FIELD REPORT

COMPLETE ANNULAR SOLAR ECLIPSE COVERAGE! p. 36

MARCH 2024

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Vol. 52 • Issue 3

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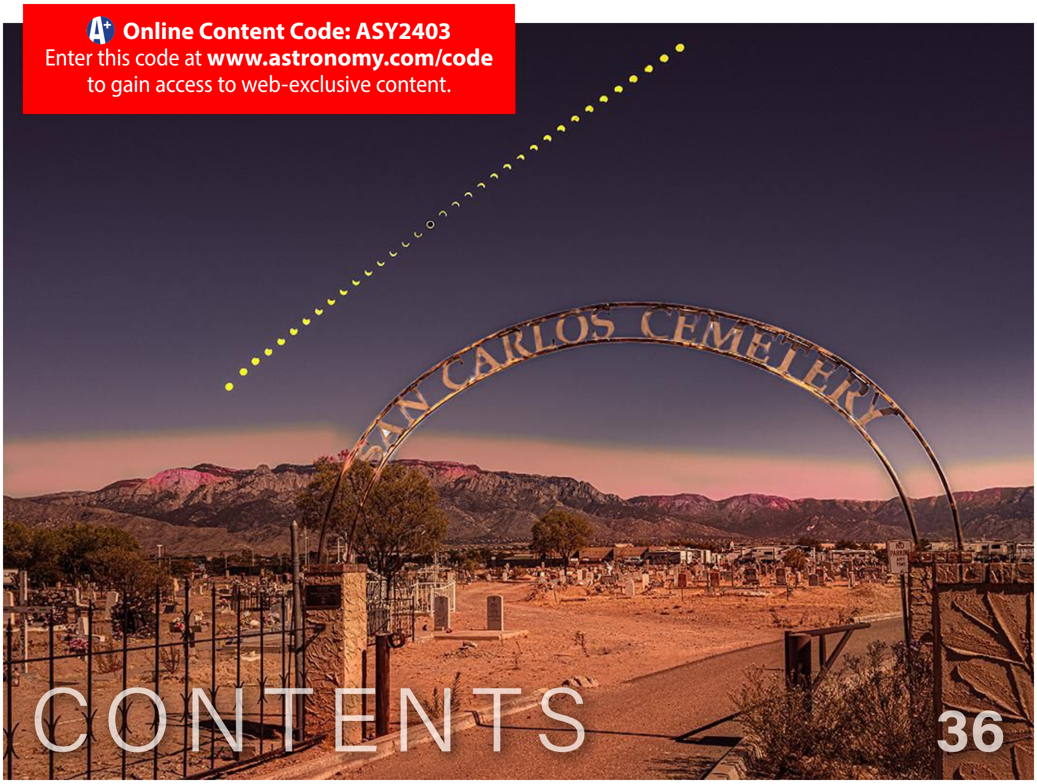

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JOHN DILEO

MARCH 2024
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ON THE COVER

Earth faces a plethora of threats, from coronal mass ejections to radiation from supernovae.
RON MILLER

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QUANTUM GRAVITY

Everything you need to know about the universe this month: See a glittering galactic core, read up on planets in sync, learn about a telescope team-up, and more.

IN EVERY ISSUE

»

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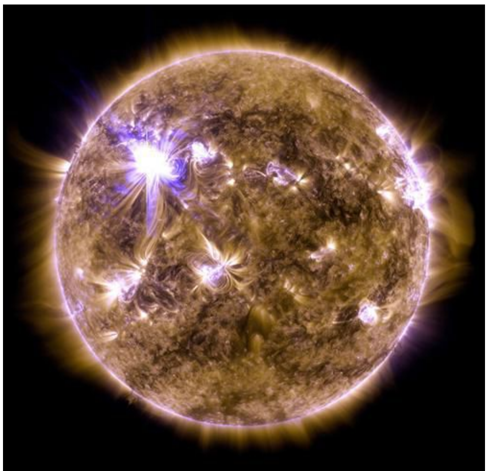
The end of it all



Solar flares, such as these shown in an image from NASA's Solar Dynamics Observatory, represent one danger the cosmos poses to the continued health of life on Earth. NASA'S SCIENTIFIC VISUALIZATION STUDIO, THE SDO SCIENCE TEAM, AND THE VIRTUAL SOLAR OBSERVATORY.

Hey folks, if you didn't already know this, the universe is a dangerous place.

Life can seem pretty nice down here on Earth — well, sometimes. But our daily lives carry us away from contemplating that we're orbiting one star in a gigantic disk of stars and gas, and our galaxy is but one of at least 100 billion others in this vast cosmos. And despite our human stories, fables, and fairy tales, the universe is indifferent about our existence. The universe just *is* — we don't have protection from imaginary forces keeping us safe from real hazards.

In this month's cover story (page 16), science journalist Randall Hyman carries us through a catalog of potential cosmic dangers. We all know the well-told story of 66 million years ago, when the K-Pg Impact ruined the weekend for the dinosaurs and allowed us to eventually rise up to our current level.

But varieties of other troubles could sweep in from beyond our fragile atmosphere. Asteroids and comets could (and will eventually) impact us again — just because we now know that no rock large enough to be a civilization killer orbits in near-Earth space does not mean that other big ones couldn't approach from farther away.

You might remember a couple of years ago when the bright star Betelgeuse, in Orion, seemed a little unstable in its light output, and everyone started hoping that it might be about to go supernova? Well, don't hold your breath, but it will within the next 100,000 years, give or take. At 550 light-years, it's pretty close, and other elderly supergiants are in the neighborhood too. And, believe me, a dose of sterilizing radiation from a nearby supernova would put an abrupt end to people wishing for exploding stars.

What about a superflare from our own Sun? A neighborly visit of antimatter? A micro black hole whizzing past us? Lots of dangers are out there, if they stray too close.

Enjoy the story, and peer into the cosmos tonight with just a little different idea in mind about what awaits us.

Yours truly,

David J. Eicher
Editor

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Amateur radio operators bounce long-range radio signals off auroral displays like this one. JOSHUA SWANSON/NSF

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Roger that

That was a very interesting article on auroral emissions ("Aurorae dazzle across the universe," October 2023), but it was missing an aspect of aurorae that is actually used by certain people here on Earth. Strong auroral events, when highly ionized, were found about 60 years ago to be very good reflectors of radio waves in the range of very high to ultra-high frequencies. It is a phenomenon often exploited by amateur radio operators, especially after a massive coronal mass ejection (CME) on the Sun, using the intense ionization to bounce their radio signals off the auroral curtain. This new phenomenon was a puzzle until amateur radio operators discovered that if everyone pointed their antennas north, they could hear each other. **—William P. Gerhold,** Hewitt, NJ

Truth in naming

I enjoyed reading "Where is our super-Earth?", but I also had to grit my teeth the whole time. Why? It's this super-Earth term that appears on the cover and in the title, and gets repeated throughout.

Who came up with that label for a class of planets, the members of which are likely to be less Earth-like than Mercury, Venus, and Mars? Worlds that are tidally locked, blasted with radiation, and have crushing gravity can hardly be considered Earth-like in any meaningful way. This matters because repeated use of the term in the popular media gives the public the perception that many Earth-like worlds have already been discovered. I feel that the scientific community is doing a disservice to the public by perpetuating such a misleading term for these worlds. **—Randall Henderson,** Warrenton, OR

Erratum

The cover image for the January 2024 issue was incorrectly labeled as the Crescent Nebula. It is an image of IC 443, the Jellyfish Nebula, which is No. 48 on the list. The image was taken by Martin Bracken.

The cover of our January 2024 issue, featuring the Jellyfish Nebula. MARTIN BRACKEN

SNAPSHOT

UNPARALLELED LOOK AT GALACTIC CORE

JWST's near-infrared view is a showcase of active star formation.

NASA's James Webb Space Telescope (JWST) strikes again, this time by capturing never-before-seen details in the dense core of the Milky Way Galaxy. The image shows Sagittarius C (Sgr C), a star-forming region located 26,000 light-years from us and 300 light-years from the Galaxy's supermassive black hole, Sagittarius A*. JWST's incredible level of resolution and sensitivity provides stunning features, both explained and unexplained.

This colorful section of Sgr C contains a mosaic of around 500,000 shining stars spread across the frame. The azure emission and "needles" that appear to be pointing in every direction comprise a large-scale region of ionized hydrogen (HII) gas. Extending down from the top of the frame is an infrared-dark cloud, a dense region of cold gas and dust that appears to blot out the light of background stars. At the lower edge of this infrared-dark cloud, nestled among the HII gas, lies a luminous protostar cluster.

The cluster contains stars that are forming and gaining mass, causing them to produce bright outflows of gas and materials, all the while emitting energetic photons that cause the nearby HII to glow. The core of the cluster contains a massive younger star with over 30 times the mass of our Sun. Despite how bright the cluster appears, the clouds forming it are so dense that not all the stars within can be observed by JWST. This means the cluster is far more crowded and packed than it appears. —DANIELA MATA

HOT BYTES

FOLLOW THE BRIGHT LIGHT

A 200-second-long gamma-ray burst (GRB) detected March 7, 2023, and designated GRB 230307A was over a million times more luminous than our entire galaxy. JWST follow-up observations suggest the GRB resulted from a collision of neutron stars 1 million light-years distant.

DISK MATTERS

The first extragalactic circumstellar disk around a forming star was found located in the Large Magellanic Cloud about 160,000 light-years away. After a jet from the star hinted at the disk's presence, the researchers used data from the Atacama Large Millimeter/submillimeter Array to confirm.

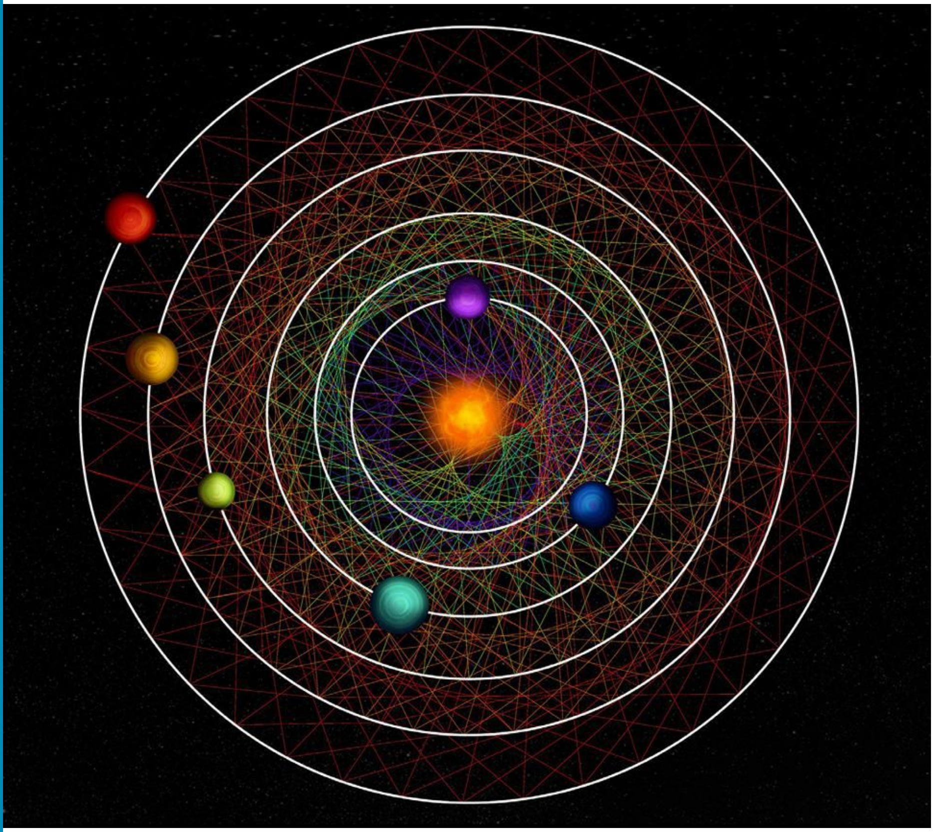
REMEMBERING SPACE TRAVELERS

Ken Mattingly, who orbited the Moon on Apollo 16, died Oct. 31, 2023. One week later, Frank Borman, who commanded Apollo 8, died Nov. 7. Shortly after on Nov. 27, the 10th female astronaut in space, Mary Cleave, passed.

NASA/ESA/CSA/STSCI/SAMUEL CROWE (UNIVERSITY OF VIRGINIA), BOTTOM FROM LEFT: NASA; NASA/ESA/CSA/STSCI/ANDREW LEVAN (IMAPP, WARW); EUROPEAN SOUTHERN OBSERVATORY

ASTRONOMERS FIND SIX PLANETS ORBITING IN RESONANCE

These half-dozen sub-Neptunes are an undisturbed treasure trove for understanding planet formation.



CHAINED HARMONY. The six planets of the HD 110067 system, shown in this artist's depiction, orbit in a resonant chain that links their periods mathematically. © CC BY-NC-SA 4.0, THIBAUT ROGER/NCCR PLANETS

» A newly discovered system of six planets circling a nearby Sun-like star, HD 110067, may be the key to unlocking how planetary systems form. All between the size of Earth and Neptune, the worlds are orbiting in a so-called resonant chain — a rare configuration that offers a window into the system's uniquely gentle history. The discovery was published Nov. 29 in *Nature*.

The chain of discoveries began with an initial detection in 2020 by NASA's Transiting Exoplanet Survey Satellite (TESS), which searches for dips in brightness as planets cross in front of their parent star. At that time, based on the dips, researchers were able to confirm one planet and posit a second possible world.

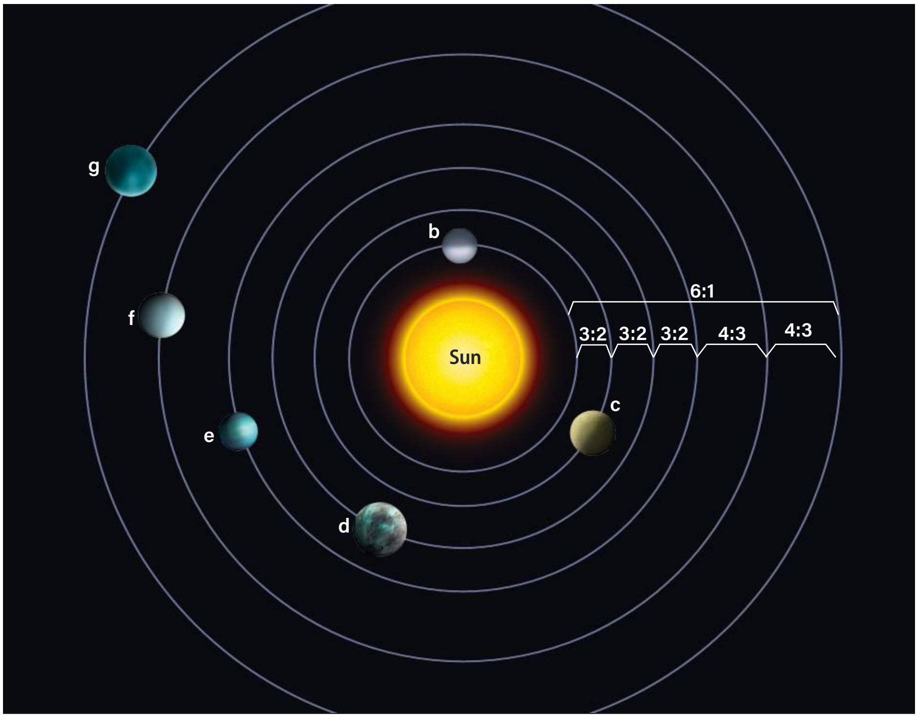
Then, using the European Space Agency's CHaracterising ExOPlanets Satellite (CHEOPS), they watched for additional transits from further planets. And after five or six observations, "we got a hit, like a battleship," said study co-author Hugh Osborn, an astrophysicist at MIT and the University of Bern in Switzerland, during a Nov. 28 press briefing.

They'd found a third planet. And the researchers noticed something intriguing: Each planet's orbital period was related to the next in line. The inner planet (called b) orbits every 9.114 days, the next planet out (c) every 13.673 days, and the last (d) every 20.519 days. Each of those periods is about 1.5 times the next, meaning the planets are in a configuration called a 3:2 mean motion resonance. For every three orbits of the innermost world, b, the next planet out (c) makes two. Then, for every three orbits of c, d makes two.

The team followed the pattern to look for more worlds in this "resonant chain." First, they modeled how often various additional planets in different resonances would transit, picking out the configurations that were most stable. Then, they went looking for the transits they expected from those models — and found three more planets: e, f, and g, with periods of 30.793, 41.059, and 54.770 days, respectively. The entire system could fit inside the orbit of Mercury.

In all, the innermost four planets are in 3:2 resonances. The outer planets f and g are in 4:3 resonances — each planet makes three full revolutions for every four orbits of the planet interior to it. Overall, for every six orbits the innermost planet b makes, the outermost planet g makes one full revolution.

Osborn was "shocked and delighted" when they began spotting planets transiting right when their models suggested. "My jaw was on the floor," he said. "Often we make the predictions and nature finds a way to do something else, to not quite match what we expect." But in this case, their predictions were spot-on.



DEEP RESONANCE. The orbital resonances of the planets of the HD 110067 system are shown in this diagram. For instance, in the time it takes planet b to complete three orbits, planet c completes two. *ASTRONOMY:* ROEN KELLY, AFTER ESA

Such resonant chains should be exceedingly common in nature — but they're not. That's because over time, chaotic events such as passing stars, meteorite impacts, and wandering giant planets muddy any resonances until they are gone.

But HD 110067's resonant chain has persisted for the billions of years since these planets formed, indicating "the evolution of this system has been very quiet, very gentle," said lead author Rafael Luque of the University of Chicago.

A KEY SYSTEM

HD 110067 isn't the first six-planet resonant system discovered, but it still stands out. The star is roughly 80 percent the size and mass of the Sun and glows brightly in the sky at magnitude 8.4, just 100 light-years away in the constellation Coma Berenices. And all six planets are some two to three times the diameter of Earth, falling into the category of planets called sub-Neptunes. In addition to cores of ice or rock, they also have thick atmospheres of hydrogen and helium.

This makes the planets prime targets for JWST to peer through their atmospheres as they transit, using the star as a backlight to look for the presence of light-absorbing molecules such as methane, carbon dioxide, water, and ammonia.

By contrast, the famous red dwarf TRAPPIST-1 is just 1/10,000 the brightness of HD 110067 at optical wavelengths. Further, TRAPPIST-1's seven planets are all rocky worlds with thin atmospheres — if any atmosphere at all.

In HD 110067 and its planets, Luque said, astronomers have a single, perfect testbed for studying how sub-Neptunes form and planetary systems evolve without outside influences. Each of the six planets formed from the same material and has experienced the same history as its peers. This lets astronomers compare these worlds to study how subtle differences in size, mass, temperature, and distance from their star might affect their evolution. The system is a "controlled experiment … that is going to set us up to learn so much in the coming years," said Luque. — ALISON KLESMAN

QUICK TAKES

SANDSTORMS

JWST observations of exoplanet WASP-107 b reveal that the gas giant has an analogue to Earth's water cycle based on silicates, the main component of sand. The silicates evaporate with trace amounts of water deep in its atmosphere, rise and form sand clouds, then rain drops of sand.

CROSSED WIRES

OSIRIS-REx's drogue parachute failed as the mission reentered Earth's atmosphere Sept. 24 with its precious sample of asteroid 101955 Bennu. NASA said Dec. 5 that loose usage of the word *main* in the craft's blueprints led engineers to mistakenly connect two "main" wires that caused the drogue's cord to be cut before it was deployed. Luckily, the main chute ensured a safe landing.

TIT FOR TAT

In an emerging inter-Korean space race, North Korea successfully launched a spy satellite Nov. 21, 2023, after two failed attempts earlier in the year. South Korea's first spy sat launched days later on Dec. 1 on a SpaceX Falcon 9.

GAMMA-RAYS BLAST EARTH

The gamma-ray burst GRB 221009A induced changes in current in Earth's upper ionosphere 300 miles (500 km) high, physicists reported Nov. 14. It's the first time such perturbations from a burst have been detected at those heights.

PARTICLE PHYSICS' DECADAL

The influential Particle Physics Project Prioritization Panel (P5) issued its once-a-decade slew of recommendations Dec. 7. Top priority went to the CMB-Stage 4 radio telescope array, which would study the cosmic microwave background. Neutrino experiments and dark matter detectors also made the list.

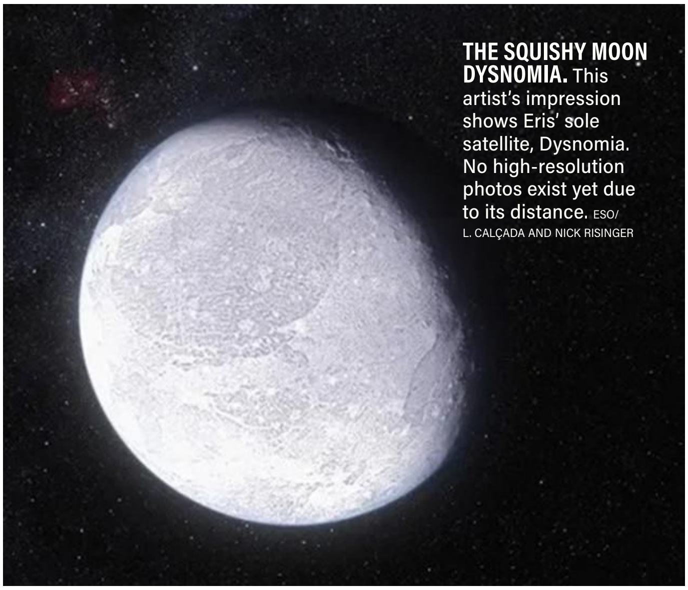
— MARK ZASTROW

Icy worlds' secrets

» The distant dwarf planet Eris is nearly the same size as Pluto and occupies the same frozen region of our outer solar system, called the Kuiper Belt. It's so distant that trying to collect data through telescopes poses many challenges. However, a research team published a new paper in *Science Advances* Nov. 15 demonstrating that by studying how Eris' moon, Dysnomia, affects its parent body as the two orbit each other, researchers can uncover clues about the internal makeup of this distant world.

Pluto and Eris dominate the Kuiper Belt, with the latter just 30 miles (48 kilometers) smaller in diameter than the former. Each has at least one satellite large enough to exert influence on its parent body as the two orbit a mutual center of mass. Francis Nimmo, a planetary scientist at the University of California, Santa Cruz, says that just as Earth's Moon slowed our planet's early rotation rate, the same thing happened with Eris; resulting in Dysnomia and Eris becoming tidally locked.

Analysis of the orbits of Eris and Dysnomia revealed that, based on how the system has evolved, Eris must be differentiated into a denser core and a less-dense crust. Dysnomia is rather small, so for it to have spun Eris down, Eris must be "squishy," with a composition that isn't all hard rock all the way through — i.e., it must have an icy mantle or even an ocean above a more solid, rocky core. This is identical to Pluto, which astronomers believe hosts a liquid ocean beneath its top layer of ice. Ultimately, the study shows that distant bodies like Pluto and Eris, once thought to be rocky, dead worlds, may not be as "boring" as once thought. However, determining which have liquid oceans is still difficult, if not impossible. Nonetheless, "I think the lesson from Pluto is that even out there, oceans are things we should be thinking seriously about," Nimmo said. – JOHN WENZ



THE SQUISHY MOON DYSNOMIA. This artist's impression shows Eris' sole satellite, Dysnomia. No high-resolution photos exist yet due to its distance. ESO/ L. CALÇADA AND NICK RISINGER

PLANETARY MACROSOMIA. The light of the red dwarf LHS 3154 scatters off the Neptune-sized planet LHS 3154 b in this artist's concept. PENN STATE UNIVERSITY

A PLANET TOO BIG FOR ITS STAR

In the annals of planet hunting, LHS 3154 b is a head-scratcher: a giant exoplanet tightly orbiting a star so tiny, it's hard to understand how the star could have birthed it. Reported Nov. 30 in *Science*, the planet tips the scales at 13.2 times the mass of Earth or more, putting it roughly on par with Neptune's 17.1 Earth masses. Yet, its host star has just 11 percent the mass of the Sun.

"Previously, it was just thought that, 'Oh, no, there's no way the lowest-mass stars can actually form this type of planet,'" says Guðmundur Stefánsson, an astrophysicist at Princeton University in New Jersey and the paper's first author.

Stefánsson and his colleagues found the planet with the 10-meter Hobby-Eberly Telescope at McDonald Observatory in Texas by detecting a periodic shift every 3.7 days in the spectrum of light coming from the red dwarf LHS 3154. Follow-up analysis of data from NASA's Transiting Exoplanet Survey Satellite (TESS) and the European Space Agency's Gaia satellite confirmed that the tug of a close-in, unseen planet was causing the star to wobble.

