. Again, the very presence of Venus appeared to enhance the glory of the Beehive.

The reason may simply be one of proximity. Anyone who has ever looked for Venus in the daytime knows how difficult it can be to fix one's eyes on the planet in a vast blue sky. They'll also know how easily Venus appears when the Moon is in conjunction with it. The simple explanation for this is that the proximity of the Moon helps the eye lock onto the position of the planet, making it appear brighter and more motionless than if the Moon weren't there.

This point was made clear with another planet on July 14, 2023. I observed a daytime conjunction of Jupiter with the waning, 14-percent crescent Moon, allowing me to clearly see Jupiter shining at magnitude –2.1 with the unaided eye until 10 minutes after sunrise.

Now, the question that remains is whether the Beehive will receive the same glow up from Mars.

As 2024 draws to a close, Mars will be within 2° of M44 and appear nearly stationary, especially toward the end of November, as the planet starts its retrograde motion Dec. 7. The planet will also be approaching Earth, brightening from magnitude –0.5 in late November to magnitude –1.0 in late December. That's about 16 times dimmer than what Venus' magnitude was in June 2023. So while Mars will not be as bright or come as close to M44 as Venus did in June 2023, the conjunction will be worth investigating.

Prior to my Venus observation, Mars was conjunct with the Beehive on the evenings of June 1 and 2, 2023. But the Red Planet was shining dimly at around magnitude 2 — more than 600 times fainter than Venus. Unfortunately, I was not able to observe that passage, so I cannot comment on the effect during that event.

It was as if Venus had lent the Beehive some of its light.

However, on the morning of June 6, 2024, a 1st-magnitude Saturn was positioned only about 2.5° from the visual grouping of Psi^1 (ψ^1), Psi^2, and Psi^3 Aquarii — three 4th- and 5th-magnitude stars in an area of sky only 1° apart. With a quick glance, these stars appear fuzzy, especially with averted vision, but with direct vision, they resolve. I also experimented with Saturn and the appearance of the stars, and there the effect surfaced: The presence of the planet enhanced the visibility of the three stars.

Will the presence of a bright Mars enhance the Beehive's visibility? Will the warm color of the planet diminish the visual effect? I would like to know what, if anything, you experience. Send reports to sjomeara31@gmail.com.

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HOLIDAY GIFT GUIDE

RENAMING THE Hubble constant

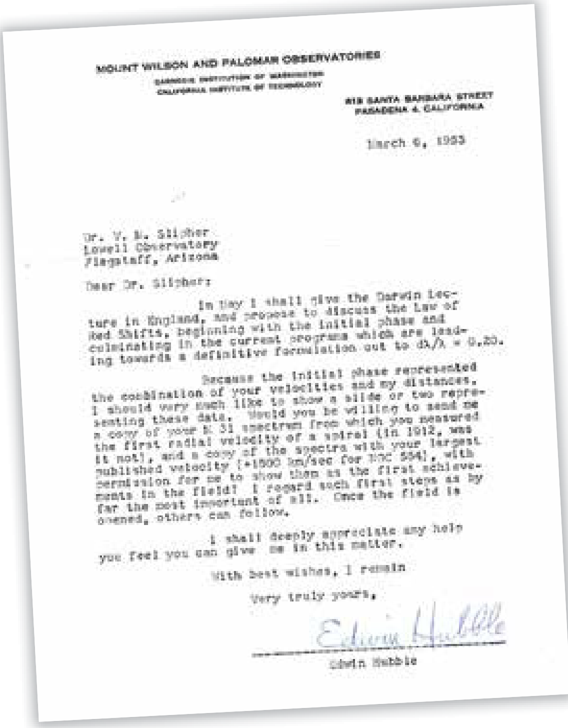
Vesto Slipher was not as well known as Edwin Hubble. But his groundbreaking observations helped uncover one of astronomy's most fundamental relationships, and he deserves equal credit. BY DOUGLAS MACDOUGAL, JOSEPH MARCUS, AND MARCIA BARTUSIAK

Vesto Slipher and Edwin Hubble presented quite the contrast: Slipher (left) was more reserved, while Hubble (above) was well known for his good looks and forceful personality. SLIPHER: LOWELL OBSERVATORY ARCHIVES. HUBBLE: IMAGE COURTESY EDWIN HUBBLE PAPERS, HUNTINGTON LIBRARY, SAN MARINO CALIFORNIA

MOST PEOPLE ASSOCIATE the discovery that faraway galaxies are receding from us — and thus, that the universe is expanding — with Edwin Hubble, thanks to his landmark 1929 paper. It was one of the most fundamental discoveries in the history of science.

But Hubble did not discover the expansion. In the 1910s, a Lowell Observatory astronomer named Vesto Slipher found that spiral nebulae, as galaxies were called, are "fleeing" from us at what were then unheard-of speeds. This was the first observational evidence of the expanding universe. Hubble's paper established a linear relationship between Slipher's nebulae velocities and the distances Hubble had measured — a relation that later became known as Hubble's law — but failed to cite Slipher's own publications containing his indispensable measurements or even to mention his name. Yet Slipher had done half the work!

It was only after Hubble had secured worldwide recognition and lasting fame that he acknowledged his use of Slipher's data. But by then the damage had been


MOUNT WILSON AND PALOMAR OBSERVATORIES
CARNEGIE INSTITUTION OF WASHINGTON
CALIFORNIA INSTITUTE OF TECHNOLOGY

813 SANTA BARBARA STREET
PASADENA 4, CALIFORNIA

March 6, 1953

Dr. V. M. Slipher
Lowell Observatory
Flagstaff, Arizona

Dear Dr. Slipher:

In May I shall give the Darwin Lecture in England, and propose to discuss the Law of Red Shifts, beginning with the initial phase and culminating in the current programs which are leading towards a definitive formulation out to dλ/λ = 0.20.

Because the initial phase represented the combination of your velocities and my distances, I should very much like to show a slide or two representing these data. Would you be willing to send me a copy of your M 31 spectrum from which you measured the first radial velocity of a spiral (in 1912, was it not), and a copy of the spectra with your largest published velocity (+1800 km/sec for NGC 584), with permission for me to show them as the first achievements in the field? I regard such first steps as by far the most important of all. Once the field is opened, others can follow.

I shall deeply appreciate any help you feel you can give me in this matter.

With best wishes, I remain

Very truly yours,

Edwin Hubble

Edwin Hubble

In 1953, Hubble wrote to Slipher with a request to use his images and spectra alongside Hubble's own on distance measurements in his upcoming George Darwin Lecture for the Royal Academy of Sciences. In addition to doing Slipher the courtesy of acknowledgement, Hubble notes Slipher's work as "the first achievements in the field" and "by far the most important of all." LOWELL OBSERVATORY ARCHIVES

done: Slipher had been eclipsed, and has never been properly commemorated for his critical contribution.

Today, astronomers continue in the footsteps of both Hubble and Slipher, measuring the velocities of receding galaxies and their distances. These crucial observations tell us how quickly the universe is expanding. Yet, the famous mathematical parameter that defines the relationship between Slipher's velocities and Hubble's distances bears a single name: the Hubble constant.

Modern science has made many strides in setting the historical record straight. In that tradition, we suggest the International Astronomical Union (IAU) formally rename the Hubble constant to the Hubble-Slipher constant, in long overdue recognition of Slipher's historic achievement.

The challenge of the spirals

The son of an Indiana farmer, Vesto Melvin Slipher joined Lowell Observatory in Flagstaff, Arizona, in 1901, under the leadership of the flamboyant Percival Lowell. Slipher's charge was spectroscopy, and he made good use of Lowell's 24-inch Alvan Clark refracting telescope with its brand-new Brashear spectrograph. Within a few years he began reaping important results, such as confirming the rotation periods of Mars, Jupiter, and Saturn.

Slipher became a virtuoso in the new art of acquiring and interpreting spectra — the data obtained when light from astronomical objects is spread out into its constituent wavelengths, revealing details about composition and motion. And there were spectroscopic surprises everywhere he looked. Among his subsequent discoveries were methane and ammonia in the giant planets' atmospheres; interstellar gas throughout the Milky Way; and the first known reflection nebula, in the Pleiades, which led to the discovery of interstellar dust.

But his next challenge tested his skills more profoundly. On Lowell's instructions, he started to photograph spectra of the faintest of all objects: spiral nebulae.

These nebulae were the subject of an ongoing debate among astronomers in the early 20th century. Were they baby solar systems forming within our own Milky Way? Or were they instead remote "island universes," each like the entire Milky Way, floating loose in the cosmic void?

Spectroscopes, attached to large

EINSTEIN'S ROLE

Albert Einstein (second from the left) poses with his wife (third from the left) and several Hopi individuals near the Grand Canyon, following a trip to Pasadena during which he turned down an invitation from Slipher to visit Lowell Observatory. EUGENE OMAR GOLDBECK, *[DR. AND MRS. ALBERT EINSTEIN AT HOPI HOUSE, GRAND CANYON, ARIZONA]*, 1931, GELATIN SILVER PRINT, THE MUSEUM OF FINE ARTS, HOUSTON, GIFT OF TERRY ETHERTON. © THE MUSEUM OF FINE ARTS, HOUSTON; ALBERT SANCHEZ

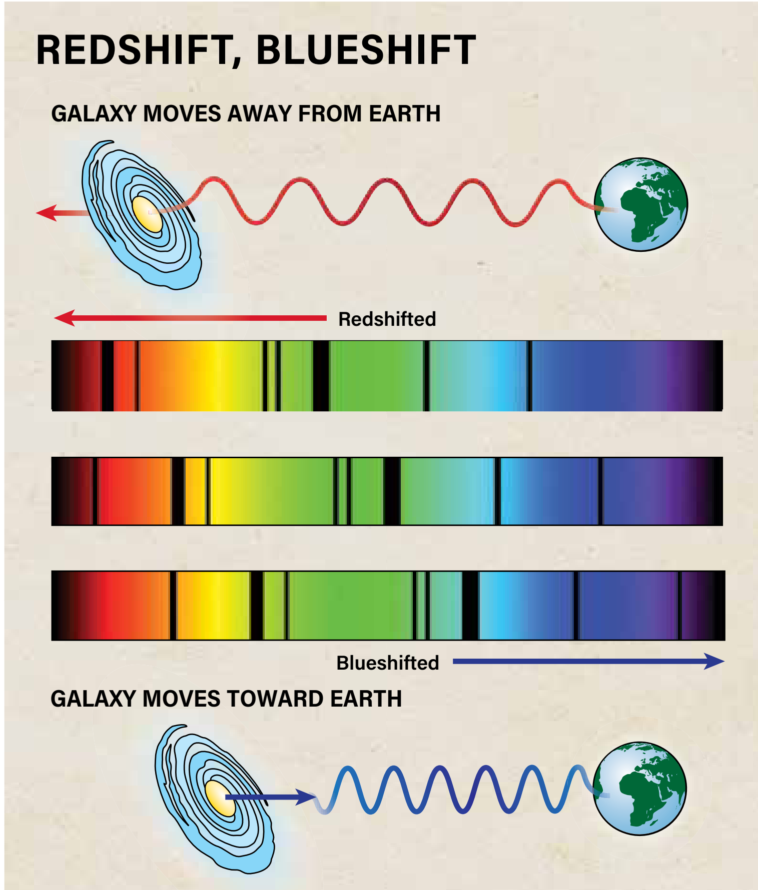
Albert Einstein unwittingly deepened the diminution of Slipher's role. A pure theorist, he was largely oblivious to Slipher's accumulated galaxy redshifts until he realized they would require him to abandon the *ad hoc* cosmological constant he had added to his general relativity equations in 1917 to counteract gravity and produce a static universe — as was believed to be the case at the time — rather than an expanding one. (That addition was "my biggest blunder," he reportedly said later; his equations might otherwise have allowed him to predict the universe's expansion.)

He axed the cosmological constant in 1931 during his extended visit to Caltech in Pasadena, where he spent much of his time with Hubble and the cosmologist Richard Tolman. In the breathless national press coverage of Einstein and the redshifts, Hubble and Tolman were frequently mentioned, but never Slipher.

Sensing a public relations opportunity, Constance Lowell, Percival's widow, urged Slipher to invite Einstein to visit Lowell Observatory on his way back to the East Coast. Einstein turned him down, writing cordially that "my time and energy do not allow me to visit institutes outside Pasadena." However, that did not prevent him from stopping off in light-gathering telescopes, held the best promise of providing an answer. Importantly, they could determine an object's radial velocity — its motion toward or away from the observer — through subtle shifts in the object's spectral features compared to a stationary reference. Displacement toward the red end of the spectrum (a redshift) means the object is receding from us; a blueshift signifies that it is approaching.

Slipher knew that long exposures would be required to produce detailed, high-quality spectra of the vexingly faint spirals. Switching out the slow spectrograph camera lens for a faster one enabled him to cut exposure times more than 30-fold. Even so, obtaining a single spectrum often required dozens of hours.

The obvious target for a first effort was the biggest and brightest spiral nebula of all, majestic M31 in the constellation Andromeda. An exposure over several nights in December 1912 produced a stunning surprise: M31's spectral lines were shifted toward the *blue* end of the spectrum. The Andromeda Nebula was approaching our solar system at some 186 miles (300 kilometers) per second, the highest celestial velocity ever measured at the time.



The change in the observed wavelengths of light from a moving source is called the Doppler effect. First observed as a change in the pitch of sound waves, this effect also applies to light emitted by astronomical objects, such as stars and galaxies. Motion toward the observer causes light to shift toward the blue end of the spectrum — a blueshift — while motion away from the observer causes a shift toward the red, or redshift. All lines in an object's spectrum shift by an equal amount, and the offset can be measured from a stationary reference spectrum. *ASTRONOMY:* ROEN KELLY

An expanding universe

Encouraged by Lowell to continue the effort, Slipher turned his instrument in April 1913 to the Sombrero Nebula (M104), a dramatic edge-on spiral in the constellation Virgo. This time the lines were shifted immensely toward the *red* end of the spectrum, suggesting an extraordinary recession speed of 684 miles (1,100 km) per second.

Slipher continued his survey and in August 1914 traveled to Northwestern University in Evanston, Illinois, to present his findings at the annual meeting of the American Astronomical Society. By then, he had gauged the velocities of 15 spiral nebulae: Three were approaching Earth, while the rest were zooming away. The historic manuscript from which Slipher read is not well known and has never been published. It now resides in the Lowell Observatory Archives.

The conclusions he pitched to his audience were powerfully worded: "The striking

Flagstaff to catch the train north to the Grand Canyon, where he accepted an honorary headdress from the chief of a local Hopi tribe.

The snub largely had to do with Slipher's circumstances. Long after visiting him in 1953, the eminent British cosmologist Fred Hoyle lamented, "Slipher, working at the Lowell Observatory, had a weaker organization behind him than Hubble had at Mt. Wilson, and it is regrettable that such inconsequential issues can have an effect on how priorities are accorded."

In his influential 1945 textbook *The Meaning of Relativity* and its subsequent editions, Einstein himself repeatedly misattributes Slipher's redshift and expansion discoveries as "Hubble's shift of spectral lines" and "Hubble's expansion." He seemed to be "unaware that Hubble's 1929 graph relied heavily on the redshift observations of the astronomer Vesto Slipher," Irish physicists Cormac O'Raifeartaigh and Brendan McCann wrote in a 2014 paper. "Indeed, Einstein's exclusive reference to Hubble (here and elsewhere) may have contributed to the eclipsing of Slipher's contribution to the discovery of the expanding universe."

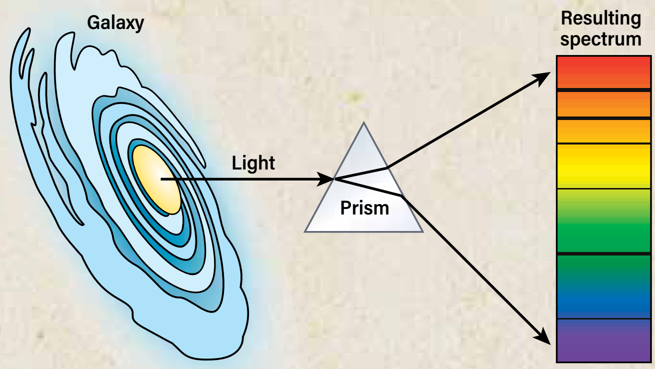
This unfortunate canard propagates to the present day. Prominent writers, including cosmologists, still misattribute the redshifts and expansion discoveries to Hubble alone. —*J.M.*

HOW SPECTROSCOPY WORKS

A spectroscope (for visual study) or spectrograph (for photography) separates incoming light, such as starlight, into its constituent wavelengths using either a prism or a diffraction grating, both of which spread light out by wavelength. The result is called a spectrum.

Atoms absorb or emit light of specific wavelengths that correspond to the differences between the energy levels where electrons reside. Absorption occurs when a photon, a particle of light, strikes an electron and provides the energy to boost it to a higher energy level. Emission occurs when the electron falls back down to a lower energy state, releasing a photon of the same energy. Absorption lines appear dark while emission lines appear bright. Each element and molecule produces a unique set of lines that can be used to identify its presence in a given spectrum.

If the source is moving, its spectral lines — as a set — will shift either toward the red (motion away from the observer) or blue (motion toward the observer) end of the spectrum due to the Doppler effect. All the lines shift by the same factor, so the pattern of lines and their relative spacing does not change.



ASTRONOMY: ROEN KELLY

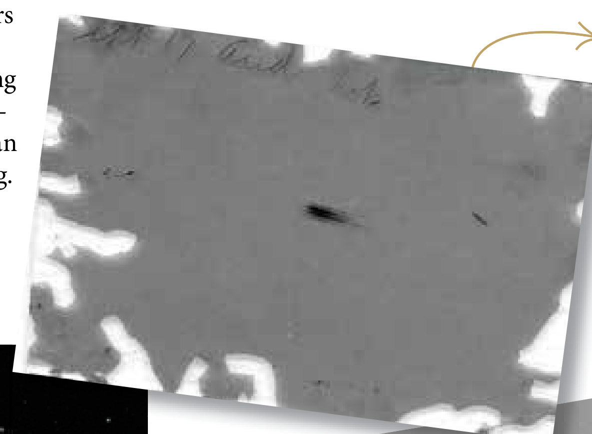
During spectroscopy, researchers first create a reference spectrum produced by a known source, such as a single element like hydrogen, to calibrate the instrument. It also provides a reference point for any shifting of spectral lines due to motion.
—*Alison Klesman*

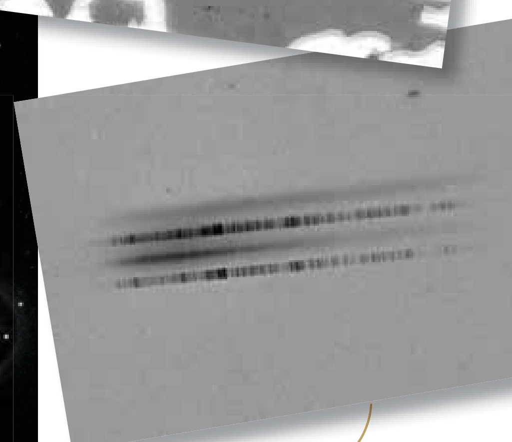
preponderance of the positive sign [meaning recession] indicates a general fleeing from us or the Milky Way." Moreover, *most* of the spiral nebulae were receding. Allowing that the data were not yet definitive, he nonetheless felt that "they do strongly indicate that the spirals are leaving the Milky Way, which fits in with their non-galactic distribution." In other words, Slipher's findings gave strong evidence for the controversial island universe hypothesis.

It was an astonishing finding. Although no one appreciated it at the time — including Slipher — he in effect had staked his claim for the observational discovery of the expansion of the universe. Over time, this realization would fundamentally transform our idea of the cosmos and our place in it.

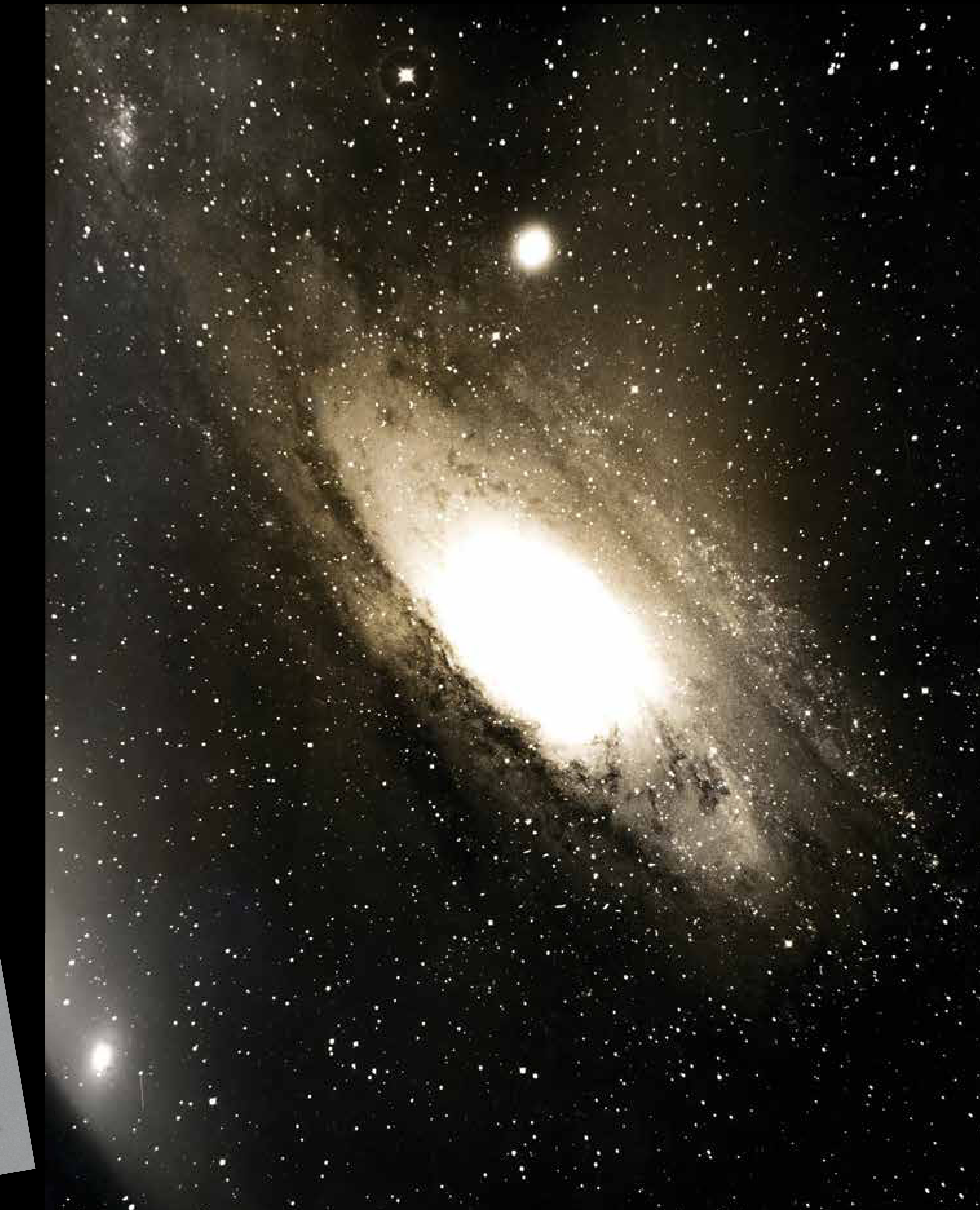
When Slipher finished delivering his news of the great recession, his fellow astronomers rose to their feet and gave him a resounding ovation — an unprecedented spectacle at an astronomical meeting. Interestingly, Hubble was in the audience, attending the meeting just before he began his Ph.D. that fall at the University of Chicago's Yerkes Observatory in Williams Bay, Wisconsin. It's possible that witnessing this momentous reaction inspired Hubble to choose spiral nebulae as his dissertation topic.

