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Where: N1 = number of nucleons in body 1. N2 = nucleons in body 2. En = mass-energy of a nucleon. L = Hubble distance
NU = nucleons in the entire Universe.
R = distance between bodies.
What? Math ? Yes, dear reader. Gravity is best understood when constrained by the rigor of math. Thus this equation tells us that the strength of gravity is diluted by the nucleons of the entire Universe. That, the space-energy condensed to make the nucleons determines gravity.

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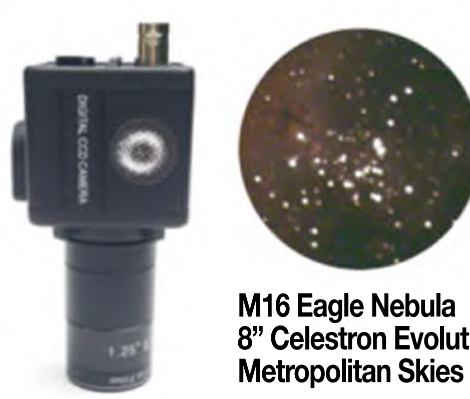

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FEBRUARY 2021
VOL. 49, NO. 2

ON THE COVER

Comet C/2020 F3 NEOWISE stormed into our skies in July and put on a spectacular — though relatively brief — show. JOSE CHAMBO

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COLUMNS

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A renewal for stargazing

The Orion and Horsehead nebulae in the winter Milky Way are among numerous treasures rediscovered by housebound skywatchers.
TONY HALLAS

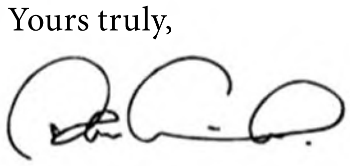
As I write this in late 2020, the world has been upended by a pandemic for over eight months now. More significant than any health crisis in a century, the coronavirus outbreak has changed all our lives, in some ways perhaps permanently. Despite all the negative aspects of the pandemic — social distancing away from friends and family, economic fallout, and, most importantly, the terrible toll of death and sickness — there has been one apparent benefit from these circumstances. We've seen quite a surge of astronomy hobbyists and their neighbors, friends, and acquaintances discovering or rediscovering the sky.

This year has been a good one for observational astronomy, no doubt. We had a beautiful naked-eye comet, C/2020 F3 NEOWISE. On the days before and following perihelion, July 3, it shone brighter than first magnitude and displayed magnificent ion and dust tails. For Northern Hemisphere observers, the comet was visible all night in mid-July, bright enough to get non-astronomers to take notice.

We've also had wonderful planetary oppositions this year. Jupiter and Saturn reached their brightest, opposite the Sun in the sky, in the second and third weeks of July. Perched in the southeast beside Sagittarius, the two planets gleamed brilliantly. And novice skygazers were impressed that a pair of binoculars with 10x magnification could reveal the Galilean moons of Jupiter astride the big planet's disk. The array of planets continued when Mars reached opposition in mid-October, displaying some of its amazing features for observers and astroimagers.

The joy that we've seen in people observing the sky, some for many years and some for the first time, has never been stronger. I hope that when the pandemic is resolved, we'll not forget our rediscovery of this love affair. There is so much out there for us to see, to capture our minds and our imaginations, and to give us amazing perspective on the challenges we face on our little blue planet.

Yours truly,



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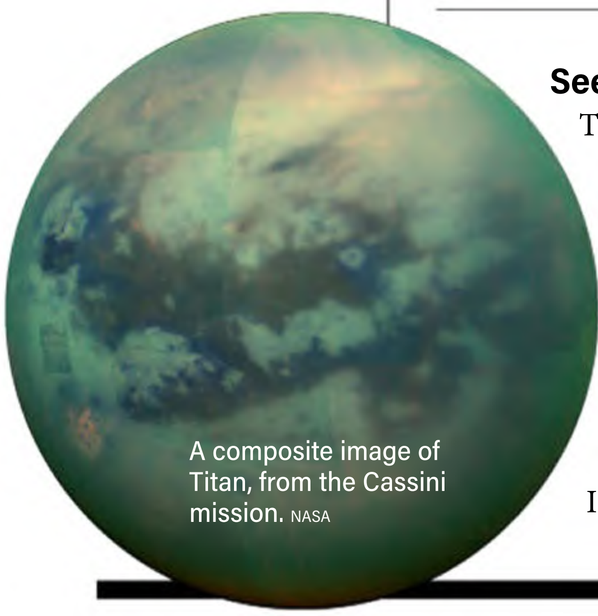
Teaching the teacher

I taught high school biology for 42 years. I always mentioned the sense of smell could evoke a strong memory or emotional response, but I never knew why this was true. Then comes along Associate Editor Jake Parks, who beautifully taught the teacher with his explanation of how smell works in the sidebar for "What does Titan smell like?" in the September issue. To my more than 5,000 former students: I apologize for not explaining "the why" of the issue as well as Jake Parks can.
—Jim McLeod, Charlotte, NC