LHS 3154 b weighs in at 0.35 percent of the mass of its host star. Among planets with orbits less than 10 days, that's more than twice the ratio of any other known system. (For comparison, Jupiter is less than 0.1 percent the Sun's mass.)

Because planets form alongside their stars from the same disk of material, astronomers have long assumed that low-mass stars also tend to form low-mass planets in their protoplanetary disks, as solid bits and pieces clump together. This left the team at a loss to explain LHS 3154 b with computer models of planet formation. "We were really struggling — like, we said, 'OK, how can we actually form this type of planet?'" says Stefánsson.

But by increasing the amount of dust in the protoplanetary disk by a factor of 10 compared to observations, the simulations could produce close-in planets with the girth of LHS 3154 b. This suggests that there is more material available to nascent planetary systems than astronomers have suspected. – MARK ZASTROW

NASA/ESA/NSF'S NOIRLAB/MARK GARLICK/MAHDI ZAMANI

IN A FLASH. An Luminous Fast Blue Optical Transient, or LFBOT, reaches peak brightness — much brighter than any surrounding galaxies — in this artist's concept.

A LOONEY STAR

In September 2022, astronomers saw a bright, distant flash of light. This mysterious signal from about 4 billion light-years away was named AT2022tsd and nicknamed the Tasmanian Devil. It was a rare example of a Luminous Fast Blue Optical Transient (LFBOT) — an object that shines in blue light, quickly increasing to its peak brightness before fading away within just a few days. Due to their brevity, only a handful of LFBOTs have been captured since the first detection in 2018.

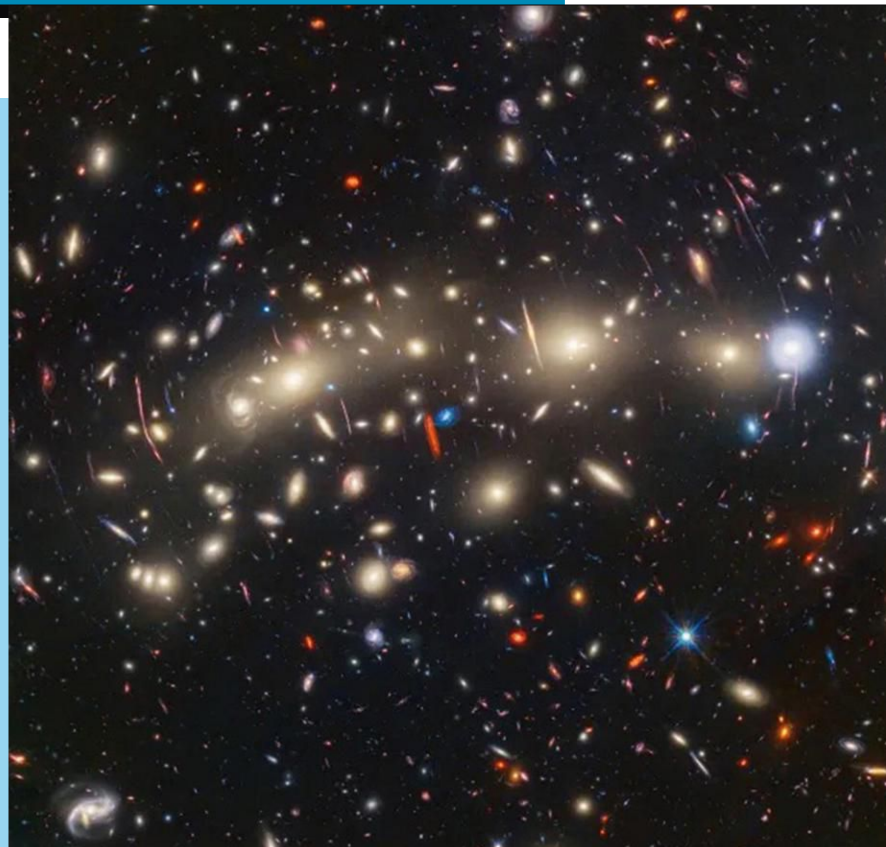
What separates the Tasmanian Devil from all other LFBOTs is that after astronomers first saw it peak in brightness, it continued to flash more than a dozen times, each time for just minutes. This behavior is leaving astronomers absolutely puzzled, because each time the Tasmanian Devil flashes, it is nearly as bright and as powerful as the initial explosion.

The LFBOT in question was observed by 15 different telescopes and is located about 4.4 billion light-years from Earth. The combined data recorded a minimum of 14 irregular and highly energetic bursts over the course of 120 days. Anna Ho, lead author of the study and assistant professor at Cornell University, stated in a press release that the observed flashes are most likely only a fraction of the total number. Despite the Tasmanian Devil's unusual behavior pushing the limits of physics, astronomers are hopeful the supernova-like flashes will offer some insight into what's causing such activity.

Researchers suggest the driving source could be powerful jets from either a black hole or neutron star. One theory suggests the LFBOT's original flash may have formed such an object, with the subsequent intense flashes caused as material falls inward, with some of it being funneled away by the jets. "We don't think anything else can make these kinds of flares," said Ho in a press release. If you're curious to learn more, the team's paper was published Nov. 15 in *Nature*. — D.M.

122 The grams of oxygen extracted from the martian air by the Mars Oxygen In-Situ Resource Utilization Experiment (or MOXIE) on NASA's Perseverance rover since 2021. This amount of oxygen could sustain a small dog for 10 hours.

TELESCOPES UNITE



NASA, ESA, CSA, STSCI, JOSE M. DIEGO (IFCA), JORDAN C. J. D'SILVA (UWA), ANTON M. KOEKEMOER (STSCI), JAKE SUMMERS (ASU), ROGIER WINDHORST (ASU), HAOJING YAN (UNIVERSITY OF MISSOURI)

THIS NEW VIBRANT and colorful image of a massive galaxy cluster dubbed the Christmas Tree Galaxy Cluster (cataloged as MACS0416) was created from a marvelous union of the James Webb Space Telescope's (JWST) infrared view and the Hubble Space Telescope's (HST) optical deep-field view. This behemoth of a galaxy cluster lies 4.3 billion light-years away and is composed of two massive colliding galaxy clusters.

The Christmas Tree cluster earned its nickname from its various colors and flickering lights seen as the cluster's galaxies temporarily amplify background objects via gravitational lensing, said lead author Haojing Yan of the University of Missouri in a press release. Researchers found one dozen new transient objects using the new JWST data after comparing four different epochs of images to look for "lights" that appeared and disappeared over the course of 126 days. — D.M.

$150,000

The amount that the Federal Communications Commission fined TV provider Dish Network Corp. in October for failing to move a dead satellite to a safe orbit — the first space littering fine of its kind.

Cosmic cotton candy

Lying 90 million light-years away in Aquarius, the peculiar galaxy NGC 7727 is the product of an ongoing galactic merger, captured with the Gemini South Telescope in Chile. The result is a mixture of active star-forming regions and molecular clouds, twining the galaxy's features into what looks like a hazy ball of cotton candy. But NGC 7727's most remarkable feature lies at its center: not one, but two supermassive black holes, the closest such pair to Earth yet discovered. The more massive of the two weighs in at 154 million times the mass of the Sun, while the other is 6.3 million solar masses. Though the pair is currently 1,600 light-years apart, the black holes are expected to merge within the next 250 million years. — ELIZABETH GAMILLO

INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA; ACKNOWLEDGMENT: PI: C. ONKEN (AUSTRALIAN NATIONAL UNIVERSITY); IMAGE PROCESSING: T.A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE/NSF'S NOIRLAB), J. MILLER (INTERNATIONAL GEMINI OBSERVATORY/NSF'S NOIRLAB), M. RODRIGUEZ (INTERNATIONAL GEMINI OBSERVATORY/NSF'S NOIRLAB), M. ZAMANI (NSF'S NOIRLAB)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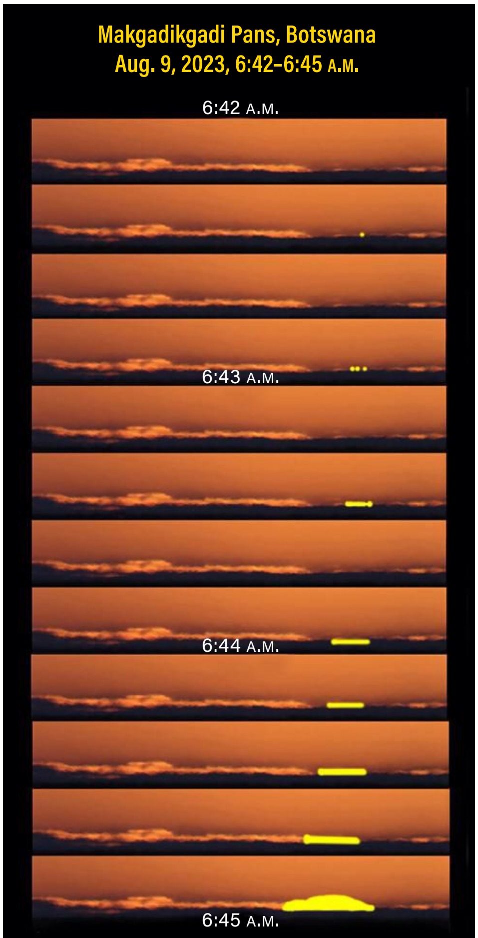
Tropical Novaya Zemlya effects

Now you see me, now you don't.



During the dry season at Botswana's Makgadikgadi salt pan, temperature inversions lead to all manner of mirages. 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.

Any reference will tell you the Novaya Zemlya effect is a polar mirage — and it is. But Novaya Zemlya-like effects are not limited to the Arctic.

The Novaya Zemlya effect is an atmospheric refraction phenomenon that causes a viewer to perceive the premature birth of the Sun as the long polar nights near an end. On Jan. 24, 1597, Gerrit de Veer, a member of Willem Barentsz's icebound third arctic expedition, became the first known person to record the phenomenon; the Novaya Zemlya effect is named after the archipelago in northwestern Russia where he witnessed it. On that day, two other crew members also glimpsed the Sun two weeks before it was expected to rise.

Further observations by Barentsz and his crew, as well as observations from other artic explorers in later years — including Ernest Shackleton during his 1914–1917 expedition to Antarctica — lent credence to the reality of the phenomenon. But as Siebren Y. van der Werf and colleagues explain in the January 2003 issue of *Applied Optics*, the sightings met with disbelief from their contemporaries and triggered heated discussion among scientists, including German astronomers Johannes Kepler (1571–1630) and Michael Maestlin (1550–1631). Investigations and atmospheric modeling by van der Werf and others, however, have now placed the truthfulness of these sightings beyond doubt.

The flat lid of the Sun soon made a second showing.

Today, Novaya Zemlya-like effects in the form of segmented Suns have been seen well beyond the Arctic: from the Channel Islands off the coast of Normandy, France (49° north latitude); Boston (42° north latitude); Santa Croce Camerina, Sicily, and San Francisco (both 37° north latitude); and even Mount Wilson, California (34° north latitude), to name a few. Apparently, it is possible to observe variations of the Novaya Zemlya effect wherever temperature variations are just right to produce strong atmospheric refraction over large, flat areas of Earth's surface. It's now common to refer to such effects as either a premature rising or delayed setting of the Sun on a much smaller scale — in a matter of minutes, rather than weeks.

A tropical sighting

On the morning of Aug. 9, 2023, a group of friends and I had the opportunity to witness a tropical Novaya Zemlya-like effect from the Makgadikgadi Pans in Botswana (20° south latitude). This 6,178-square-mile (16,000 square kilometers) salt pan is one of the largest and flattest on the planet. During the dry season, the region's desert climate can bring a 30-degree Fahrenheit (17 degrees Celsius) or more difference between day and night, making it prone to strong temperature inversions, which occur on clear nights when the ground cools off rapidly by radiation.

After sleeping out under the stars, we grouped together that morning to wait for a possible green flash. Around 6:40 A.M., with Earth's shadow still visible in the western sky, I was surprised to see a bead of light from the upper rim of the Sun already manifesting just over the eastern horizon. As the Sun normally makes its appearance in the east when Earth's shadow sets in the west, I knew something was askew.

Indeed, the Sun was still about 2° below the horizon when we first glimpsed that bead of light, which vanished about 15 seconds later — only to reappear some 30 seconds later as three beads strung out along the horizon (two close together, and one father south). Once again, the beads vanished, only to return this time as a long, flat ribbon of light before it too blinked out. The flat lid of the Sun soon made a second showing, when it swelled slightly into a flattened rectangle. Then, over the course of a minute or two, this flattened form slithered northward along the horizon until 6:45 A.M. (the predicted time of sunrise), when the rest of the Sun began rising.

If you have witnessed a similar phenomenon beyond the Artic, send reports to sjomeara31@gmail.com.

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

These are

the ways OUR WORLD WILL END

Whether by the bang of a supernova or the whimper of a faltering magnetic field, Earth and everything on it is doomed. Sorry.

BY RANDALL HYMAN

THE UNIVERSE IS A TERRIFYING PLACE, filled with existential threats. Earth may seem quite solid beneath our feet, but the continued existence of the thin layers of rock, water, and air that sustain us is in no way guaranteed. Errant asteroids, soaring superflares, and exploding supernovae are just a few of the calamities that might befall our fragile world.

In the short term, we may be able to manage or mitigate some of these threats. Asteroids can be diverted and power grids hardened. But other apocalypses are inevitable as the solar system ages: a runaway Moon, Earth's collapsing magnetosphere, the Sun's flagging heart. Each one represents a countdown to a different apocalypse, with some more imminent than others.

After NASA's Double Asteroid Direction Test smashed a half-ton spacecraft into Dimorphos, the asteroid sprouted a tail of dust. The blue dots in this image are boulders ranging in size from 3 to 22 feet (0.9 to 6.7 m) that were thrown off the asteroid's surface by the impact. NASA, ESA, D. JEWITT (UCLA)

PREVIOUS PAGES: Earth faces a plethora of threats in this collagelike illustration. From upper right, an incoming asteroid impacts Earth. At the bottom, an active Sun bedecked with prominences unleashes a flare and a coronal mass ejection. At left, a nearby supernova bombards Earth with fatal radiation, causing aurorae to dance above the planet. And Earth's oceans are in the process of boiling away — the ultimate fate of our world in roughly 1 billion years, due to the Sun's gradual increase in brightness. RON MILLER

Moving mountains

The most obvious threat is the one that has been featured in countless sci-fi stories and films: asteroids. Most famously, 66 million years ago, a miles-wide asteroid slammed into the ocean near the Yucatán Peninsula and plunged the planet into chaos. Wildfires that consumed continents and bone-chilling nuclear winters ended the 180-million-year reign of giant reptiles in the geological blink of an eye.

Until recently, we were no better prepared to ward off these collisions than the dinosaurs. But that changed in September 2022 when NASA's Double Asteroid Redirection Test (DART) proved that humans could, in principle, deflect asteroids from catastrophic collisions with Earth. Weighing just over half a ton, the DART spacecraft smashed into an asteroid called Dimorphos, the junior partner of a binary system, at nearly 14,000 mph (22,500 km/h) — generating the energy equivalent of three tons of TNT.

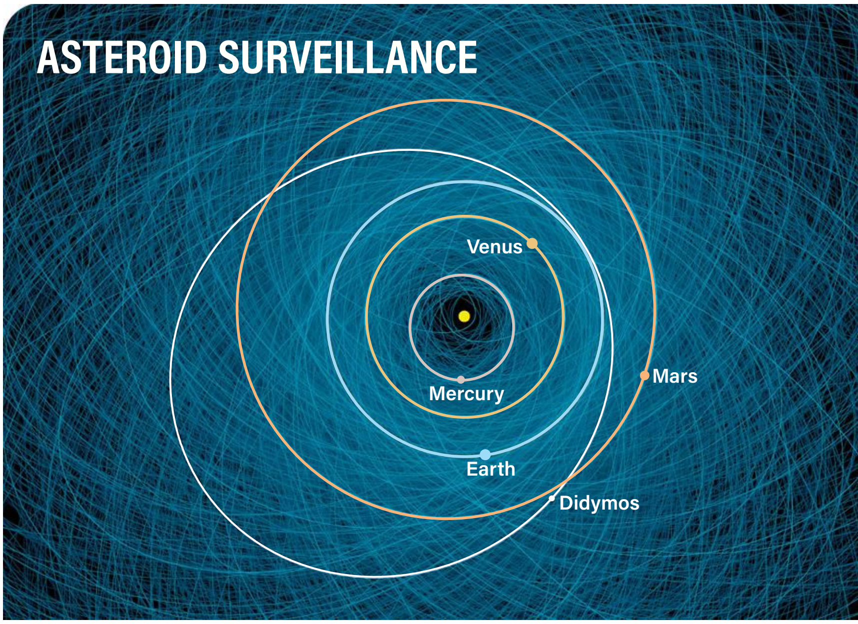
The results of the experiment have been both enlightening and sobering.

"The impact of DART was just a tiny event in the life of this asteroid," says David Jewitt, a professor of astronomy at the University of California, Los Angeles, who published a study about DART's aftermath in July 2023. "If you wanted to deflect a bigger asteroid — for example, something 10 times larger — then you'd need 1,000 DARTs to get the same minuscule deflection. This deflection business is very, very tough."

One of the reasons NASA chose Dimorphos is that it is locked in a binary system with an asteroid called Didymos — which, at half a mile (0.8 kilometer) wide, is five times Dimorphos' size. This made any change generated by the impact easier to track.

"The idea is that you hit a binary that has an initial orbit period of about 12 hours, and change that by a few minutes every orbit," says Jewitt. "Even though the deflection is incredibly small, after 100 orbits it becomes a very measurable quantity. That's what gave us success."

As it turned out, the impact shortened the system's 12-hour orbital tango by 32 minutes. Compared to the tens of miles per second at which the 5.5-million-ton Dimorphos whips around the Sun, this translates to a tiny fraction of its momentum — tenths of



Astronomers deem an asteroid potentially hazardous if it is wider than about 460 feet (140 m) and comes within 5 million miles (8 million km) of Earth's orbit. This chart plots the orbits of 2,200 such potentially hazardous asteroids. Highlighted in white is the orbit of Didymos; its smaller companion, Dimorphos, was the target of NASA's Double Asteroid Redirect Test (DART) mission. NASA/JPL-CALTECH an inch per second. Jewitt says that any useful deflection of a larger asteroid would require a far greater shove or need to occur decades ahead of an impending terrestrial collision to have a cumulative effect.

A larger impact, however, means more debris — and more headaches. As Hercules saw, decapitating the Hydra only multiplies its deadly heads. Months after the DART collision, Jewitt and colleagues studying Hubble images discovered a swarm of previously undetected boulders, some as large as houses, drifting away in all directions at an average speed of 0.6 mph (1 km/h).

"It's possible they were blasted out in the same way as all the smaller debris," says Jewitt, "but it's also possible that, because of the very low gravity, the boulders that were preexisting on the surface were shaken off."

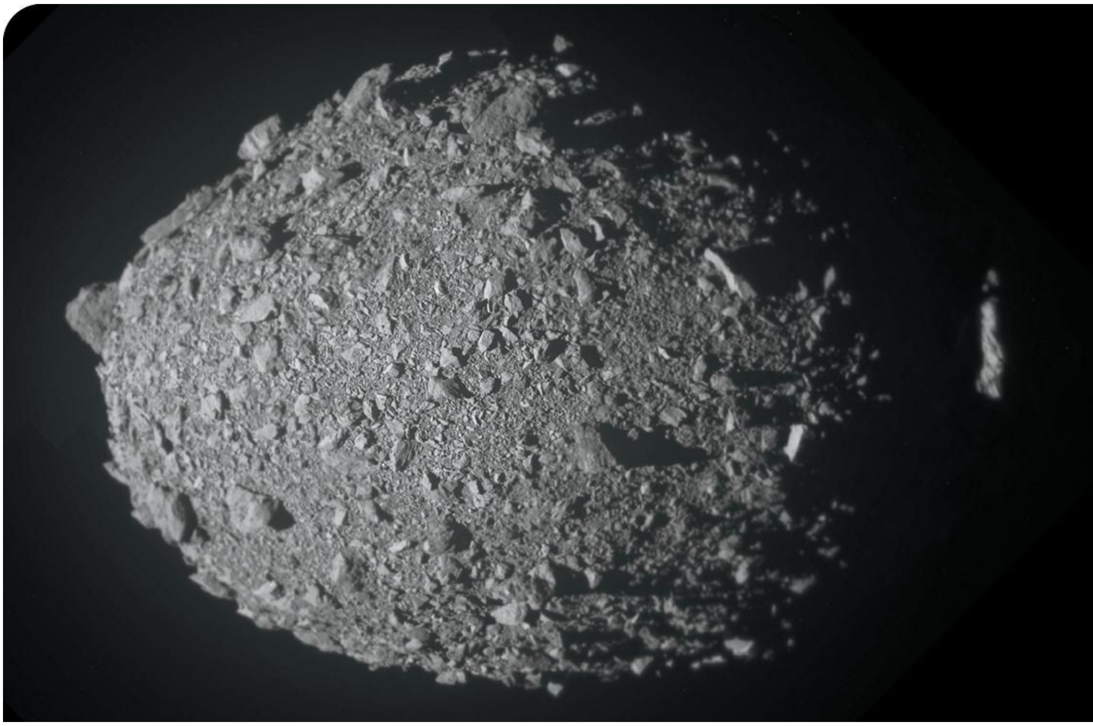
The difference matters. If we hope to intercept incoming asteroids in nondestructive ways, we need to know how to execute a gentle nudge. Jewitt believes that the boulders are blast collateral, but he won't know until July, when the binary system returns to Hubble's view. Comparing the previously charted trajectories of the boulders with new imagery, he and his colleagues hope to reconstruct how they were cast into space.

After that, the boulders will not be visible from Earth for 15 years, until Dimorphos and Didymos' orbit brings them closer to Earth. However, they will be visited in the interim by the European Space Agency's (ESA) Hera spacecraft in late 2026.

Even assuming we could deflect an incoming object, the challenge remains to find potentially hazardous asteroids with the months to years of advance notice needed to mount a mission. NASA's Center for Near-Earth Object Studies currently lists only a few space rocks of immediate concern, but new ones show up frequently with little warning. With barely a day of advance notice, asteroids whipped past Earth in 2012, 2019, and 2021, ranging in size from a football field to several city blocks. The 11,000-ton Chelyabinsk meteor that exploded over the Russian Urals in 2013, damaging thousands of buildings and injuring over 1,000 people, was not on anybody's radar.

This lack of awareness should begin to change with the opening of the Vera C. Rubin Observatory in Chile in 2025 and the launch of NASA's Nancy Grace Roman Space Telescope in 2026. Rubin will be able to survey the entire southern sky every three days, generating 20 terabytes of data each night and issuing on average 10 million alerts regarding any detected changes — all processed and shared worldwide in less than 60 seconds. Roman will pack the same crisp sub-arcsecond resolution as Hubble, but with 100 times the field of view, generating a separate mountain of data on changing and moving objects in the sky.