Over the next three years,





ALL IMAGES AT RIGHT: Slipher's spectral measurements of the Andromeda (far right) and Sombrero spiral nebulae, as they were called at the time, showed these objects were moving through space at extraordinary velocities of hundreds of miles per second. The former is approaching Earth, while the latter is receding from our location. LOWELL OBSERVATORY ARCHIVES



Attendees of the 17th meeting of the American Astronomical Society, held in August 1914 at Northwestern University in Evanston, Illinois, pose for a group photo. Edwin Hubble stands in the front row, second from the right, in the dark suit. V.M. Slipher is second from the left in the second row from the rear, centered beneath the large stone at the end of the archway and facing forward. AIP EMILIO SEGRÈ VISUAL ARCHIVES

Slipher measured more velocities. By 1917 he had a total of 25, all but four of which were receding. Buoyed by this trend, he conservatively opined in a 1917 paper in the *Proceedings of the American Philosophical Society* that the island universe theory, "seems to me, gains favor in the present observations." By 1922, he had topped off his survey with a further 17 spiral nebulae, all of which were receding — the fastest at an unprecedented 1,120 miles (1,800 km) per second.

Hubble steps in

In 1924, Hubble nailed down the proof that spiral nebulae were separate galaxies using Cepheid variable stars. These "standard candles" allow the accurate measurement of distance through an established relationship between their period and intrinsic luminosity. Measuring a star's period allows an astronomer to deduce its inherent brightness; any dimming can therefore be attributed to distance.

By 1928, he began focusing on the nature of Slipher's discovered cosmic exodus, searching for any pattern in the redshifts of galaxies as they rushed headlong through space. To do this, he teamed up with Milton Humason, a colleague at Mount Wilson. Hubble would continue to measure the galaxies' distances (his specialty), while Humason would obtain the velocities.

Within a year, Hubble had prepared his first publication on his findings, that 1929 landmark paper titled "A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae." In it, he paired the distances of 24 galaxies with their velocities. The pattern, captured in a famous graph, jumped off the page: The velocity of galaxies steadily increased in a linear fashion as one looked farther into space. At double the distance from Earth, a galaxy's speed doubled as well. When the distance triples, the velocity triples, and so on. By the late 1930s, astronomers were coming to refer to the slope of Hubble's graph — the rate at which this recession increases with distance — as Hubble's constant, and later simply the Hubble constant, or H_0.

But in the lead-up to Hubble's 1929 paper, his partner Humason was only getting started on his velocity measurements. He was primarily focused on getting redshifts of previously unmeasured targets that had been too faint for Slipher to determine with his smaller telescope. Nearly all the redshifts that Hubble used in calculating the rate of recession were *Slipher's* measurements. In other words, half of the data that went into formulating the original Hubble constant came from Slipher. Yet anyone perusing Hubble's paper would not have known this. Hubble used Slipher's measurements without direct citation or acknowledgment — a serious breach of scientific protocol.

Hubble later made partial amends: In his next big paper on the redshift law, published in 1931, he inserted a sentence praising "the great pioneer work of V. M. Slipher at the Lowell Observatory." And two years later, the Royal Astronomical Society (RAS) in England presented Slipher with its highest award, the Gold Medal, seven years before Hubble would earn the honor. During the presentation, RAS President Frederick Stratton announced that "if cosmogonists today have to deal with a universe that is expanding in fact as well as in fancy, at a rate which offers them special difficulties, a great part of the initial blame must be borne by our medalist."

Although Hubble again praised Slipher's work in his 1936 book *The Realm of the Nebulae*, ultimately, it was too late. Hubble's law and the Hubble constant became entrenched among astronomers, while Slipher's contribution was nearly forgotten. By nature, Slipher was never a showman and preferred publishing in his observatory's *Bulletin* rather than well-known journals. He was simply too humble and reserved to demand his share of the glory. Hubble, by contrast — so handsome, so manly, so erudite — was a force of nature, far more accomplished in garnering publicity and protecting his legacy.

So, Hubble became the main protagonist in the discovery of the modern universe. As science historians Helge Kragh and Robert Smith wrote in their 2003 paper published in *History of Science*, "A growing community of American astronomers … were concentrating to an unprecedented degree on the study of galaxies [and] fashioned a hero, a founding father and a figure around whom they could drape a single version of the history of the discovery of the expanding universe."

Slipher eclipsed

Hubble's initial failure to cite Slipher was a major slight, but his jealous hegemony over the velocity-distance relationship extended beyond Slipher. In a 1930 letter, Hubble warned the Dutch cosmologist Willem de Sitter, who had innocently commented in a review article that several other astronomers had previously looked at the relationship, that he considered it "a Mount Wilson contribution and I am deeply concerned in its recognition as such."

Colleagues also long complained that Hubble engaged in "selective referencing," such as when he failed to mention Belgian cosmologist Georges Lemaître's work in *The Realm of the Nebulae* or to specifically cite Harvard University's Harlow Shapley in the same book for his early look at the velocity-distance relation. And when Hubble in 1941 again failed to cite Slipher — this time over Slipher's priority in determining that a spiral nebula's arms trail as it rotates — Slipher was compelled to pen an irritated note to *Science* in 1944 to correct the record.

In fairness, Slipher shares some blame for the lack of appreciation for his contribution. In 1915 and 1917 publications reporting his accumulating galaxy redshifts, instead of describing the galaxies as "fleeing," "receding," or "leaving" the Milky Way, as he earlier did in his 1914 talk, he substituted the more diffuse term "scattering." Although astronomers understood its meaning (and Hubble subsequently used it), the word was unnecessarily conservative.

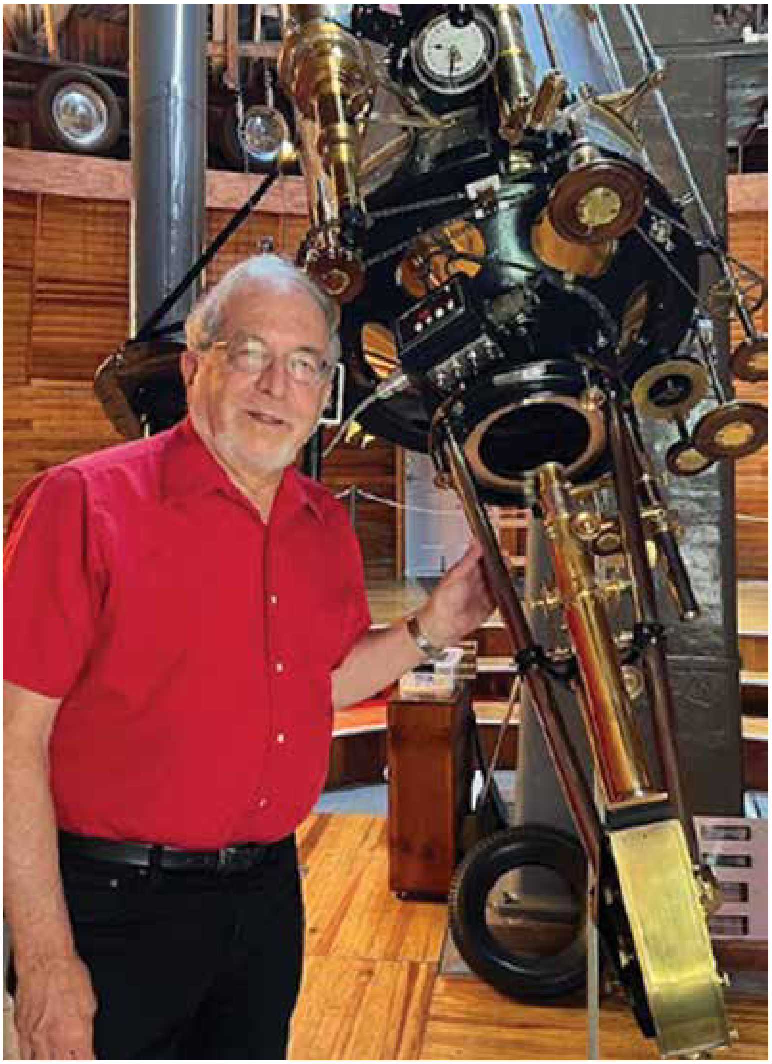
A deeper problem was that Slipher's results appeared in second-tier journals rather than premier outlets like *The Astrophysical Journal*. Worse, he generously allowed his final list of 42 redshifts to be published in 1923 and 1925, with attribution, but under other authors' names!

Yet Slipher's data were unique, accurate, and determinative. His findings were communicated to the scientific community and his work spoke for itself, under whatever auspice it appeared. His lack of visibility is no reason to deny him priority for his discovery.

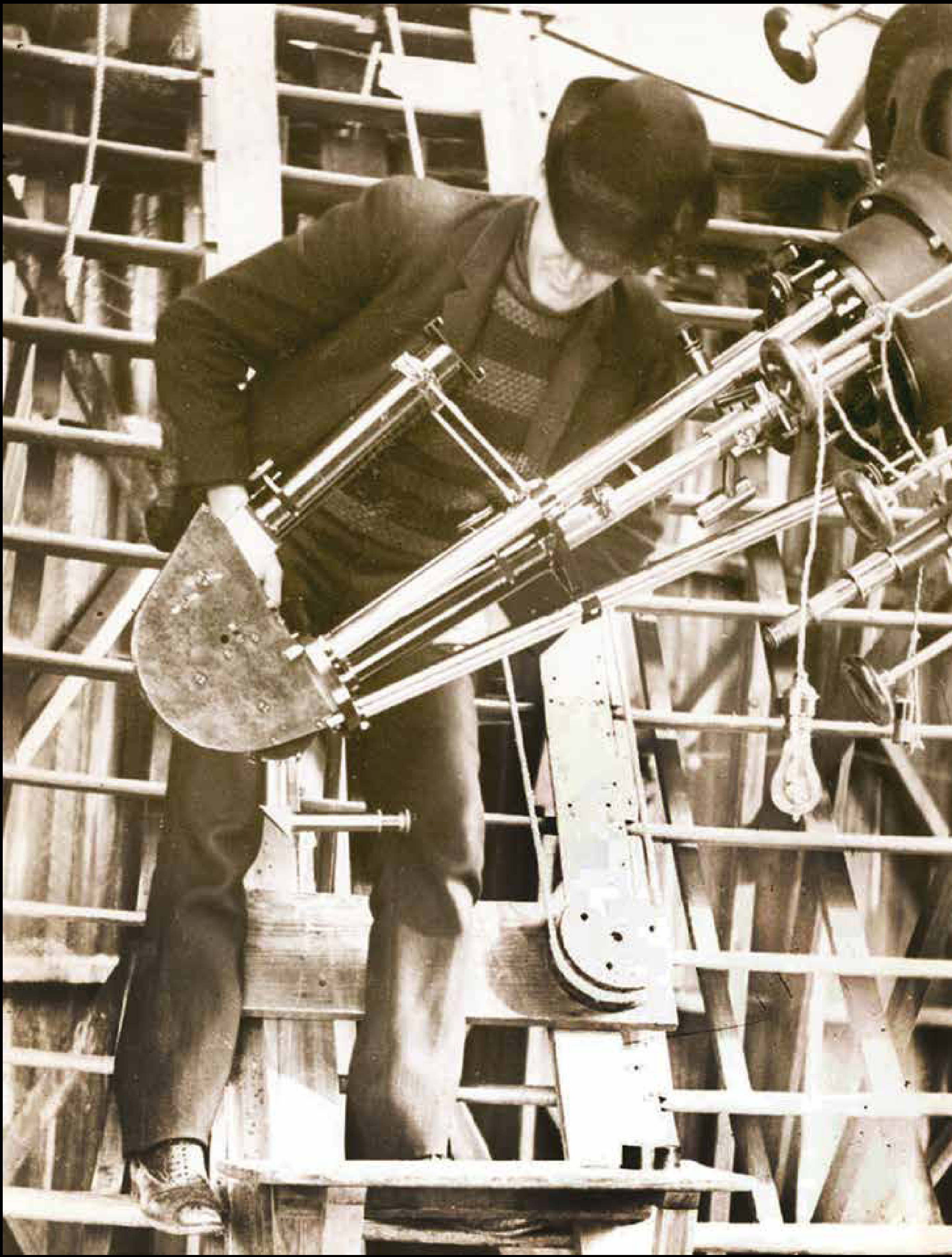
The Hubble-Lemaître law

Astronomers have made progress in undoing Hubble's hegemony — though not yet to Slipher's benefit. In 2018, the IAU, by vote after its 30th General Assembly in Vienna, adopted a resolution to rename the Hubble law to the Hubble-Lemaître law, to honor Lemaître for his 1927 dynamic solution to Einstein's general relativity equations. His result, published two years before Hubble's, predicted that the universe is expanding in such a way that galaxy redshifts are proportional to their distances. Lemaître even computed what came to be known as the Hubble constant, based on Hubble's galaxy magnitudes and Slipher's redshifts. (Although like Hubble, Lemaître also failed to cite Slipher.)

The decision to rename the Hubble law without including Slipher was met with pushback. In January 2019, cosmologist Emilio Elizalde of the University of Barcelona published a meticulous historical review in the journal *Symmetry*: "Reasons in favor of a Hubble-Lemaître-Slipher law."



Author Joseph Marcus stands with the Brashear spectrograph, once again attached to the Lowell Observatory 24-inch Clark refractor, in June 2024. It had been more than a half-century since the spectrograph was last mounted on this scope. MARGARET A. OLSEN

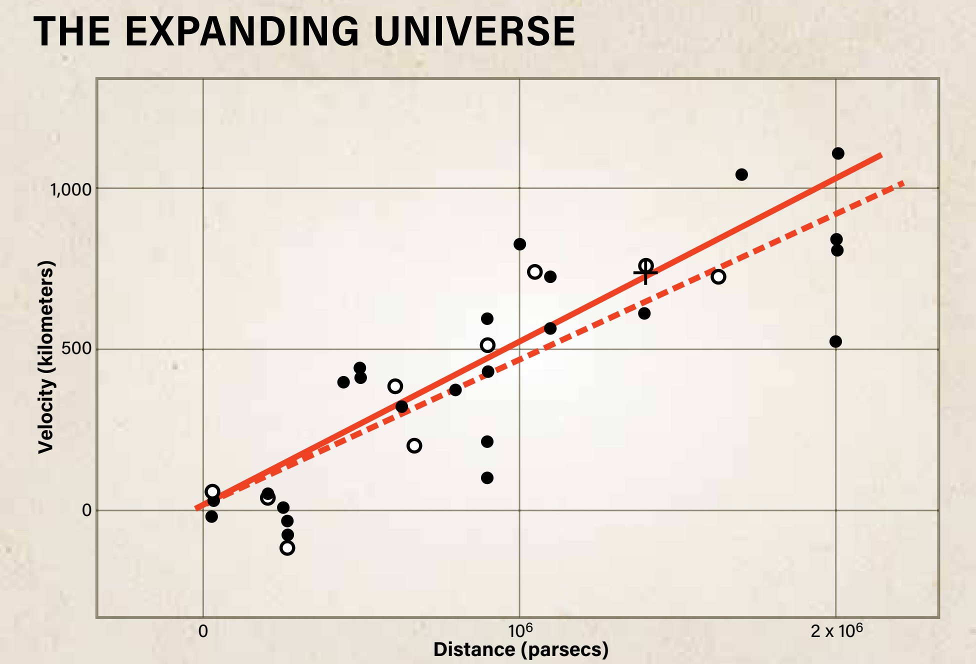


And in *Astronomy* magazine's February 2020 issue, Lowell Observatory's Director Jeff Hall and Historian Kevin Schindler also advocated for the addition of Slipher's name to the law.

Why was Slipher denied yet again? The explanation offered at the IAU meeting was that he and others "did not use their data nor invent new theory to discover the universal expansion." But as we have shown, Slipher in fact *did* use his redshift data to conclude, as early as 1914, that the spiral nebulae were "receding," or "scattering," from the Milky Way — which amounts to the observational discovery of universal expansion.

The IAU requirement that a law be derived from theory runs counter to the conventional view that a scientific law is simply a relation between observables. Hubble recognized this distinction in his George Darwin lecture to the RAS in 1953: "I propose to discuss the law of red-shifts — the correlation between the distances of the nebulae and the displacements in their spectra."

But even conceding that Slipher did not "invent new theory" to explain the expansion, neither did Hubble. For all his life, Hubble, unlike Slipher, was wary that redshifts truly represented recession and worried this interpretation might be overturned.



The famous "discovery graph" appeared as Figure 1 in Hubble's March 1929 paper, "A relation between distance and radial velocity among extra-galactic nebulae," published in *Proceedings of the National Academy of Sciences of the United States of America*. It plots the radial velocities of 24 galaxies (then called nebulae) against their distances in parsecs. (One parsec is 3.26 light-years.) The solid dots and line show the relationship between distance and velocity using all 24 galaxies, while the open circles and dashed line show the relationship when the galaxies are combined into nine groups, based on their direction and distance. The plus sign represents the mean velocity and distance of 22 additional galaxies for which distances could not be individually measured. The slope of the lines is the value now known as the Hubble constant, or H_0. Virtually all the velocities in this figure were Slipher's measurements, yet Hubble did not cite his name or his work in the paper. *ASTRONOMY*: ROEN KELLY, AFTER E. HUBBLE, "A RELATION BETWEEN DISTANCE AND RADIAL VELOCITY AMONG EXTRA-GALACTIC NEBULAE," *PNAS* 15, 168-173 (1929)

For a Hubble-Slipher constant

For all these reasons, we too support renaming the Hubble-Lemaître law the Hubble-Lemaître-Slipher law. But we acknowledge such a reconsideration would likely be difficult.

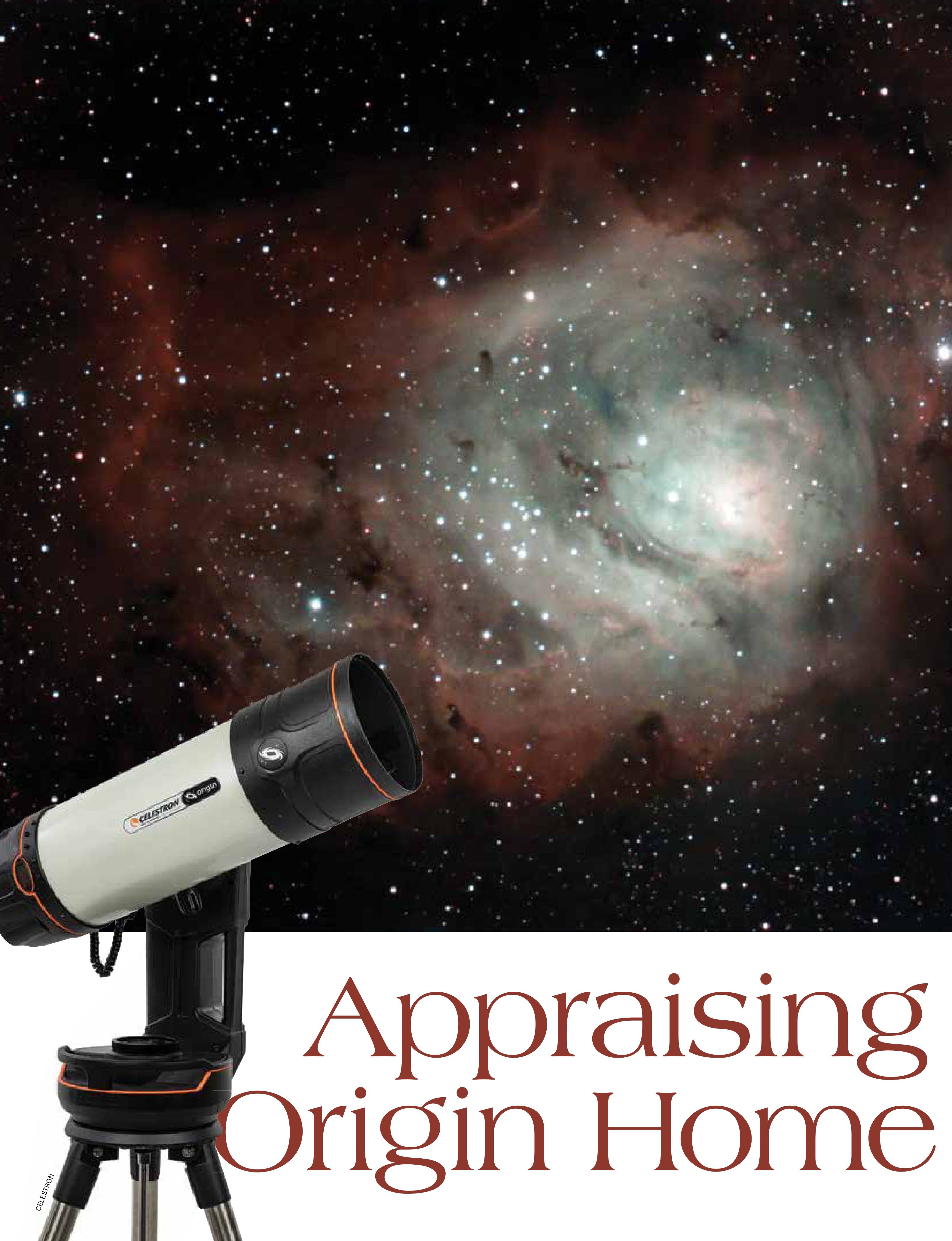
So instead, given how the newly titled Hubble-Lemaître law set a precedent in honoring the overlooked, we propose that the Hubble constant, H_0 — the proportionality between the recession velocities and distances of the galaxies — be renamed the Hubble-Slipher constant. This proposal is similar to that of Irish physicist Cormac O'Raifeartaigh, who suggested that Hubble's famous "discovery graph" of 1929, whose slope is simply H_0, could also be known as the Hubble-Slipher graph.

In the end, our proposal is best supported by Hubble's own final accounting of events. The relationship between Slipher and Hubble largely remained collegial and respectful over the years, and in 1953, the year of his death, Hubble finally made full amends. During a RAS lecture, Hubble noted that his discovery "emerged from a combination of radial velocities measured by Slipher at Flagstaff with distances derived at Mount Wilson. … Slipher worked almost alone, and 10 years later … had contributed 42 out of the 46 nebular velocities then available." In a letter to Slipher that same year, he cited Slipher's first steps "as by far the most important of all" in "the combination of your velocities and my distances."

What better argument for accepting a Hubble-Slipher constant than the case made by Hubble himself?

OPPOSITE PAGE: Slipher stands with the Brashear spectrograph, mounted on the 24-inch Clark Telescope, with which he made his many spectroscopic discoveries — including his observations of multiple spiral nebulae, most of which were rushing away from Earth at great speed, signaling the expansion of the universe. LOWELL OBSERVATORY ARCHIVES

Douglas MacDougal *has published an undergraduate textbook on celestial mechanics as well as numerous articles on the history of mathematical astronomy, astrophysics, and the culture of scientific inquiry.* **Joseph Marcus** *serves on the Lowell Observatory Advisory Board and is the author of peer-reviewed and popular articles on comets.* **Marcia Bartusiak** *is Professor of the Practice Emeritus of the Graduate Program in Science Writing at MIT and author of* The Day We Found the Universe *(Knopf Doubleday, 2010).*



Appraising Origin Home

CELESTRON

the Observatory

Celestron continues to lead the way in developing state-of-the-art smart telescopes and opening doors for anybody to become an astrophotographer in seconds. BY PHIL HARRINGTON

I'M IN LOVE. I don't often begin a review by saying that a product has wooed me, but the Celestron Origin Home Observatory has done just that.

Not that I'm surprised. Since it first introduced the venerable C8 Schmidt-Cassegrain in 1970, Celestron has established itself as a leading manufacturer of cutting-edge telescopes and accessories for amateur astronomers. That tradition continues with the new state-of-the-art Celestron Origin Home Observatory. It comes complete with everything you'll need to begin viewing and imaging the universe on the first clear night.

Anatomy

The Origin's heart is a 6-inch Rowe-Ackermann Schmidt Astrograph (RASA) optical system optimized for wide-field astrophotography. It combines a Schmidt corrector plate with a Rowe-Ackermann lens group to create a fast f/2.2 system that produces sharp, clear images across the field. An integrated digital imager in front of the corrector records the light gathered by the RASA's optics and connects it to smartphones, tablets, and other compatible devices, so that users can see and photograph celestial objects on a screen. Like other smart telescopes, there is no eyepiece to look through.

The telescope's optics feature Celestron's StarBright XLT coatings, which enhance the light transmission and contrast. Additionally, the Origin includes a removable dew shield and an integrated heating ring that turns on automatically when needed to prevent moisture from lowering image quality, a common issue in humid or cold conditions. The shield also helps to minimize local light pollution infiltrating into the optical path.