When the two join forces, both



The loose rubble-pile nature of 581-foot-wide (177 m) Dimorphos is apparent in this mosaic stitched together from the last 10 images sent by the DART spacecraft before it crashed into the asteroid. NASA/JOHNS HOPKINS APL

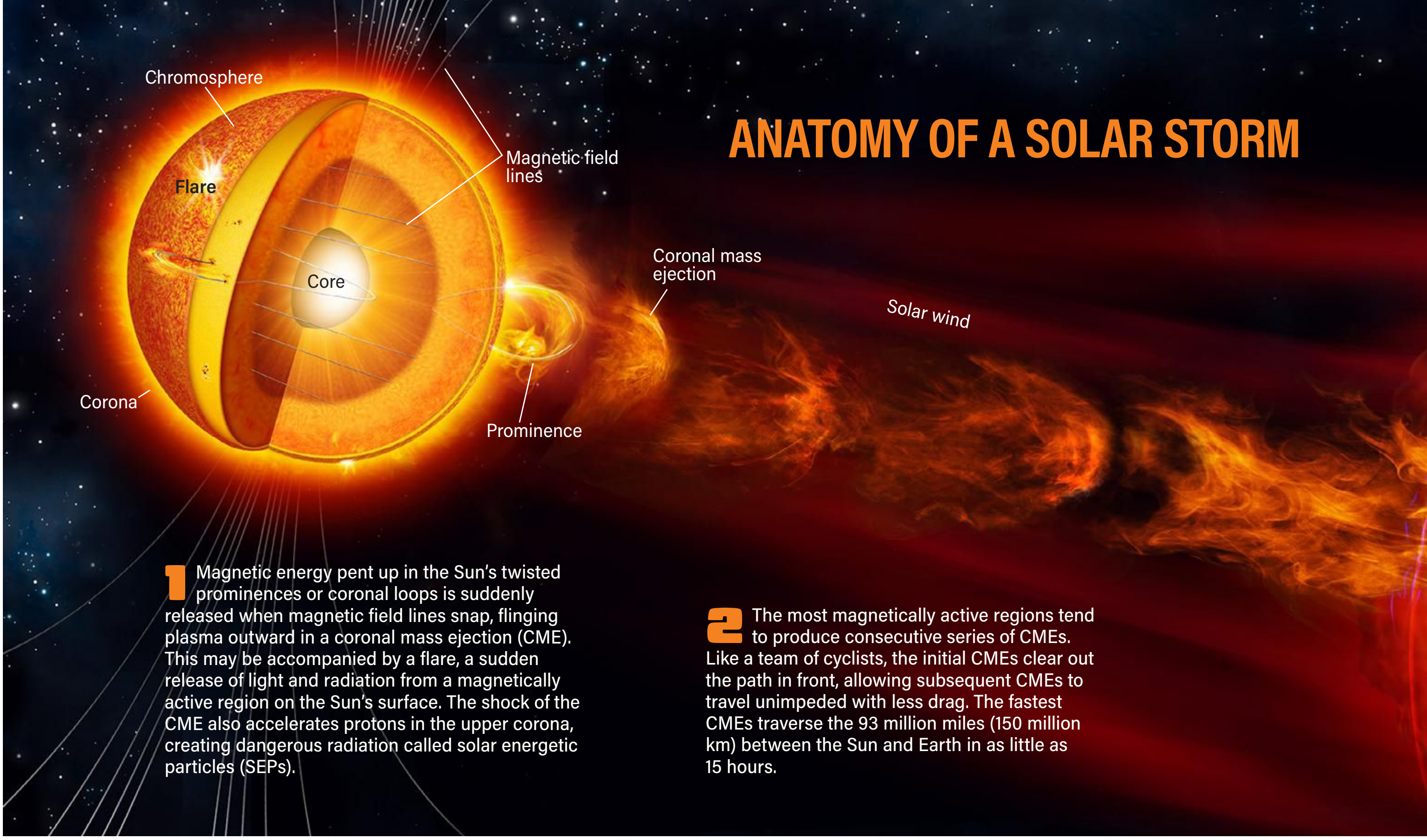
HOW ASTEROIDS COULD SAVE THE WORLD

Developing the technology and methods for moving asteroids intact could be handy for averting a collision. But if some astronomers' visions come to fruition, these techniques could also help solve another planetary threat, perhaps the most urgent of all: climate change.

In a paper published in *Proceedings of the National Academy of Sciences* in July 2023, cosmologist István Szapudi at the University of Hawai'i suggested that it would be feasible to park a 35,000-ton asteroid at the gravitationally stable L1 point between Earth and the Sun. The motivation for doing so would be to anchor a giant tethered reflector that would reduce terrestrial solar heating by 1.7 percent. Such a reflector by itself would naturally be pushed away from L1 by the pressure of the sunlight it reflects. The asteroid would serve as a counterweight, keeping the reflector tethered in place.

Though the anchor would be 150 times lighter than Dimorphos, the rockets needed to capture and transport even a small asteroid do not yet exist. Nevertheless, the proposal demonstrates that not all asteroids in the vicinity of Earth are necessarily harbingers of doom. *—R.H.*

BROOKS BAYS/UH INSTITUTE FOR ASTRONOMY



Space weather is unpredictable and scientists still don't understand much of the underlying physics. But the account above is a plausible sequence of events in some of the largest solar storms, like a Miyake event. *ASTRONOMY*: ROEN KELLY

hemispheres of the sky will come under intense scrutiny for everything from asteroids to supernovae.

Bracing for a flare-up

Even as Rubin and Roman scour the skies, another doomsday clock continues ticking: solar superflares. Solar flares are commonplace and generally benign. They are outbursts of light and radiation launched from regions of the Sun with intense magnetic fields, whose endpoints are marked on the solar surface by the cooler dark patches known as sunspots.

Above sunspots, the Sun's magnetic field can stretch out for tens of thousands of miles, carrying tendrils of superheated, magnetically bound plasma. The magnetic field lines store energy like stretched and twisted rubber bands — and when they snap, they can release huge quantities of plasma, called coronal mass ejections (CMEs). If a CME happens to be aimed at Earth, a geomagnetic storm will hit us days later. Thanks to the protective magnetosphere generated by Earth's molten iron core, most CMEs are harmlessly deflected.

But once in a great while, a flare hundreds or thousands of times more powerful than normal — a superflare — belches a wallop that penetrates Earth's magnetosphere.

Analysis of radiocarbon spikes preserved in the rings of ancient trees shows that in the past 10,000 years, at least six such solar storms have showered Earth. These are named Miyake events after physicist Fusa Miyake, who in 2012 reported the first such event, detected in Japanese cedar tree rings from 774 C.E. Subsequent studies uncovered another spike in 993 C.E., and then four more in the years 663, 5259, 5410, and 7176 B.C.E.

There is still much debate surrounding the exact nature of Miyake events. A paper published in October 2022 suggests that some Miyake events may be series of consecutive solar storms within a given year. But the leading explanation for these occurrences are superflares from our Sun.

To our prehistoric ancestors, these events likely went unnoticed, aside from spectacular auroral light shows at unusually low latitudes. But in modern times, CMEs from superflares pose a serious threat. They could hobble satellites, crash GPS systems, and disrupt global communications. Electrical grids could overload and take months to be rebuilt. Cellphones, laptops, and other electronic devices would survive, but many would be limited by the lack of functioning telecommunications.

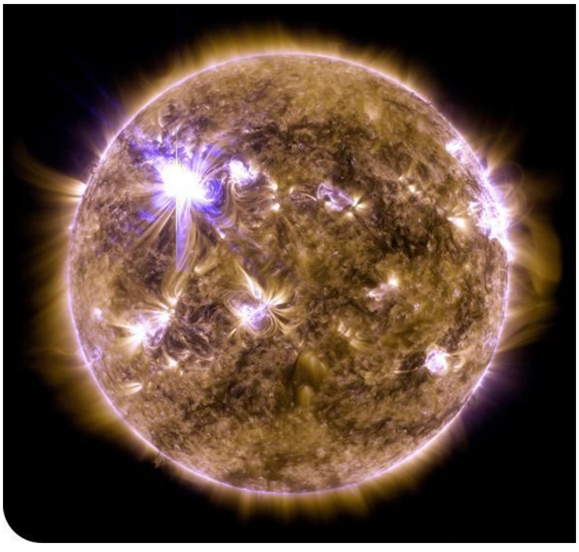
Modern civilization already experienced a small dose of these consequences in 1989, when a sizeable CME glanced across Québec, frying high-voltage lines and causing widespread blackouts. The last superflare before that was the Carrington Event of 1859; the ensuing geomagnetic storm sent currents coursing through telegraph wires, setting fires in telegraph offices across the U.S.

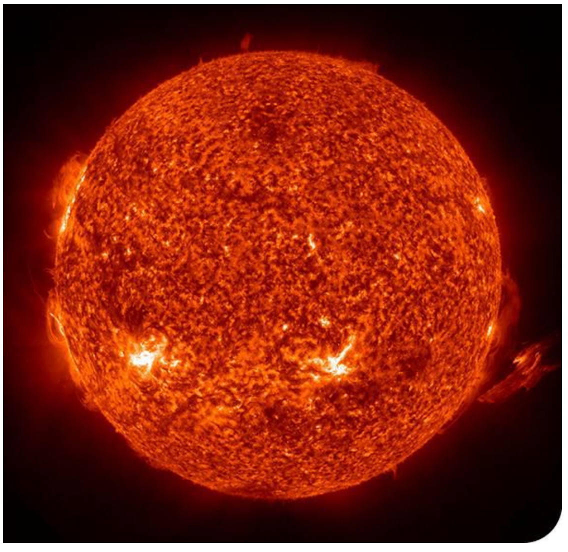
To learn how to predict superflares, astronomers are looking not just at the Sun but also to other stars. Young, hot, massive stars that burn blue and spin quickly can generate superflares at the blazing pace of one a day. Our Sun, a yellow dwarf, is much cooler and longer lived, so superflares are relatively rare.

But how rare? In 2019, a team led by Yuta Notsu of the University of Colorado Boulder used data from NASA's Kepler space telescope and the ESA's Gaia star-mapping satellite to determine that on Sun-like stars, Carrington-size flares occur every 500 to 600 years. High-end superflares — 100 times more powerful than Carrington — arise every 2,000 to 3,000 years.

By that measure, we aren't yet overdue for another Carrington Event. But the Federal Energy Regulatory Commission is hedging its bet. In 2013, it issued Order 779 directing the North American Electric Reliability Corporation, a nonprofit power grid overseer, to develop plans for "blocking geomagnetically induced currents from entering the Bulk-Power System."

Observing superflares in other star systems also gives a dramatic





FROM LEFT TO RIGHT: A solar flare flashes in the upper left quadrant of the Sun in this extreme ultraviolet image taken by NASA's Solar Dynamics Observatory (SDO). The flare is so bright that it creates a starlike diffraction pattern on the image.

A powerful coronal mass ejection (CME) is flung into space at lower right in this SDO image taken July 23, 2012. This CME was not directed at Earth, but if it had been, it would have triggered a geomagnetic storm similar to the Carrington event of 1859. NASA'S SCIENTIFIC VISUALIZATION STUDIO, THE SDO SCIENCE TEAM, AND THE VIRTUAL SOLAR OBSERVATORY (2)

Ancient trees — like the one at right, found in the eroded banks of the Drouzet River, near the town of Gap in the southern French Alps — hold the keys to dating the most powerful solar storms. These storms, known as Miyake events, cause radiocarbon spikes to appear in the trees' rings (above). CÉCILE MIRAMONT (2)

sense of the threats any other life-forms in the galaxy might face. In another sobering paper that Notsu co-authored in April 2023, he and colleagues described the largest superflare and prominence ever recorded in real time using ground- and space-based telescopes — albeit in a binary star system (V1355 Orionis) unlike our Sun.

"The observed velocity of that prominence far exceeded the escape velocity of its star," says Notsu, "indicating that the eruption was capable of becoming a CME. Such eruptions are very important for evaluating the potential effects on planetary atmospheres."

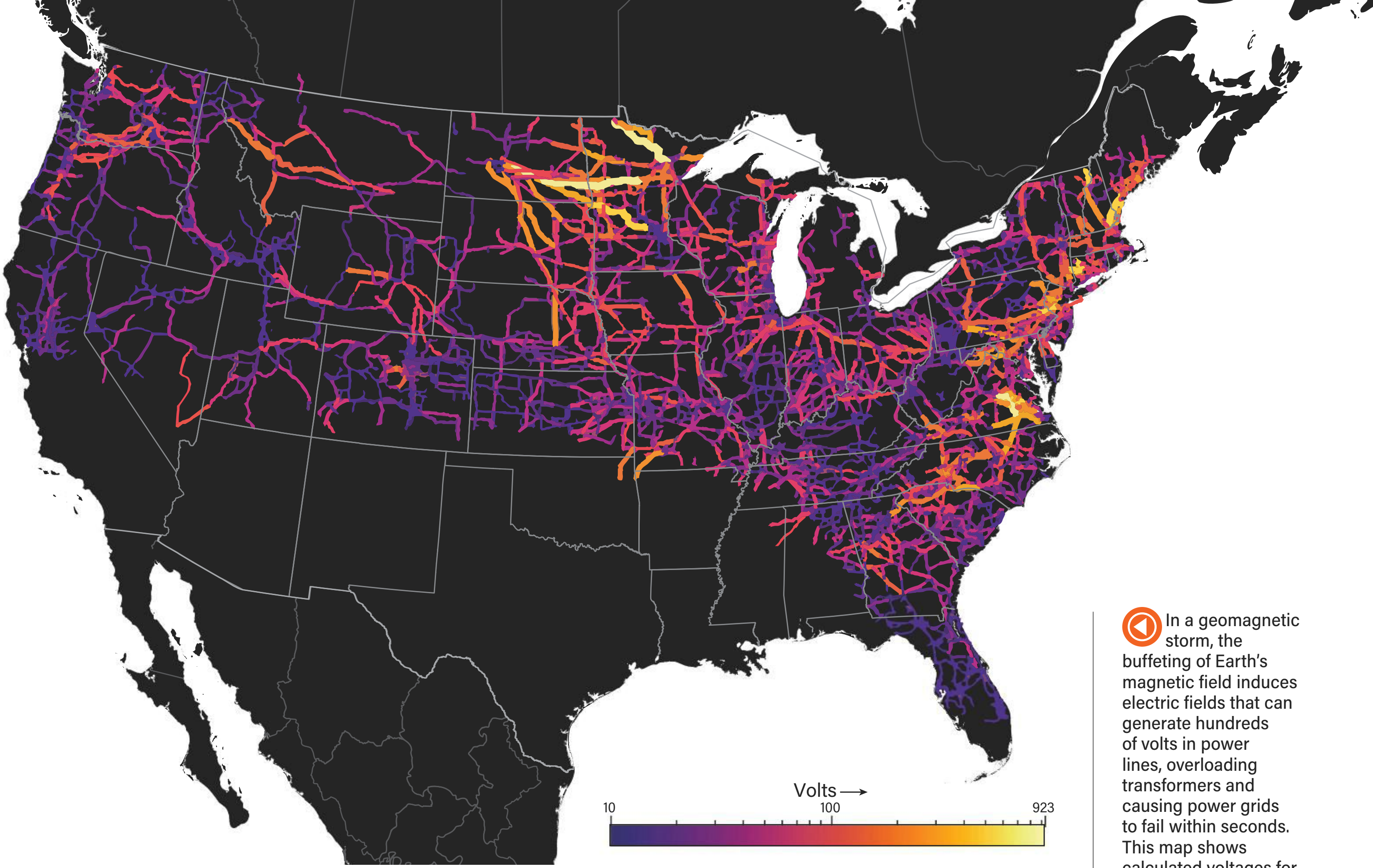
Notsu notes that the size and speed of the ejected material — trillions of tons traveling at 3 million mph (4.8 million km/h) — shows how large CMEs can get. The V1355 Orionis event was 10 times more powerful than anything the Sun is known to have ever produced, potentially enough to strip any nearby planets of their atmospheres.

Stardust to stardust

Perhaps nothing symbolizes the cosmic cycle of life and death like a supernova. These events are either the explosive final act of a massive star or a white dwarf triggered by runaway nuclear fusion. Just like asteroids and superflares, there is ample evidence that supernovae have bombarded Earth and even shaped life throughout our planet's history.

"We are the children of supernovae," says Brian Fields, an astronomer at the University of Illinois Urbana-Champaign. "Life would not be possible without them. The iron in your blood, the oxygen you're breathing, the silicon in your computer, all are from supernovae that blew up long before the solar system was formed."

While supernovae provide the building blocks of life, they can



In a geomagnetic storm, the buffeting of Earth's magnetic field induces electric fields that can generate hundreds of volts in power lines, overloading transformers and causing power grids to fail within seconds. This map shows calculated voltages for the entire U.S. high-voltage power grid during a once-per-hundred-years storm. The magnitude of the voltage depends not only on latitude, but also the electrical properties of the bedrock in that region. For instance, the Superior Craton in the Upper Midwest is made of crystalline rocks that are highly resistive, which increases the induced voltages during a magnetic storm. Similarly, just east of the Appalachians, a thick layer of resistive minerals in Earth's crust increases the risk to the Eastern Seaboard. *ASTRONOMY*: ROEN KELLY, AFTER LUCAS ET AL. DOI: 10.1029/2019SW002329, CC BY 4.0 DEED

also destroy it. Being too close can mean instant incineration or lethal irradiation. Although the gamma rays supernovae produce cannot penetrate the upper reaches of our atmosphere, they can destroy our protective ozone layer through a chain of chemical reactions.

There are several types of supernovae, but it is the death throes of high-mass stars — weighing at least eight times our Sun — that spark the colossal core-collapse or type II supernovae. These supernovae produce nearly all atomic elements besides hydrogen and helium. Within our Milky Way Galaxy, two or three supernovae occur every century.

When shrouded in gas, type II supernovae become particularly potent. Months or years after the initial burst of gamma rays, superheated shock waves reverberate within the gas bubble and generate copious amounts of X-rays. Millennia later, as the blast barrels through space, it interacts with dust and radiation, producing high-energy particles called cosmic rays.

To understand the reach and frequency of these multistage killer events, scientists need more than Miyake dating. Tree-ring records go back only 15,000 years and carbon-14 dating isn't reliable after 60,000 years (too much of the sample has decayed away), so uncovering traces of nearby supernovae in the geological record requires different techniques.

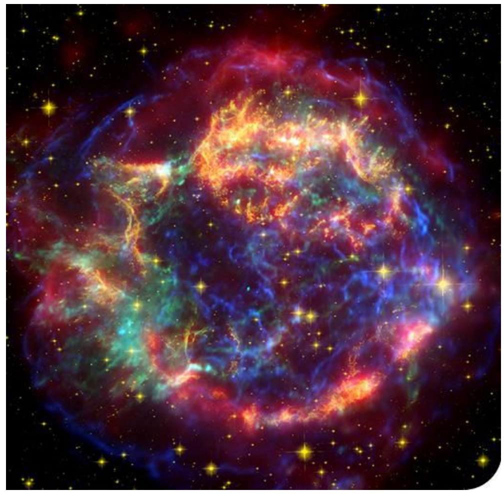
In 2015, a team of scientists perfected the use of an isotope called iron-60, a byproduct of supernovae, as a powerful chronometer with a half-life of 2.6 million years, providing reliable dates up to 10 million years in the past.

"It's basically like tree rings," says Fields. "We know there were recent nearby supernovae explosions because there is a wealth of iron-60 in two specific layers on the ocean floor as well as on the Moon and in Antarctic snow. Something brought it here 3 million years ago, and another pulse 7 million years ago."

While iron-60 does an excellent job of detecting past supernovae, it can also help determine how far away they were. "The farther away you stand, the less iron-60 you intercept," says Fields. "By seeing how much is there, we can work out the distance."

Until a recent paper that Fields co-authored with principal investigator Ian Brunton, scientists deemed 10 parsecs — about 33 light-years — to be a safe

WHILE SUPERNOVAE PROVIDE THE BUILDING BLOCKS OF LIFE, THEY CAN ALSO DESTROY IT.



ABOVE, LEFT TO RIGHT: The size of a fossilized megalodon tooth demonstrates the power of the giant prehistoric shark, which could grow up to 67 feet (20 m) long. Some researchers have proposed that the megalodon and other large ocean species died out in part due to the blast of radiation from a nearby supernova. W. SCOTT MCGILL/DREAMSTIME.COM

The explosive death of a massive star 325 years ago created the Cassiopeia A supernova remnant. This composite image includes infrared data from the Spitzer Space Telescope (red), visible imagery from the Hubble Space Telescope (yellow), and X-ray data from the Chandra X-ray Observatory (green and blue). The X-rays — which pose a threat to the atmospheres of nearby planets — are emitted by gases that are caught in the expanding shock wave and heated to temperatures of up to 18 million F (10 million C). NASA/JPL-CALTECH/O. KRAUSE (STEWARD OBSERVATORY)

The inevitable collision between the Milky Way and Andromeda galaxies will create a spectacular skyscape 4 billion years in the future. NASA, ESA, Z. LEVAY AND R. VAN DER MAREL (STSCI), T. HALLAS, AND A. MELLINGER

enough distance for surviving supernovae. Their new research significantly expands the kill zone for gaseous type II supernovae to about 160 light-years, multiplying the affected volume of space about 125 times over.

"That's why we wrote the paper," says Fields. "We realized that this kind of supernova can be dangerous to a much larger region than ordinary supernovae."

Fields notes that the supernova 3 million years ago coincided with a notable megafauna die-off in the Pliocene.

According to one theory, muons may be the reason. These subatomic particles, about 200 times heavier than electrons, are produced by gamma rays. Large megafauna even half a mile (0.8 km) underwater would have been especially subject to their lethal effects. Based on iron-60 traces in seafloor sediments, astrobiologists have linked the die-off of whale-sized megalodon sharks with at least one supernova 2.6 million years ago in the Local Bubble, some 160 light-years away, at that very time.

The good news is that because supernova candidates are supermassive stars, they are also hard to miss, pumping out 100,000 times more light than the Sun. When they're nearby, we know it, and even those shrouded in gas are brilliant in infrared wavelengths.

When this next occurs, it won't likely be from any star we know by name today. Spica in Virgo is the nearest supermassive star likely to go supernova, and it lies some 250 light-years away — well outside the supernova danger zone.

But as our star system orbits the center of the Milky Way, it passes through our galaxy's spiral arms every 100 million years or so. By some estimates, each passage is likely to bring Earth within 33 light-years of a supernova, leaving it potentially exposed to its devastating effects.

March of time

Beyond Earth's most pressing cosmic countdowns, the faltering dynamics of an aging solar system await. They are far in the future — several times as long as life itself has populated our planet — but they are fascinating to contemplate.

The first to go could be our planet's magnetic core. A January 2022 study of thermal conductivity at Earth's core-mantle boundary found that a mineral called bridgmanite is transferring heat out of the core 50 percent faster than previously thought. Once our core cools enough, its magnetic properties will fail. Without the magnetosphere to protect us, solar storms will gradually strip away our atmosphere.

While the atmosphere decays, the Moon's tidal pull will continue sapping Earth's momentum. The law of conservation of angular momentum dictates that Earth's deceleration will accelerate the Moon, launching it farther outward. Total eclipses will become mere transits as the Moon tidally locks over a single point on one side of the Earth. This dance will then reverse as gravity draws Earth and Moon together again, ultimately ripping our satellite asunder and throwing our orbit and seasons into disarray.

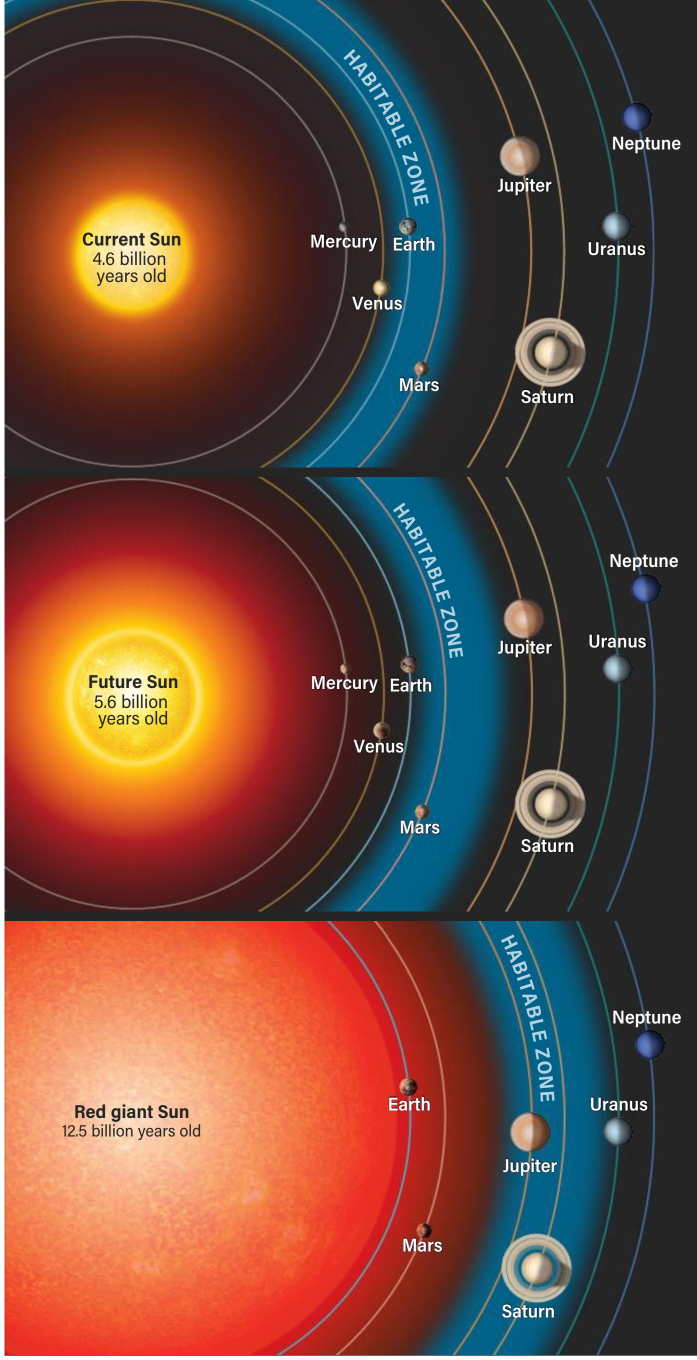
Meanwhile, the evolving Sun will play havoc with Earth and its temperature regulation. As stars like the Sun mature, they burn brighter — by about 10 percent every billion years. This will push the solar system's habitable zone outward, beyond Earth. A billion years from now, Earth will be too hot to maintain liquid water on its surface. The oceans will evaporate, thickening the atmosphere into an oppressive greenhouse and leaving behind a barren, scorched landscape.

Prospects for any surviving life are grim. Eventually, the Sun will lose its nuclear gusto when the hydrogen supply in its core runs out. As its now-helium core contracts, a shell of hydrogen around the core will temporarily ignite. The Sun will swell into a red giant and its fiery outer layers will consume Earth's orbit (but fall short of Mars). For a few million years, the moons of Jupiter and Saturn may sit in the habitable zone.

Ultimately, the outward pressure of the Sun's radiation will weaken and its own gravity will trigger its demise. Five billion years from now, the Sun's core will collapse into a small, dense white dwarf, even as its outer layers are expelled into a planetary nebula. At about the same time, the Milky Way and Andromeda galaxies will collide in a spectacular maelstrom of light and energy. Eventually the merged galaxies will settle down as an elliptical galaxy, a homogenous ball of aging suns with little dust, gas, or new star production.

Finally comes the fate of the universe itself. Scenarios range from a Big Crunch — the reversal of the Big Bang toward a new singularity — to a Big Freeze or Big Rip, an infinite expansion driven by dark energy that flings stars and galaxies so far apart that the night sky becomes a blank slate. A June 2023 paper suggested an alternate finale in which gravity and the theoretical force known as Hawking radiation cause all matter in the universe to simply evaporate, starting with black holes.

Contemplating these catastrophes and the ticking clocks that mark their inexorable approach can be a bit of a downer, no doubt. But perhaps we should instead count ourselves lucky, and savor this moment in the universe's chronology — a brief window between clock resets — that has allowed life on our planet to flourish.



THE END OF HABITABILITY

Earth currently lies in the Sun's habitable zone (top) — the region of our solar system where the surface temperature of a body can support liquid water. But as our Sun ages, the location of this zone will change. As the Sun burns through its nuclear fuel, fusing hydrogen to inert helium, its core will shrink and get denser. This boosts the Sun's fusion rate, causing it to burn brighter.

In about 1 billion years (middle), the Sun will be about 10 percent brighter and the solar system's habitable zone will move outward, leaving Earth behind. A runaway greenhouse effect will cause the oceans to boil away. But even before that, the Sun's increased radiation will break down carbon dioxide in the atmosphere, asphyxiating plant life. Oxygen levels will plummet as the entire carbon cycle breaks down, terminating all complex life.

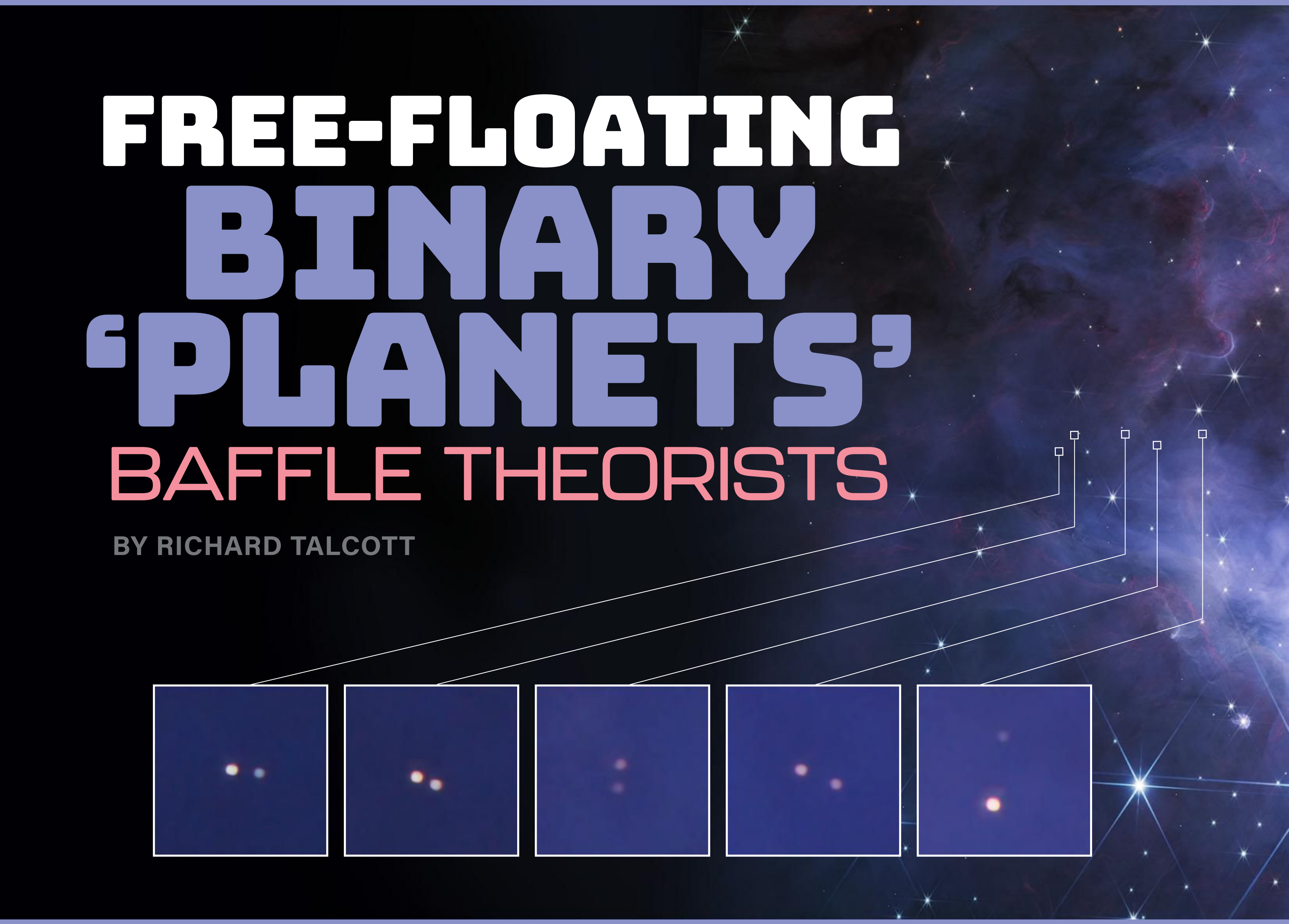
Eventually, in about 5 billion years (bottom), the Sun's core will become hot and dense enough to start burning the previously inert helium. The Sun will become a red giant and expand outward, engulfing our planet once and for all.

ASTRONOMY: ROEN KELLY

Randall Hyman *is a journalist and photographer whose work has been featured in numerous publications, including* Smithsonian, Science, *and* The Atlantic.

FREE-FLOATING BINARY 'PLANETS' BAFFLE THEORISTS

BY RICHARD TALCOTT



JWST found 40 Jupiter-mass objects with binary companions in the Orion Nebula. Now scientists have to figure out how they got there.

EVER SINCE THE James Webb Space Telescope (JWST) opened its eye to the universe in 2022, astronomers have been inundated with astounding new views that threaten to overturn what seemed to be solid ideas dating back decades. Early on, for instance, researchers discovered massive galaxies that existed just a few hundred million years after the Big Bang — far earlier than anyone expected.

Now, astronomers Samuel Pearson and Mark McCaughrean of the European Space Agency's European Space Research and Technology Centre in Noordwijk, the Netherlands, have brought the revolution closer to home. Their observations of the Orion Nebula (M42) reveal dozens of Jupiter-mass objects orbiting in pairs. The findings cast doubt on models that predict how planet-sized bodies form.

The researchers turned JWST's Near-Infrared Camera on M42 for 34.9 hours. They zeroed in on the nebula's core, a region about 3.9 by 2.6 light-years across that includes the Trapezium Cluster. The hottest and brightest stars in this cluster radiate the ultraviolet light that ionizes the entire nebula and causes it to glow.

The scientists chose the Orion Nebula because it contains stars from the most massive O-types to the smallest M dwarfs, a plethora of sub-stellar brown dwarfs, and lots of even smaller objects with planetary masses. When you combine this with its young age (less than 2 million years), its proximity to Earth (1,350 light-years away), and its advantageous location nearly 20° from our galaxy's plane (which reduces foreground contamination) and just in front of the massive Orion Molecular Cloud 1 (which lessens background interference), you have an ideal

JWST captured the inner region of the Orion Nebula, including the bright stars of the Trapezium Cluster just left of center, at near-infrared wavelengths. NASA/ESA/CSA/S. PEARSON AND M. MCCAUGHREAN (ESTEC)

INSETS: These close-up images reveal five JuMBOs. All 10 of these planetary-mass objects have masses less than 7 Jupiters.

laboratory for studying how stars and planets form.

Young brown dwarfs and planetary-mass objects glow as they contract, converting gravitational energy into light. Nearly all of their radiation is in the infrared part of the spectrum, making JWST essential for detecting them. Pearson and McCaughrean found 540 objects with masses no more than 13 times that of Jupiter, putting them in the realm of planetary masses and below that of brown dwarfs. Of these, 168 have masses ranging from 5 Jupiters down to 0.6 Jupiter.

But what really threw the scientists for a loop was the number of binary objects in their sample. Forty of the objects have a companion and two appear to be part of triple systems. The separations range from 25 AU to 390 AU. (One AU, or astronomical unit, is the average Earth-Sun distance — 93 million miles [150 million kilometers].) And even JWST can't separate objects closer than 25 AU at M42's distance, so the count could be higher.

The number of Jupiter-Mass Binary Objects (JuMBOs for short) far exceeds expectations. Nearly all high-mass stars have at least one companion. This drops to around 50 percent for Sun-like stars, 15 percent for high-mass brown dwarfs, and 8 percent for low-mass brown dwarfs. If this trend continued to planetary-mass objects, as theory predicts, the number of binary objects should be around zero. But the percentage actually climbs back up to brown-dwarf levels.

The researchers stress that theorists must be missing something in their explanations for how planetary-mass objects form. If they arise by collapsing gravitationally, as stars do, then an unknown factor must assist the process because no current theory can produce these low-mass objects in this way.

If such objects come about by coalescing in a circumstellar disk, as planets do, then they must be ejected violently from their host stars. But the JuMBOs would have to miraculously weather this storm to stay together. Pearson and McCaughrean suggest that some combination of these two ideas might solve the problem, though a brand new third way seems equally likely.

Contributing Editor **Richard Talcott** *wrote about JWST's discovery of a building block of life in the Orion Nebula in December 2023.*

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

Enter the springtime sky

Mercury (seen here near center during its best 2023 evening elongation) reaches its best evening elongation of 2024 this month. ALAN DYER

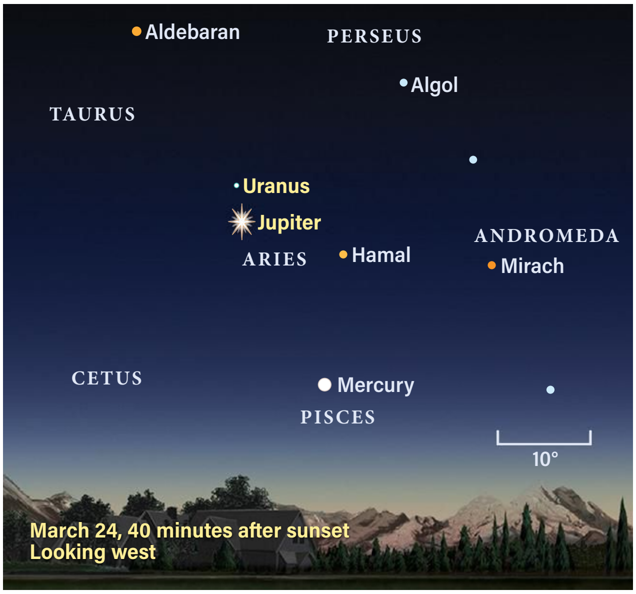
The evening sky of springtime hosts Mercury, Jupiter, and Uranus. It's a good last chance to catch the richness of the jovian atmosphere, plus a few interesting events involving the Galilean moons. Venus dominates the morning sky, visible in brightening twilight, while Mars and Saturn progressively come into view late in the month. And if we're lucky, Comet 12P/Pons-Brooks might put on a good show for binoculars as it crosses Andromeda, Pisces, and Aries.

Mercury reaches its best evening appearance for the year as it extends its elongation from the Sun out to 19° by March 24. However, it is brighter before this date — catching it in mid-March at magnitude –1.5 on the 9th is likely one of your earliest views. While it is bright, it stands only 3° high in the western sky 30 minutes after sunset and sets shortly before 7 P.M. local time.

After the clocks move forward an hour on the 10th, a crescent Moon aids finding Mercury on the 11th. The thin crescent stands 15° high 30 minutes after sunset and Mercury is 4.5° high, to Luna's southwest. Through a scope, Mercury spans 6" and is almost full at 89 percent lit.

The phase changes quickly for the speedy planet. Shining at magnitude –1.2 on the 15th, Mercury is now easy to spot above the western horizon and remains visible for more than an hour after sunset. The gibbous disk is 11 percent narrower, at 78 percent lit. A week later, on the 22nd, Mercury reaches 50 percent lit and spans 7". It remains bright,

Sunset show



Mercury reaches its greatest elongation from the Sun on March 24, when it is visible long after sunset. Jupiter and Uranus (the latter will require binoculars) are nearby as well. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

MERCURY reaches greatest elongation from the Sun on the 24th, its best evening appearance for the year.

now at magnitude –0.5, and stands 6° high a full hour after sunset. You might even spot some of the fainter stars of Pisces in the background. Jupiter stands 24° away in neighboring Aries.

Two days later (March 24), Mercury reaches its greatest elongation, now at magnitude –0.3 and on view for more than an hour after sunset. Only four days later (the 28th), it's dimmed to magnitude 0.4 and shows a fine 27-percent-lit crescent spanning 8". Mercury is moving rapidly toward conjunction with the Sun and quickly dims as the crescent diminishes, dropping to magnitude 1 by the end of March.

Jupiter is a brilliant object high in the western sky this month. It remains visible until nearly 11 P.M. local time in early March. However, the observing window narrows at the end of the month, when Jupiter stands only 15° above the horizon at 9 P.M. local daylight time and sets within 2.5 hours.

Early March is the best period to catch good views of Jupiter. Its higher elevation avoids the hazy and turbulent air nearer the horizon, which results from the Sun heating the ground during the spring daytime. Starting the month at magnitude –2.2, it's hard to miss the planet's location within Aries, one of the fainter

— Continued on page 34

RISING MOON | Ticks on the timeline

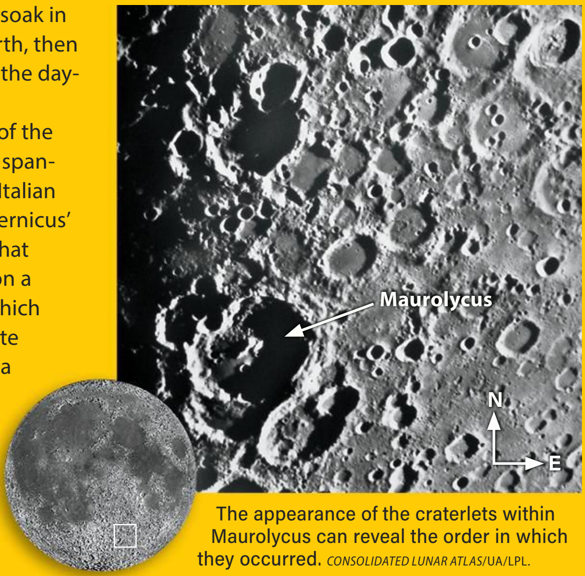
RIDING HIGH in the southwest during spring evenings, our sister Luna is bright and white. On the evening of the 16th, at First Quarter, soak in the breathtaking series of seas in the north, then scan southward across the craters lining the day-night terminator.

Anchored in the southernmost third of the lunar disk is the large crater Maurolycus, spanning some 70 miles and named after an Italian mathematician who disagreed with Copernicus' Sun-centered solar system. The impact that carved out this classic beauty occurred on a thin enough spot to fracture the floor, which later allowed lava to seep up but not quite cover the complex of central peaks with a smooth skin. The event half-wiped out a crater to its immediate south as well as one to the northwest.

As the bombardment continued, newer, sharper features left their mark by breaking up and softening the ones that came before. The smaller craterlets on the floor are the freshest. Can you figure out the sequence of the impacts that created the group on the northwest edge of Maurolycus? The picture here helps a lot, but your own observations at the eyepiece on the 16th and following evenings will help to set the timeline straight. A similar story plays out on the crater group Gemma Frisius a short hop to the north.

Once the Moon begins to approach Full phase, note how a ray from Tycho crosses Maurolycus. Use high magnification to help you pick out the subtle stripe.

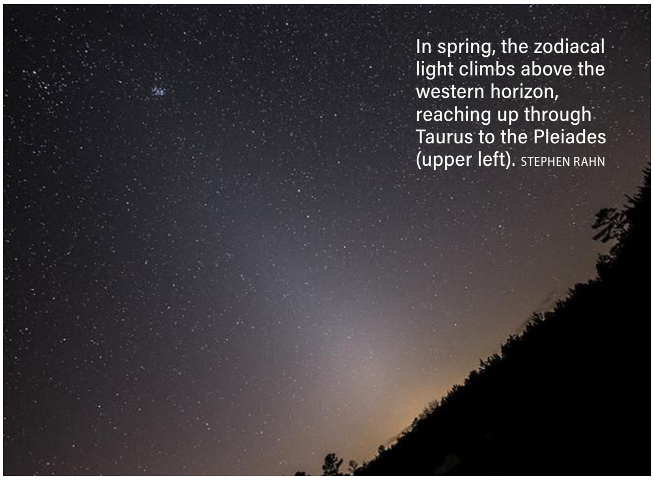
Maurolycus



The appearance of the craterlets within Maurolycus can reveal the order in which they occurred. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | False dusk lingers

Piercing the Pleiades



In spring, the zodiacal light climbs above the western horizon, reaching up through Taurus to the Pleiades (upper left). STEPHEN RAHN

IT'S ANOTHER QUIET MONTH for meteors, with no major showers. However, keep an eye on the sky for the random fireball.

March is a peak time to view the zodiacal light in the evening sky. The steeply inclined ecliptic, rising from Pisces though Aries and into Taurus, is where this cone-shaped glow can appear as twilight diminishes. It is fainter than the Milky Way. Try using averted vision by scanning your eyes back and forth along the western sky to render the zodiacal light visible.

You need a very dark western horizon with no city lights in that direction, and higher altitude aids viewing this ethereal glow. Avoid the Moon as well. The first two weeks of March are best, followed by the last few days after the Full Moon passes into the morning sky.

The zodiacal light is the result of sunlight reflecting off billions of dust particles that pervade the solar system — the remnants of eons of dusty comets. Whenever Earth encounters these trails, we see a meteor shower. But in March, we can see the full expanse of this dust stretched out across space.

STAR DOME

HOW TO USE THIS MAP

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

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

10 P.M. March 1
10 P.M. March 15
9 P.M. March 31

Planets are shown at midmonth

MAP SYMBOLS

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

STAR MAGNITUDES

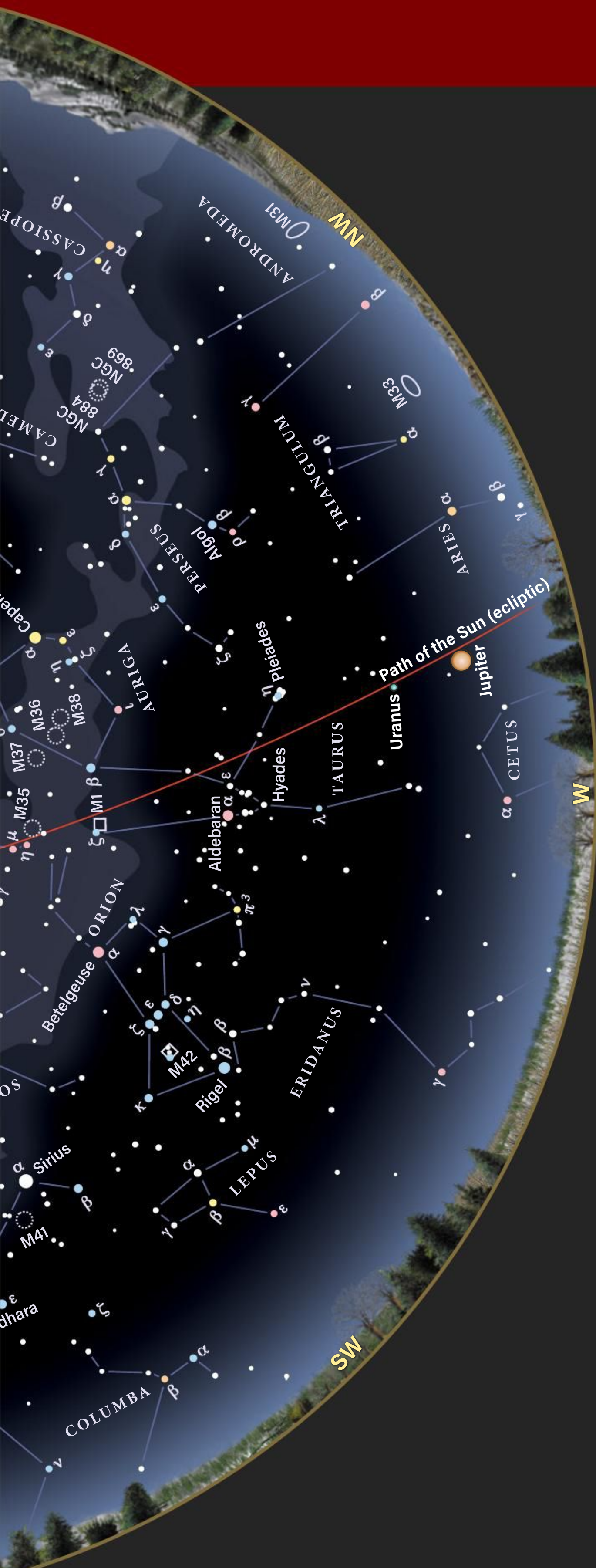
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

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.**



MARCH 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

3 The Moon passes 0.3° north of Antares, 4 A.M. EST
Last Quarter Moon occurs at 10:23 A.M. EST
Asteroid Juno is at opposition, 1 P.M. EST

7 The Moon passes 4° south of Mars, midnight EST

8 The Moon passes 3° south of Venus, noon EST

10 The Moon is at perigee (221,764 miles from Earth), 3:04 A.M. EDT
New Moon occurs at 5:00 A.M. EDT

13 The Moon passes 4° north of Jupiter, 9 P.M. EDT

14 The Moon passes 3° north of Uranus, 8 A.M. EDT

17 First Quarter Moon occurs at 12:11 A.M. EDT
Neptune is in conjunction with the Sun, 7 A.M. EDT

19 Vernal equinox occurs at 11:06 P.M. EDT

21 Venus passes 0.3° north of Saturn, 10 P.M. EDT

23 The Moon is at apogee (252,460 miles from Earth), 11:45 A.M. EDT

24 Mercury is at greatest eastern elongation (19°), 7 P.M. EDT

25 Full Moon occurs at 3:00 A.M. EDT; penumbral lunar eclipse

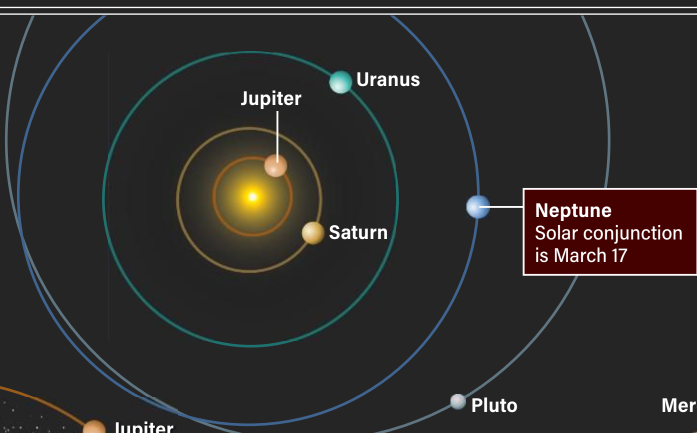
30 The Moon passes 0.3° north of Antares, 11 A.M. EDT

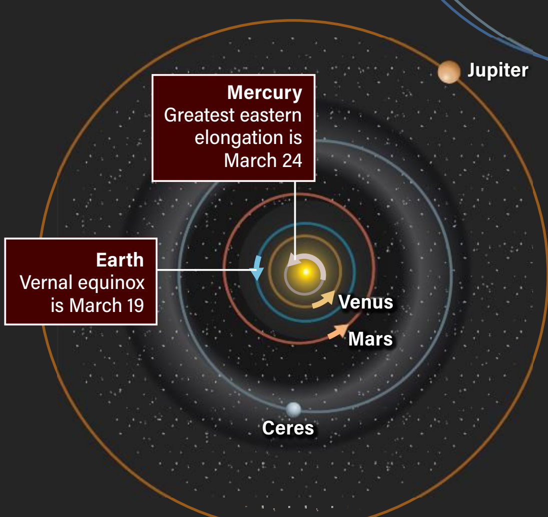
PATHS OF THE PLANETS

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.