The Origin incorporates Sony's STARVIS IMX178 color CMOS sensor. This back-illuminated sensor is well-known for its high sensitivity, low noise, and fast readout speeds — ideal for astrophotography. The 2.4-micrometer pixels produce detailed, high-resolution images, capturing more light in shorter exposure times than many other sensors.

The Origin captures multiple hues of the hydrogen gas and dust within the emission nebula M8, also known as the Lagoon Nebula. ALL IMAGES BY PHIL HARRINGTON UNLESS OTHERWISE NOTED

As the Origin captures the incoming light from the Dumbbell Nebula (M27) beautifully, it also gathers light from the thousands of colorful objects in the background, forming nearly perfect pinpoints.

A built-in 97.9-watt-hour lithium-iron-phosphate (LiFePO4) rechargeable battery provides the Origin with power. The battery's charge provides more than six hours of operation on a single charge. The Origin can also be plugged into an external power source for extended observing sessions.

Star clusters and galaxies don't require filters to be recorded successfully, but narrowband emission objects, like emission and planetary nebulae, benefit greatly, especially in light-polluted areas. To switch targets without losing quality, Celestron incorporated a filter drawer cleverly built into the support holding the imager in place. It accepts all standard 1¼" and 2" astronomical filters, which lets users experiment with any they may already own. Additionally, Celestron offers a specialized nebula filter for the Origin (sold separately).

Celestron works hard, you play harder

To prove that the Origin lives up to its promises, I put one through its paces this past summer.

Everything arrived triple-boxed directly from Celestron's headquarters in Torrance, California. The printed, well-illustrated instructions made assembling the scope, mount, and tripod a snap. I was finished in about 20 minutes even without tools.

I greatly appreciated the tool-free design each time I brought the Origin outside. Fully assembled, the Origin weighs 41.6 pounds (18.6 kilograms), so most users will find it best to take it apart in two or three pieces to move around and set up. The optical tube assembly weighs 10.6 pounds (4.8 kg) and the one-armed mount weighs 17 pounds (7.7 kg), while the tripod weighs 14 pounds (6.4 kg). I found it easiest to set up the tripod and then bring out the telescope and mount combination together. Built-in handles on the mount made it trouble-free to carry both. Understanding the challenge of setting up a telescope in the dark, Celestron added a centering pin and cast-in indentations on the top of the tripod to mate them together effortlessly by feel.

PRODUCT INFORMATION

Origin Intelligent Home Observatory
Type: Rowe-Ackermann Schmidt Astrograph
Focal ratio: f/2.2
Focal length: 13.18 inches (335mm)
Field of view: 1.27° x 0.85°
Tube weight: 10.6 pounds (4.8 kg)
Total weight: 41.6 pounds (18.87 kg)
Battery life: 6+ hours
Price: $3,999.00
Contact: USTechSupport@celestron.com
1-800-421-9649

The telescope is controlled via the Celestron Origin app, available for both iOS (16 and higher) and Android (12 and higher) devices. The app was codeveloped by Simulation Curriculum and designed to allow users to select celestial objects for viewing or imaging by simply tapping on the screen. It also supports live-casting of images to a smartphone, tablet, or a smart TV or projector, allowing you to share the observing experience with others in real time.

Piloting the Origin is a fully computerized go-to alt-azimuth mount that autonomously aligns, focuses, and tracks targets. After setting up the telescope and flipping the switch, the user needs only to click "Initialize" on the Origin's app to activate Celestron's StarSense sky-recognition technology. Using Origin's CMOS sensor, StarSense plate-solves the scope's aim by comparing the images with an internal star database to identify the exact R.A. and Dec. needed for that perfect final image.

I found the Origin app to be comprehensive and user-friendly. It features a celestial database with more than 120,000 objects, including stars, planets, and deep-sky objects. It shows a real-time star atlas of the visible sky, detailed object information, and stargazing tips. Objects can also be selected either by using the "Tonight" feature (showing a selection of objects currently visible), browsing categories, searching by name or catalog number, or using the virtual, interactive sky chart in the app's Planetarium View. Once an object is chosen, the app automatically aims the telescope toward the quarry. StarSense's auto-alignment worked perfectly for each observing session, and the drive's brass gearing delivered smooth tracking.

When the power switch is flipped on, a red circular light on the back of the telescope will gradually glow brighter; it should turn off after no more than 30 seconds. However, this is more than just a decorative feature; it is designed to

The globular cluster M4 is finely resolved with Celestron's Origin Intelligent Home Observatory — so much so that the central "star bar" can be seen across the core.

The Helix Nebula's (NGC 7293) striking central star and vibrant, expanding gas shell brightens the photograph without any processing. The Origin's AI-powered algorithms allow it to shoot, stack, and display images in real time.

Celestron's Origin Home Observatory performs excellently when resolving individual stars. The Hercules Cluster (M13) is a clear example of this.

inform you of the status of the instrument. For instance, a solid ring means that Origin has established a connection with the mobile app and is awaiting your next command. If it fills in a clockwise direction, that means an exposure is occurring, and so on.

The initiation process also autofocuses images, although I found that I had to tweak the focus on a few occasions. But once it was set, the focus stayed sharp throughout each session.

Another feature I really came to appreciate was the ability to schedule observations. The Origin can be set to capture images of selected celestial objects at predetermined times over the course of a night. This let me formulate an entire observing session the afternoon before, allowing the most efficient use of the telescope's time that night. By dawn the next morning, the Origin had produced an impressive set of images that were waiting to be viewed.

Target acquired

After I finished setting the Origin up, I chose my first target: M13, the Hercules Cluster. Within seconds, the telescope slewed to M13, centered it perfectly, and began to accumulate its photons. As it did, the globular's image, with its myriad pinpoint stars, blossomed on my tablet's screen. The end result was striking and required no processing!

That same evening, I programmed the Origin to image six more Messier globulars. Each cluster was resolved into countless points of light, some with prominent colors. The image of M4 was especially striking. The Origin managed to reveal the cluster's signature central "star bar" cutting across the core; this unusual feature often goes unseen in photos due to overexposure.

The next clear night, I popped in Celestron's Nebula Filter — specifically for the Origin — and set out in search of planetary nebulae. The resulting shots of the Dumbbell Nebula (M27) and the Helix Nebula (NGC 7293), were especially breathtaking. In both cases, the central stars were easily visible, wrapped in swirling, vibrantly colorful clouds.

I was amazed by the Origin's real-time image-processing capability regardless of the type of object viewed. Using AI-powered algorithms, the telescope can shoot, stack, and display images in real time, allowing users to view and share celestial observations almost instantly. This feature is especially valuable for those new to astrophotography, as it flattens the steep learning curve of manual image-stacking and processing. Images can be saved wirelessly to your device or downloaded to your computer using the telescope's USB port. They can also be further processed using third-party programs, if desired.

The Celestron Origin is a revolutionary product that brings the wonders of the universe closer to home, making stargazing and imaging more accessible and enjoyable than ever before. Whether you're looking to capture stunning images of deep-sky objects or simply share the experience of stargazing with friends and family, the Celestron Origin delivers on its promise of a high-tech, intelligent home observatory. Make no mistake, it's not cheap. But then again, it's not just another smart telescope. The Celestron Origin Home Observatory is a genius.

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

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

Jupiter looks finest when at opposition, and this year promises to be particularly dazzling. The Hubble Space Telescope snapped this shot of the gas giant just before opposition in 2017. NASA, ESA, AND A. SIMON (NASA GODDARD)

Jupiter at its best

Jupiter reaches its best apparition in a decade for northern observers and offers a wealth of detail. Joining in late evening is brilliant Mars, now a month from opposition. Saturn is visible in the early evening, along with Venus soon after sunset. Uranus and Neptune remain visible with binoculars, and Mercury makes a fine morning appearance.

Venus shines brilliantly shortly after sunset. It starts the month in eastern Sagittarius at magnitude –4.2. The crescent Moon stands less than 3° due south of Venus on the 4th.

Venus enters Capricornus Dec. 6 and stands north of Delta (δ) Capricorni on the 28th. The planet reaches Aquarius by the 31st.

Follow the changing phase of Venus with a telescope. On the 1st it shows a 67-percent-lit disk 17" across. By year's end, the disk grows to 22", while the phase drops to 55 percent.

As soon as it's dark, **Saturn** is 40° high in the south, among the stars of Aquarius. It shines at magnitude 0.9 and dims 0.1 magnitude by midmonth. The planet is about 2° southeast of Lambda (λ) Aquarii, and stands 4° northeast of a seven-day-old Moon Dec. 7. Saturn sets shortly before midnight on the 1st and by 10 P.M. local time on the 31st, so try to observe it in the two to three hours after sunset.

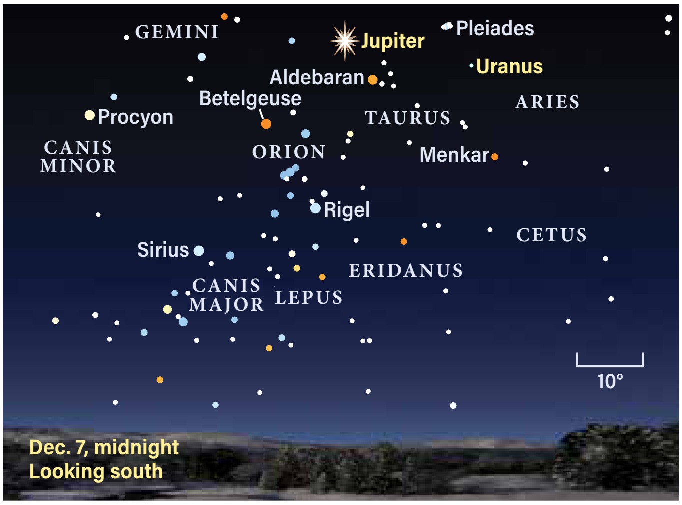
Through a telescope, Saturn's disk spans 17". The rings span 38", while the minor axis is a mere 3".

Titan, Saturn's largest moon, is 8th magnitude — an easy target for any telescope. It is near the planet Dec. 5/6, 13/14, 21/22, and 29/30. Tenth-magnitude Tethys, Dione, and Rhea congregate close to the rings and occasionally pass in front of or behind the disk. High-speed video may capture these events.

On the 11th, Rhea begins a transit at 9:30 P.M. EST, followed four minutes later by Tethys. Tethys' shadow appears about 40 minutes after it. Rhea exits the disk around 10:30 P.M. CST and Tethys follows at 11:20 P.M. CST (note the change to CST, as Saturn has set on the East Coast).

Look for three of Dione's transits: One on the 4th begins at 9:17 P.M. EST and lasts about 2.7 hours. A repeat occurs on

The king holds court



Jupiter stands more than 70° high at local midnight this month, reaching opposition on the 7th. Uranus, nearby, will likely require optical aid to view.

ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

JUPITER reaches opposition Dec. 7 — its best in a decade for Northern Hemisphere observers.

the 15th, starting soon after 9 P.M. EST, and again on the 26th just before 8 P.M. EST.

Iapetus reaches inferior conjunction Dec. 10, when the 11th-magnitude moon is 45" due north of Saturn. The next night, it is 1' northwest of the planet. It continues west, brightening to magnitude 10 on the 31st, when it reaches western elongation 8' west of Saturn.

Neptune ends its retrograde path on the 8th. You'll find the magnitude 7.8 planet with binoculars, just a Moon's width northwest of magnitude 5.5 20 Piscium. This star lies at the western end of a line of three stars of similar brightness, all 5° to 7° southeast of Lambda Psc. Neptune sets before midnight in late December. The distant planet lies 4° northeast of the Dec. 8 First Quarter Moon.

Uranus spends December about 7° southwest of the Pleiades (M45). A waxing gibbous Moon stands 4.5° northwest of Uranus on the 12th. The planet is an easy object in binoculars at magnitude 5.6, fading only 0.1 magnitude throughout the month. A telescope shows its 4"-wide disk.

In early December, Uranus tracks south of a 7th-magnitude field star, which is 2.5° southeast of 5th-magnitude Tau (τ) Arietis. Binoculars will easily show 4th-magnitude Delta and Zeta (ζ) Ari forming a triangle with Tau. The ice giant is visible until well after midnight all month.

Jupiter reaches opposition Dec. 7. It rises around 5 P.M. local time on Dec. 1 and is visible all night. The giant planet is at its best for a decade

— *Continued on page 34*

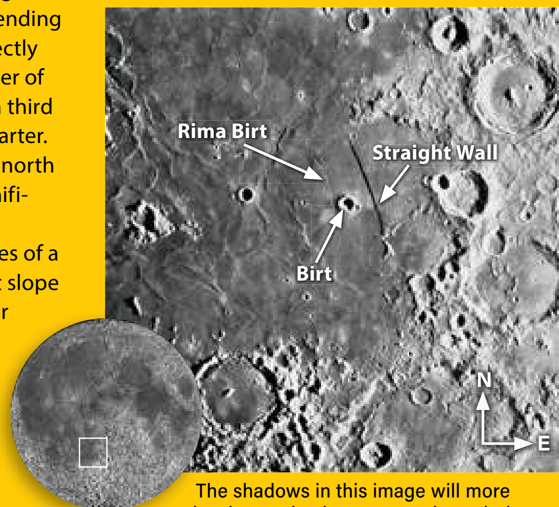
RISING MOON | Sunrise scarp

THE STRAIGHT WALL is the best-known scarp feature on Luna's frontside, an outstanding treasure in the form of a long black blade extending outward from its bejeweled hilt. It is perfectly placed on relatively flat lava near the center of a large, half-buried crater on the southern third of the Moon, appearing just after First Quarter. Find this fault in the terrain on Dec. 8 just north of the bright highlands that include magnificently rayed Tycho.

Although its very name conjures images of a cliff, in fact the Straight Wall has a modest slope between 12° and 20° — a decent grade for driving, but not enough for tobogganing. Officially labeled as Rupes Recta in many lunar atlases, it is 75 miles long and rises some 1,300 feet above the plain. The scarp likely formed when Mare Nubium's lava-flooding episode ended, the terrain sinking and pulling westward away from the land to the east. You'll see Mare Nubium on the following night.

Thanks to the extent of the shadows on the 8th — longer than those in the accompanying image — the intriguing feature Rima Birt is also ripe for viewing. It won't be easy to see this worming channel extending north of the crater Birt, so use some patience and the highest power the atmosphere will allow to trace out the groove, likely carved out by once-running lava. Watch Birt's shadow retreat during a two-hour session.

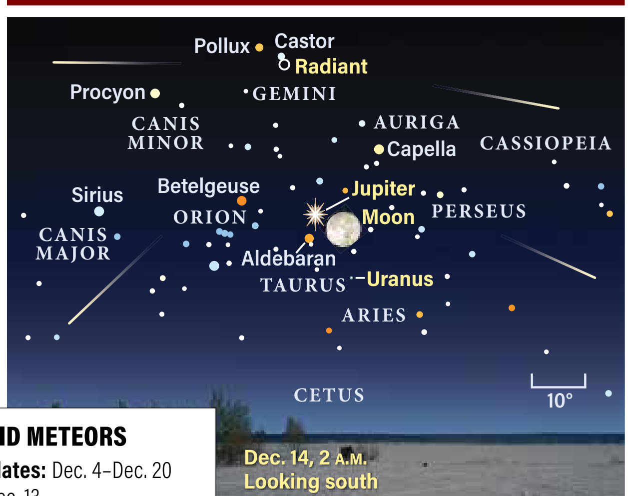
Straight Wall and Rima Birt



The shadows in this image will more closely match what you see through the eyepiece on Dec. 9. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Low chances

Geminid meteor shower



The best time to observe the Geminids is early on Dec. 14. Only a few meteors will be visible, thanks to the bright Moon. Note that Uranus will require binoculars or a telescope.

GEMINID METEORS
Active dates: Dec. 4–Dec. 20
Peak: Dec. 13
Moon at peak: Waxing gibbous
Maximum rate at peak: 150 meteors/hour

TWO MAJOR METEOR SHOWERS occur in December. The Geminids are active between Dec. 4 and 20, and peak late on Dec. 13. A nearly Full Moon on the peak night interferes strongly with this shower. Some Geminids are particularly bright, and will show up in a moonlit sky, although much lower rates than those advertised will be experienced.

More favorable this year are the Ursids, with a peak coinciding with a Last Quarter Moon. The Ursids are active between Dec. 17 and 26, and peak early on the 22nd. The radiant, located in Ursa Minor, is visible all night. The Moon rises around local midnight, so late-evening observing will offer dark skies. However, rates are low, with no more than a half-dozen to a dozen meteors visible in an hour period.

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:

9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth

MAP SYMBOLS

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

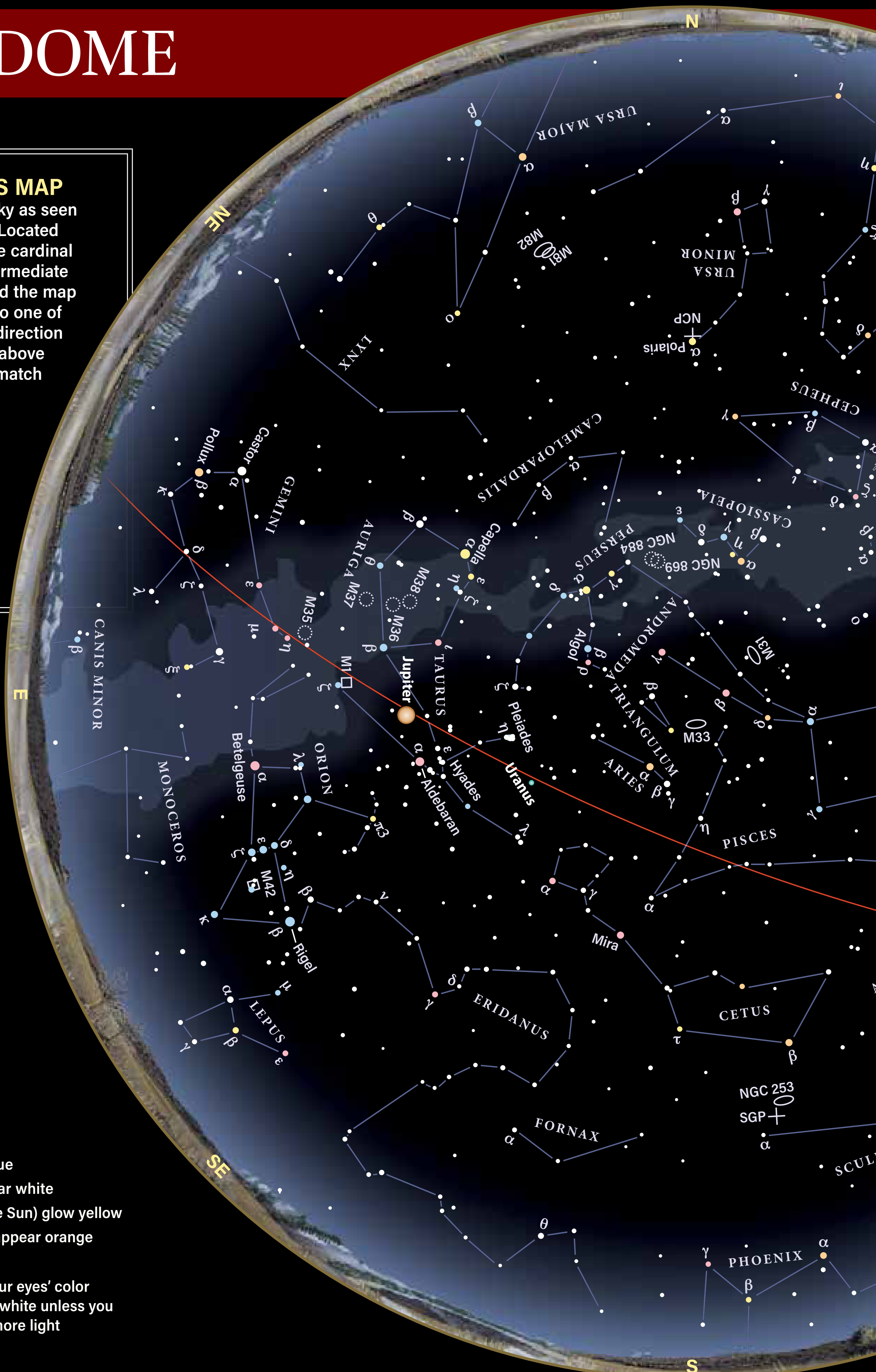
STAR MAGNITUDES

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

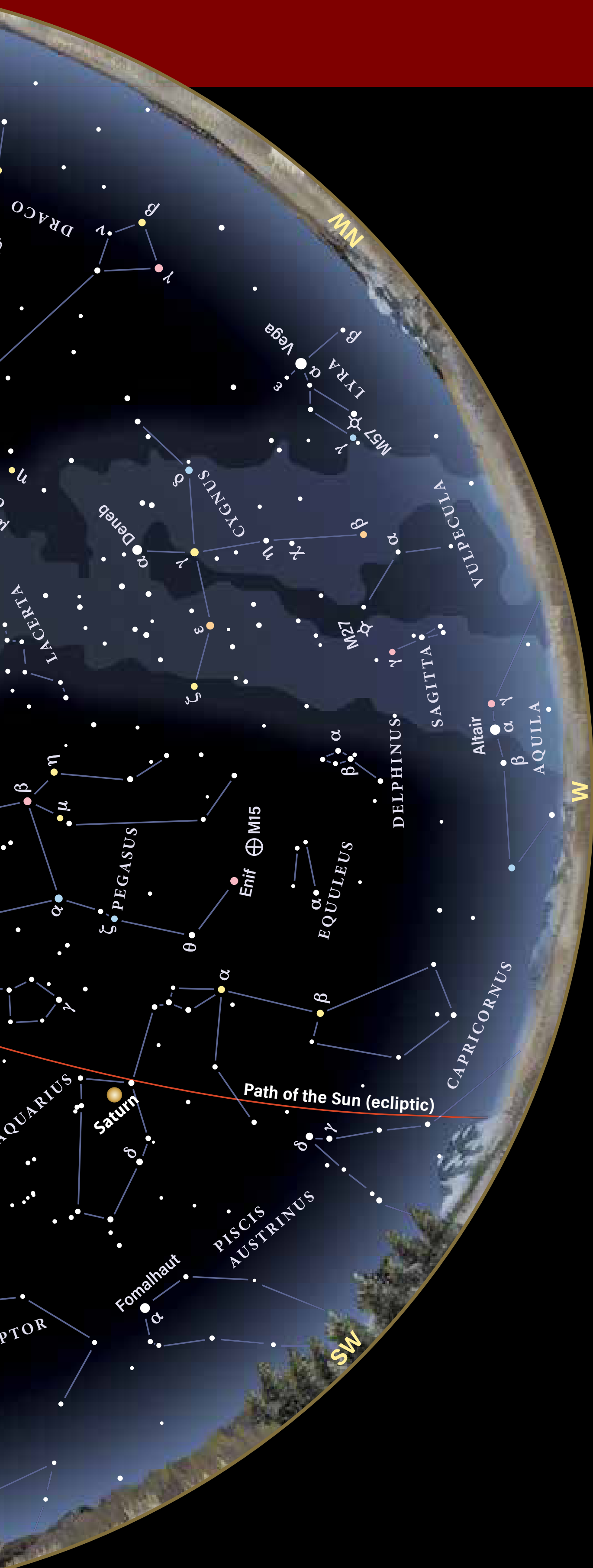
STAR COLORS

A star's color depends on its surface temperature.