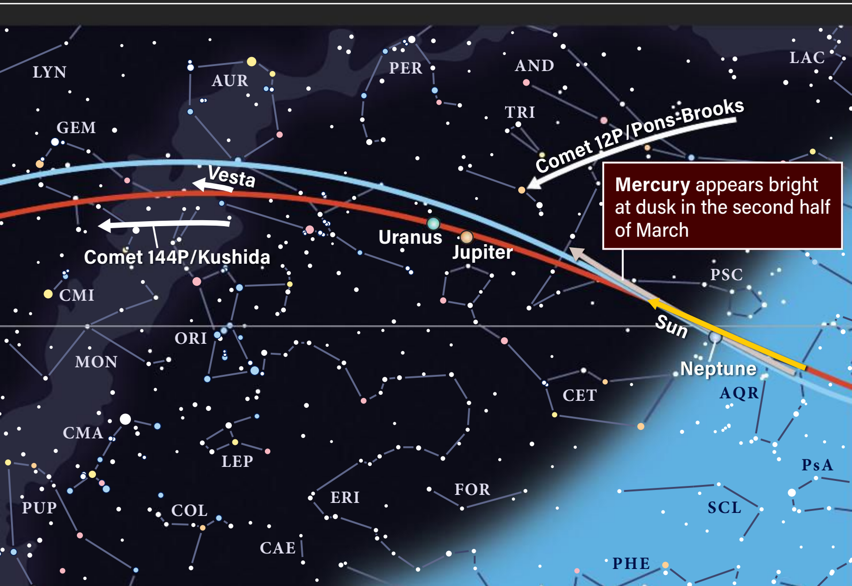
THE PLANETS IN THE SKY

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.

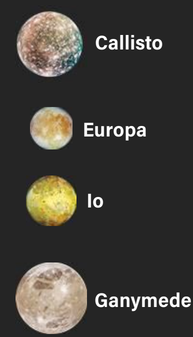
PLANETS	MERCURY	VENUS
Date	March 15	March 15
Magnitude	–1.2	–3.9
Angular size	5.8"	10.7"
Illumination	81%	94%
Distance (AU) from Earth	1.156	1.562
Distance (AU) from Sun	0.310	0.728
Right ascension (2000.0)	0h31.4m	22h23.4m
Declination (2000.0)	3°49'	–11°19'

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.

MARCH 2024

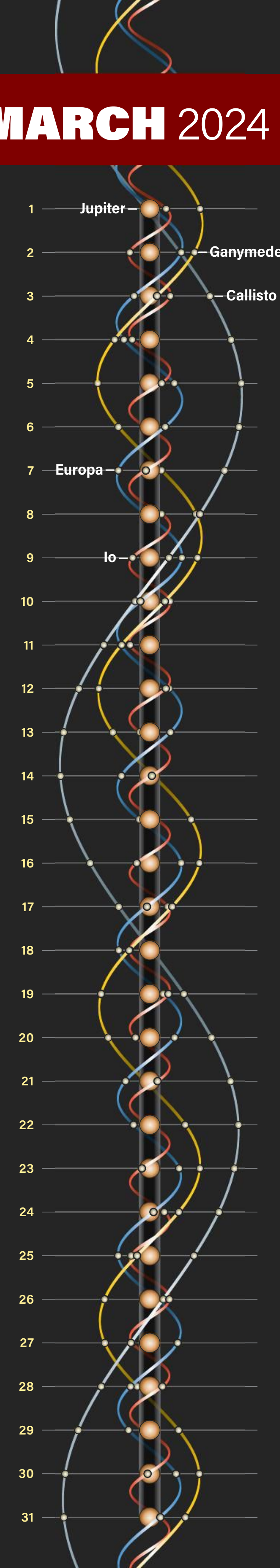


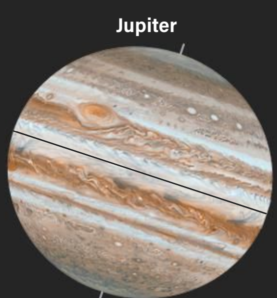
Early evening

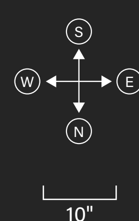


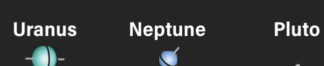
JUPITER'S MOONS

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









MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
March 15	March 15	March 15	March 31	March 15	March 15	March 15
1.2	9.0	–2.1	1.0	5.8	7.8	15.3
4.3"	0.5"	35.2"	15.7"	3.5"	2.2"	0.1"
97%	97%	99%	100%	100%	100%	100%
2.156	2.945	5.596	10.589	20.153	30.895	35.557
1.402	2.820	5.000	9.712	19.602	29.902	34.973
21h44.7m	18h50.4m	2h45.4m	23h00.5m	3h09.4m	23h50.7m	20h16.6m
–14°47'	–23°13'	15°04'	–8°09'	17°24'	–2°20'	–22°43'

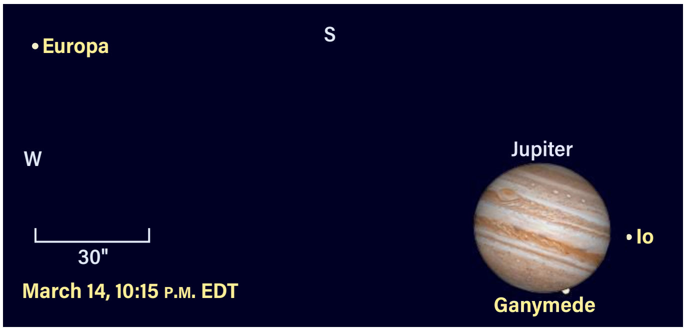
 — *Continued from page 29*

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Jupiter (west)
Uranus (west)

MORNING SKY
Venus (east)
Mars (east)
Saturn (east)

Peeking out



On March 14, most U.S. observers can catch Ganymede's slow emergence from behind Jupiter over the course of about 10 minutes. Meanwhile, Io is closing in for a transit. Callisto lies farther west, outside this field of view.

constellations along the ecliptic.

Try viewing the bright planet in twilight to minimize the intense glare. The apparent diameter of Jupiter spans 36" on March 1 and drops to 34" by March 31. Telescopes reveal the four Galilean moons as well as a rich display of atmospheric features crossing the disk. Most apparent is the pair of dark equatorial belts straddling the equator. The Great Red Spot comes into view every other day or so as it rounds the planet once every 10 hours.

Io, Europa, Ganymede, and Callisto orbit Jupiter with periods ranging from nearly 1.8 to 17 days. As the Jupiter observing season comes to an end, the number of transits and occultations diminishes. Even so, there's a couple you can catch.

Watch on March 8 as Europa is visible early in the evening, then disappears behind Jupiter's limb just after 9:30 P.M. CST. On March 14, lucky observers from the eastern two-thirds of the country experience Ganymede reappearing from behind Jupiter at 10:09 P.M. EDT (note the change to DST), just as Io is approaching the same limb to begin a transit. Io begins transiting around 10:40 P.M. EDT.

On March 17, Europa is transiting as darkness falls in the Midwest. The moon is followed at length by its shadow, which appears shortly before 10:35 P.M. EDT.

Wrap up the month with a fine transit of Io and its shadow on March 30. It's underway by nightfall across the Midwest. Io leaves the disk at 10:22 P.M. CDT, with Jupiter very low in the western sky. The shadow departs 48 minutes later, visible from the Pacific time zone and some parts of the Mountain time zone.

If you're wondering why Callisto isn't undergoing any events, it's because the tilt of the satellites' orbital plane relative to our line of sight is sufficient that Callisto misses Jupiter. You can see this on March 18, when the large moon skirts above the northern edge of the planet.

March opens with **Uranus** 8° northeast of Jupiter; the planets close in to 3.5° on the 31st. Uranus shines at magnitude 5.8 and is most easily spotted in binoculars. At the end of March Uranus stands 2° south of Delta (δ) Arietis, a 4th-magnitude star also known as Botein, located 9.5° southwest of the Pleiades (M45).

MARCH 10 Daylight saving time starts March 10 at 2 A.M. local time, when clocks "spring" forward to 3 A.M. local daylight time.

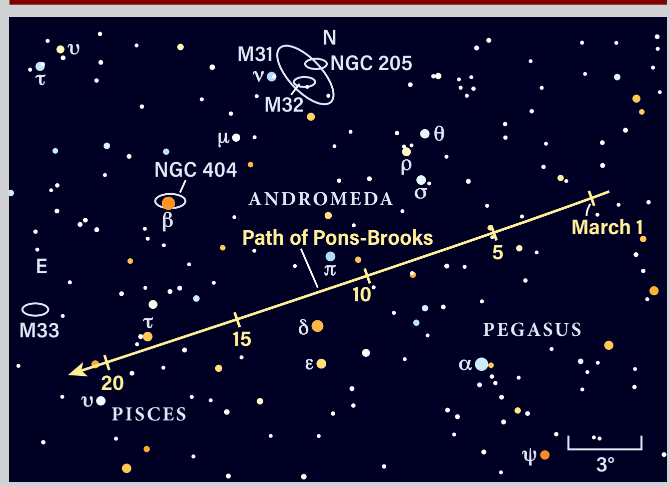
COMET SEARCH | Fine or fantastic?

EXPECT A NICE binocular comet — but hope and plan for the hyped-up eruption. Comet 12P/Pons-Brooks floats about 15° high in the west when the sky is fully dark some 90 minutes after sunset. That's also the direction to travel to keep the most city skyglow behind you. Moonlight interferes after midmonth, but keep watching.

Picturesque wide-field viewing and imaging occurs when the crescent Moon joins Jupiter from the 12th to the 14th. Perhaps shoot a little earlier — say, 75 minutes after sunset — to catch some dim orange skyglow at the horizon and deep blue above. If we get a super-long ion tail, the blue streak could cross in front of the Andromeda Galaxy on the 8th and 9th. To see horns and gaps in the inner coma, bump the magnification past 100x and experiment with even higher power.

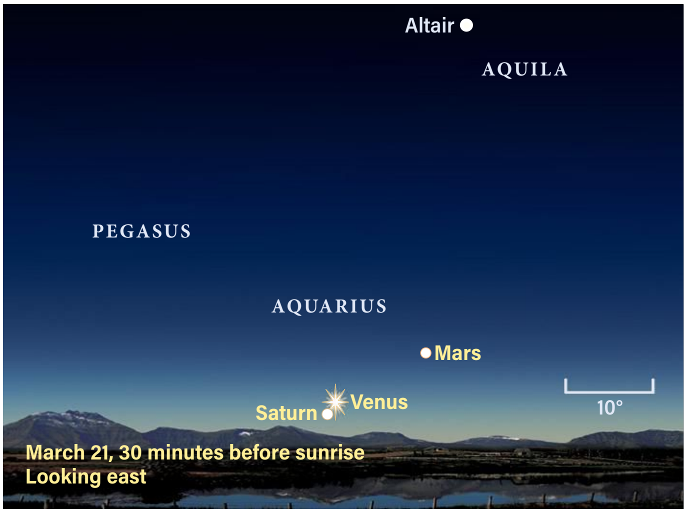
But wait, there's more! Eighth-magnitude 144P/Kushida is stepping on the feet of Gemini, which carry wonderful star fields and nebular clouds. And 62P/Tsuchinshan 1 masquerades as one of the brighter Virgo Cluster galaxies. As the heart of the Milky Way rises before dawn, spot 7th-magnitude C/2021 S3 (PanSTARRS) running up the gorgeous Great Rift in Aquila, which sports the binocular star clusters NGC 6633 and IC 4756 in nearby Serpens.

Comet 12P/Pons-Brooks



Comet Pons-Brooks is close to Earth and crossing a lot of sky. Check out our website for more details on where to find it later in the month — and whether it cracks naked-eye magnitude!

Challenge yourself



On March 21, spotting Saturn before sunrise will be a challenge — but you can use bright Venus nearby as a guide.

A fine crescent Moon joins Uranus and Jupiter March 13, the same night 243 years ago that William Herschel discovered Uranus from his backyard in Bath, England. Uranus lies about 6° due east of the Moon. This distant planet, once thought to be at the outer edge of the solar system, now lies 20.1 astronomical units (1.87 billion miles) from Earth and through a telescope shows off a tiny, bluish-green, 3"-wide disk. (One astronomical unit, or AU, is the average Earth-Sun distance.)

On March 30 and 31, Comet 12P/Pons-Brooks stands within 1° of Hamal, the brightest star in Aries. The comet could be an easy binocular object. Last seen in 1954, it underwent outbursts that were also observed in 2023, so there's a chance it could even exceed binocular visibility for short periods. In the second week of March the comet lies in Andromeda, passing 9° south of M31 on the 12th. After crossing northern Pisces, Pons-Brooks lies 3° due south of M33, the Triangulum Galaxy, on March 23.

The morning sky hosts Venus, Mars, and Saturn, although the viewing window is limited.

On March 1 you'll find **Venus** and **Mars** less than 4° apart and very low in the eastern sky less than an hour before sunrise. Venus rises about an hour before the Sun and shines at magnitude –3.9, an easy object to spot. Mars, on the other hand, glows at magnitude 1.3 and will require binoculars to find in the rapidly growing twilight. Each morning Venus pulls farther away from Mars; the pair is joined by the waning crescent Moon on March 7 and 8. Look on the 7th for the slender crescent 18° west of Venus — Mars lies just above a point midway on a line between them. The crescent Moon is more difficult to spot on the 8th, almost 6° south of Venus. The Moon stands only 1° high 30 minutes before sunrise and competes with the bright twilight.

Venus passes 0.3° north of **Saturn** on March 21, the latter of which recently came out of solar conjunction. It's a difficult pairing to see: Venus stands 1° high 30 minutes before sunrise, and Saturn glows at magnitude 1 some 40" to its east. Binoculars will aid in spotting Saturn, while Venus is easy to follow as the sky brightens.

On the last day of March, Venus, Saturn, and Mars are lined up along the ecliptic, spanning 17.5°. Mars rises around 5:30 A.M. local daylight time, followed 20 minutes later by Saturn. Mars is now magnitude 1.1 and Saturn is still magnitude 1. Look for the pair about 45 minutes before sunrise, low in the east. Venus rises 15 minutes later; as twilight swallows Mars and Saturn's glow, Venus remains bright enough to be seen.

Neptune reaches conjunction with the Sun on the 17th and is not visible this month.

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 | From the city to galactic neighborhoods

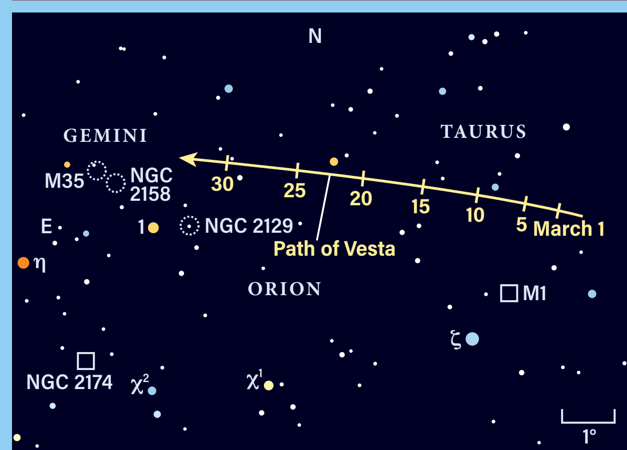
MILD SPRING EVENINGS are the best. 4 Vesta slides from the tip of Taurus' horn, Zeta (ζ) Tauri, to the splashy but thin star cluster NGC 2129 at the feet of Gemini. Though a half-magnitude fainter than last month, Vesta still shines at about 8th magnitude, brighter than the rich but faint star cloud in this arm of our Milky Way Galaxy.

Vesta is pretty easy in the smallest of scopes from the suburbs. On the 16th, you can slide 4° south of the First Quarter Moon to land on it.

It only takes five dots of a pencil on paper and a couple of clear nights between the 13th and 16th, 21st and 23rd, or 29th and 31st to pick out the main-belt asteroid by its displacement. Next month it will appear to move fast enough to see it shift in a single observing session.

Discovered 217 years ago by Heinrich Olbers, Vesta is some 300 miles across, half the size of dwarf planet 1 Ceres. Olbers was looking for a "missing" planet between Mars and Jupiter, patiently comparing star charts to his eyepiece view.

Moving along

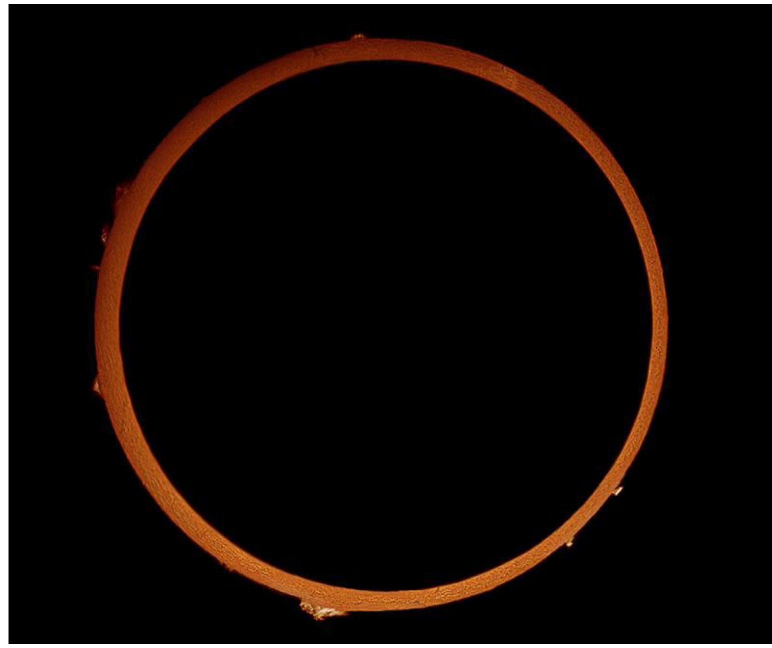


Easy-to-spot Vesta is also easy to watch move from night to night this month, using this chart or a sketch of the sky.

'RING OF FIRE' blazes across the

From city centers to scenic state parks, *Astronomy* editors caught October's annular eclipse at sites across the American Southwest. BY MARK ZASTROW

The Oct. 14, 2023, annular eclipse is captured in this composite over Pueblo Bonito, the largest structure at Chaco Culture National Historical Park in New Mexico. The great house was built by the Ancestral Puebloans between 850 and 1150 C.E. and incorporates their knowledge of solar and lunar cycles. CHIRAG UPRETI



The ring of fire glows in a Hydrogen-alpha filter in this image taken from La Ceiba, Honduras. ACQUIRED BY FRANCIS SANSIVIRINI; PROCESSED BY RENÉ SAADE

Celestron's Kevin Kawai sets up a NexStar Evolution to observe the Oct. 14, 2023, annular eclipse. MARK ZASTROW

Americas

PITY THE POOR ANNULAR ECLIPSE.

At times, the eclipse of Oct. 14, 2023, was billed as a mere opening act, a prelude to the total eclipse that will cross North America in April. This lowly annular eclipse would forge a ring from the Sun's disk but grant no view of Sol's glowing crown. It was just an hors d'oeuvre to whet the appetite for totality.

But the first annular to grace the U.S. in 11 years proved to be a visual spectacle with charms of its own.

An annular eclipse occurs when, because of its elliptical orbit, the Moon is too far from Earth to block out the entire disk of the Sun. The Oct. 14 eclipse began on a Saturday morning over the Pacific Ocean and made landfall near Gardiner, Oregon, at 9:13 A.M. PDT. Cloud cover was more prevalent on the western end of the path of annularity, which tracked across nine states from Oregon to Texas. In the Pacific Northwest, views of the eclipse were often fleeting, seen through gaps or thin layers of clouds. But as the morning went on, the clouds lifted and much of the Southwest, including Albuquerque and San Antonio, enjoyed clear views.

The eclipse continued across the Gulf of Mexico to the Yucatán Peninsula and on through Central and South America, ending at sunset off the coast of Brazil.

A crowd estimated at over 3,000 people gathered at the Scobee Education Center and Planetarium at San Antonio College to view the Oct. 14, 2023, annular eclipse. MARK ZASTROW

San Antonio prepares

I viewed the event from the campus of San Antonio College (SAC) at the Scobee Education Center and Planetarium, which had spent the last two years organizing a NASA-sponsored celebration of the Sun — La Fiesta del Sol. (The center is named for Francis Richard "Dick" Scobee, commander of the space shuttle *Challenger*'s final, fatal flight; he studied at SAC while based at Kelly Air Force Base in San Antonio.)

Flying into San Antonio two days before the eclipse, it was hard to miss that a celestial event was about to occur. On the TVs in the hotel lobby, the local news broadcasts featured constant eclipse forecast updates on their tickers. Down by the Riverwalk, amongst the bars and whiskey distilleries, street hawkers were selling solar glasses.

Credit for that awareness falls partly to the Scobee Education Center, which

A MAGNIFICENT EVENT BY MICHAEL E. BAKICH

TO WITNESS THIS ECLIPSE, my wife, Holley, and I stayed at the Santa Fe, New Mexico, home of Michael Zeiler (my co-author of two eclipse books), for four nights. About three years earlier, he had suggested we watch the event from their hot tub. But the more we talked about it, the more we wanted to view from either the northern or southern limit to maximize the display of Baily's beads.

Zeiler picked several possible spots, but the day before the eclipse we did a site survey and chose the Vista Grande Overlook Observation Site, which was at the path's northern limit, just a 40-minute drive from his house. It stands at 10,288 feet (3,136 meters) in the middle of an aspen forest that was in full fall color. About a dozen other eclipse chasers joined us, including meteorologist Jay Anderson and mapmaker Xavier Jubier.

The eclipse began under a cloudless sky, which remained so for the duration. As usual, I was first to scream, "First contact!" (It's a thing with me.) Holley and I set up small refractors and provided visitors many views of the partial phases. But the central eclipse was ours alone.
As mid-eclipse approached, the temperature dropped markedly. I wasn't recording it, but it forced me and many others to don another layer of clothing.

The bottom line: We observed seven minutes of Baily's beads, although to be fair, a few near the end may have been due to the black-drop phenomenon, in which a transiting object seems to bulge like a teardrop as it nears the limb of the Sun. It was an amazing display. The cusps were incredibly thin and delicate. I imagined a minute or more of beads, and was hopeful of two minutes, but seven? I'd rate the experience as equal to or better than half of the 14 total solar eclipses I've observed. I never thought it would be so dramatic.

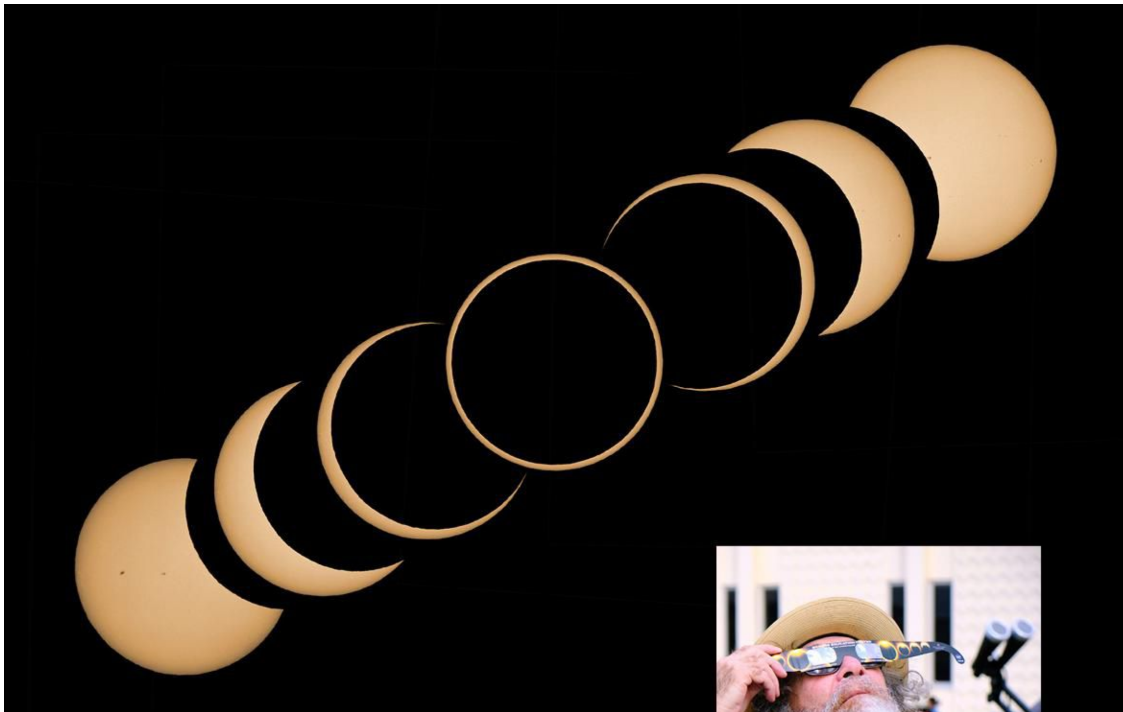
Michael E. Bakich *is a contributing editor of* Astronomy. *This was his fourth annular eclipse.*

contacted the local tourism board immediately after the 2017 total eclipse to alert them to the event's potential. "It's going to happen, whether you plan or not," Scobee director Richard Varner recalled telling them, speaking to me at dawn on Oct. 14 as he directed a flurry of last-minute setup on the center's grounds. Buy-in about the eclipse's potential "was slow to start," he said, but eventually spread to local businesses and school curricula. "Within the last four months, probably, it has taken off, and it's been something that everybody's embraced."

Scobee was just one of many places in San Antonio hosting a viewing party, but it was a hub of activity. A team from Celestron arrived on Friday to set up an array of telescopes on the center roof. The main one, a modified C6, was rigged to capture a video feed for The Weather Channel, which had sent a crew to cover the eclipse. And heliophysicist Alex Young of NASA's Goddard Space Flight Center in Greenbelt, Maryland, was on hand, along with me, to provide commentary.

Eclipse morning dawned cool, cloudy, and windy, but food trucks, vendors, astronomy clubs, and thousands of curious skywatchers were undeterred, filling the leafy campus grounds and creating a festival atmosphere. And the forecast was optimistic, calling for clearing skies later in the morning.

I had the chance to team up with longtime *Astronomy* contributor and expert lunar observer Robert Reeves (a San Antonio native) to give a talk to the crowd just before 10 A.M. As we wrapped up, we were apprehensive: The cloud cover had only increased. But as we returned to the rooftop, we could see blue sky to the west. The question was whether it would reach us in time.



The progression of the eclipse is seen in this sequence taken from Sevier, Utah, very near the eclipse's center line. PHILIPPE MOUSSETTE

An attendee gazes at the Sun with proper filtration. MARK ZASTROW

Shadows can be a source of endless fascination during an eclipse's partial phases. While shadows initially became sharper as the Sun's disk began to narrow, they eventually began to blur again as the Sun's horns emerged. Here, some edges appear sharp and others appear blurry, depending on the geometry. And the Moon's shadow comes into focus at the gaps between fingers, where they narrow to create a pinhole effect. MARK ZASTROW

Heliophysicist Alex Young of NASA's Goddard Space Flight Center speaks with Weather Channel meteorologist Alex Wilson. MARK ZASTROW

Annularity arrives

Our view of first contact at 10:23 A.M. was lost to the cloud cover. But views of the partially eclipsed Sun periodically appeared through gaps in the clouds, eliciting cheers from the crowd. Then, about 20 minutes before annularity, clear skies moved in for good. Thanks to the previous cloud cover and the Sun's reduced strength, the temperature had barely cracked 70 degrees Fahrenheit (21 degrees Celsius).

As annularity approached, Young and I spent much of our time with Weather Channel meteorologist Alex Wilson, staring not at the Sun but at the ground, marveling at the shadow and projection effects. As the Sun's disk narrowed, shadows took on more definition, with sharper edges. But as the crescent's tips began to extend around the Moon, the shadows became blurry on one side — to an extent that is unique to an annular eclipse.

In a total eclipse, the final thrilling moments leading up to totality are marked by the surreal sight of the Sun's disk winking out of view, disappearing from its tips. An

PICTURE PERFECT BY RICHARD TALCOTT

SOUTHERN UTAH lays claim to five spectacular national parks, three of which fell within the path of annularity during Oct. 14's solar eclipse. So why choose an observing site in a "lowly" state park? First, it's actually difficult to find an unappealing vantage point in this part of the state. And second, my wife and I witnessed the spectacle with a few dozen fellow eclipse chasers, not the thousands who crowded the national parks.

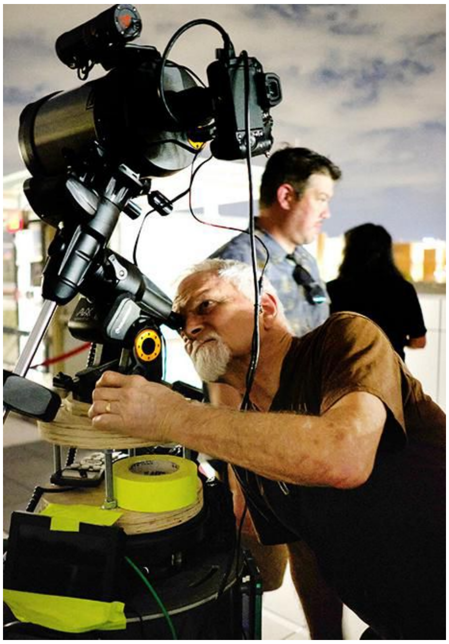
Kodachrome Basin State Park was named in 1949 by the National Geographic Society — with consent from Kodak Film Corp. — for its colorful and photogenic landscape. The park features more than 50 reddish sandstone spires that soar into what's typically a deep-blue sky, and Oct. 14 proved no exception. The day dawned clear and cold, and only a few thin clouds popped up as the Sun's strength waned.

The dazzling topography grew even more vivid when colors became saturated as the eclipse progressed. We watched as shadows grew sharper and pinholes in the pinyon pines and juniper trees cast images of the crescent Sun onto the hard-packed soil.

Several people at our site brought telescopes, which they freely shared with the rest of us. Others brought cameras, looking for that perfect shot. We contented ourselves with the view through eclipse glasses and solar binoculars. (I long ago gave up trying to capture the beauty of eclipses with photos — too many others do much better jobs than I could hope to.)

Because the park lay well off the center line, annularity lasted just 2 minutes 42 seconds. Still, that was time enough to enjoy the slightly lopsided ring of fire. We even managed to see about five seconds of Baily's beads as annularity began. The eclipse truly was stunning, serving to whet our appetite for April's even more impressive total eclipse.

Contributing Editor **Richard Talcott** *has now seen four annular eclipses to go along with a dozen total eclipses.*



The author speaks with Weather Channel meteorologist Alex Wilson. MATTHEW DOU

On the eclipse's eve, Robert Reeves went to Scobee's roof to align the telescope that would capture The Weather Channel's feed. The night was overcast, but a two-minute gap in the clouds allowed a quick visual alignment on Polaris. The modified C6 OTA was equipped with a StarSense Autoguider, an Advanced VX mount, and an EclipSmart 6-inch white light filter. MARK ZASTROW

annular offers an inverse but equally surreal spectacle: As the Moon moves fully onto the Sun, the Sun appears to suddenly, rapidly sprout horns, wrapping around the Moon to form a brilliant ring.

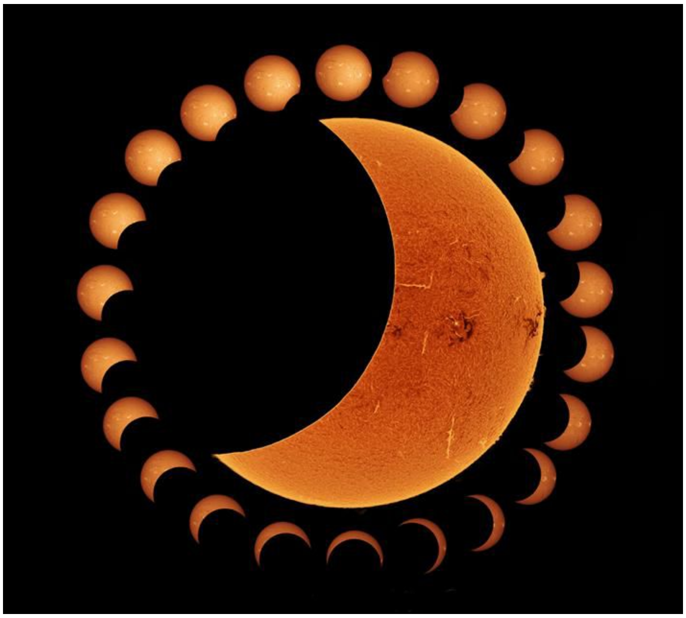
We enjoyed a perfect view of this at 11:54 A.M. — to the roar of the crowd. No magnification was required (just protective solar glasses) to see Baily's beads, the bright dots that can appear like beads on a string, formed by light streaming through low points and valleys on the Moon's limb.

For just over four minutes, we basked in the dim glow of annularity. The magnitude of this eclipse was 0.952, meaning that during annularity, just about 4.8 percent of the Sun was visible. But because the edges of the Sun's disk appear darker than its center, the actual strength of sunlight was only around 2 percent.

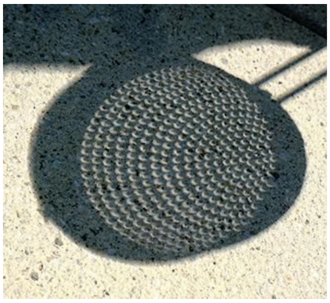
This is still much brighter than the dramatic darkness of a total eclipse. But as I looked out across the landscape, I took a moment to allow my mind to be transported to an alien world with equivalent lighting. At 2 percent strength, the Sun is weaker than it would feel on one of Jupiter's moons. Or, if you prefer to let your mind wander 6 billion years into the future, it's about the same strength of light at Earth's orbit if the Sun were replaced by a white dwarf.

Another string of Baily's beads marked the moment of third contact, when the ring was broken and the Moon began to move off the Sun's disk.

It had been a close call with the weather, but we signed off still buzzing from the visual high. "This was much cooler than it gets credit for," said Wilson. "Everyone treats [an annular eclipse] like the



The Moon moves across the Sun in a partial eclipse seen in Dallas. ARTURO BUENROSTRO



Crescents and rings appear during annularity, projected through the holes of a colander supplied by Alex Young. MARK ZASTROW

The ring of fire bursts through a thin cloud layer, as seen from a cave at Capitol Reef National Park in Utah. GREG MEYER

Skipper to Barbie, but it was a really cool experience!"

Coming attraction

And now, the main course: the total solar eclipse of April 8, 2024, which will deliver up to 4 minutes 28 seconds of totality to viewers across North America.

The Scobee Education Center will miss out on being able to throw a repeat party by the slimmest of margins: It lies outside the path of totality by a mere 2.5 miles (4 kilometers). It's perhaps the one time when the center will be telling people *not* to turn up at its doors. "We have to have a campaign, because people will come here," said Varner. "Truthfully, we're going to take out an ad that says 'Go away!' … Drive the mile! Be in totality."

It's advice that will surely be followed. An estimated 31.6 million people already live in the path of totality, and it's a short trip for millions more. For many in North America, it could be the eclipse of a lifetime.

Senior Editor **Mark Zastrow** *is looking forward to viewing April's eclipse from Torreón, Mexico.*

Contest winner Vicki Wilson poses with her Celestron telescope. VICKI WILSON

ESSAY CONTEST WINNER

A personal Perseids story

This poignant tale of sharing the night sky won our 50th-anniversary contest — and a Celestron telescope.

BY ASTRONOMY STAFF

THROUGHOUT *ASTRONOMY* magazine's 50-year history, we have covered the gamut of space stories, from cosmology to observing. However, besides the occasional comment published in our Astro Letters section, we don't often get to hear about our readers' own experiences with astronomy.

So to celebrate the magazine's half-century birthday last August, we teamed up with the telescope manufacturer Celestron to create a contest asking those with eyes on the sky to write about their most memorable viewing experiences.

We were overjoyed by the response: More than 100 letters came in, answering the call. Participants wrote about seeing Saturn for the first time, unexpectedly sharing their telescopes with strangers, and catching more than a few unexplainable nighttime objects.

There were so many great letters, but we could pick only one winner: Vicki Wilson of Clinton, New York.

Vicki received a Celestron StarSense Explorer 8-inch Smartphone App-Enabled Dobsonian Telescope, worth $799.95. Thanks to our friends at Celestron for donating it, and to all our readers who participated in the contest!

RIGHT: The Perseid meteor shower, which our contest winner wrote about in her essay, occurs during August each year. JOHN FOWLER/FLICKR

WOOD BACKGROUND: NOIPORNPAN/DREAMSTIME.COM. BLUE RIBBON: RACHELWEBDESIGN/DREAMSTIME.COM. CELESTRON TELESCOPE: CELESTRON

The same sky

By Vicki Wilson

My still new-ish husband and I sat on our car in a quiet country cemetery on an August night in the early 2000s, watching the Perseids. I knew that my father would be sitting on his deck at his house in another town an hour away watching too, so we called him.

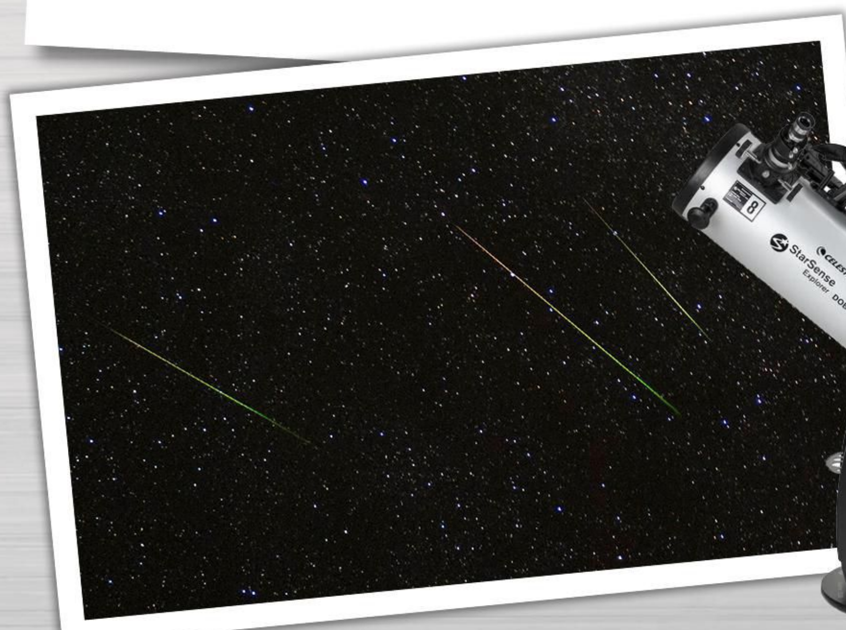
"Hey Dad," I said when he answered. "You watching?"

"Yup," he said.

I suppose an aging cemetery isn't a popular place to hang on a summer night, but it was the best place to see the Perseids and we had it to ourselves. We stayed for an hour with my dad on the phone, watching the meteors draw in the sky like a celestial Etch A Sketch. Every now and then, one would be brighter or longer or seem bigger and one of us would say "Whoa!" and I would say, "Did you see that, Dad?" into the phone and he would answer, "Yes, I did."

We had work the next morning, so the stargazing had to end. But already on the car ride home when I said goodbye to my father, I knew that night was special. The sky had solidly connected the new life I was creating with my husband to my past and to the people who had created me.

We lost my dad in 2017. I hope that, like the Perseids that night, he and I are still now somehow seeing all the same wonders: his grandson's 800-meter run in track and the twin fawns on our lawn and the sweet corn I grew. Sitting on my own deck at night, I ask the stars, "Did you see that, Dad?" I imagine his voice answering, "Yes, I did."




STELLARVUE

REVIEWING the amazing STELLARVUE 180MM REFRACTOR

This hand-crafted apochromat raises the bar for refinement in build and image quality. STORY AND PHOTOS BY TONY HALLAS

THE *CAMBRIDGE DICTIONARY* defines *magnificent* as "deserving to be admired." I had no trouble doing that when I walked into the offices of Stellarvue to get an extension ring for my SVX140T and to visit my friend and Stellarvue owner Vic Maris: While there, I witnessed an SVX180T 180mm f/7 refractor being prepared for shipment to some lucky customer.

Until that moment, I had been happy with my Stellarvue 140mm f/6.7, but the power of 180mm dwarfed it by comparison. Completely captivated, I put a deposit down on a 180mm and waited — these hand-crafted instruments can take months to assemble. Fortunately, Stellarvue was in full production and just four months later I got the long-awaited call saying "Your scope is ready, come pick it up!"

THE TIME HAS FINALLY ARRIVED

The first thing you notice when you see this telescope is that it is massive. No effort was spared to make this the ultimate refracting telescope. For example, although the objective is 180mm, its fully baffled tube is 8 inches (203 millimeters) across. This aids in thermal stability as heat currents are more likely to stay out of the optical path. The dew shield is also large enough to give the front of the objective room to breathe and ample space for dew control. The 180mm scope has three options for the focuser; I chose the Starlight Instruments 3.5" focuser, which is extremely rugged and well made. Stellarvue built a huge field flattener for imaging — as an optional add-on — that fastens directly to the focuser and covers any size camera with the right adapters.

To see how well a telescope baffles light, do this experiment: Place a white, well-lit board in front of the telescope, remove the eyepiece and diagonal, and look through the scope. What do you

All photographs were taken with the SVX180T f/7 and a ZWO ASI6200MM Pro CMOS camera with Chroma filters on an Astro-Physics 1600GTO mount. The images were processed using CCDStack, RegiStar, Photoshop, and MaxIm DL. TELESCOPE: STELLARVUE. BACKGROUND: TONY HALLAS

The Cocoon Nebula (IC 5146) is a reflection and emission nebula that lies 4,000 light-years away in Cygnus. The author captured this image with HαRGB filters and exposures of six, three, three, and three hours, respectively.

The Bubble Nebula (NGC 7635) in Cassiopeia appears in sharp detail in this Hα/OIII/RGB image with exposures of four, four, three, three, and three hours, respectively.

PRODUCT INFORMATION

Stellarvue SVX180T
Type: Apochromatic refractor
Aperture: 7 inches (180mm)
Focal length: 1,260 mm
Focal ratio: f/7
Focuser: Choice of three (3" or 3.5")
Tube length: 54 inches (1,370 mm)
Tube weight: 38 pounds (17 kg)
Weight: 44.5 pounds (20.2 kg)
Price: $18,395
Contact: Stellarvue
11802 Kemper Road
Auburn, CA 95603
530-823-7796

This wide-field view of the Ring Nebula (M57) in Hα/OIII/RGB filters comprises exposures of eight, three, three, three, and three hours, respectively.

see? A well-made refractor should show you nothing but the bright white circle of the lens surrounded by a black void, whereas a poorly made refractor will make a bright star look like a colorful blur. When you perform this test on the Stellarvue 180mm refractor, a clear, bright point is exactly what you'll see. The scope is extremely well baffled, so any spurious light is blocked from reaching the eyepiece or camera.

A WHOLE NEW VIEW

My original intent for purchasing this telescope was for visual use, as I own a large corrected Dall-Kirkham reflector for astrophotography. And for several months, that is how I employed the 180mm. As expected, the contrast was superior, the illumination was beautifully even, and the smallest stars were mere pinpricks. The planets and the Moon appeared the best I have ever seen them during moments of good seeing.

One event really stands out: One night I was looking at the craterlets in the lunar crater Plato. As I looked at one of the craterlets, it seemed to split into two. Bad seeing? Thermal effects? But the more I looked, the more I was convinced I was seeing a real double craterlet. The next day I looked up a NASA picture of Plato and lo and behold, there is indeed a double craterlet there. It was the first time I saw this with any telescope. I was also surprised at how well the 180mm handled deep-sky objects. It was nice to see M81 and M82 in the same field of view with an added Pentax 40mm XW eyepiece. The views through this fine instrument are excellent.

But Vic was curious how the scope would perform photographically in my hands — and so was I. With the assistance of some friends, I pulled my reflector from its imaging mount and installed the 180mm in its place. For the next several nights, I ran the scope through several tests with my complementary metal-oxide semiconductor (CMOS) camera and noted how sensitive the scope was to temperature changes. I decided to also add the automated Starizona's Microtouch focus motor, with built-in software for temperature compensation, to the rig.

THE POWER OF AN APO LENS

One of the questions I hear about the 180mm is whether it is a true apochromatic (APO lens), where all the colors focus in the same spot. This question highlights a classic difference between a reflecting telescope and a refracting telescope. A reflector brings all the

ACHIEVING THE IDEAL IMAGING SETUP

Once I made the decision to add Starizona's Microtouch focus motor to the rig, next came the challenge to attach it. The heavily geared telescope motor fastens directly to the focus shaft, eliminating any chance of focus backlash — unlike less powerful motors that attach through the 10:1 reduction gearing. After installing the focus motor, I ran the easy-to-use temperature compensation "learning feature" (included in motor's software), which calculates the focus shift in relation to temperature drop. The focus motor continually keeps the image in focus by adjusting every 0.18-degree-Fahrenheit (0.1 degree Celsius) drop in temperature. Using the motor allows me to run my rig all night without having to refocus, and stars maintain the exact sharpness from the first image of the evening to the final image, even with an overall drop of nearly 22 F (12 C) through the night.

One of the recent game changers in astrophotography has been the advent of small-pixel CMOS cameras with low noise and good quantum efficiency. That last item means the photo sensor captures a large percentage of the photons that hit it. Unlike their older, larger reflected light to the same point, regardless of wavelength. But a refractor bends the incoming light through a lens, so the colors come to a focus in slightly different positions. In traditional refractors, images of bright stars often produce a purple-red ring around them. This "false-color" issue really becomes a problem when using narrowband filters, particularly when pairing those with more disparate wavelengths.

An apochromatic refractor uses a number of lenses to remove this issue and get all wavelengths of light to come to a common focus. Stellarvue uses Ohara S-FPL-55 super-low-dispersion glass in a unique lens design to achieve this, creating a true apochromat. During manufacture, the objectives are repeatedly tested with a Zygo phase-shifting interferometer to detect irregularities — if any are found, the opticians carefully remove them. This process can take months, as each objective must be tested over and over again after each correction. Stellarvue doesn't stop until the lens is as perfect as can be. The telescope can then deliver a final figure centered on the green wavelength of light and showing a commonly known projection effect, a Ronchigram.