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



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



DECEMBER 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: ROEN KELLY

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

CALENDAR OF EVENTS

1 New Moon occurs at 1:21 A.M. EST

4 The Moon passes 2° south of Venus, 6 P.M. EST

5 Mercury is in inferior conjunction, 9 P.M. EST

7 Mars is stationary, 4 P.M. EST

Jupiter is at opposition, 4 P.M. EST

8 The Moon passes 0.3° north of Saturn, 4 A.M. EST

Neptune is stationary, 6 A.M. EST

First Quarter Moon occurs at 10:27 A.M. EST

9 The Moon passes 0.8° north of Neptune, 4 A.M. EST

10 Mercury passes 7° north of Antares, 6 A.M. EST

12 The Moon is at perigee (227,025 miles from Earth), 8:20 A.M. EST

13 The Moon passes 4° north of Uranus, 5 A.M. EST

Geminid meteor shower peaks

14 Asteroid Eunomia is at opposition, 1 A.M. EST

The Moon passes 5° north of Jupiter, 3 P.M. EST

15 Full Moon occurs at 4:02 A.M. EST

Mercury is stationary, 4 P.M. EST

18 The Moon passes 0.9° north of Mars, 4 A.M. EST

21 Winter solstice occurs at 4:21 A.M. EST

Mercury passes 7° north of Antares, 7 P.M. EST

22 Last Quarter Moon occurs at 5:18 P.M. EST

24 The Moon is at apogee (251,335 miles from Earth), 2:25 A.M. EST

The Moon passes 0.2° north of Spica, 3 P.M. EST

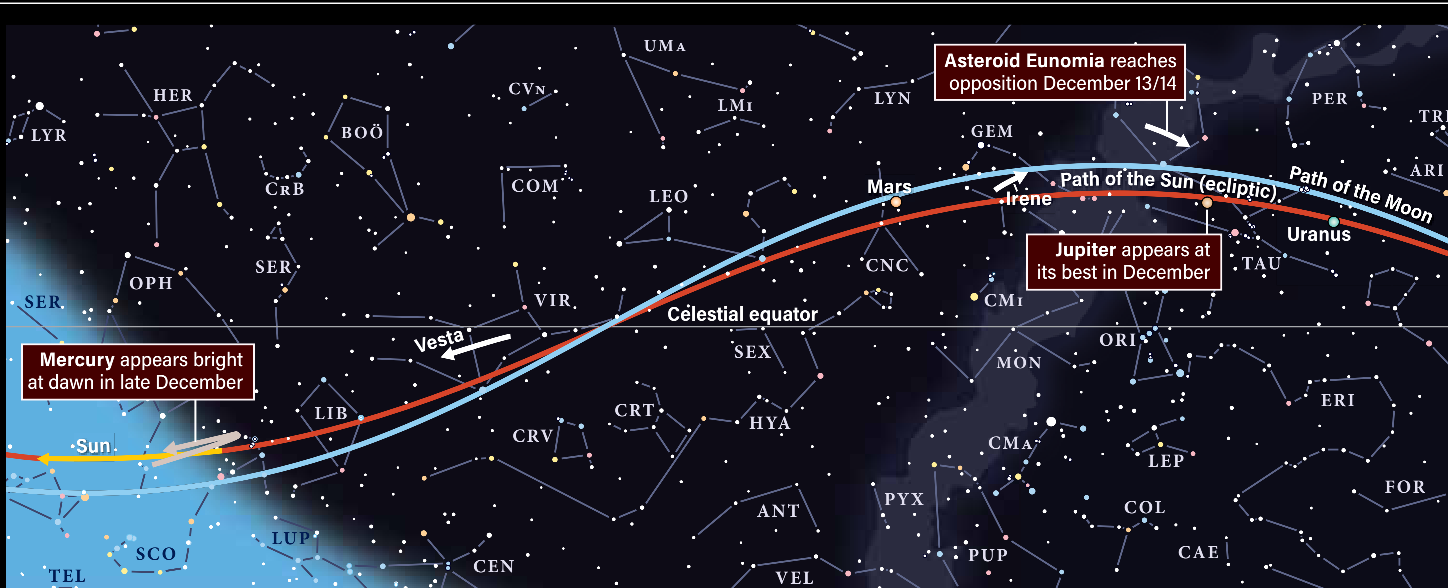
Mercury is at greatest western elongation (22°), 10 P.M. EST

28 The Moon passes 0.09° south of Antares, 10 A.M. EST

The Moon passes 6° south of Mercury, 11 P.M. EST

30 New Moon occurs at 5:27 P.M. EST

PATHS OF THE PLANETS

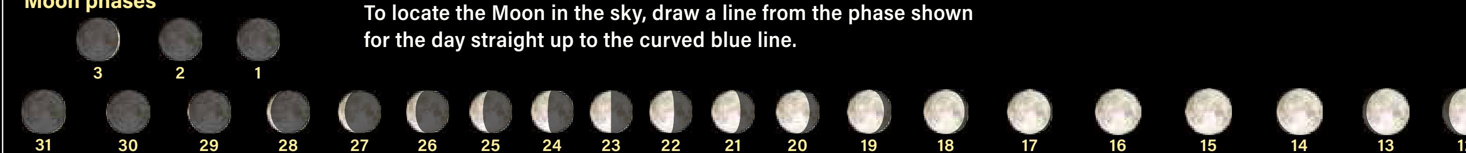


Dawn

Midnight

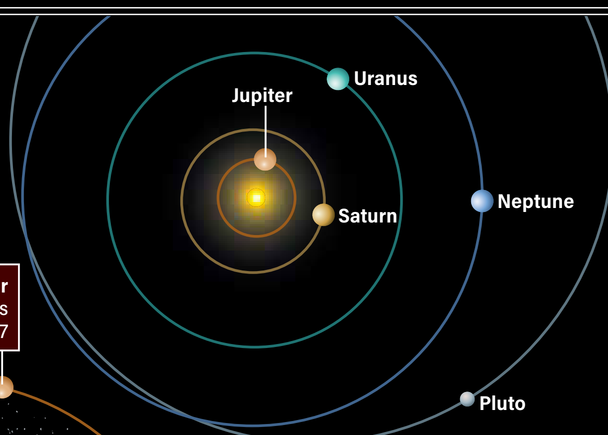
Moon phases

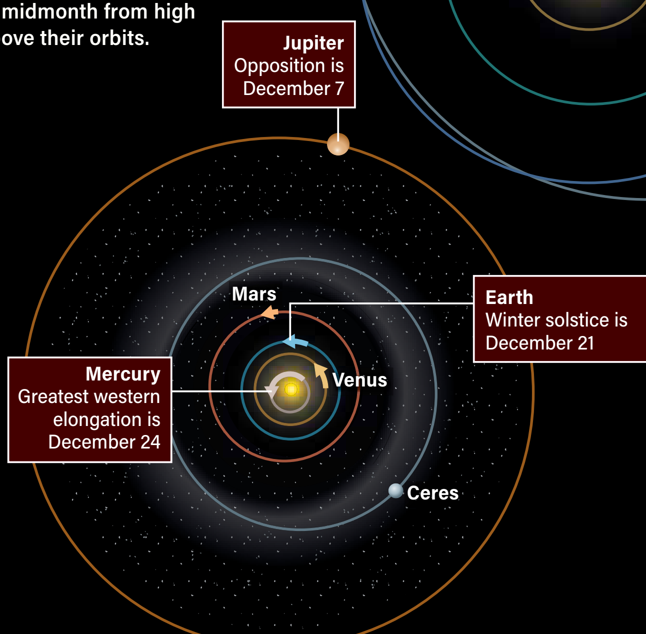
To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.



THE PLANETS IN THEIR ORBITS

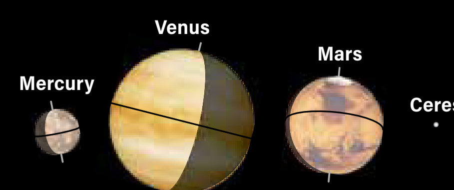
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

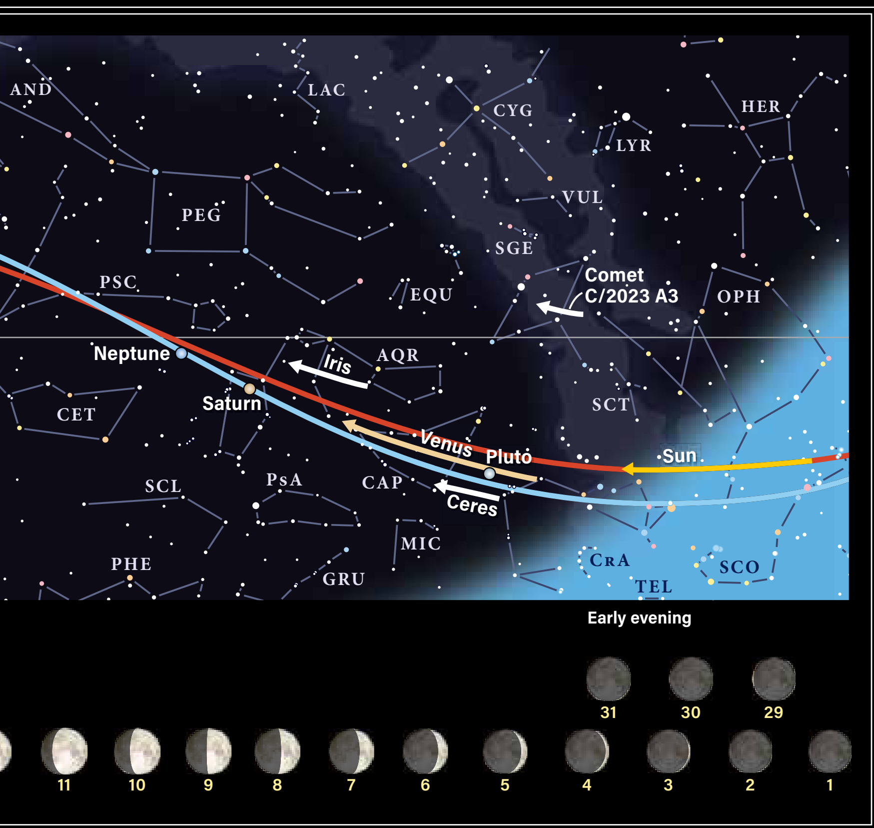
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Dec. 31	Dec. 15
Magnitude	–0.4	–4.3
Angular size	6.0"	19.1"
Illumination	76%	63%
Distance (AU) from Earth	1.131	0.875
Distance (AU) from Sun	0.415	0.725
Right ascension (2000.0)	17h09.4m	20h46.3m
Declination (2000.0)	–21°40'	–20°17'

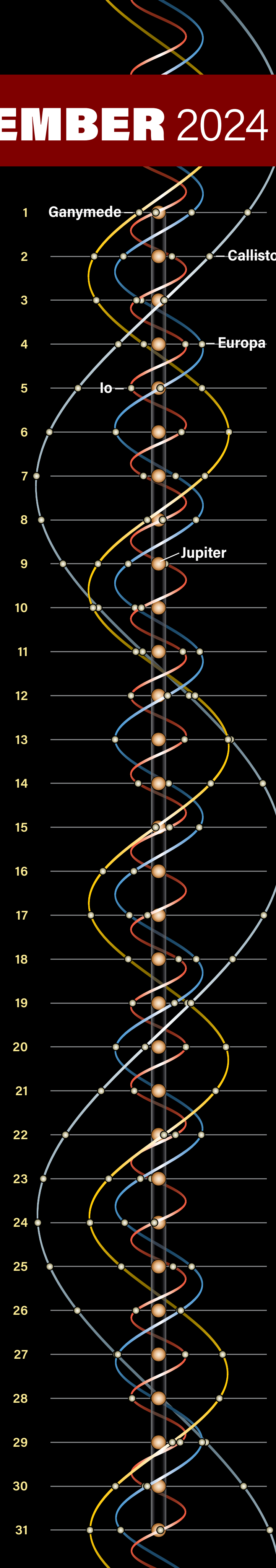
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

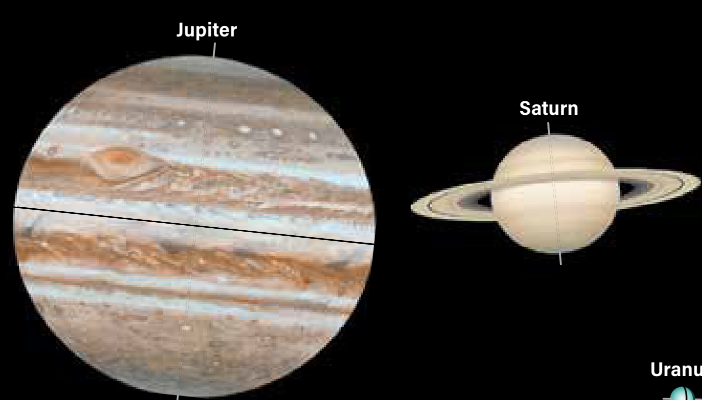
DECEMBER 2024

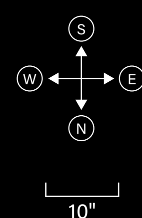


JUPITER'S MOONS

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

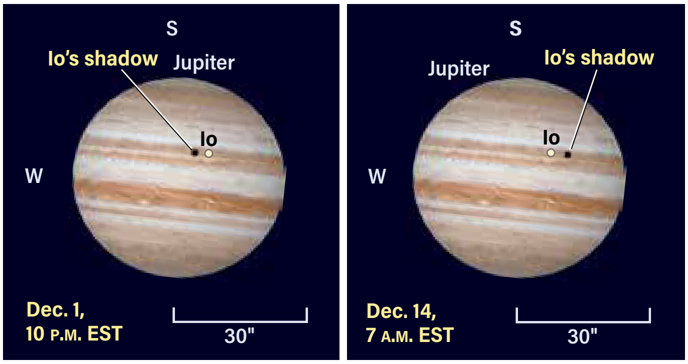






MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 15
–0.8	9.3	–2.8	1.0	5.6	7.8	15.3
12.9"	0.4"	48.1"	17.0"	3.8"	2.3"	0.1"
95%	99%	100%	100%	100%	100%	100%
0.723	3.662	4.101	9.758	18.692	29.816	35.938
1.595	2.973	5.077	9.636	19.556	29.895	35.160
8h34.3m	20h25.6m	4h54.9m	23h00.8m	3h25.9m	23h50.3m	20h12.7m
22°01'	–26°26'	21°56'	–8°30'	18°28'	–2°28'	–23°17'

Ahead and behind



Io and its shadow illustrate the changing perspective of the Sun, Earth, and Jupiter's relative positions at opposition. On Dec. 1, Io transits behind its shadow; by Dec. 14, the shadow trails.

for Northern Hemisphere observers.

Located in Taurus, Jupiter climbs to 70° altitude at local midnight for mid-latitude U.S. observers. At magnitude –2.8, it dominates a sky already brilliant with winter constellations The planet wanders west, ending the month 6° northeast of Aldebaran. A near-Full Moon stands 10° northwest of Jupiter on the 13th; M45 lies 6° west of the Moon on this evening. The next night, the Moon is 7° northeast of Jupiter.

A small telescope reveals a few details on the disk, which spans 48". Moderate (100x–150x) magnification shows a pair of belts straddling the equator. The equatorial region rotates in nine hours and 50 minutes, while higher latitudes take five minutes more, resulting in violent storms at the interfaces. The churning atmosphere provides constantly changing features. A full rotation can be observed in a night.

Occasionally the Great Red Spot is visible, plus the dusky northern and southern polar regions. Larger telescopes (8 inches or greater) reveal even more. Higher magnification increases the effect of atmospheric turbulence on the image, so don't overdo it.

Io, Europa, Ganymede, and Callisto orbit every two to 17 days. The innermost three moons are locked in a 1:2:4 resonance, so their relative positions repeat. The moons also transit in front of or become hidden behind the disk. Here are some, but not all, of the month's events: Io and its shadow transit the disk on the evening of the 1st. The shadow appears on Jupiter's eastern limb at 9:02 P.M. EST, leading Io by only 10 minutes. It's one week before opposition. Watch again on the morning of the 14th, a week after opposition, when the transit repeats. This time Io leads, starting at 6:13 A.M. EST; the shadow follows 10 minutes later.

Io is occulted on the 16th, around 10 P.M. EST — plan to be watching at least 10 minutes before this to locate Io off the western limb of the planet and catch the disappearance.

Europa and its shadow transit Dec. 12/13, beginning at 12:31 A.M. EST (the 13th in the Eastern time zone). The shadow follows just under 20 minutes later — a bigger difference than Io and its shadow, although we're only five days past opposition. This is because Europa orbits farther from Jupiter.

On the 15th, Ganymede begins a transit just before 8:50 P.M. EST, followed by its shadow at 9:37 P.M. EST. For over an hour, moon and shadow cross the dusky southern polar region, until Ganymede leaves around 10:55 P.M. EST.

There's a repeat Dec. 22/23,

WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (southwest)
Jupiter (east)
Saturn (south)
Uranus (east)
Neptune (south)

MIDNIGHT
Mars (east)
Jupiter (southwest)
Uranus (west)
Neptune (west)

MORNING SKY
Mercury (east)
Mars (west)
Jupiter (west)

COMET SEARCH | Soaring in sinking Aquila

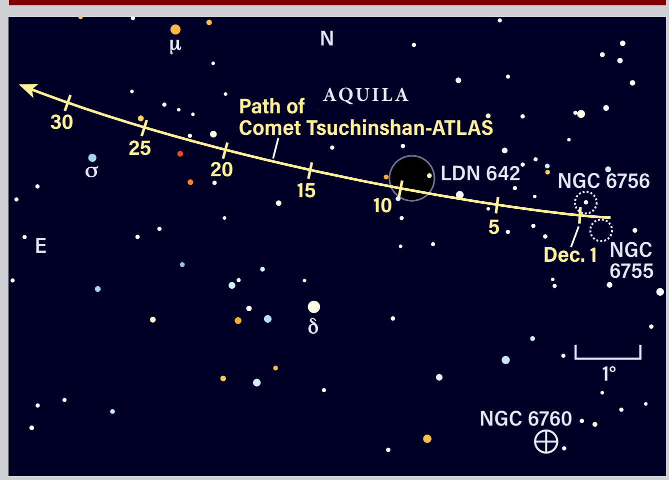
TO WATCH THE END of Comet C/2023 A3 (Tsuchinshan-ATLAS)'s story, be prepared at the eyepiece 90 minutes after sunset. Dropping to the horizon and out of easy binocular range, 8th-magnitude Tsuchinshan-ATLAS demands a country sky to the west with a clear horizon.

Its diatomic carbon emission shuts down near December's end due to increasing distance from the Sun. The celestial snowball floats in front of the dust cloud LDN 642 on the 9th and 10th.

Visually, the comet will draw your attention to star clusters NGC 6755 and 6756 as December opens. Try different magnifications and sweep around. These sparse groupings aren't at all cometlike, so swing to nearby globular NGC 6760 to compare shape, brightness profile, and edge softness with Tsuchinshan-ATLAS.

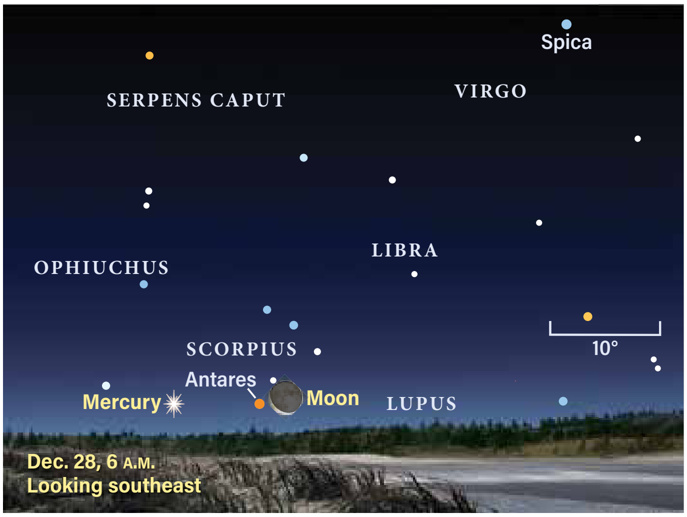
When the evening dark window reopens on the 20th, turn your sight to softly glowing Comet 333P/LINEAR, brighter than M102 in Draco. You'll need several finder charts or an app for short-period LINEAR (8.7 years), since it launches from the Hunting Dogs, passes near Alcor and Mizar, then flies over the Dragon to reach the Swan, unfortunately missing many big-name objects.

Comet C/2023 A3 (Tsuchinshan-ATLAS)



For the last weekend of November, Tsuchinshan-ATLAS' green glow will be a nice jewel for imagers, outshining the patchy red nebulosity and skimming the dark dust clouds nearby.

Three's a crowd



Mercury and the crescent Moon rise side by side Dec. 28, near the bright star Antares. The Moon crosses due south of Antares at 7 A.M. MST.

moments after midnight in the Eastern time zone. Ganymede's shadow appears some 95 minutes later, half an hour before Ganymede leaves the disk.

Callisto avoids the disk altogether; overnight on Dec. 3/4, you can catch this moon due south of Jupiter.

Mars opens the month at magnitude –0.5 and brightens to magnitude –1.2 by the end of December. We are a few weeks from its January opposition.

Mars rises at 8:30 P.M. local time on the 1st and stands more than 30° high in the east by midnight, in the constellation Cancer. It outshines nearby stars Procyon, Castor, and Pollux.

Mars halts its rapid easterly motion on the 7th and begins a retrograde loop 2.3° north of the Beehive star cluster (M44). A waning gibbous Moon lies within 0.9° of Mars Dec. 18. The Red Planet ends the month less than 9° southeast of Pollux.

Through a telescope, Mars' disk begins to reveal more features. It hits 13" in diameter by the 10th, and 14" by the 21st. Its phase grows from 93 percent to 99 percent lit during December.

Mars' rotation period of 24.6 hours means that if you observe at the same time each night, features appear to wander backward. About 25 days show a full rotation. The following are visible at local midnight on (and a few days on either side of) the given date from the central U.S.: Dec. 1, Tharsis Ridge; Dec. 5, Valles Marineris and Solis Lacus; Dec. 8, Mare Erythraeum; Dec. 13, Sinus Meridiani; Dec. 20, Syrtis Major and the Hellas basin; Dec. 27, Mare Cimmerium; Dec. 31, Mare Sirenum. If you pick a date, say the 20th, then Sinus Meridiani, previously visible at midnight on the 13th, will reach the center of the disk four hours later, at 4 A.M. local time.

The best images are acquired using high-speed monochromatic video cameras with RGB and IR filters. Practice now, before we reach opposition.

Mercury quickly appears in the morning sky after its Dec. 5 inferior conjunction. It reaches 1st magnitude by the 12th and is 3° high in the east 50 minutes before sunrise. Mercury brightens to magnitude 0 by the 18th, climbing to 6° in elevation an hour before sunrise. A telescope shows a crescent disk growing to 50 percent lit by Dec. 20 and spanning 7", then becoming a gibbous through the end of the year, while its apparent diameter shrinks to 6".

On Dec. 21, Mercury stands 7° due north of Antares (the star is hard to see in twilight — try binoculars). Greatest western elongation occurs on the 26th, with Mercury at magnitude –0.3 and 22° west of the Sun. On the 28th, the waning crescent Moon rises alongside Mercury. They stand 9° apart and rise shortly after 5:30 A.M. local time. Depending on location, you may catch the Moon passing 0.7° south of Antares. Thirty minutes after they rise, they are more than 3° high in a dark sky — you'll need a very clear southeastern horizon.

On the last day of 2024, Mercury rises one hour and 40 minutes before the Sun, clearly visible in the predawn sky.

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.*

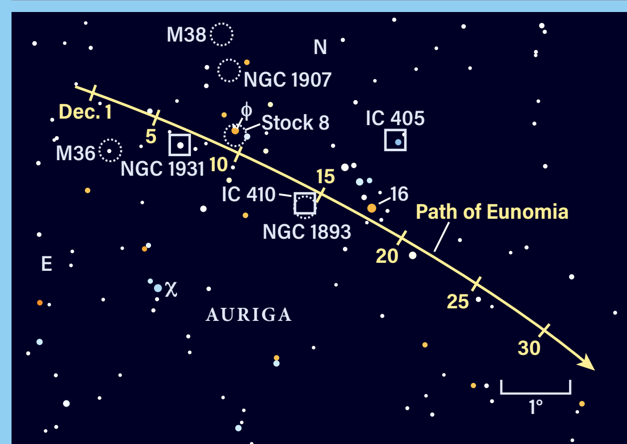
LOCATING ASTEROIDS | Sharing the chariot

RISING IN THE NORTHEAST along with Jupiter during the evening hours, asteroid 15 Eunomia slides through object-rich central Auriga while outshining most of the background stars.

Peaking at magnitude 8.1, about the brightest it can possibly get, Eunomia is a straightforward target to follow across the fainter outer spiral arm of the Milky Way. In fact, none of the stars in the splashy star cluster M36 (less than a degree to the south) are brighter. On the 7th, Eunomia shares a medium-power field with the reflection nebula/mini-cluster combo NGC 1931, one of the sky's best comet lookalikes.