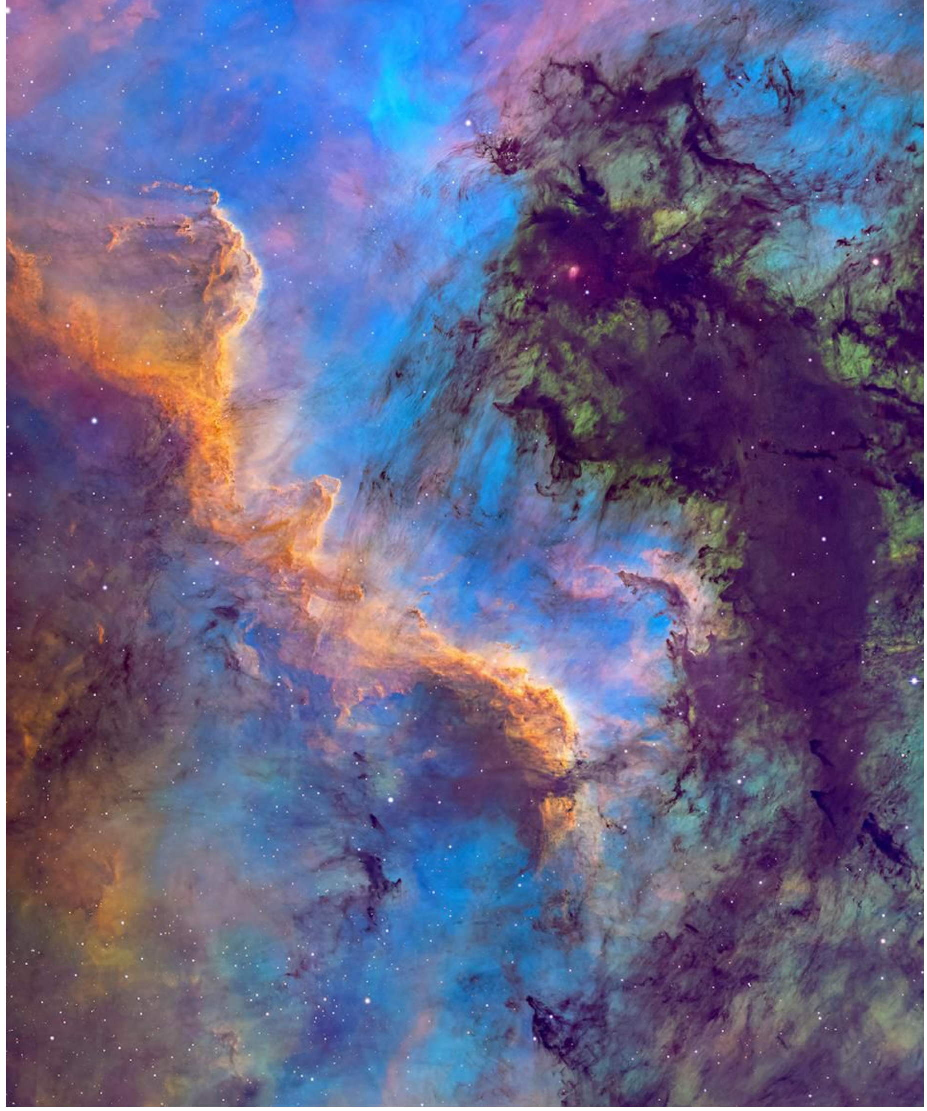
The 180mm — with its modern lens design and use of the finest materials — transmits RGB and narrow bands such that that they all come to a focus at the same point.

ONE-OF-A-KIND TELESCOPE FOR ONE-OF-A-KIND PHOTOS

Unlike mass-produced telescopes, Stellarvue telescopes are custom made in the U.S. at the company's Auburn, California, facilities.

All this perfection would be useless if the lens cell, which holds the large lens elements, were made from an improper material such as aluminum. Aluminum expands and contracts with temperature, meaning lens elements can be pinched in colder temperatures, which changes the shape of the lens and affects the quality of the image. To avoid this, Stellarvue makes the lens cell from steel that has a low coefficient of expansion, thereby avoiding any pressure on the lens elements even as the temperature changes.

The Stellarvue 180mm f/7 APO triplet refracting telescope represents the finest large refractor available to the discriminating consumer. With limited choices for color correction available on the market, this air spaced triplet has been built with no compromises by dedicated opticians and machinists. It is the result of years of telescope building, research, and experimentation in the quest for perfection. A large refractor is more than just excellent optics — the entire telescope has to work seamlessly together to create a unified whole. And this is what you experience with Stellarvue's magnificent telescopes.



The Cygnus Wall star-forming region is a cosmic fight of light vs. dark — glowing gas and dense dust. The author exposed for three hours in Hα/OIII/SII and two and a quarter hours through each RGB filter.

9-micropixel CCD predecessors, these 3.7-micropixel CMOS cameras can resolve incredibly fine detail. This plays directly to the strengths of large, razor-sharp, high-contrast refractors.

I started a typical imaging run by setting up the scope just before sunset so it had time to reach thermal equilibrium. Once it was dark enough, I slewed to my chosen target and framed it, entering its position into the mount memory. I then generated a V-curve with an autofocus software application to achieve pinpoint focus. At this point, I opened the focus motor control and turned on temperature compensation, allowing the motor to monitor the temperature and adjust the focus accordingly. Next, I started up my image acquisition software application to find a guide star and start tracking. My final step was to set up the imaging sequence and start imaging.

I keep my mount on an analog timer both to prevent it from running the telescope into the pier and to shut off the power when the session is complete. Although there are many automated programs that will do all this for you, I am still a bit old-school. *— T.H.*

Tony Hallas *is one of the world's top imagers.*

What Messier missed

The best-known deep-sky catalog is far from definitive.

LEFT TO RIGHT: The Leo Triplet comprises NGC 3628 (top) and M66 and M65 (bottom, left and right respectively). This image was captured with a ZWO ASI294MC Pro on a Takahashi FSQ-106N over 13 hours and 35 minutes of exposure.

NGC 4565, the Needle Galaxy, was imaged with a ZWO ASI294MC Pro on a Takahashi FSQ-106N with 18 hours and 50 minutes of exposure. MOLLY WAKELING (2)

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

In 1781, French astronomer Charles Messier published a catalog of 103 objects in the heavens. He was primarily interested in comets, but kept finding fuzzy smudges that did not move against the background stars — so he published a list of objects to avoid while comet hunting. The list includes diffuse nebulae, planetary nebulae, open clusters, globular clusters, and galaxies visible from Europe. With some additions by other astronomers, gleaned from Messier's notebook margins, the list now has 109 objects (or 110, depending on who's counting). It's a familiar companion for observers, especially at this time of year, when amateurs across the Northern Hemisphere gear up for a Messier marathon: an attempt to observe every Messier object over the course of one night. (This year's best date will be the weekend of March 9 and 10, near New Moon.)

But as I peruse the sky both in the eyepiece and with my camera, I've found many objects that I'm surprised did not end up in the Messier catalog. Here are a few that are worth a visit!

The Leo Triplet is a popular wintertime target — three bright galaxies forming a nice eyepiece-sized triangle (or a short hop from one to the next at higher magnifications). Two of the trio earned Mssr. Messier's notice: M65 and M66. But the third, which goes by **NGC 3628**, somehow did not. It's only slightly dimmer than M65 and its apparent size is a little larger than the other two. Perhaps because it is more edge-on to us it was more difficult to see in an 18th-century 4-inch refractor. Nevertheless, it is worth a brief stopover during your Messier marathon.

The **Needle Galaxy** is especially puzzling to me. Cataloged as NGC 4565, it's easy to spot, being relatively bright and of a moderate size. At 16.8' long and magnitude 9.6, it's not so large as to be diffuse and faint, but not so small that it requires a long-focal-length instrument. At declination 26°, it would certainly have reached a reasonable altitude in downtown Paris, where Messier did most of his observing (small amounts of precession notwithstanding). Perhaps it was simply lost in the sea of galaxies that grace the constellation Coma Berenices, or in the fog of coal smoke suffusing the city air. I'm not sure how many of those galaxies Messier could have seen, but surely this one would have stood out. Fortunately, Sir William Herschel noticed it just a few years after Messier's catalog was published. Of course, Herschel had the distinct advantage of superior and far larger reflector telescopes, with which he discovered thousands of binary and multiple-star systems, galaxies, nebulae, and the planet Uranus.

The **Double Cluster** (NGC 869 and NGC 884) might seem an odd one to imagine Messier might have considered listing — who would mistake such a large and bright collection of stars for a comet? But Messier included several other objects that are easy to distinguish — M7 (Ptolemy's Cluster), M44 (the Beehive Cluster), and that double star M40, to name a few. One might argue that because the Double Cluster was known from ancient times, any astronomer would know it was not a comet. But the Pleiades was known even earlier and makes No. 45 on his list. The Double Cluster is relatively large on the sky, spanning about 60' or two Full Moons. Its hundreds of bright stars make it a joy to observe with everything from binoculars to Dobsonians to Schmidt-Cassegrains. Under darker skies, you will likely stumble upon it with the naked eye.

I've found many objects that I'm surprised did not end up in the Messier catalog.

There are hundreds of galaxies, nebulae, and star clusters in the sky that are brighter, larger, or generally easier to see than some objects in the Messier catalog. So why did Messier only include 103? Perhaps he thought it was more obvious that those other dim, fuzzy smudges weren't comets. Or perhaps he just picked his favorites!

If you are new to observing, don't be afraid to step off the Messier list — there is so much more that is just as easy to see. And for those attempting the Messier marathon this year, consider swinging by a few of these beautiful non-Messier objects along the way.

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In *Dark Star: A New History of the Space Shuttle*, Harvard University aerospace historian Matthew Hersch details NASA's Space Shuttle Program and its many highs and lows, including the *Challenger* disaster in 1986. Hersch illustrates the shortfalls in engineering and technology that were built into the program and addresses the needs of space travel in future years.

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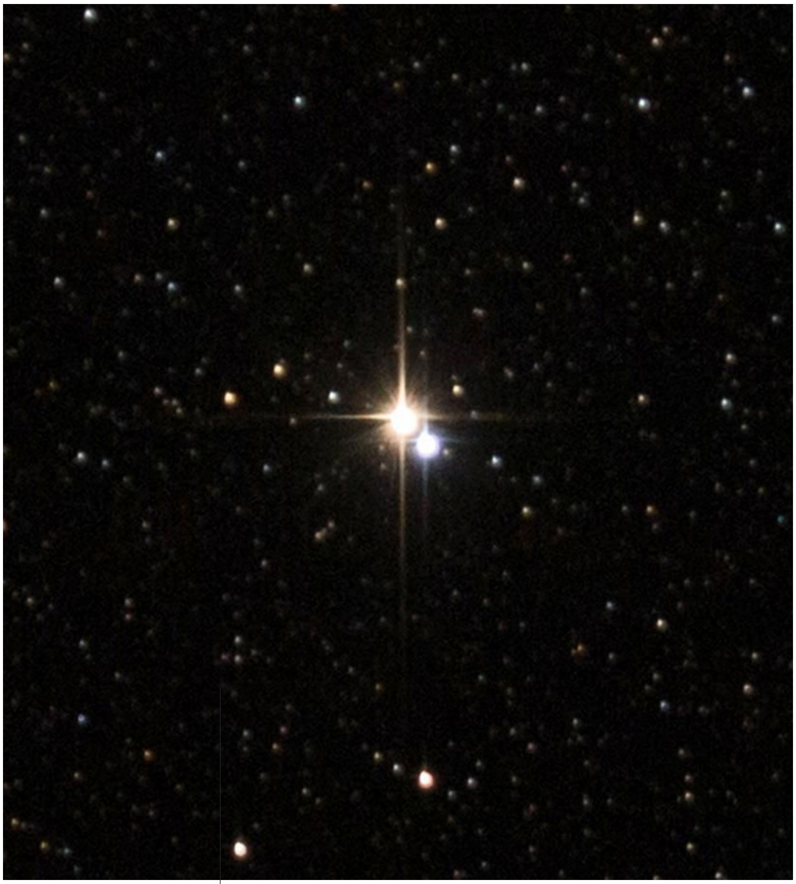


The double star Albireo in Cygnus shows off beautiful contrasting colors of orange and blue, which also reveal the stars' differing temperatures.
STEPHEN RAHN

Green stars

Q | ON THE COLOR-WAVELENGTH SPECTRUM, GREEN FALLS BETWEEN YELLOW AND BLUE. WHY ARE THERE NO GREEN STARS?

Jeff Franklin
Surprise, Arizona

A | This is an excellent question! It seems weird, right?

The color of stars, or anything that gets really hot, is connected to its temperature. This is because hot objects emit light, which is called thermal radiation. The color of this light — or in physical terms, its frequency — depends on the temperature. As any object gets hotter, it emits more and more of its light at higher frequencies. The same way it takes you more energy to jump at a faster rate, it takes more energy to emit light at higher frequencies. These higher frequencies appear blue to our eyes, while lower frequencies appear red. So as an object gets hotter, it generally gets bluer. As a result, the hottest stars appear to us as blue, but cooler stars appear red.

So why can't stars with temperatures in between appear green? The answer is a result of the way our eyes see combinations of frequencies: Our eyes add up all the colors that come in, and the color we see is the result of this addition.

"Green" is a very specific frequency, but stars emit light smoothly across a broad spectrum. Think of this spectrum like a playground seesaw with a rainbow painted on it, blue on one end and red on the other. This seesaw tilts based on temperature, and the color we see is a mixture of all the colors on the seesaw. Here's the trick, though — we see more of whichever colors are higher off the ground. If a star is really hot, the blue end is tilted up, so blue dominates over the other colors and we see this star as blue. If it's cool and the red end is tilted up, red dominates and we see this star as red.

On a seesaw, you can't make the middle any higher than the ends. If the temperature is moderate so that we are in the middle of the board, then the board remains horizontal and we have to add up all the colors equally, which comes out as white. In fact, that's why our own Sun is white — its temperature corresponds to a frequency in the middle of the seesaw.

Green is also near the middle of the seesaw, but there is just no way to tilt the seesaw to make green higher than any other color; our only options are blue, white, or red.

Matthew Murphy
Graduate Student, Department of Astronomy and Steward Observatory, University of Arizona, Tucson

Q | IF A BLACK HOLE BEGINS AS A STAR SOMEWHERE IN A GALAXY, HOW DOES IT END UP IN THE GALAXY'S CENTER? IS THE GRAVITATIONAL PULL SO STRONG THAT ALL THE STARS IN THE GALAXY START REVOLVING AROUND IT?

Paul Simon
Raleigh, North Carolina

A | The black hole created by a single star's death is called a stellar-mass black hole. These black holes have masses about two to 100 times that of the Sun. When a star explodes to create a stellar-mass black hole, it might give itself a little "kick" and start flying through space, but this kick is random and could send it inward, outward, or in any direction in 3D. So, these black holes don't tend to end up in a galaxy's center unless the star that created them happened to be there.

The type of black hole that's sitting in the center of a galaxy is different. This is a supermassive black hole, or SMBH, and — as its name implies — it's much heftier. SMBHs have masses of at least a million solar masses, up to several billion solar masses. The one in the center of the Milky Way is about 4.3 million solar masses, while the one in the center of the elliptical galaxy M87 is more like 6.5 billion solar masses.

SMBHs are not born the same way as stellar-mass black holes, nor do they seem to be typically made up of many smaller black holes all smooshed together. In fact, we don't entirely know how SMBHs are born, but we do believe they arise roughly around the same time a galaxy is assembling itself, and we know that the two evolve together over time. But while they can influence each other, the gravitational interactions between an SMBH and its host galaxy are very minor.

Just because the SMBH is sitting in the center of a galaxy doesn't mean all the stars are revolving around it. Even with its super-hefty mass, an SMBH may only account for some one-millionth the mass of the galaxy as a whole. That's such a tiny fraction that the stars in the galaxy barely even know the SMBH is there, gravitationally speaking. Plus, the strength of gravity falls off incredibly quickly the farther you get from the black hole. So, only stars that are close to the black hole orbit it; the vast majority of stars in a galaxy orbit the center of mass of the galaxy as a whole, which is also in the center but is not actually the SMBH.

Alison Klesman
Senior Editor

ALL THE ATOMS AND RADIATION IN THE UNIVERSE MAKE UP LESS THAN 5 PERCENT OF ITS CONTENTS.

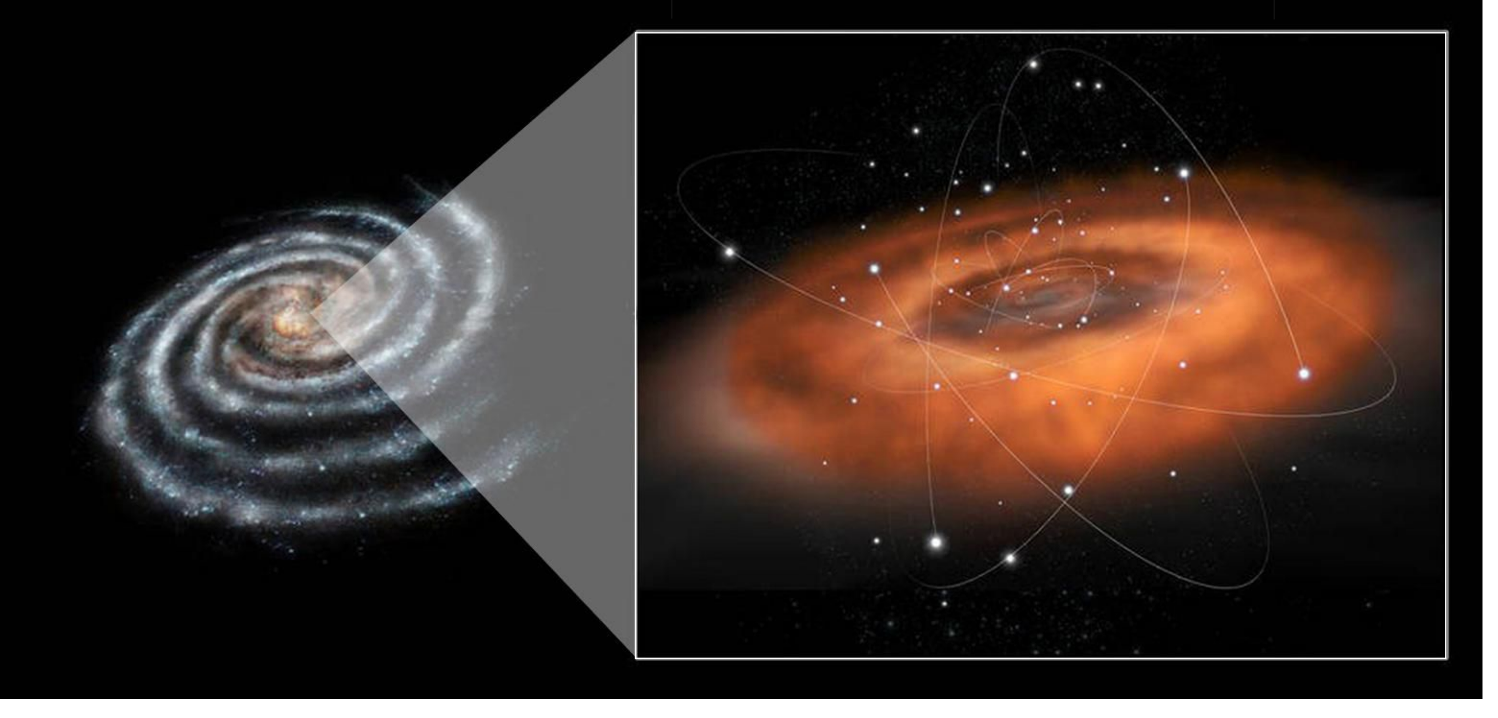
Q | ARE THE PERCENTAGES OF DARK MATTER AND DARK ENERGY STABLE, OR IS THE RATIO OF DARK MATTER TO DARK ENERGY TO OBSERVABLE MATTER CHANGING?

Charles Martin
The Villages, Florida

A | All the atoms and radiation in the universe make up less than 5 percent of its contents. The rest is composed of two invisible, enigmatic entities: dark matter and dark energy. Together they govern the behavior of the universe.

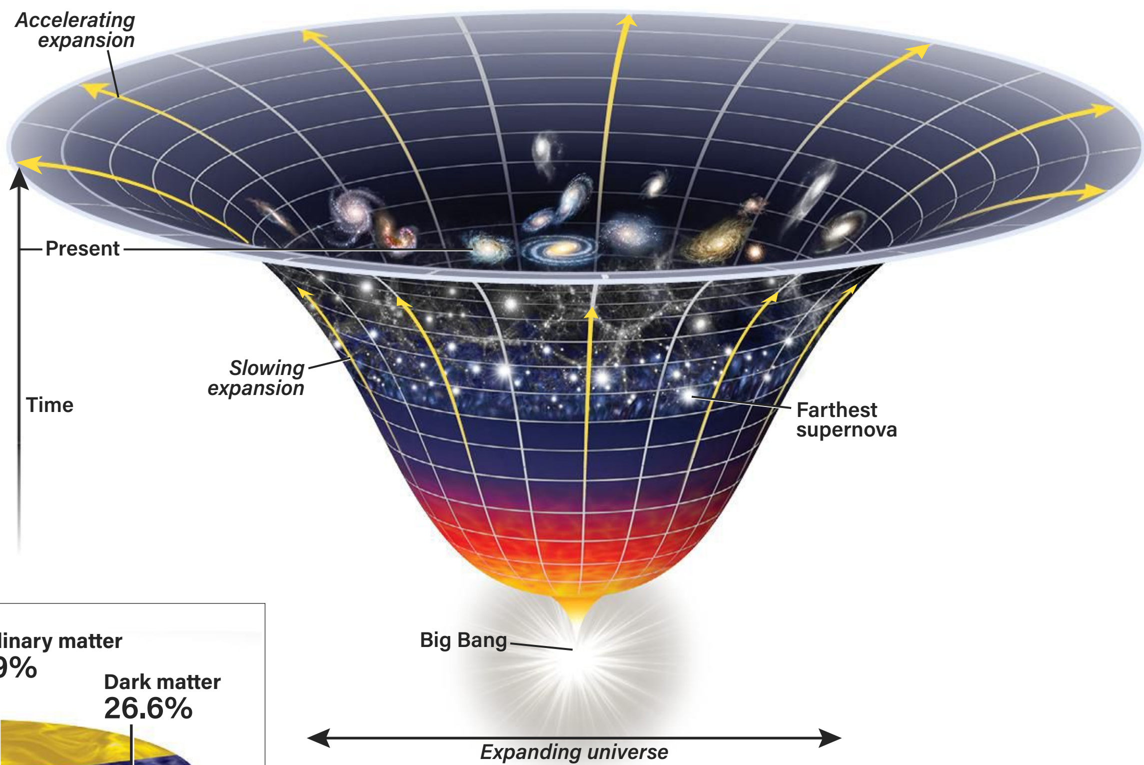
Evidence for dark matter has been accumulating for 50 years. It makes up most of the mass of all galaxies, including the Milky Way, controls the organization of galaxies on the largest scales, and represents 27 percent of the universe. The visible parts of galaxies are outweighed by dark matter, which holds galaxies together. Dark matter exerts gravity but doesn't interact with light.

Astronomers still don't know what dark matter is, but they've eliminated many possibilities: It can't be made of black holes, dim stars, free-floating planets, space rocks, or dust particles. That leaves fundamental subatomic particles as the only option. (The alternative

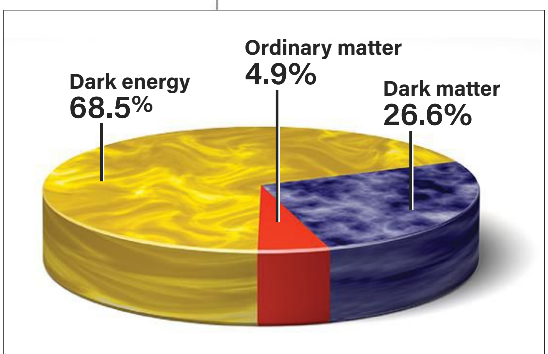


The supermassive black hole (depicted at right in this artist's concept) in the center of a galaxy only has enough gravitational pull to influence the closest stars, shown as the white dots circling the black hole. For the most part, the entire galaxy (left) rotates around its center of mass, rather than the black hole. ESA–C. CARREAU

THE EXPANDING UNIVERSE



RIGHT: The expansion rate of the universe is influenced by competing forces: that of gravity, which slows down expansion, and that of dark energy, which speeds it up. This diagram shows the expansion rate over the universe's history, with shallower curves representing faster expansion and steeper curves showing times of slower expansion. A noticeable change in the expansion rate occurred about 7.5 billion years ago, when the universe began accelerating. *ASTRONOMY*: ROEN KELLY, AFTER NASA/STSCI/ANN FEILD



ABOVE: Ordinary matter such as that in people, planets, stars, and galaxies, comprises only some 5 percent of the universe. Dark matter accounts for roughly a quarter, while dark energy is the largest component of the cosmos. *ASTRONOMY*: ROEN KELLY, AFTER NIST

is to decide that the law of gravity needs altering, but this is unpalatable to most astronomers.)

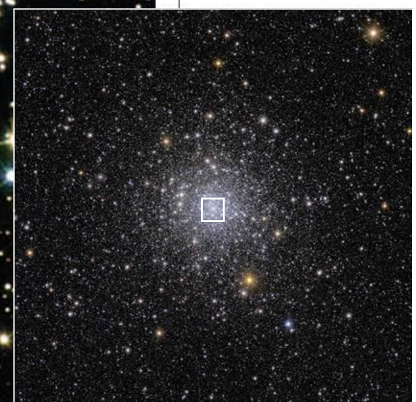
Dark energy is causing the universe to expand at an ever-faster rate. It represents 68 percent of the universe. The discovery of dark energy in the 1990s was a surprise, because the expectation in cosmology had been that the gravity of all the matter in the universe would slow down the expansion discovered by Edwin Hubble. Think of the universe as having a brake (gravity) and an accelerator (dark energy), with both being pushed at the same time. Currently, the accelerator is twice as strong as the brake, so the universe is accelerating.