The 18th is the best night to see the space rock move relative to the background, sliding less than 10' from 16 Aurigae, which shines at magnitude 4.5. An 8th-magnitude field star to the southeast provides an anchor to reveal the asteroid as the trio forms a crooked line that straightens and then re-kinks in under two hours.

A rich view



This chart only shows stars down to magnitude 8.5, but there are many additional fainter stars in this region.

A BLAST FROM THE PAST

JWST changes the debate on what created the Crab Nebula.

BY RICHARD TALCOTT

ON JULY 4, 1054, A BRILLIANT new "star" appeared in the constellation Taurus the Bull. It remained visible in daylight for 23 days and at night for nearly two years. Once the object faded below naked-eye visibility, it wouldn't be seen again until 1731. That's when English astronomer John Bevis spotted a fuzzy glow in the same position through a 3-inch telescope.

In the three centuries since Bevis' discovery, scientists have studied this intriguing object — the Crab Nebula (M1) — with every tool at their disposal. They now know it to be an expanding cloud of gas and dust created when a massive star exploded as a supernova and lit up Earth's sky 970 years ago. A pulsar, a highly magnetized and rapidly spinning neutron star, near its center provides the energy that keeps the remnant aglow.

WHAT KIND OF STAR EXPLODED?

Yet the Crab remains mysterious. That's why astronomers eagerly awaited the first observations of the remnant with the powerful James Webb Space Telescope (JWST). Princeton University's Tea Temim led a research team that imaged and took spectra of the nebula. The observatory's unparalleled sensitivity and resolution at infrared wavelengths provided the most accurate measurements yet of the Crab's composition. The scientists reported their results in the June 20 issue of *The Astrophysical Journal Letters*.

What the team found suggests that astronomers have been wrong about the type of star that exploded. Normal stars end their lives in one of three ways. Those with less than 8 solar masses puff off their outer atmospheres, forming a planetary nebula and leaving behind a white dwarf.

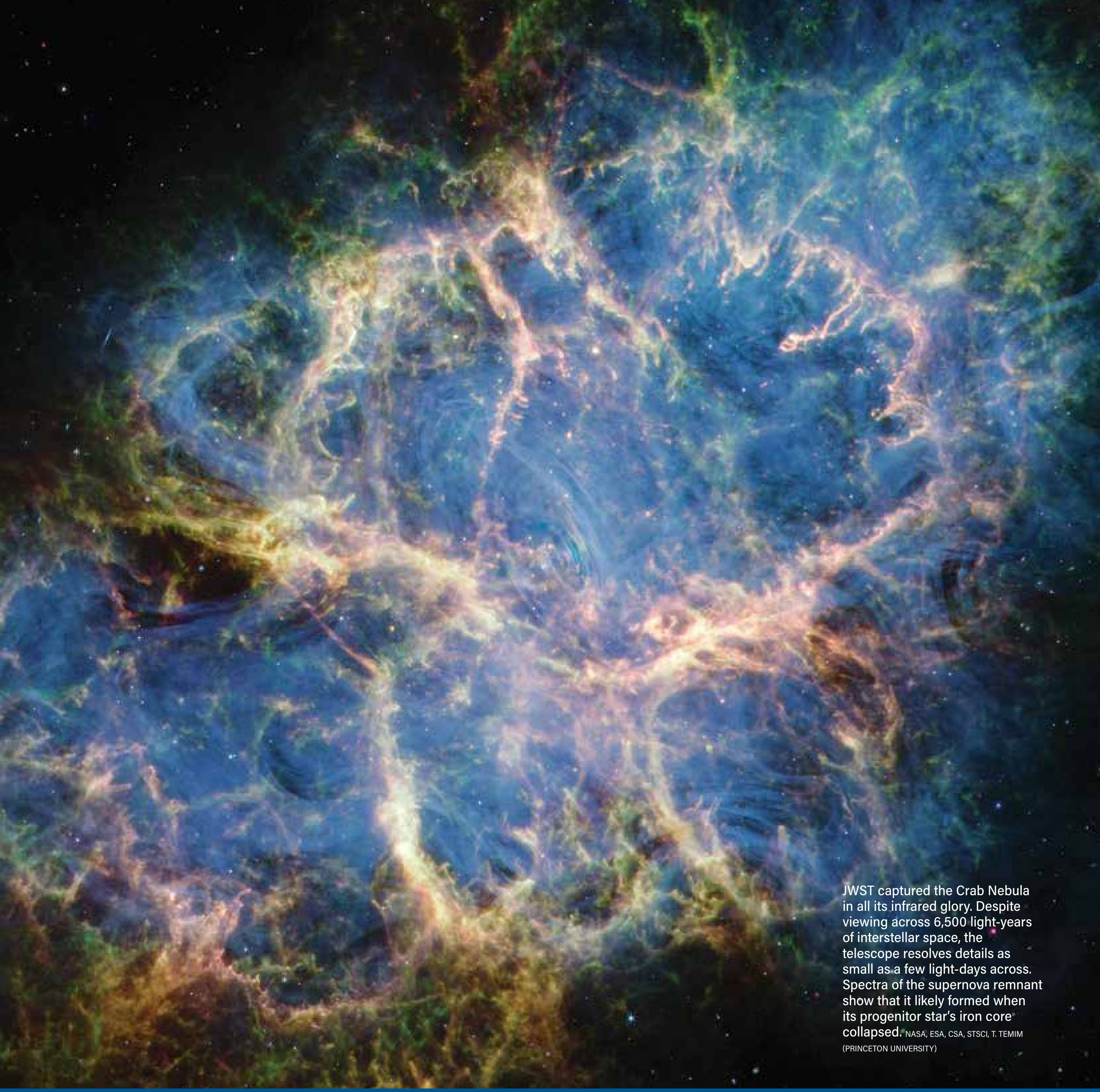
Those with more than about 11 solar masses ultimately develop an iron core that no longer can generate the energy to support the weight of its outer layers. The core collapses, triggering a shock wave that blows the rest of the star apart. The explosion leaves behind either a neutron star or black hole.

The one that spawned M1 falls into the nebulous region between. Its gaseous filaments hold about seven times the Sun's mass, suggesting the progenitor star possessed about 9 solar masses. The Crab stands apart in other ways. First, the blast generated less than 10 percent of the energy seen in a typical iron core-collapse supernova. And observations in visible light show the ratio of nickel to iron in the nebula's filaments appears 50 to 75 times that found in the Sun, far higher than in other iron core-collapse supernovae.

This led most astronomers to think the Crab formed in a rare electron-capture supernova. Such explosions occur in this intermediate-mass range among stars with a less-evolved core comprising oxygen, neon, and magnesium. The blast occurs when neon and magnesium atoms start to capture the free-floating electrons that exert the outward pressure keeping the core stable. The core then collapses, triggering the supernova and leaving behind a neutron star.

WEBB WEIGHS IN

The JWST observations are writing a new chapter in the Crab's story. Spectra of two spots in the nebula's inner filaments show a nickel-to-iron ratio between three and eight times that of



JWST captured the Crab Nebula in all its infrared glory. Despite viewing across 6,500 light-years of interstellar space, the telescope resolves details as small as a few light-days across. Spectra of the supernova remnant show that it likely formed when its progenitor star's iron core collapsed. NASA, ESA, CSA, STSCI, T. TEMIM (PRINCETON UNIVERSITY)

the Sun, more in line with an iron core-collapse supernova. The researchers also reanalyzed the previous abundance measurements and found that taking dust into account along with modern atomic data lowered the ratios so they are consistent with the JWST results.

Another factor favoring an iron core-collapse supernova is the high velocity of the Crab's pulsar, which speeds through space at 100 miles per second (160 kilometers per second). Computer simulations show that electron-capture events produce much more symmetric explosions than their cousins and would be hard-pressed to give the pulsar such a strong kick.

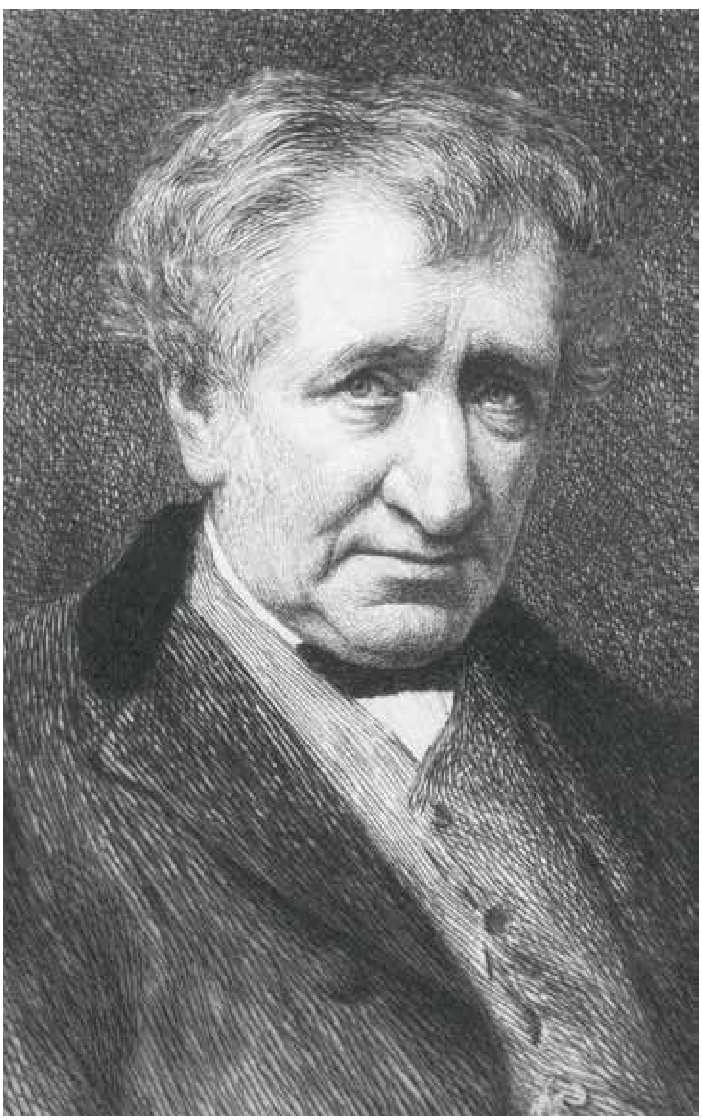
The astronomers admit that they can't rule out an electron-capture supernova, but conclude the introduction of their paper saying, "The observational properties [of the Crab] are most consistent with a low-mass iron core-collapse supernova."

Contributing Editor **Richard Talcott** *wrote about JWST's observations of the Serpens Nebula in the November issue.*

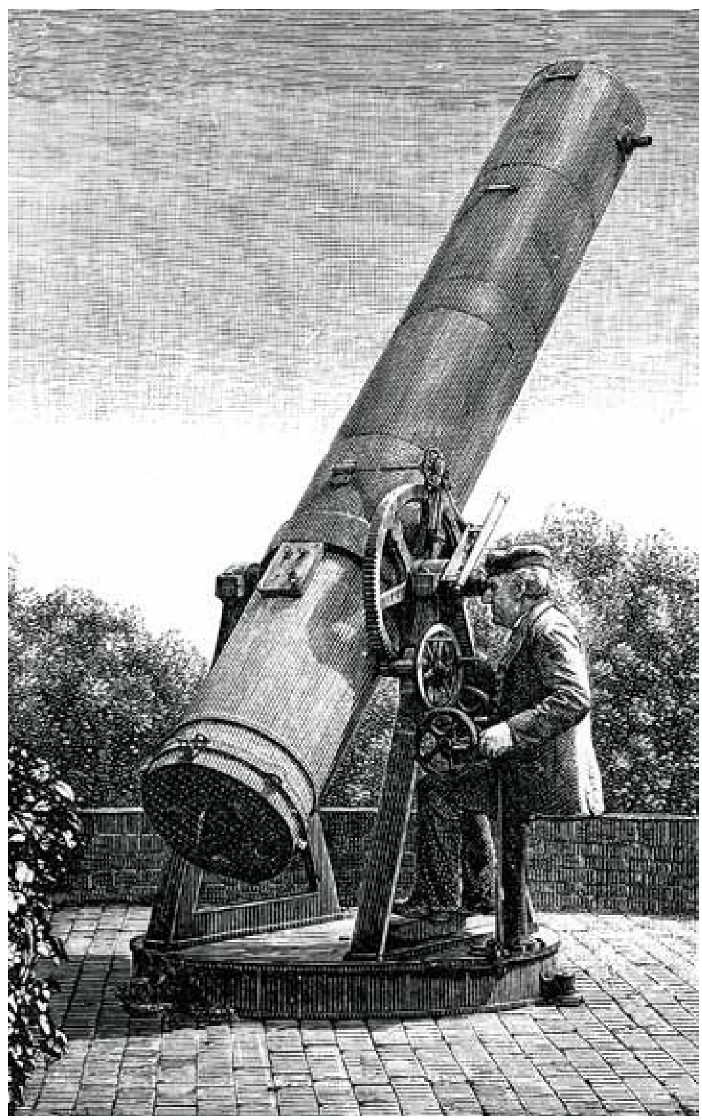
Despite having the wrong ideas about how the Moon's craters formed, these 19th-century astronomers created highly accurate plaster models. BY KLAUS BRASCH AND LEO AERTS

THE

as it never



French painter Paul Adolphe Rajan etched this portrait of James Nasmyth in 1883, nine years after *The Moon*. PAUL ADOLPHE RAJAN/GEORGE REID/WIKIMEDIA COMMONS



James Nasmyth used his 20-inch Cassegrain-Newton telescope for many of his personal illustrations and to create his plaster models. WIKIMEDIA COMMONS

MOON *was*

In 1865, pioneer of astronomical photography Lewis M. Rutherfurd captured some of the higher quality photos of the Moon at the time. WIKIMEDIA COMMONS

In 1874, James Nasmyth and James Carpenter published a remarkable book: *The Moon: Considered as a Planet, a World, and a Satellite.* Lavishly illustrated with spectacular images of lunar features based on their own observations and exquisite plaster models, it served as a platform for the authors to advance their views on the nature and evolution of the lunar surface.

In a book review from the same year, British astronomer Sir Joseph Norman Lockyer wrote: "The illustrations to this book are so admirable, so far beyond those one generally gets of a celestial phenomenon, that one is tempted to refer to them first. No more truthful or striking representations of natural objects than those here presented have ever been laid before his readers by any student of Science; and may I add that, rarely, if ever, have equal pains been taken to insure such truthfulness."

New models

Carpenter was a British astronomer at the Royal Observatory in Greenwich, England. Nasmyth was a prominent Scottish engineer and inventor, as well as an amateur astronomer, philosopher, and artist. Among other things, he invented the steam hammer and the Nasmyth-Cassegrain telescope design. Both men were later honored by having lunar craters named after them.

But what made their book so extraordinary? A major scientific question at the time centered on the nature and origin of the Moon's craters. The authors were strong advocates of the widely favored theory that craters were formed through volcanism, which drew parallels with the Campanian volcanic arc that includes Mount Vesuvius in the Gulf of Naples. This theory had been introduced in Robert Hooke's 1665 *Micrographia* as one of two possible ways lunar craters might have formed. The other was the impact theory of crater formation, which was not formalized until 1892 by geologist Grove Karl Gilbert — and not universally accepted until well into the 20th century. It finally gained real traction in 1960, when Eugene Shoemaker showed that — in sharp contrast to the surrounding volcanic terrain in northern Arizona — the famed Meteor Crater (or Barringer Crater) was created by a large extraterrestrial impactor.

Working together, Nasmyth and Carpenter put forth an ingenious mechanism for the putative formation of craters through volcanism, called the fountain model. It explained how many of the most prominent and relatively young lunar craters, such as Tycho and Copernicus, had formed their protruding walls and central peaks. It could theoretically encompass almost any size crater, including lava-filled ones.

They proposed that as the Moon gradually cooled and shrank after its formation, its outer casing was breached, and underlying molten lava was ejected through the surface, much as in volcanos on Earth. Moreover, since the Moon lacks an atmosphere and oceans, this must have been be a global phenomenon to create the widely cratered surface we see today. In the authors' own words: "When the molten substratum had burst its confines, ejected its superfluous matter, and produced the resulting volcanic features, it would, after final solidification, resume the normal process of contraction upon cooling." Eventually, "the skin, so to term the outer stratum of solid matter, becomes shriveled up into alternate ridges and depressions or wrinkles."

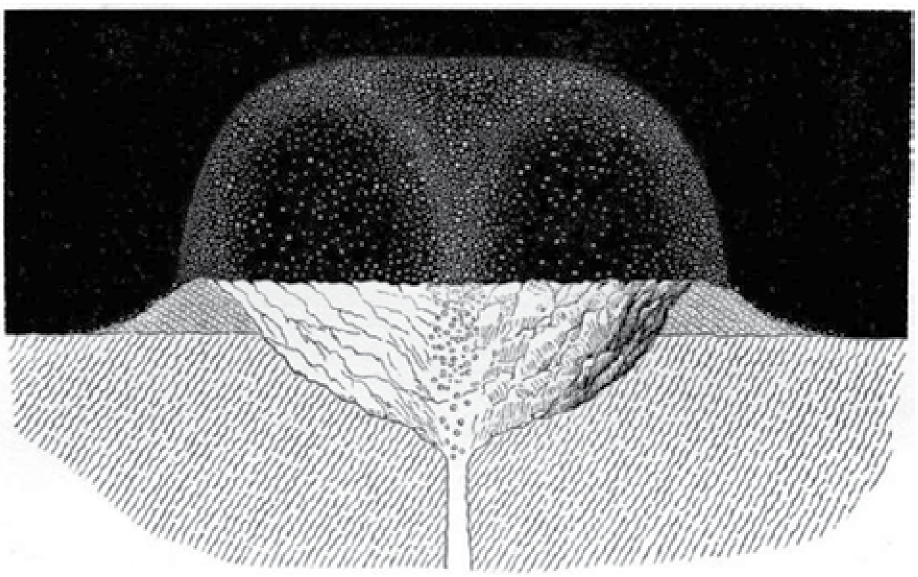
Re-creating the Moon

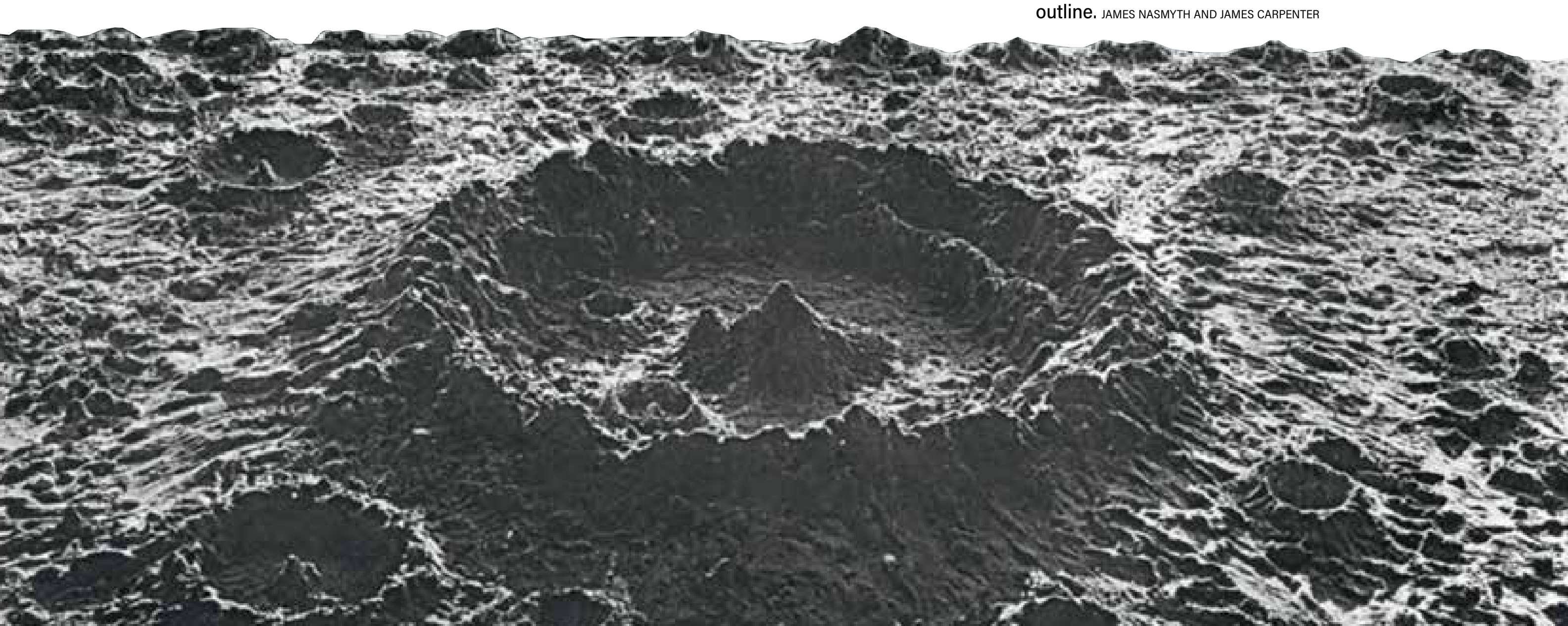
Apart from promoting their theories on lunar surface formation, Nasmyth and Carpenter were also eager to produce Moon charts more accurate than hitherto hand-drawn maps, as well as to provide a level of three-dimensional realism that existing charts lacked. Photography, though helpful, was still in its infancy and incapable of resolving the finer surface details readily visible through moderate-sized telescopes (see the lunar image on page 39).

Consequently, Nasmyth embarked on an ambitious but appealing method of producing far superior representations of selected regions of the Moon. Based on his extensive collection of exquisite drawings made at the telescope, he created plaster models and illuminated them obliquely to match the sunrise and sunset shadow angles corresponding to his observations. These were then photographed and reproduced as woodcuts for the book. The results, in the words of Lockyer, "were perfect; far more perfect than any enlargement of photographs could possibly have been."

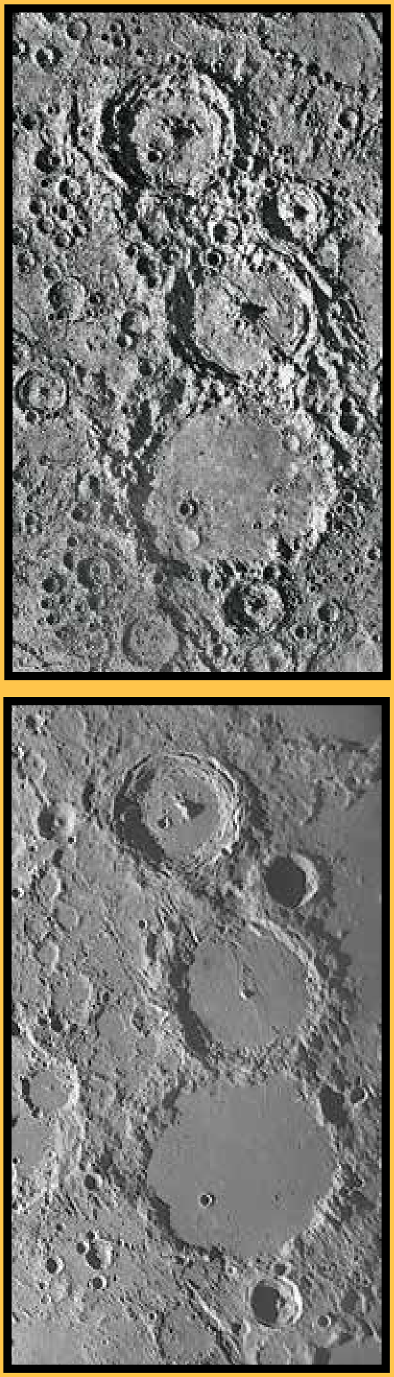
Though exquisite works of art, Nasmyth's images are not perfect in one vital aspect: Their vertical elevation is greatly overestimated. In their book *Epic Moon*, William Sheehan and Thomas Dobbins note that because Nasmyth used his models and not actual measurements of shadow angles to quantify elevations, they portray lunar features taller and more jagged than they are.

But this error does not detract from the realistic appearance and positional accuracy of his models. To demonstrate that, we have directly compared some of them with telescopic digital images of the same regions obtained under comparable angles of illumination. All digital images were taken with a Celestron 14-inch (C14) telescope (except where otherwise stated) and various cameras, and processed by Leo Aerts.