We know far less about dark energy than dark matter, but it seems to be a property of space. Physics tells us that space is not nothing — it has the potential to create energy. Albert Einstein formulated a version of his gravity theory where the energy in empty space is not diluted as space expands. As more space comes into existence, more space energy appears, causing the universe to expand faster and faster. So, the idea that the amount of dark energy grows as the universe expands has been around for a while. But we still lack a physical explanation to test this idea.

Are dark matter and dark energy stable and constant? Since we don't understand their true physical nature, we can't be sure. But astronomers can see if they vary depending on which direction in space they look. This is a test of whether the universe is lopsided or the same everywhere (the physics term for this is *isotropic*). It turns out that the amount of dark matter surrounding galaxies is the same in every direction, and the strength of dark energy is also the same in every direction.

To see whether the influence of dark matter and dark energy has changed over cosmic time, astronomers look deep into space. Distant light is old light, so telescopes act as time machines, probing billions of years into the past. By measuring the redshift and brightness of distant objects, astronomers map out the expansion history of the universe. Dark matter dominated for most of that history since the Big Bang. That's because when the universe was smaller, the gravity exerted by dark matter was stronger, while the force exerted by dark energy has stayed the same. Now is the only time in the entire history of the universe when the two entities' influences are about equal. In the future, the effects of dark energy will increasingly dominate, and the universe will accelerate forever.

Chris Impey
Distinguished Professor, Department of Astronomy, University of Arizona, Tucson



The image at left shows the very center of globular cluster NGC 6397 (below), which contains several stars known as blue stragglers — stars thought to be created through collisions. HUBBLE HERITAGE TEAM (STSCI/AURA), A. COOL (SFSU) ET AL., NASA. INSET: ESA/EUCLID/EUCLID CONSORTIUM/NASA, IMAGE PROCESSING BY J.-C. CUILLANDRE (CEA PARIS-SACLAY), G. ANSELMI, CC BY-SA 3.0 IGO

Q | HOW DO GLOBULAR CLUSTERS REMAIN INTACT FOR SO LONG? AS STARS ORBIT THE COMMON CENTER OF MASS, SHOULDN'T THEY CROSS ORBITS AND COLLIDE REGULARLY, DESTROYING THE CLUSTER IN RELATIVELY SHORT ORDER?

Terrence Schell
Kelowna, British Columbia, Canada

A | Globular clusters are ancient, spherical groups of stars that are often as old as the galaxies they orbit. The stars in a globular cluster orbit the center of mass of the cluster, and the angular momentum of the stars as they move in their orbits keeps the cluster from simply collapsing in on itself. This is the same reason the planets of our solar system don't fall into the Sun.

But what about stars within the cluster colliding? There are a few factors at play here. First, remember that the stars are always moving — to get a star-star collision, you would have to have two stars whose orbits cross both meet in the same place at the same time. This is like trying to hit one moving target with a second moving target. It's not impossible, but it is unlikely.

And second, although stars in a cluster are closer together than out in the field (i.e., not in a cluster), the average distance between two stars in a globular cluster is still about 1 light-year. That's quite far apart! So, most orbits aren't likely to cross.

Of course, there are exceptions: Stars are only an *average* of 1 light-year apart, so some are much closer, down to a few light-hours apart — the size of our solar system — or less. So, despite all the reasons I've just given for why collisions are not the overall norm, stars can and do collide, particularly in the centers of the most densely populated globular clusters. Astronomers think such collisions might be how certain stars called blue stragglers are created. These stars are particularly massive and bright, meaning they should not live long, yet they are found in these ancient clusters. One way such a star could be produced is if two smaller, older stars collide, creating one massive star that suddenly has a lot of new fuel to burn and looks artificially young.

Even though most stars in a globular cluster are unlikely to collide, stars *do* often interact with each other gravitationally. If two stars pass close enough to each other, they might exchange energy, giving one a boost so it moves faster and perhaps even orbits a little farther out than before, while the other loses energy and orbits a little slower and closer to the center. In this way, globular clusters change dynamically over time, with heavier stars sinking toward the center and lighter stars moving to the outskirts or perhaps getting kicked out of the cluster altogether.

Alison Klesman
Senior Editor

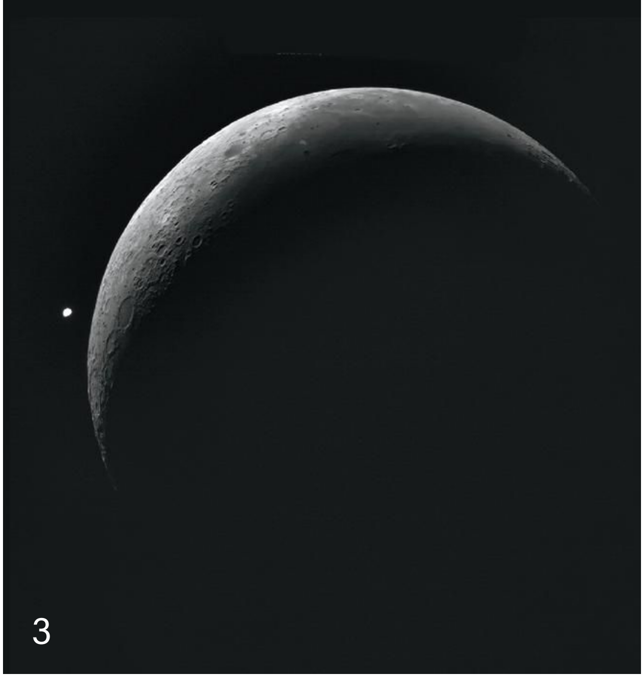
SEND US YOUR QUESTIONS

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits

1. MILK AND FIRE
The Guatemalan stratovolcano Fuego erupts below the glow of the Milky Way and Sagittarius. This image is a single 20-second exposure at f/2.8 and ISO 2000 with a modified mirrorless camera. ▪ ***Chirag Upreti***

2. THE DEVIL COMET NEARS
Comet 12P/Pons-Brooks — nicknamed the Devil Comet for its horned appearance during recent outbursts — is swinging through the inner solar system for the first time since 1954, and will reach perihelion on April 21, 2024. This LRGB image was taken with a 10-inch scope and 92 minutes of exposure. ▪ ***Gerald Rhemann/Gerhard Bachmayer***



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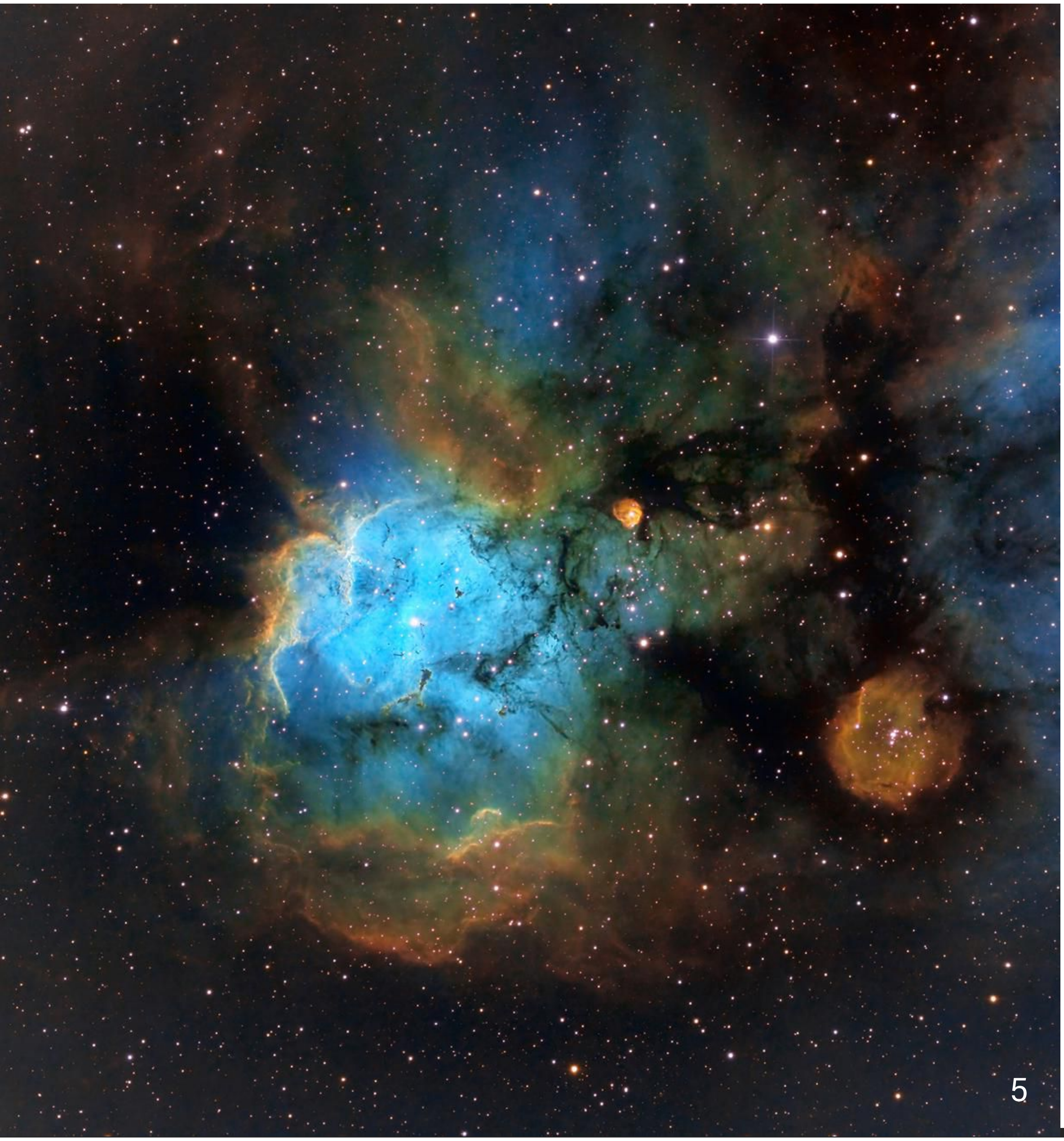

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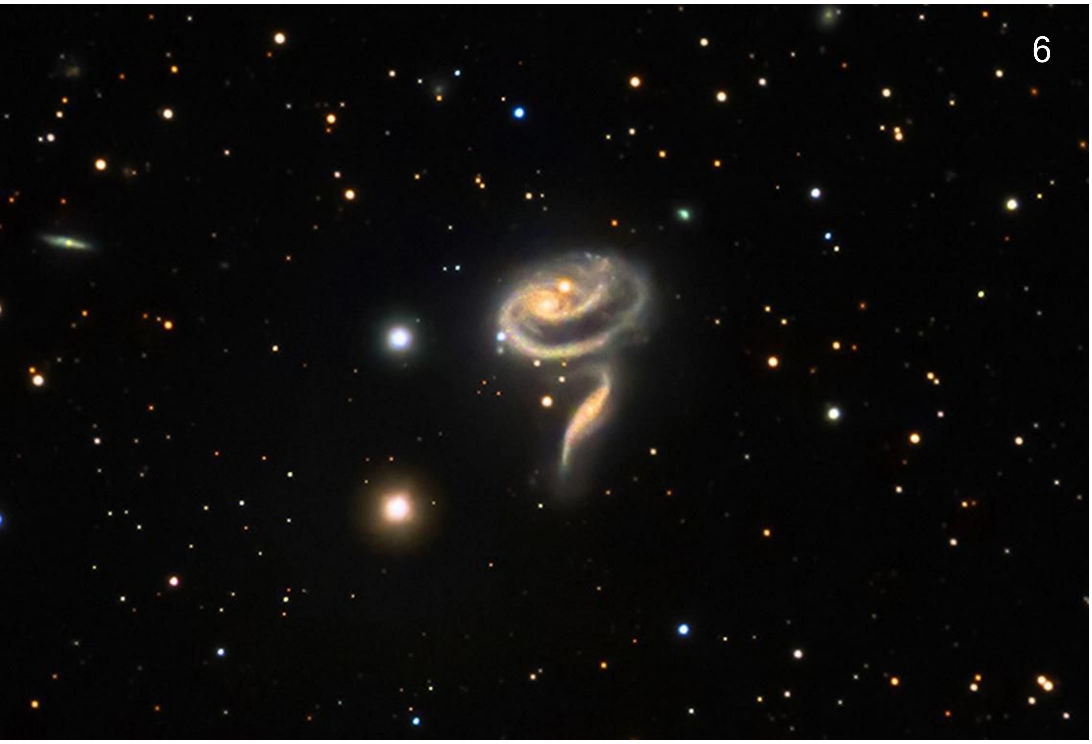
3. PHASE TO PHASE
A gibbous Venus reaches conjunction with a crescent Moon Nov. 9, 2023. This image was taken in daylight from Syracuse, Italy, at 11:37 A.M. local time with the use of an IR pass filter and a 3.2-inch refractor. ▪ ***Salvo Lauricella***

4. A NEARBY CHALLENGE
The planetary nebula Purgathofer-Weinberger 1 (PuWe 1) lies just 1,300 light-years away in the constellation Lynx. Though faint, it is large in angular extent — nearly two-thirds the width of the Full Moon. The nebula was imaged with an Hα/OIII dual-band filter and 27.5 hours of exposure on an 8-inch reflector and 33 hours, 40 minutes on a 3.2-inch refractor, plus two hours with a UV/IR cut filter on the refractor for the star field. ▪ ***Massimo Di Fusco***

5. HOIST THE COLORS
The Skull and Crossbones Nebula (NGC 2467) is a star-forming region that lies in the northernmost reaches of Puppis the Stern, as if flying high above the poop deck of Argo Navis, the great ship that plows the southern skies. This Hα/OIII/SII/RGB image represents roughly 52.5 hours of observations with a 16-inch scope. ▪ ***Warren Keller***



6. BY ANY OTHER NAME
Whether called by its designation Arp 273 or its nickname, the Rose, this interacting pair of galaxies roughly 300 million light-years away in Andromeda is a sweet photographic target. This image was taken with an 11-inch scope and 8.4 hours of exposure with a multi-bandpass filter. • ***Lorenzo Busilacchi***

7. TRIPLE THREAT
NGC 2626 is a nebula that exhibits the blue hues of reflected light from young stars, the red glow of emission from hydrogen gas, and dark patches of absorption. It lies about 3,300 light-years away in Vela the Sails. This LRGB image represents 5.6 hours of exposure on a 24-inch scope.
• ***Harshwardhan Pathak***

8. SAFE AND SOUND
The Cocoon Nebula (IC 5146) in Cygnus is an emission and reflection nebula, appearing at the end of the dark nebula Barnard 168 like an glowing orb held by a shadowy tentacle. This HαLRGB image was taken with a pair of 3.2-inch refractors and nearly 37.5 hours of integration.
• ***Francisco Serrano/José García/Ignacio Blanco***

9. PERSEID PALETTE
A Perseid meteor leaves a brilliant, colorful trail and a train of vaporized dust as it zips past the Andromeda Galaxy (M31) in this image captured In the early morning hours of April 13 near Cuenca, Spain.
• Jose Pedrero

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.

A WILD PILEUP IN WESTERN VIRGO

American astronomer Halton Arp had an eye for the unusual. He studied galaxies with strange shapes in the hope they would lead to understanding galactic evolution. His 1966 *Atlas of Peculiar Galaxies* serves as a grand resource for studying interacting galaxies. This Hubble Space Telescope image shows Arp 248, a trio of island universes also known as Wild's Triplet. Here we see the nearly face-on spirals PGC 36723 (lower right) and PGC 36733 (upper left); the third member lies off the top edge of this field. The trio lies some 200 million light-years from Earth. The smaller edge-on spiral between the two larger galaxies is an unrelated background object. ESA/HUBBLE & NASA/DARK ENERGY SURVEY/DOE/FNAL/DECAM/CTIO/NOIRLAB/NSF/AURA/J. DALCANTON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May 2024

And then there were three

Jupiter has now disappeared from the evening sky and **Venus** no longer graces the morning twilight. Sadly, this means we have only three naked-eye planets to follow this month, and all appear in the hours before sunrise.

Saturn is the first of this trio to rise, and it also is the farthest from Earth. At the beginning of May, the ringed planet clears the eastern horizon more than four hours before the Sun. From mid-southern latitudes, it climbs some 30° high by the beginning of astronomical twilight. The planet shines at magnitude 1.0 and moves slowly eastward against the backdrop of eastern Aquarius the Water-bearer.

The planet's high altitude delivers marvelous observing opportunities for those with telescopes. The great views come despite the rings being far less conspicuous than usual. They currently tilt just 3° to our line of sight. Although this makes the dark Cassini Division that separates the outer A ring from the brighter B ring harder to discern, it opens up other opportunities.

Now is a good time to look for atmospheric details on Saturn's disk, which measures 17" across the equator at midmonth. This is also prime time for viewing the planet's moons. Eighth-magnitude Titan — the fifth-brightest moon orbiting another planet, after Jupiter's four Galilean satellites — is always easy to spot. But all you need is a 10-centimeter or larger instrument to bring in the 10th-magnitude trio of Tethys, Dione, and Rhea.

A nearly Last Quarter Moon occults Saturn on May 31 for observers in the southern third of South America. From Buenos Aires, Saturn's disk begins to disappear behind the Moon's bright limb at 6h42m UT; it takes about 50 seconds for the Moon to complete the job. The rings start to reappear from behind the Moon's dark limb at 7h30m UT.

Look well below Saturn to pick up the ruddy glow of **Mars**. The magnitude 1.1 Red Planet trails Saturn in the morning darkness. It travels eastward through the constellation Pisces the Fish for most of the month but clips the corner of Cetus the Whale during May's second week.

Mars still lies far from Earth, so it appears only 5" across through a telescope. Although you likely won't make out much detail, you might catch a brief glimpse of the planet's south polar cap.

To the lower right of Saturn and Mars lies the last of our morning planets, **Mercury**. The innermost planet reaches greatest elongation May 9, when it lies 26° west of the Sun, stands 13° high in the east-northeast an hour before sunrise, and shines at magnitude 0.5. A telescope shows a disk that spans 8" and appears 40 percent lit. This is Mercury's finest morning apparition of 2024, so don't pass up the opportunity to view it.

The starry sky

A year ago, I gave a public address in Mizoram, India, on some of the great contributions women have made to astronomy. I talked about Indian physicist Bibha Chowdhuri (1913–1991), who performed important research on cosmic rays, and mentioned that the International Astronomical Union (IAU) had named a star after her. HD 86081, which lies just south of the celestial equator in the constellation Sextans the Sextant, is now officially called Bibha.

Despite being in the southern sky, the star reaches fairly high in India's sky because Mizoram lies at a relatively low northern latitude.

Not only is astronomy for everyone, but the sky's equatorial region is accessible to all. This made me reflect on the fact that although we often talk of northern and southern constellations, the celestial equator passes through many of these star groups (including Sextans). I decided to see how many constellations belong to both hemispheres, and found 15: Pisces, Cetus, Taurus, Eridanus, Orion, Monoceros, Canis Minor, Hydra, Sextans, Leo, Virgo, Serpens, Ophiuchus, Aquila, and Aquarius.

You may be surprised at some of the members on this list. Most people think Taurus the Bull lies well to the north, but this rather large constellation extends just over 1° south of the equator in the region near 10 Tauri. Another intriguing entry resides just to the east, where the northernmost part of Eridanus the River juts barely north of the equator.

Another "northern" constellation, Leo the Lion, actually has more than 50 square degrees that belong to the southern sky. The region includes the 4th-magnitude stars Upsilon (υ) and Phi (φ) Leonis. This part of the sky stands high in the north on May evenings.

The IAU officially adopted the constellation boundaries in 1928, following the work of Eugene Delporte, and published them in 1930. These were based on the equator and equinox of 1875, when the northern edge of Eridanus and the southern edge of Canis Minor coincided exactly with the celestial equator. The IAU chose the epoch of 1875 because decades before it approved all the borders, Benjamin Gould (1824–1896) already had drawn up borders for the southern constellations based on 1875 coordinates.

However, precession has altered not only the right ascensions and declinations of the stars, but also the coordinates of the constellation boundaries. This means our list must inevitably change. For example, by around the year 2460, all of Taurus will reside in the northern celestial hemisphere.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

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

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

Planets are shown at midmonth

MAP SYMBOLS

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

STAR MAGNITUDES

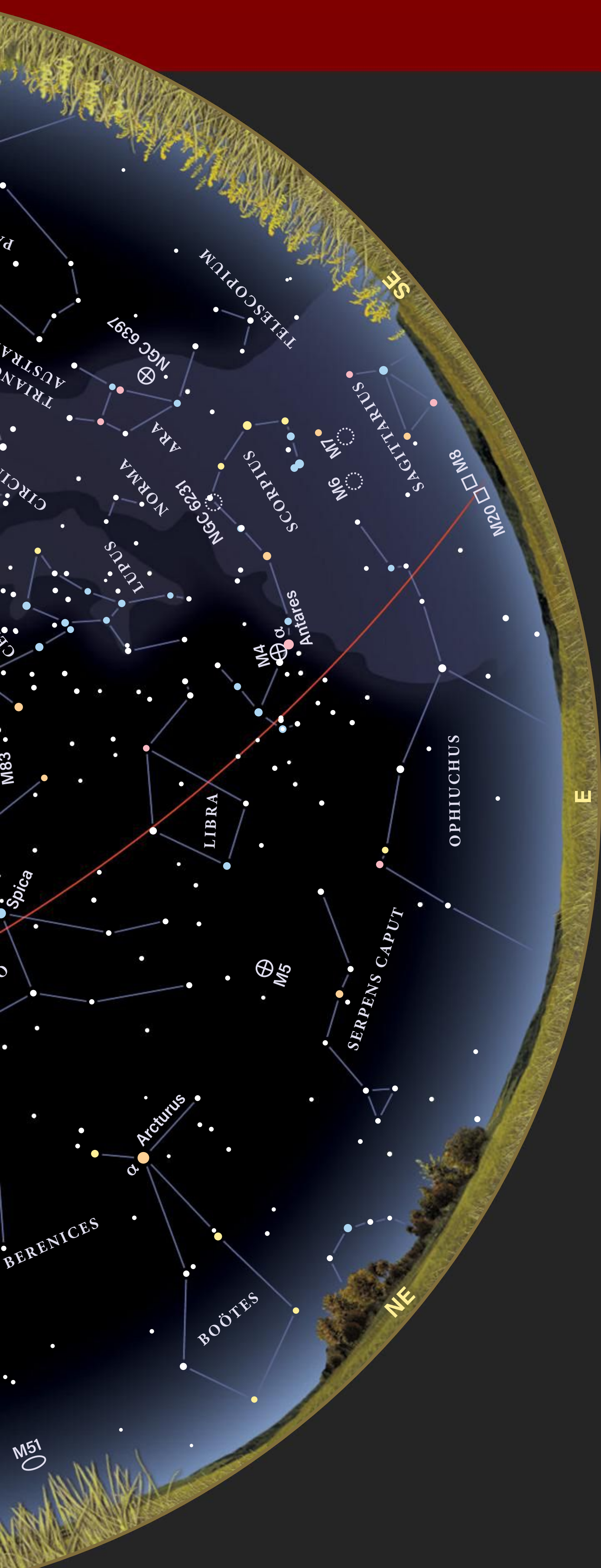
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

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.**



MAY 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 Last Quarter Moon occurs at 11h27m UT

3 The Moon passes 0.8° south of Saturn, 23h UT

4 Pluto is stationary, 3h UT

The Moon passes 0.3° south of Neptune, 19h UT

5 The Moon passes 0.2° north of Mars, 2h UT

Eta Aquariid meteor shower peaks

The Moon is at perigee (363,163 kilometers from Earth), 22h04m UT

6 The Moon passes 4° north of Mercury, 8h UT

8 New Moon occurs at 3h22m UT

Mars is at perihelion (206.7 million kilometers from the Sun), 11h UT

9 Mercury is at greatest western elongation (26°), 22h UT

13 Uranus is in conjunction with the Sun, 9h UT

15 First Quarter Moon occurs at 11h48m UT

16 The Moon passes 1.1° north of asteroid Juno, 13h UT

Dwarf planet Ceres is stationary, 23h UT

17 The Moon is at apogee (404,640 kilometers from Earth), 18h59m UT

18 Jupiter is in conjunction with the Sun, 19h UT

19 Asteroid Pallas is at opposition, 15h UT

23 Full Moon occurs at 13h53m UT

24 The Moon passes 0.4° north of Antares, 3h UT

27 The Moon passes 0.9° south of dwarf planet Ceres, 5h UT

30 Last Quarter Moon occurs at 17h13m UT

31 The Moon passes 0.4° south of Saturn, 8h UT