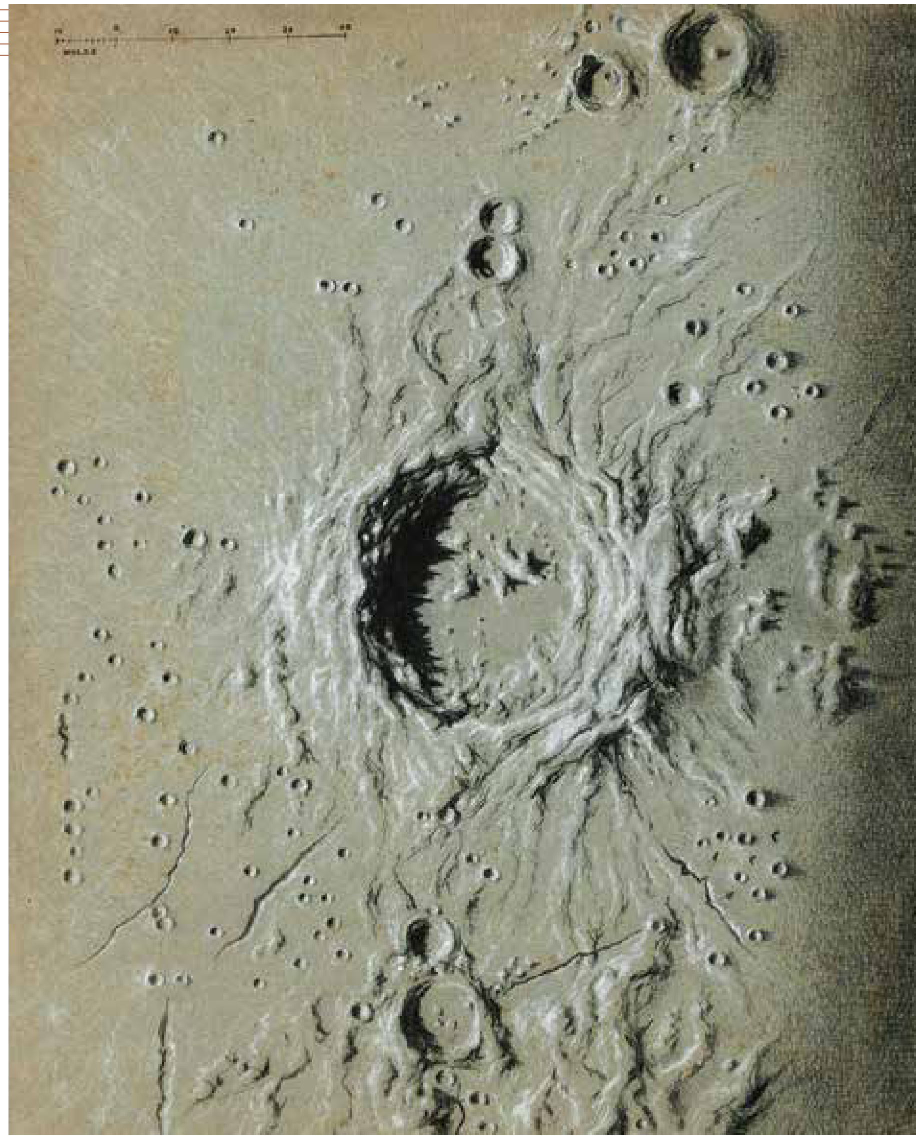




Nasmyth created this plaster model of a lunar crater (bottom). The volcanic fountain model depicted at left attempts to explain its formation through the ejection of lava from a central fissure in an umbrella-like outline. JAMES NASMYTH AND JAMES CARPENTER



Compare Nasmyth's model of Arzachel (top crater), Alphonsus (middle), and Ptolemaeus (bottom) at top with the corresponding C14 image, with similar illumination, below it. North is down and east is left. JAMES NASMYTH AND LEO AERTS



Nasmyth was a photography enthusiast, but given its limitations, created numerous intricate illustrations of lunar craters — for example, this one of Copernicus. JAMES NASMYTH

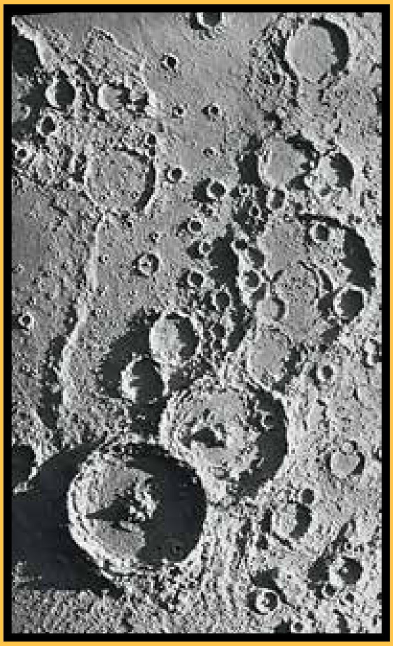
Telling a story

One of the book's most imposing images is the Theophilus, Cyrillus, and Catharina group of craters (page 42). Their age differences are made apparent by the progressive erosion of their respective walls and central peaks.

Theophilus, the northernmost crater, sports terraced walls, a flat floor, and a tall central peak, all marking it as the youngest of the trio. To its southwest is Cyrillus with a similar appearance, though less well preserved, only slightly older than Theophilus. Nasmyth and Carpenter found these two craters the perfect examples for their fountain model. Conversely, the largest and flattest crater of the trio, Catharina (to Cyrillus' southwest) didn't support their idea of crater formation. It is now clear that Catharina has been modified by several subsequent impacts, particularly its destroyed ancient rim, marking it as the oldest of the three.

Another showpiece trio of craters, from youngest to oldest, are Arzachel, Alphonsus, and Ptolemaeus. (See the images at upper left.) Nasmyth and Carpenter saw this grouping as a near-clear example of their fountain model progression of crater formation. Arzachel's prominent circular wall and central peak indicated the early stage of post-volcanic activity, whereas Alphonsus was in the intermediate stage and Ptolemaeus was in the final stage, with the lowest walls and a central peak completely engulfed by a smooth layer of lava. However, the latter posed quite a challenge for them.

As it lacked a central volcanic peak, or *cone* as they termed it, Ptolemaeus, with a size of 95 miles (154 kilometers), did not readily fit within the theoretical size range of the fountain model. Like the crater Petavius, with a true size of 110 miles (177 km) in diameter (at the time of the book's publication, the crater



The Theophilus (lower left), Cyrillus (middle), and Catharina (far upper right) group of craters as modeled by Nasmyth are at top. The bottom photo shows them imaged at a similar angle of illumination; apart from vertical exaggeration of some features, the model displays remarkable positional accuracy. North is down and east is left. JAMES NASMYTH AND LEO AERTS

The passionate Nasmyth also created photomechanical images as Woodburytype prints. Crater Vesuvius is depicted here with a smoking volcano at its center. WIKIMEDIA COMMONS

was measured to be 78 miles [125 km] wide), Ptolemaeus had "no central cone" and was, "therefore, not manifestly volcanic as those which possess this feature."

Nasmyth and Carpenter concluded that the only feasible method to explain why enigmatic basins like Mare Crisium had such expansive smooth floors was a spherical upheaving force below the lunar surface: "[W]e see that an intense but extremely confined explosion … beneath the moon's crust must disturb a circular area of its surface, if the intervening material be homogeneous."

Curiously, despite being such strong advocates of large-scale volcanism on the lunar surface, the authors did not consider massive lava flooding of basins such as Ptolemaeus as the most likely mechanism for its appearance. Ample evidence of past lava flooding can be seen in their models of the Archimedes and Aristillus regions, along with the Plato-Montes Alpes complex. Both regions fall near Mare Imbrium, which was formed by a collision with a large impactor about 3.9 billion years ago and was later flooded by basaltic lava. This formed the smooth volcanic surface evident today, which still shows protruding mountaintops and long wrinkled ridges.

Advanced for its time

Nasmyth and Carpenter were far off the mark with their volcanic theory of crater formation. Yet they showed remarkable foresight in proposing that the Moon's surface contracted as it gradually cooled and shrank since its formation.

Based on moonquake activity recorded by surface seismometers left by Apollo astronauts and more recent Lunar Reconnaissance Orbiter data, NASA scientists have concluded that while the Moon's exterior is now cold and solid, the interior is still in the process of cooling and contracting. This internal contraction has the global effect of forcing the total surface area to decrease and the crust to shrivel up.

In retrospect, it is easy to see why *The Moon: Considered as a Planet, a World, and a Satellite* attracted so much attention at the time. It was not universally accepted; Sheehan and Dobbins note in *Epic Moon*, "Though the volcanic theory flourished in the years after Nasmyth and Carpenter published their fountain theory, it did not go entirely unchallenged." Scientists eventually surmised that the moons and planets were formed by a process of accretion, which ultimately exposed our airless Moon to bombardment and left it as we see it today, pockmarked by countless craters and solidified lava basins.

Yet while their theories were ultimately inaccurate, Nasmyth and Carpenter were among the first to propose credible mechanisms to account for the Moon's chaotic-looking topography — and they did so with groundbreaking and unique illustrations.

Klaus Brasch *is a co-editor with William Sheehan, and* **Leo Aerts** *a contributing author, of the book* The Space Age Generation *(University of Arizona Press, 2024).*

NGC 1514
The Crystal Ball Nebula (NGC 1514) was discovered by German-born English astronomer William Herschel in 1790. ERIC COLES/BOB FERA

Gaze into the eyes of the BULL

From famous star clusters to spectacular nebulae, Taurus is bursting with deep-sky objects to explore.

BY MICHAEL E. BAKICH

The constellation Taurus the Bull is an easy one to find in the Northern Hemisphere's fall and winter skies. It stands opposite the Sun at the beginning of December.

The head of the figure is a large V of stars, and standing out among them is the ruddy 1st-magnitude star Aldebaran (Alpha [α] Tauri) marking one of its eyes. This star, along with Antares in Scorpius, Fomalhaut in Piscis Austrinus, and Regulus in Leo, were the four Royal Stars of ancient Persia.

If you're new to constellation identification, the best way to locate Taurus is to wait until the easily recognized constellation Orion the Hunter rises into view. Then, using the three stars that mark Orion's belt, draw a line upward, and you'll arrive at Aldebaran.

A bit of stellar trivia involves the star Elnath (Beta [β] Tauri). On many star charts dated before 1928, it was a shared star with Auriga, being designated as both Beta Tauri and Gamma (γ) Aurigae. Once the International Astronomical Union formalized the constellation boundaries, however, Elnath was made part of Taurus, probably because the letter Beta comes before Gamma in the Greek alphabet.

Taurus also is the location of an important discovery made by Italian astronomer Giuseppe Piazzi on Jan. 1, 1801, when he found Ceres roughly 3° north of the 4th-magnitude star 5 Tauri. It was the first asteroid to be discovered.

As to our observing list, the objects are in order of right ascension, from west to east. So, if you start with the first object high in the sky, the others will rise in order after it, giving you more observing time when they're best seen.

Starting off with a bang, our first target is the **Pleiades** (M45), and it couldn't be easier to find. Just extend the line from Orion's Belt that you used to find the V of Taurus and it will lead you to this magnificent open cluster.

At magnitude 1.6, M45 is tied for seventh place in brightness among all deep-sky objects. It's also deceptively huge. With a diameter of 1.8°, it covers as much area as 12½ Full Moons.

We don't know why French comet hunter Charles Messier chose to include it in his now famous catalog of nebulous objects that aren't comets. Even thousands of years before he lived, skywatchers knew it wasn't a comet. In fact, the Greek astronomer Eudoxus, who lived in the 4th century B.C.E., referred to the group as the Clusterers, and considered it a constellation.

One of the most popular names for M45 is the Seven Sisters. This implies that there are seven visible stars in this group, but human eyesight varies a lot. The majority of people can only see six stars, but if you have great eyes and are at a dark site on a night of good seeing (atmospheric steadiness), you may be able to identify 10 or more Pleiades.

Probably the best way to observe this cluster is to use binoculars. Any will give good views, but the finest come from high-quality 7x50, 10x50, and 11x80 instruments.

If your observing site is dark, try to see the Merope Nebula (NGC 1435). This reflection nebula surrounds (in an irregular way) the star Merope (23 Tauri). I've seen it through a 4-inch scope using a

Hind's Variable Nebula (NGC 1555) surrounds the star T Tauri. It's a tough catch, so use the largest telescope you can to spot it. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

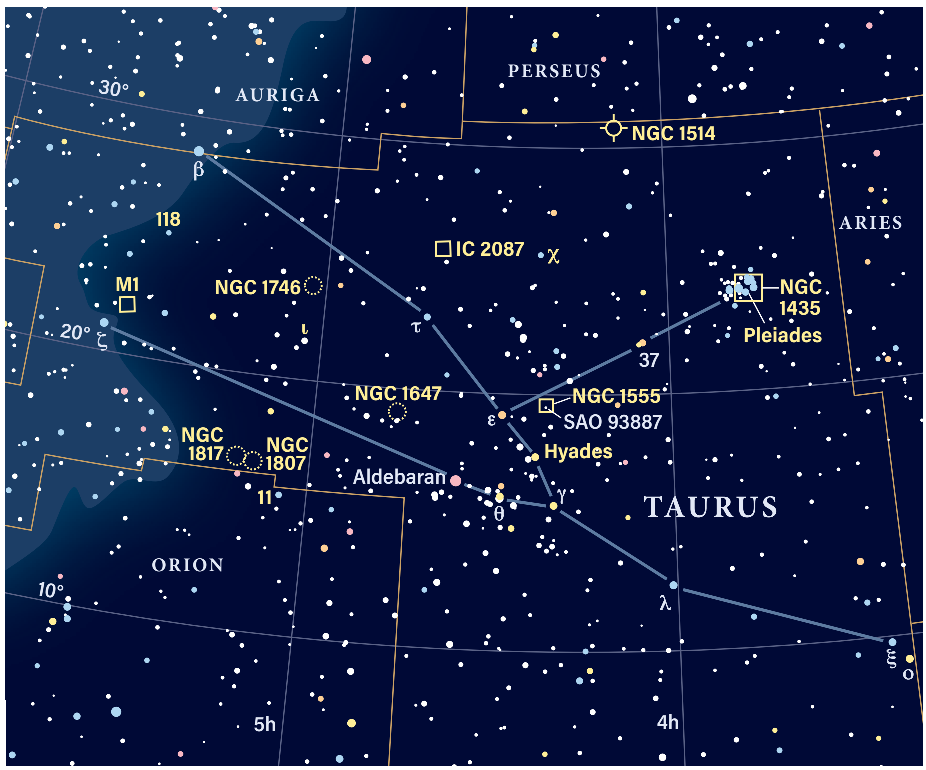
CLOCKWISE FROM UPPER LEFT:

The Pirate Moon Cluster (NGC 1647) is an open cluster that lies some 1,800 light-years from Earth. GERALD RHEMANN

The Crab Nebula (M1) got its name after William Parsons, Earle of Rosse, sketched it in 1843. He didn't name it, however. Other astronomers noticed the nebula's resemblance to a crab. Its outer layers are zooming into space at more than 900 miles per second (1,450 km/sec). SERGEY TRUDOLYUBOV

The Hyades is a V-shaped group of stars marking the head of Taurus. Interestingly, its brightest member, ruddy Aldebaran, doesn't travel through space with the rest of the cluster. BIJAN MORAVEJ ALAHKAMI

Use this chart to locate the deep-sky objects mentioned in the story. *ASTRONOMY*: RICHARD TALCOTT/ ROEN KELLY



magnification of 30x, but it was tough. A larger aperture will certainly help, but keep the power low.

Next on our list is a planetary nebula called the **Crystal Ball Nebula** (NGC 1514). It glows softly at magnitude 10.2 and has a diameter of 114". To find it, look roughly 3½° east-southeast of Atik (Zeta [ζ] Persei).

To properly view NGC 1514, use at least an 8-inch telescope. That's because you also should use an Oxygen-III filter to dim the nebula's 9th-magnitude central star, and that filter doesn't let much light through it.

Although an 8-inch will give a satisfying view, if you can step up to a 16-inch or larger scope, the Crystal Ball will explode with detail. Rather than simply a round haze, you'll see an irregular central section with a few dark zones, surrounded by a faint outer ring.

Our next target is the double star **Chi** (χ) **Tauri**. It's not too bright, so if you can't find it from the chart, look roughly midway between brighter Elnath and the Pleiades, slightly closer to the latter.

This is a pretty binary that some observers call winter's Albireo (Beta Cygni), but not as bright. The two stars in Chi glow at magnitudes 5.5 and 7.6. The brighter one (always called the primary in double-star speak) appears yellow to most people, and the fainter one (the secondary) looks blue. Of course, because color perception in human eyes varies, your view may be different.

The two stars are separated by 19.4",

In descriptions of deep-sky objects, the dimensions of galaxies, star clusters, and nebulae are usually given in arcminutes ('). However, those of planetary nebulae are given in arcseconds ("), probably because, as a general rule, such objects are the smallest in the deep sky.

so any size telescope with a medium-power eyepiece will show both components easily.

Now we come to an object that you'll need at least a 14-inch telescope to spot. It's **Hind's Variable Nebula** (NGC 1555), named in honor of its discoverer, British astronomer John Russell Hind, who found it in 1852.

NGC 1555 is a reflection nebula that we see because of its location near T Tauri. There's a problem, though. T Tau is a variable star. Usually, its magnitude hovers around 10, but it can dip to 14 and stay there for a year or more. This is why it's called Hind's Variable Nebula. When T Tau is at minimum brightness, you have no hope of spotting the nebula.

Usually, its magnitude hovers around 10, but it can dip to 14 and stay there for a year or more.

Finding Hind's Variable Nebula is a two-step process. First, look 1.7° west-northwest of Epsilon (ε) Tauri and locate SAO 93887, which glows at magnitude 8.4. Second, nudge your scope 5' to the northeast of that star, and you'll find T Tau. Next to it (if your scope is big enough and your night clear enough), you'll hopefully see an unevenly lit wedge of light. That's NGC 1555.

Our next target is the **Hyades**, whose luminaries are Alpha, Beta[1], Beta[2], Gamma, Delta (δ), and Epsilon Tauri. On other lists, it goes by Melotte 25, Collinder 50, and Caldwell 41. This object is an open cluster. Well, most of it, anyway; Aldebaran isn't part of the cluster. That bright star lies 65 light-years from Earth, while the other stars are 150 light-years away. But Aldebaran is lumped in, giving the Hyades the impressive magnitude of 0.5. It's also quite large, having a diameter of 5½°.

Because of its large size, don't use a telescope to observe it unless you're looking to split some of its double stars. You'll get your best views through binoculars.

Now turn your gaze to the **Pirate Moon Cluster** (NGC 1647), which glows at magnitude 6.4 and measures 45' across. To find it, point your scope 3½° northeast of Aldebaran. If the seeing at your site — and your eyes — are good enough, you might be able to spot a fuzzy patch without optical aid. The best way to observe NGC 1647 is through an 8-inch or larger telescope. If you start with the eyepiece that gives you the lowest magnification, the cluster should be nicely framed within the field of view. Then spend some more time with it as you crank up the power and split half a dozen or more double stars.

Next on the list is the reflection nebula **IC 2087**, which you'll find 3.9° east of Chi Tauri. An 11-inch scope shows it as a not-quite-round haze 4' across. Note the abundance of dark nebulosity in this area. Part of it hides the star whose light IC 2087 is reflecting in our direction.

Now it's time to encounter open cluster **NGC 1746**. At least, that's how it was designated shortly after it was discovered in the middle of the 19th century. Further study has revealed that NGC 1746 is actually a pair of clusters, one in front of the other. The closer one, NGC 1750, lies roughly 2,000 light-years

TOP: Reflection nebula IC 2087 lies in a region full of dark nebulae. Because it reflects the light of a nearby star, a nebula filter will not improve its appearance. THOMAS V. DAVIS

LEFT: Although NGC 1746 is a cluster of stars, it's now classified as an asterism rather than a true open cluster. EGRES73/WIKIMEDIA COMMONS/CC BY-SA 3.0

ABOVE: The Pleiades (M45) is one of the finest binocular targets in the sky. VIKAS CHANDER

LEFT: The double star 118 Tauri is easy to split. What's not so easy is seeing the subtle color difference between its two components. DIGITIZED SKY SURVEY

away, while the farther one, NGC 1758, is 2,500 light-years distant. Because the two clusters aren't physically related, NGC 1746 is now classified on most lists as an asterism. You'll find it a bit more than 2° north of Iota (ι) Tauri.

When you observe NGC 1746, you can pretty much tell which stars are in which cluster, mainly because all the stars in each region have the same brightness. So, the (apparently) brighter dozen or more belong to NGC 1750, and the fainter field stars are in NGC 1758.

Our next two targets, a pair of open clusters less than ½° apart, lie quite close to Taurus' boundary with Orion. To find the first, **NGC 1807**, move not quite 2° northeast of 11 Orionis, the topmost star in the Hunter's shield. It glows at 7th magnitude and measures 5.4' across.

The second of the pair, **NGC 1817**, stands 0.4° east-northeast of NGC 1807. At magnitude 7.7, it's a bit fainter, but nearly three times as large, having a diameter of 16'. Most observers think it's a prettier cluster than its brighter counterpart, but there's something to be said for each.

A small scope at medium power will show about 30 stars in NGC 1817, and as you increase the aperture, you'll see more and more. NGC 1807, on the other hand, shows about two dozen stars through any size scope. The main six form a jagged line, oriented north-south.

The second double star on our list is **118 Tauri**, which is 3½° south of Elnath (Beta Tauri). It's not as colorful as Chi Tauri, but seeing different colors in the two components is a fun challenge.

The primary star glows at magnitude 5.8 and is bluish-white. The secondary, at magnitude 6.6, displays a blue hue. Can you see a difference? With a separation of 4.8", splitting the two stars is easy through any scope.

The final target on our list is the first entry in Messier's list — M1. It's also known as NGC 1952, but most observers call it the **Crab Nebula**. To find it, look 1° northwest of Zeta Tauri.

M1 is a supernova remnant, an expanding shell of gas formed when a supergiant star exploded. It was first seen by Chinese astronomers in 1054, and it could be seen for a year before fading away. What amateur scopes reveal now is a whitish rectangular cloud that measures 6' by 4' and glows at magnitude 8.4.

Because of its high surface brightness, the Crab takes high magnification well. So, crank up the power until the image starts to break down because of sky conditions, and look for its irregular border and darker areas across its face.

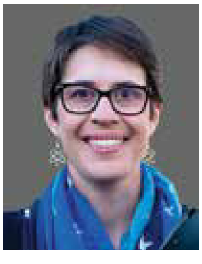
I think that as you grab the Bull by its horns (or its deep-sky objects), you'll have a great time with the cool objects in this constellation. Good luck!

Michael E. Bakich *is an associate editor of* Astronomy *who enjoys slowly moving his telescope through a single constellation.*

Examining Galileo's TOES

Transits, occultations, eclipses, and shadow transits of the jovian moons are perfect events for telescopic viewing.

Ganymede's shadow transit April 15, 2020, is captured here through an 11-inch Schmidt-Cassegrain. The moon's shadow is directly above the Great Red Spot, while the moon itself is at left. MOLLY WAKELING



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

It may be cold this month, but now is a great time to get outside and explore Jupiter's beauty and might. The fifth planet will not only reach opposition on Dec. 7, it will also be at perigee (closest to Earth) on Dec. 6, putting on its biggest and brightest show of the year.

Known for its Great Red Spot, Jupiter also boasts four bright, fast-moving moons: giant Ganymede, cratered Callisto, volcanic Io, and icy Europa. And there's no better time to brave the cold and explore some of the Galilean moons' most exciting events: transits, occultations, eclipses, and shadow transits!

Transits occur when one of the moons moves across the face of Jupiter. As the moons have orbital periods of just a few days, transits occur hundreds of times per year. At opposition Dec. 7, you can catch Io beginning to transit at 4:30 A.M. EST. Or, if you aren't an early bird, you can catch Europa transiting at 10:18 P.M. EST Dec. 5. It can be hard to distinguish the moon once it passes in front of Jupiter, but you can watch the beginning and end of its transit, as it moves onto the disk (ingress) and slides off of it (egress). Transits generally last around two to three hours. I like to use the SkySafari virtual planetarium app to visualize when and where these events will occur.

Shadow transits are my favorite to observe.

Occultations happen when one of the moons goes behind the planet and disappears from view. Around opposition, you can watch the white dot of Io vanish from sight Dec. 8 at 1:49 A.M. EST and reemerge at 4:01 A.M. EST. The Great Red Spot isn't visible during the occultation, but you can explore Jupiter's multicolored cloud bands while you wait.

Eclipses are similar to occultations, except that instead of just passing behind the planet, a moon can pass into or out of Jupiter's shadow. At opposition, Jupiter's shadow is directly behind it, but later in the year, you can watch one of the moons suddenly reappear some distance away from the planet's disk. On Feb. 1 at 12:51 A.M. EST, for example, you can witness Io emerging from Jupiter's shadow almost a half-planet-width away!

Shadow transits are my favorite to observe. These occur when one of the moons crosses the face of Jupiter; a shadow transit refers specifically to the shadow that is cast by the moon onto the jovian clouds. Near opposition, the shadow the moon casts will be close to, if not directly behind, the moon itself. At other times of the year, a moon's shadow can be visible on the disk well before or after the moon itself has transited, allowing both the moon and the shadow to be easily viewed at the same time.

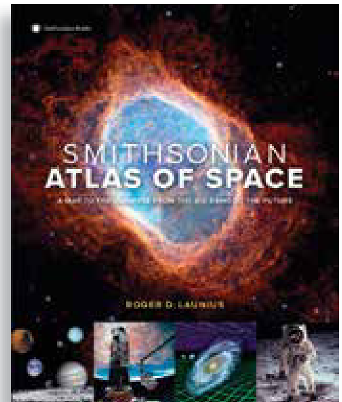
In the wee hours of Dec. 30 in the U.S., both Io and Ganymede will have shadow transits at the same time, with Io's shadow appearing at 4:42 A.M. EST at about the same latitude as the Great Red Spot, and Ganymede's at 5:37 A.M. EST toward the bottom of the planet. This is a good event for the western U.S. and gets tougher farther east. East Coast observers may see Jupiter set just before Ganymede's shadow appears, or the planet become muddy as it nears the horizon. But West Coast observers should be able to see both shadows until Io's shadow transit completes at 6:54 A.M. EST.

To spot these Jupiter phenomena, a telescope is your best option. While the moons are visible through 7x50 binoculars, if you want to catch these events in detail and enjoy the beauty of Jupiter's colorful clouds, a telescope with at least 6 inches of aperture will deliver more satisfying views.

If you are interested in recording your observing efforts, the Astronomical League offers a program called Galileo's TOES, where you observe each of these four phenomena (transits, occultations, eclipses, and shadow transits) for each of the four Galilean moons and record ingress and egress times. More on this program can be found at www.astroleague.org/galileos-toes. To see predictions for event times as well as animations of them, check out https://shallowsky.com/jupiter.

Happy observing, by Jove!

BROWSE THE "OBSERVING BASICS" ARCHIVE AT **www.Astronomy.com/author/molly-wakeling**



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MARKETPLACE

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Dark matter's influence

Q | WHY DO WE NOT SEE EFFECTS OF DARK MATTER IN OUR SOLAR SYSTEM AND OTHER NEARBY STAR SYSTEMS?

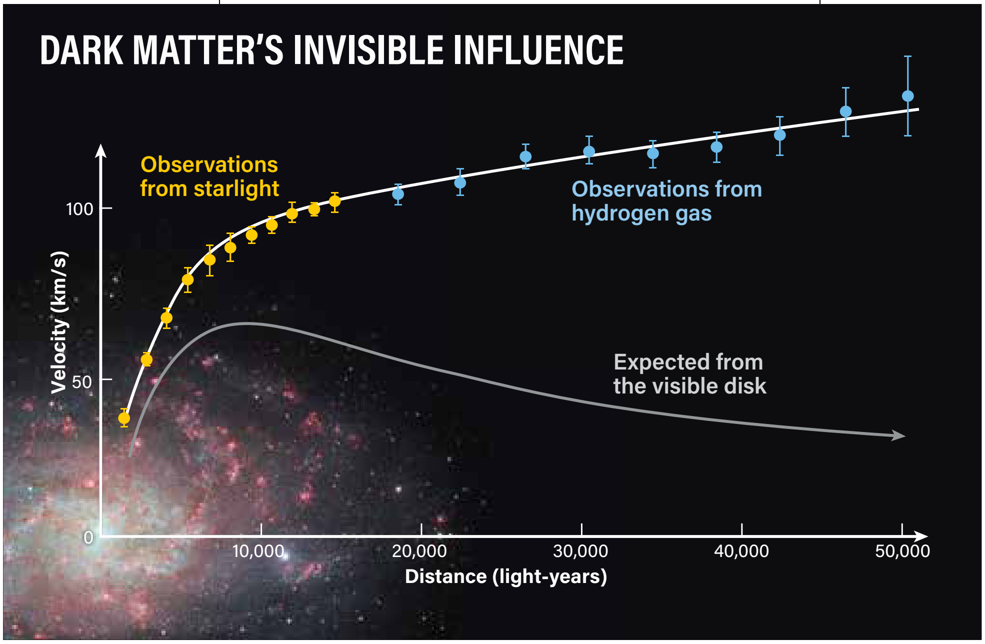
Curran Rode
Ammannsville, Texas

A | Dark matter refers to material that does not absorb, reflect, or emit any electromagnetic radiation. Astronomers have ascertained the existence of dark matter through the gravitational influence it exerts over visible matter. In fact, we estimate that approximately 90 percent of the Milky Way consists of dark matter. That figure is based principally on observations of stellar motions. The individual velocities of a galaxy's stars are proportional to the amount of material contained within it — the greater the mass, the faster the speed. Stars within the Milky Way are moving quite quickly. Even at Earth's location, about two-thirds the distance from the galactic center to the outer boundary of our galaxy, the Sun is traveling at some 138 miles (220 kilometers) per second. Visible matter alone cannot account for such rapid velocities. So, there must be much more galactic matter than meets the eye.

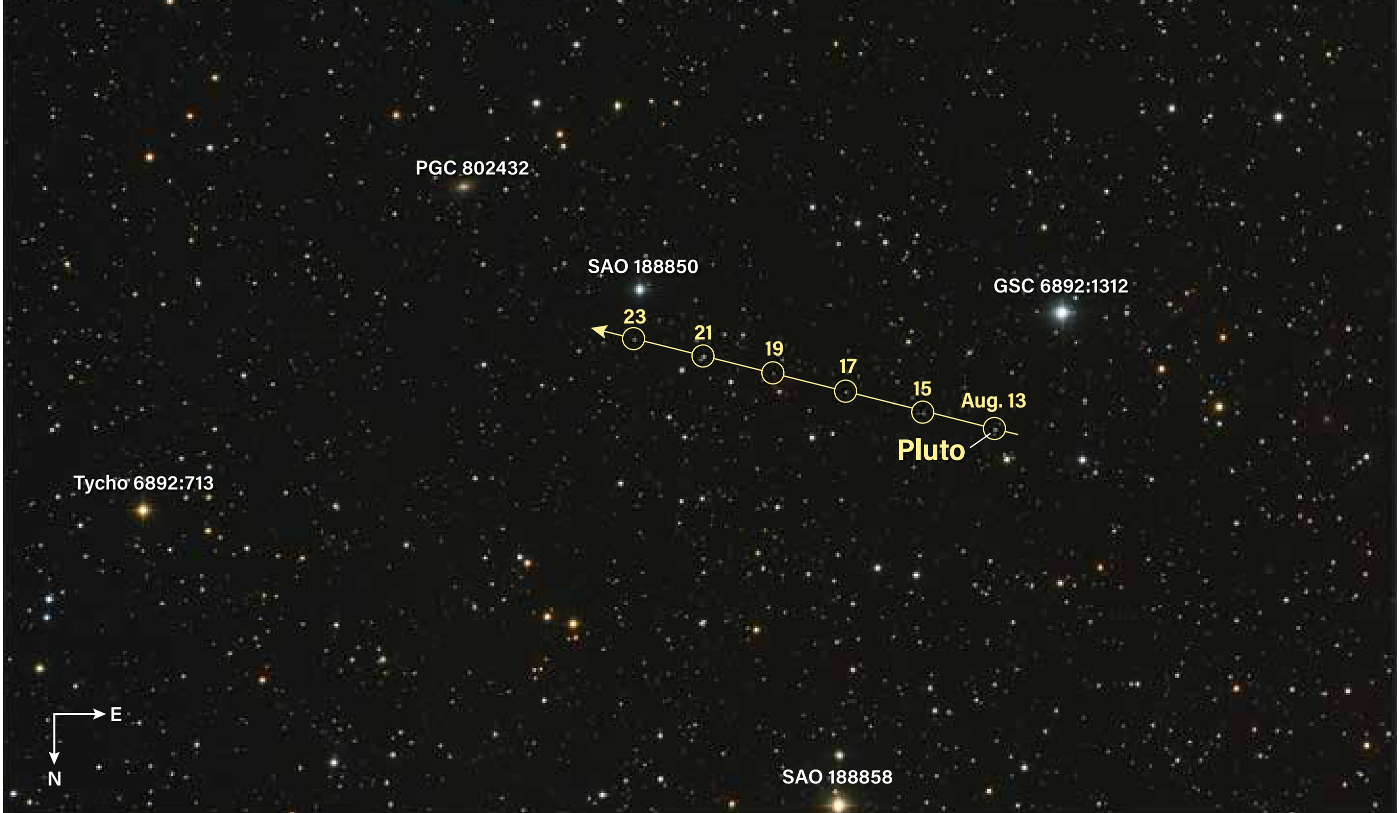
This is how the existence of dark matter was first inferred over large (galactic) scales. But could dark matter similarly affect motions within our own solar system, and could we somehow observe its effects through its interactions with normal matter?

Let's approach this question by examining the motions of objects within the solar system. Containing 99.8 percent of the solar system's matter, the Sun exerts the predominant gravitational force over everything moving around it. In other words, the solar system consists of the Sun and a comparative smattering of extraneous material (planets, asteroids, etc.) scattered about it. Thus, its matter is highly concentrated in a specific object and highly diffuse in a vast region around it. Conversely, dark matter is likely to be extremely rarefied and uniformly dense. It should permeate the solar system just as it does the galaxy, without any alteration in density. Consequently, the inner planets should experience less gravitational force than the outer planets, since the latter's orbits encompass more of this dark matter than the former. To be more specific, astronomers estimate that Earth's orbital motion should be affected by the 10^{13} kilograms of dark matter it encircles, while Uranus' orbit contains 10^{16} kg of dark matter. Although those amounts might seem considerable to us, they are negligible when compared to the masses of the Sun (2×10^{30} kg), Earth (6×10^{24} kg), and Uranus (8.7×10^{25} kg). Observing such minuscule differences between planetary orbits with and without dark matter is lamentably beyond our current detection capabilities.

However, according to a paper by Edward Belbruno and James Green published in the March 2022 issue of *Monthly Notices of the Royal Astronomical Society*, "When Leaving the Solar System: Dark Matter Makes a Difference," distant spacecraft such as Pioneers 10 and 11 or Voyagers 1 and 2 could be affected in a detectable manner by the dark matter throughout the galaxy. Unfortunately, dark matter's effect on these vessels' motions would only become detectable once they attained a distance of at least 30,000 astronomical units from the Sun. (One astronomical unit, or AU, is the average Earth-Sun distance of 93 million miles or 150 million km. For reference, Voyager 1, the most distant of all our spacecraft, was



By studying the rotation of the inner and outer regions of galaxies such as M33, astronomers can deduce the influence of dark matter in deviations from the expected model (bottom line). However, on the much smaller scales of our solar system, it's hard to measure the miniscule changes affected by dark matter, even at the distances of the outer planets. *ASTRONOMY*: ROEN KELLY. M33: ESO



This composite shows the progression of Pluto (circled) over the course of slightly more than a week in August 2023. As you can see, the tiny world is difficult to discern from the background stars; observing several times over many days is the best way to identify it. KFIR SIMON

a mere 163.8 AU from the Sun in June 2024 and will require about 8,525 years to reach the 30,000 AU mark.)

All the same, even 30,000 AU is well within the outer solar system bound of 100,000 AU as defined by the Oort Cloud. In addition, Belbruno and Green suggest that a future spacecraft at a distance of "merely" 100 AU could release a reflective ball that would establish its own trajectory independent of the spacecraft. By measuring how galactic forces, or the combined forces of normal and dark matter, affect the motions of both spacecraft and ball, scientists could then measure how dark matter can cause deviations in their respective trajectories.

So, dark matter does indeed most likely pervade the solar system like an invisible fog. We just lack the means by which to measure its effects on solar system bodies … for now.

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

AN 11-INCH SCOPE WILL REVEAL PLUTO AND A FEW SIMILARLY FAINT STARS, BUT A LARGER INSTRUMENT WILL IMPROVE YOUR ODDS A LOT.

Q | IS IT POSSIBLE TO VIEW PLUTO FROM A BACKYARD TELESCOPE?

Ethan Spyker
Wadsworth, Ohio

A | If I'm being honest, Pluto is difficult for an amateur astronomer to see. A standard 8-inch telescope just won't do the trick. That's because Pluto hasn't been brighter than 14th magnitude since the fall of 2004. It reached perihelion (its closest approach to the Sun) Sept. 5, 1989, when it peaked at magnitude 13.8. Since then, it's been moving farther away. That trend won't stop until it hits aphelion (its farthest distance from the Sun) in February 2114. As I write this, the planet's magnitude stands at 14.4.

An 11-inch scope will reveal Pluto and a few similarly faint stars, but if you have a friend (or an astronomy club) with a larger instrument, your odds will improve a lot. You'll also need a site with good seeing (atmospheric stability) and a night with no Moon.

Another thing to take into account is that you want to try to spot Pluto within the time period spanning from a month before until a month after it reaches opposition, the point in the sky opposite the Sun as seen from Earth. That's when it will stand highest in the sky at midnight. This year, Pluto reached opposition July 23. In 2025, it will be at that point July 25, still at magnitude 14.4. On that date, it will lie in southwestern Capricornus, 9.5' north of the magnitude 7.8 star SAO 189192 (also known as HIP 100386).

Now, seeing Pluto is one thing, but identifying it is another. Here's what I mean: Any high-quality go-to mount can point its telescope at Pluto after just a few button pushes. But to truly say that you've seen it, you must identify the faint dot in the field of view that's moving against the background stars. And a single night isn't long enough for that.

Neither is your memory. So, move your scope to what

you think (or what your go-to mount tells you) is Pluto's position. Insert a medium-power eyepiece. Then carefully — and as accurately as you can — make a sketch of what the eyepiece is showing you. Because Pluto moves on the order of 4" per day, make your next observation (and sketch) three or four days after the first one. Your brain will quickly identify the pattern of the "stationary" stars. The dot that moved is Pluto.

Although the process required to spot the distant world is time-consuming, you'll feel a sense of accomplishment having done it. Good luck!

Michael E. Bakich
Associate Editor

Q | WHAT BECAME OF THE DISCARDED LUNAR MODULES FROM THE APOLLO MISSIONS?

James Jarvis
San Francisco, California

A | All but one of the Apollo program's used lunar modules either crashed into the Moon's surface or burned up in Earth's atmosphere. Apollo 10's lunar module, *Snoopy*, is still out there, drifting aimlessly around the solar system, waiting for some future exo-archaeologist to snatch it up for display at the Smithsonian.

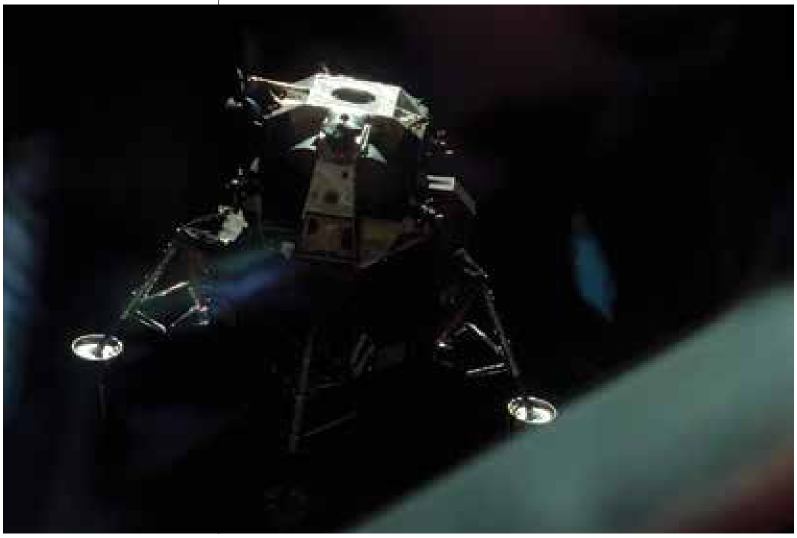
The mission was designed as a rehearsal for the main event on the Moon, but it set records of its own. History glazes over Apollo 10 because of the significance of what followed. However, the crew completed the same tasks as Apollo 11 — minus landing on the Moon.

And they used *Snoopy*, the lunar module, as well as *Charlie Brown*, the command module, to travel farther and faster than any humans have before or since.

During the mission, *Snoopy* was jettisoned into space as planned and should have entered orbit around the Sun. However, its location remains a mystery despite efforts by amateur astronomers to search for it using the last known 1969 orbital coordinates. They identified a number of target sites, but so far they've been unsuccessful.

Interestingly, at least some of the other landers' exact lunar impact sites — including Apollo 11's *Eagle* — are also a mystery that future space explorers may someday find and excavate.

Eric Betz
Science Writer, Seattle, Washington



The Apollo 10 astronauts snapped this photo of the *Snoopy* lunar module outside the window of command module *Charlie Brown* during the mission. NASA/JSC/ASU

Q | HOW DO SPACECRAFT AVOID COLLISIONS WHEN PASSING THROUGH THE ASTEROID BELT?

Val-David Smithson
Pleasant Grove, Utah

A | Let's begin by reviewing some astronomical "history": Han Solo and his rebel cohorts Leia Organa, Chewbacca, and C-3PO are nestled uncomfortably together in the *Millennium Falcon*'s cockpit while their ship is pursued by a battalion of Imperial fighters. Unable to accelerate to light-speed due to a damaged hyperdrive motivator, the supremely confident Solo recklessly directs his craft into an asteroid field. Despite C-3PO's dire warning that "the possibility of successfully navigating an asteroid field

is approximately 3,720 to 1" (he must have meant 1 in 3,720), Solo flies through the field, deftly maneuvering his ship above, below, and around the tumbling asteroids, evading his pursuers and, as stipulated in his contract, survives through the end of the movie. It's a perfect popcorn moment.

Now, please forget all that as we address the question: How can spacecraft in *this* solar system pass through the asteroid belt unscathed?

The simple answer is, it's easy. There's hardly anything there. The asteroid field we encountered in that galaxy far, far away a long, long time ago was purely fictional and preposterously overcrowded. The main belt located between the orbits of Mars and Jupiter is so sparsely populated by asteroids that spacecraft can pass through it as though it were empty space.

That notion may seem absurd because asteroids in the main belt number in the millions. Moreover, astronomers estimate there are some 1.1 million to 1.9 million asteroids there with diameters larger than about half a mile (1 kilometer). That's a lot of large, tumbling rocks darting about. However, if you gathered all those asteroids together into a single world, the resultant body would be a dwarf planet with a diameter of only 930 miles (1,500 km) — for comparison, Pluto's diameter is 1,477 miles (2,377 km) — with a mass about 3 percent that of the Moon. And again, remember that these bodies are strewn about an immensely large volume of space. The region defined as the main belt encompasses roughly 4.7 x 10^{25} cubic miles (2 x 10^{26} cubic km); see the May 2024 Ask Astro column for more details on how this is calculated. And the average distance between asteroids is about 600,000 miles (965,600 km), though this separation distance is a simple average and does not take into account asteroid families, which can cluster more closely together. Thus, even the preternaturally anxious C-3PO should be able to calmly tell any space smuggler that "the probability of colliding with an asteroid in the main belt is 1 in a billion."

To describe the situation more simply: Reduce the Sun to the size of a softball. On this scale, the main belt would be a disk with an inner boundary 76 feet (23 meters) from the softball-sized Sun, while the outer boundary would be 113 feet (34 m) away. All the asteroids put together would be half the diameter of the wire in a paperclip. Now, divide that minuscule bit of wire into millions of much smaller pieces and scatter them around the 37-foot-wide (11 m) disk, between the inner and outer boundaries. The result? A highly rarefied asteroid belt.

We should note that many spacecraft, including the Voyagers, the Pioneers, Galileo, Cassini-Huygens, and New Horizons, have all traversed the main belt unscathed, and future spacecraft will be able to pass through it without so much as seeing an asteroid, too — unless, of course, their mission is to study one of them.

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

Although movies and artist's impressions of asteroid belts — like this depiction of such a feature around the star Vega — show these regions as packed full, in truth there is so much space between asteroids in the main belt that it requires careful, intentional planning for a craft to rendezvous with one. NASA/JPL-CALTECH

SEND US YOUR QUESTIONS

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

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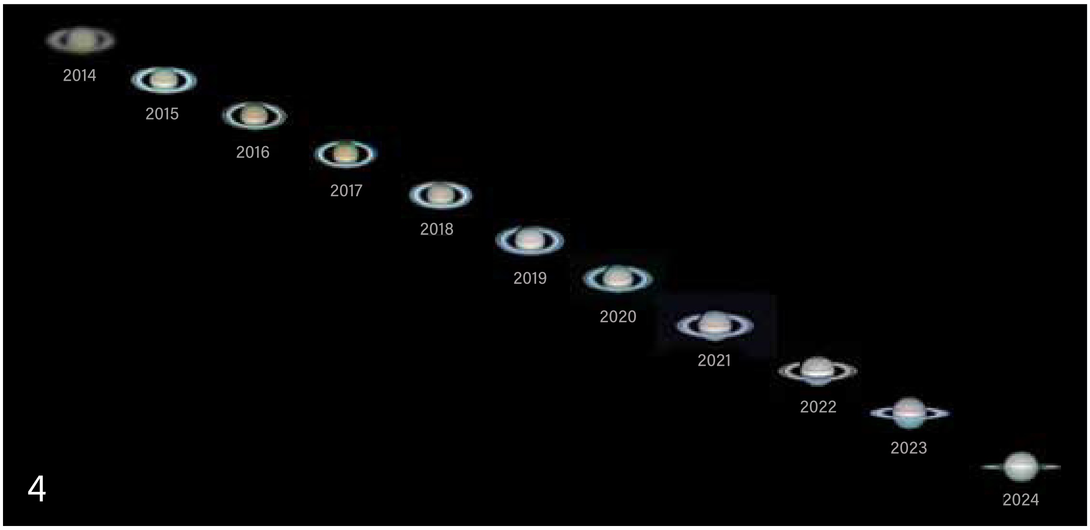

1. HUE MOON
The Moon's subtle variations in color — caused by differences in surface age and composition — are dramatically enhanced in this so-called selenochromatic rendition. The imager acquired the data with a one-shot color camera and a 14-inch scope with a UV/IR cut filter.
• Emanuele Chiapparelli

2. THAT HOODOO THAT YOU VIEW SO WELL
The Milky Way and the Rho Ophiuchi cloud complex glow over the landscape of Bryce Canyon in this springtime shot. The imager used a Canon mirrorless camera and 20mm lens at f/2. To capture the sky, he took three 2-minute frames at ISO 400, plus one 5-minute frame at ISO 3200 with a dual-band Hα/OIII nebula filter. ***• Dave Weixelman***

3. TELESCOPING ANTENNAE
The Antennae Galaxies (NGC 4038/9) are one of the most famous examples of interacting galaxies. Early computer simulations that replicated the dramatic tidal tails of the Antennae helped convince astronomers that galaxies do in fact merge. This image comprises 17.7 hours of exposure on a 1-meter scope in the Atacama Desert. ***• Team ShaRA***

4. A TILT-SHIFT VIEW
Taken over the last decade, this sequence shows how the tilt of Saturn's rings to us has narrowed. The next ring-plane crossing occurs in March 2025, although Saturn will be too close to the Sun for ideal viewing.
• Lionel Guyonnet

5. A MONSTER IN CYGNUS
Reflection nebula NGC 6914 lies in Cygnus within a dense field of emission and dark tendrils of dust. To the imager, the blue reflections appear like the eyes of an eldritch monster. The shot represents 17 hours of exposure across SHO and RGB filters with a 6-inch f/4 reflector.
• David Gluchowski


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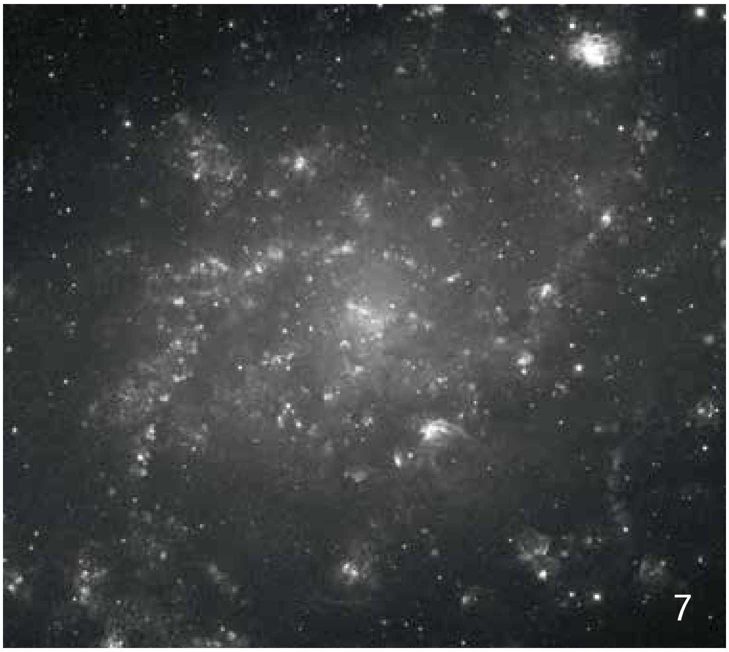
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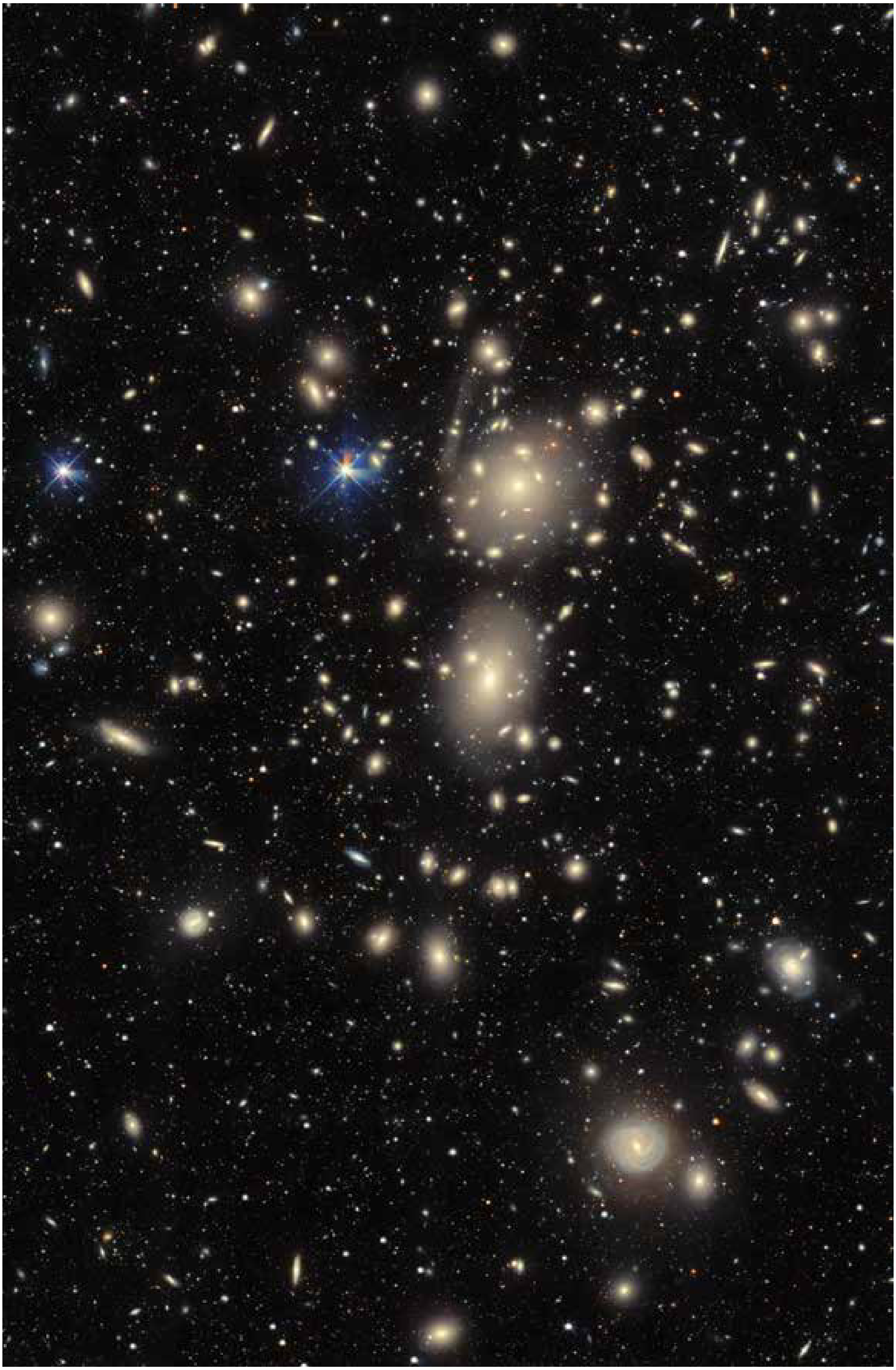
6. RECLASSIFIED INFORMATION
CTB 1 (Abell 85) is a faint supernova remnant in Cassiopeia roughly 9,800 light-years distant. Originally classified by George Abell as a planetary nebula, it's over half a degree wide — larger in apparent size than the Full Moon. This $H\alpha$/OIII/RGB image was taken with a 4.2-inch refractor at f/5 and 8¼ hours of exposure. • ***Michael P. Caligiuri***

7. A DIFFERENT LIGHT
The figure of the Triangulum Galaxy (M33) is still recognizable in this portrait taken entirely with an $H\alpha$ filter and 10 hours of exposure on a 14-inch scope. Isolating the $H\alpha$ data reveals the pockets of heated hydrogen gas dotting its spiral arms, where stars are being born. • ***Anthony Grillo***

8. MARK OF A WOLF
WR 134 in Cygnus is one of the first known Wolf-Rayet stars, a category named for their discoverers, French astronomers Charles Wolf and Georges Rayet. Such stars have intense stellar winds, which can form nebulae like this one. This image was taken over 24¾ hours with a $H\alpha$/OIII dual-band filter and an 8-inch scope at f/7.3. • ***Andrea Arbizzi***

9. STARS AND STARFISH
A rising tide envelops a starfish on the west coast of Vancouver Island in British Columbia. The photographer shot the foreground at blue hour with an astromodified Sony mirrorless camera and a 20mm f/1.8 lens, then imaged the sky separately with a star tracker and UV/IR-cut and $H\alpha$-pass filter. • ***Rob Lyons***

SEND YOUR IMAGES TO: readergallery@ astronomy.com.
Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures.



WHERE'S THE REST OF ME?

Thousands of galaxies populate the rich Coma Cluster. This vast collection of island universes spans some 20 million light-years and lies 320 million light-years from Earth in the constellation Coma Berenices. The cluster served as a great laboratory for Swiss astronomer Fritz Zwicky, who in 1933 discovered that its luminous matter had far too little mass to gravitationally bind the cluster. He coined the term *dark matter* for the invisible material that keeps the galaxies under control. Ninety years later, astronomers aren't much closer to solving the mystery of dark matter. Yet that doesn't take anything away from the cluster's visual splendor. Smaller galaxies crowd around the supergiant ellipticals NGC 4889 (center) and NGC 4874 (above it) that dominate the cluster's core. CTIO/NOIRLAB/DOE/NSF/AURA

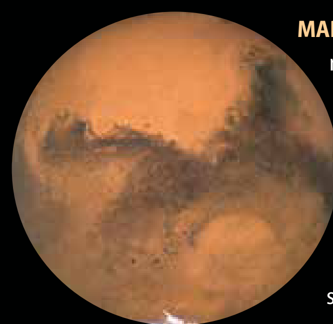
Astronomy's 2025 Guide to the Night Sky

LUNAR PHASES

New	First Quarter	Full	Last Quarter
	Jan. 6	Jan. 13	Jan. 21
Jan. 29	Feb. 5	Feb. 12	Feb. 20
Feb. 27	March 6	March 14	March 22
March 29	April 4	April 12	April 20
April 27	May 4	May 12	May 20
May 26	June 2	June 11	June 18
June 25	July 2	July 10	July 17
July 24	Aug. 1	Aug. 9	Aug. 16
Aug. 23	Aug. 31	Sept. 7	Sept. 14
Sept. 21	Sept. 29	Oct. 6	Oct. 13
Oct. 21	Oct. 29	Nov. 5	Nov. 12
Nov. 20	Nov. 28	Dec. 4	Dec. 11
Dec. 19	Dec. 27		

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.

VENUS dazzles in the evening sky from New Year's Day until mid-March. It then vanishes in the Sun's glare for two weeks, returning to view before sunrise in late March. The inner planet remains a morning object until it gets too close to the Sun in late November. Venus appears highest at dusk in early January and best before dawn in July and August. At both times it shines at magnitude –4. NASA/JPL-CALTECH



MARS reaches opposition and peak visibility in mid-January, when it shines at magnitude –1.4 and remains visible all night. It then appears 15" across and should show a wealth of surface details when viewed through a telescope. Although the Red Planet is a fixture in the evening sky until November, it dims to 1st magnitude by springtime and no longer appears prominent. NASA/ESA/THE HUBBLE HERITAGE TEAM (STSCI/AURA)

JUPITER always looks dramatic through a telescope. Even small instruments show the planet's four big moons and resolve its dynamic atmosphere into an alternating series of bright zones and darker belts. The giant planet appears best in January (a month after its previous opposition) and December (a month before its next opposition). At both times it shines brighter than magnitude –2.5. The only times you won't see it are in the weeks around solar conjunction in June. NASA/ESA/J. DEPASQUALE (STSCI)/A. SIMON (GSFC)

THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best times to observe our satellite through a telescope come a few days on either side of its two Quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/ARIZONA STATE UNIVERSITY

SATURN won't look like itself this year. Its rings tilt edge-on to Earth in March for the first time since 2009. Unfortunately, the planet then lies too near the Sun for us to see this rare event. Better views come before dawn in late April, when the rings will be backlit by the Sun, which doesn't pass through the ring plane until early May. Saturn remains an intriguing sight the rest of the year, reaching its peak in September, when it shines at magnitude 0.6 and its disk measures 19" across. The ring system then spans 44" and tilts just 2° to our line of sight. NASA/ESA/E. KARKOSCHKA (UNIVERSITY OF ARIZONA)

WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven most prominent stars form a distinctive hourglass pattern. The blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's Belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

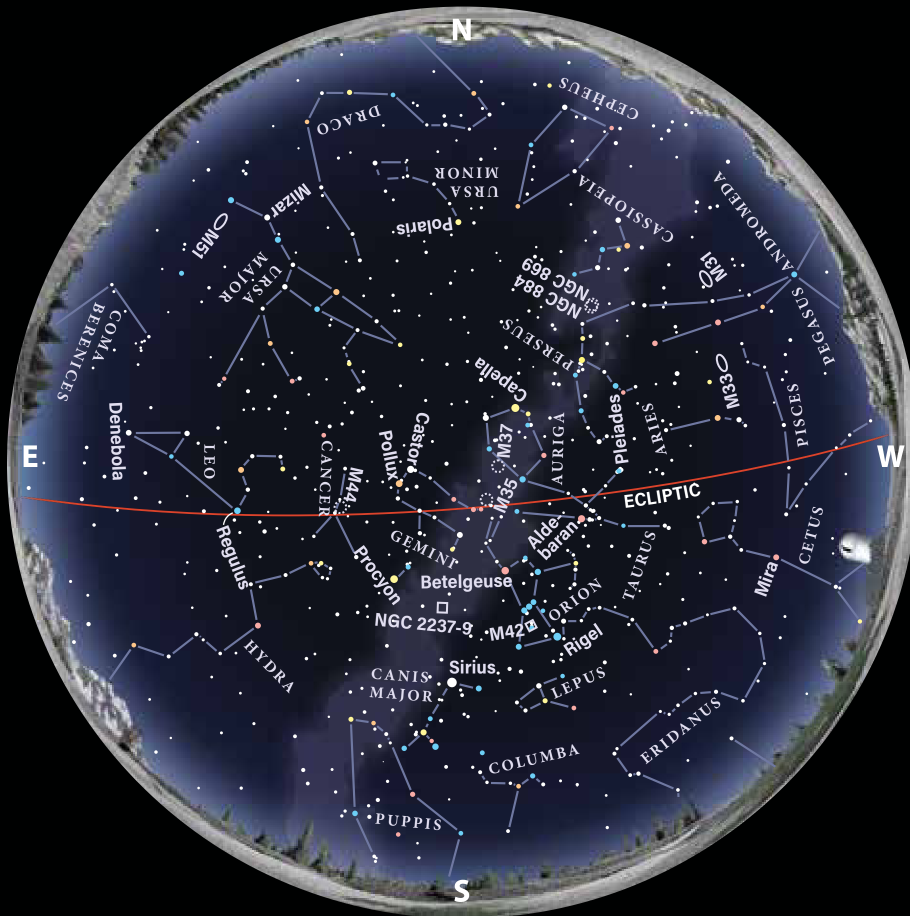
The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.



SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star: From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.

Jan. 3
Quadrantid meteor shower peaks

Jan. 9
Venus is at greatest eastern elongation

Jan. 15
Mars is at opposition

March 8
Mercury is at greatest eastern elongation

March 14
Total lunar eclipse

March 29
Partial solar eclipse

April 22
Lyrid meteor shower peaks

May 2
Asteroid Vesta is at opposition

May 31
Venus is at greatest western elongation

July 4
Mercury is at greatest eastern elongation

July 25
Pluto is at opposition

STAR MAPS BY *ASTRONOMY*: ROEN KELLY

SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius is Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

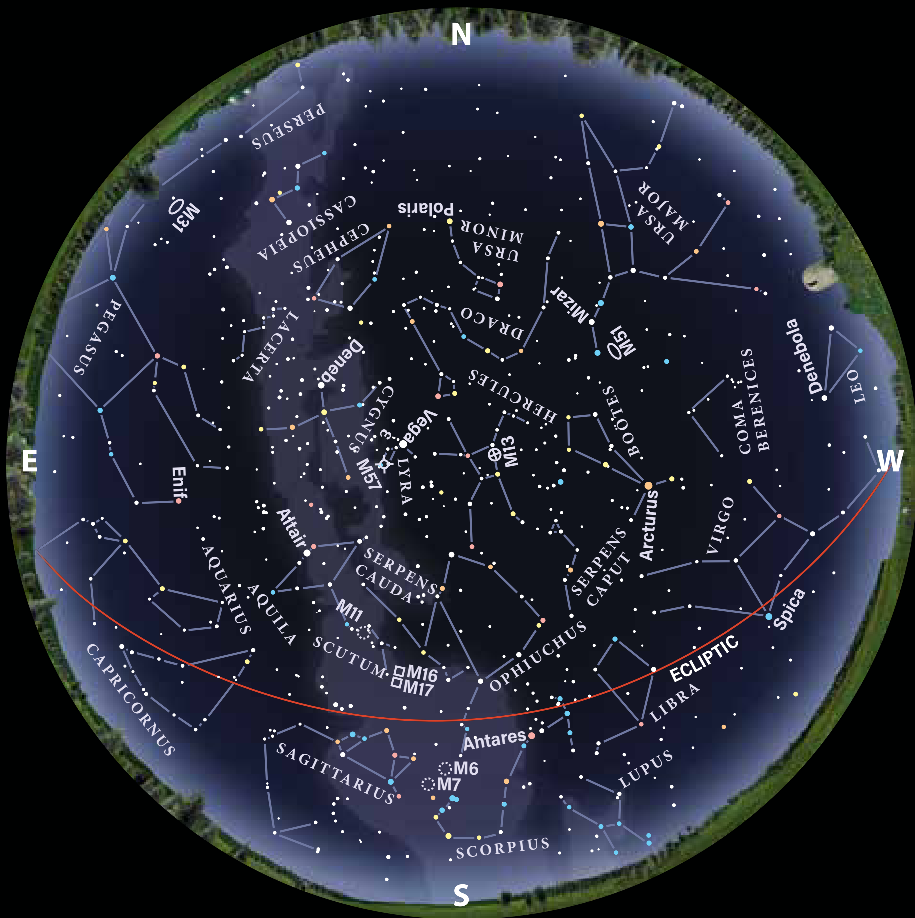
Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.



AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern U.S., it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

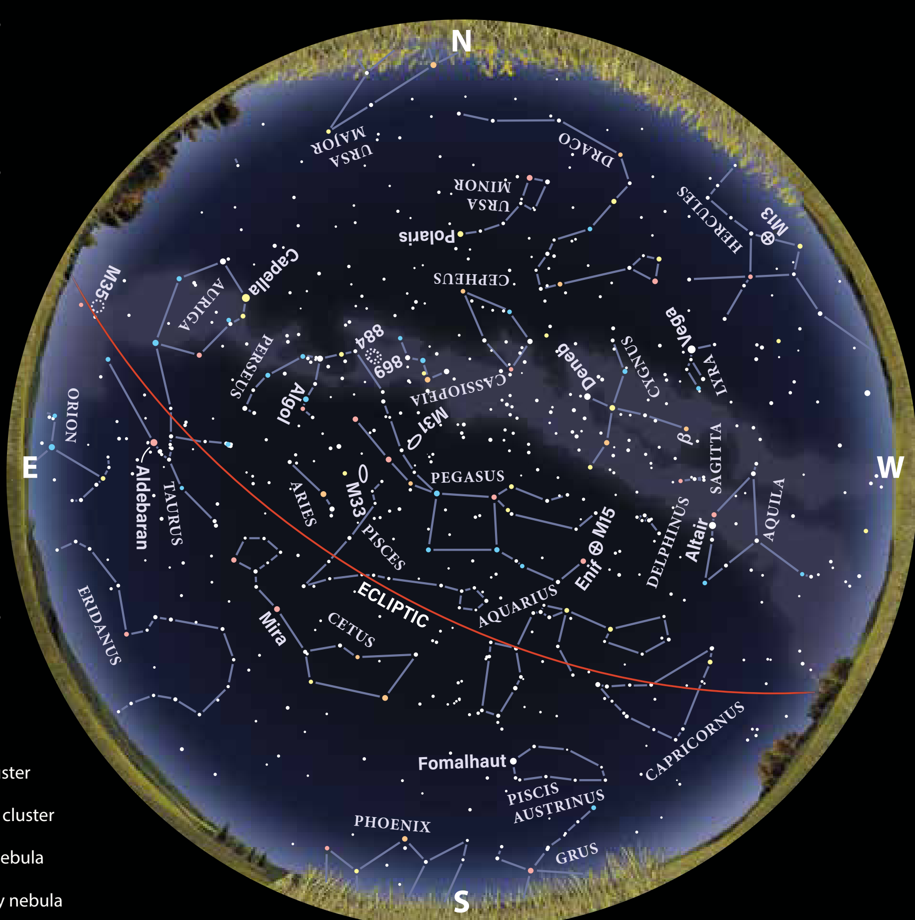
Deep-sky highlights

The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.



Aug. 12
Venus passes 0.9° south of Jupiter

Aug. 12
Perseid meteor shower peaks

Aug. 19
Mercury is at greatest western elongation

Sept. 7
Total lunar eclipse

Sept. 21
Saturn is at opposition

Sept. 23
Neptune is at opposition

Oct. 21
Orionid meteor shower peaks

Nov. 17
Leonid meteor shower peaks

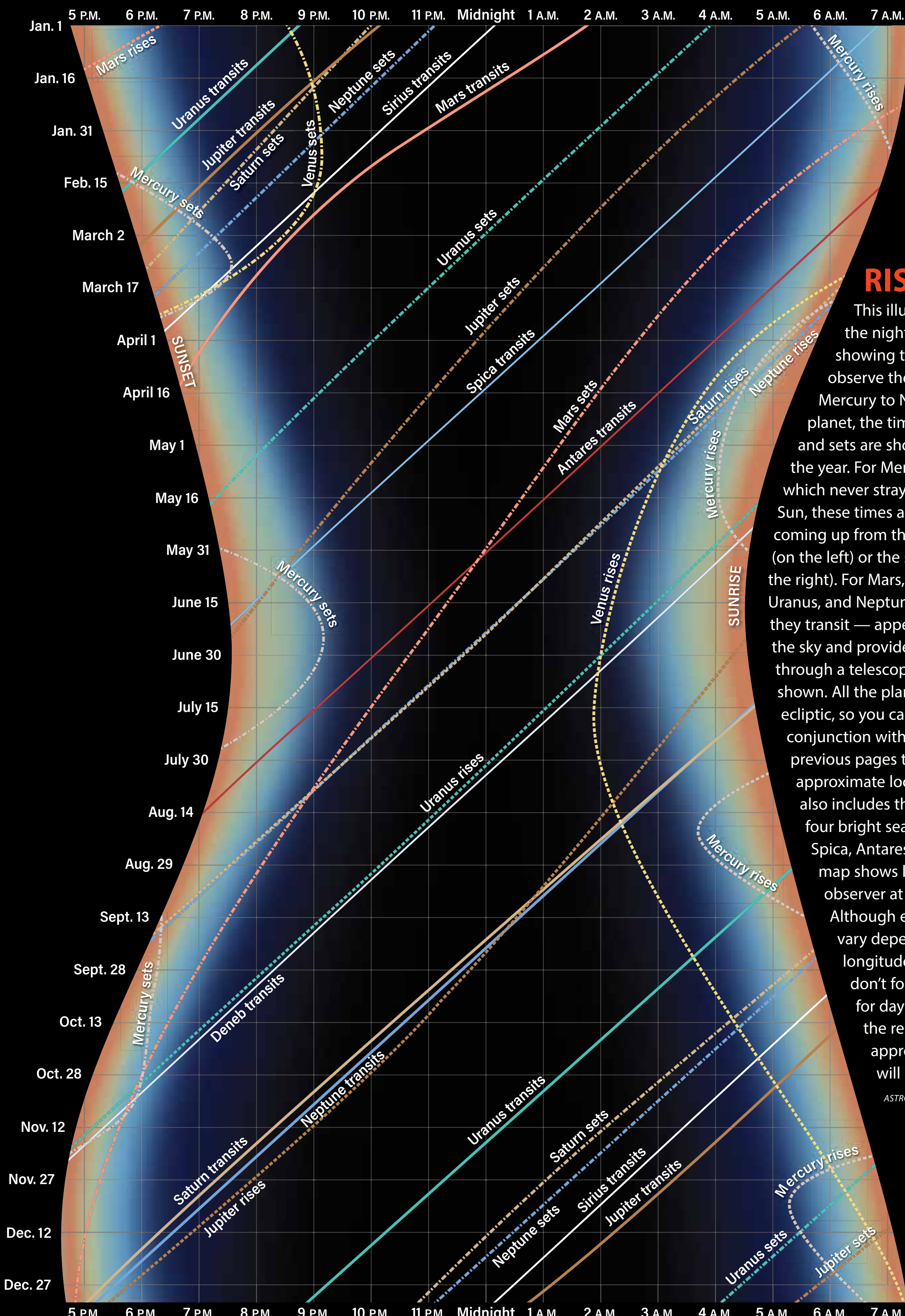
Nov. 21
Uranus is at opposition

Dec. 7
Mercury is at greatest western elongation

Dec. 14
Geminid meteor shower peaks

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

Astronomy magazine



RISE & SET

This illustration presents the night sky for 2025, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

ASTRONOMY: ROEN KELLY