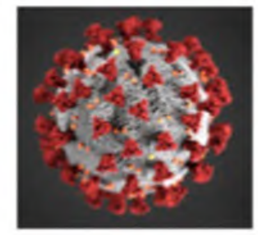


A composite image of Titan, from the Cassini mission. NASA

Seeing colors

Thank you, Stephen O'Meara, for introducing me to Haidinger's Brush in the October issue. I had never heard of it but will certainly watch for it. Decades ago, I had a shirt, and I believe it had wide horizontal stripes of blue and white. When I picked up that shirt, I would often see yellow bands running vertically across the pattern. I'd mention it to others, and I think they considered me either crazy or just making it up. Could that have been a "sighting" of Haidinger's Brush? **—Tim Geddert,** Fresno, CA

Thoughts on "Learning the hard way"



My compliments to Jeff Hester on his article, "Learning the hard way," in the September issue. It was a very succinct explanation about the workings of the virus, and it placed the blame without using names. As a retired registered nurse, I especially appreciated it, but was surprised to see a health article in an astronomy magazine, even though it affects everyone. Thanks for that very relevant article. **—Alice Mack,** Fort Myers, FL

Correction

In the article "What does Titan smell like" in the September 2020 issue, the caption on page 31 incorrectly stated the diameter of Titan is about 1,600 miles (2,600 kilometers). Rather, Titan's radius is about 1,600 miles (2,600 km).

ADVERTISEMENT

If Discoverer Ramesh Varma (India) had been academic qualified PhD scientist (not citizen scientist); discovery claim instead of being an advertisement, would have appeared in all Science Journals as publication resulting to make it viral among the concerned. (Mode of new discovery information set by the Academic World is a curse on the mankind).

A new discovery claim

over invisible state of the matter:

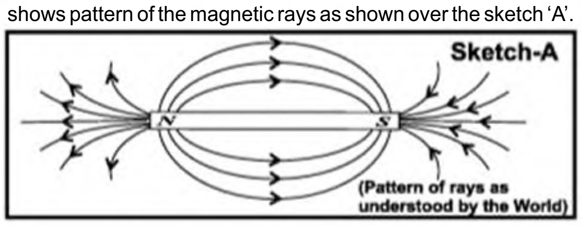
The entire Universe is materialistic; no pocket of the Universe is with absolute nothing. What we see, we understand it a matter but whatsoever (particles and rays etc) in the space we can't see that too is matter (materialistic).

Fact: Whatsoever trillions and trillions of stars release in the form of invisible matter (rays, particles, gases etc) by losing their mass in their respective galaxies or in the space that all is mixture of different kinds of the matter to be called as **white matter** which has been falsely understood by the Scientists as dark matter. Further, presence of invisible matter in the galaxies called as dark matter by the Scientists was noticed in the year 1930s whereas Scientists came to know of the solar wind in the 1940s. With the result it has been understood that Sun loses mass to generate whatsoever it ejects to solar space. It is an utmost surprise that until now no one has linked mass lost by the stars to generate invisible white matter (falsely understood as dark matter.

- Rays of all kinds are materialistic: A ray is composed of finest form of spherical particles. All spherical particles by closely touching each other form a row or a ray. Density, diameter and chemical properties of the spherical particles make a ray of different kind.
- Magnetic rays: are composed of finest form of the particle matter. Iron or any other magnetic material acting as catalyst splits a kind of stable form of white matter of the space say 'NS' to two unstable forms of white matter particles rays say 'N' and 'S'; both rays intend to re-unite to form again stable white matter 'NS'.

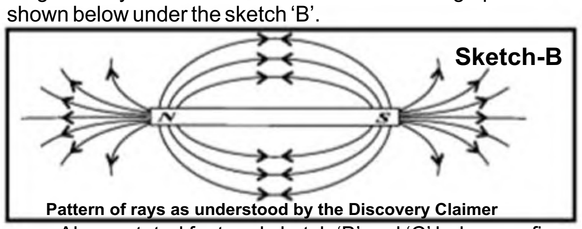
Forward direction of the magnetic particles rays:

Information taken from the academic books and Internet shows pattern of the magnetic rays as shown over the sketch 'A'.



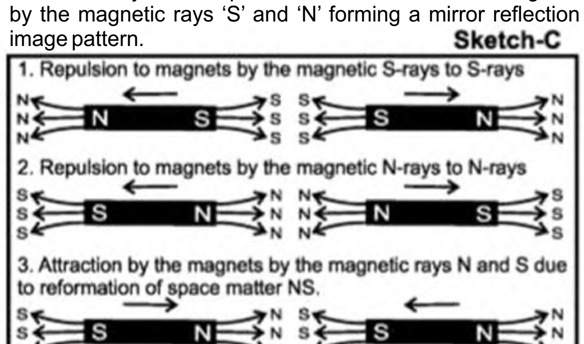
What does the Discovery claimer has understood?

Understood pattern suggests that magnetism or magnetic rays are being generated at the North Pole and on entering as South Pole; magnetic rays travel through the magnetic bar to North Pole to repeat the cycle (why is it not vise- versa?). Further; if South Pole of the magnetic compass is pointed towards the North Pole of the Bar-magnet it forms the same pattern of magnetic rays as North Pole of the compass forms with the South Pole of the bar -magnet. Then why does the forward direction of the rays differs over North and South Pole of the bar-magnet?. Pattern formed by the magnetic rays must be the mirror reflection image pattern as shown below under the sketch 'B'.



Above stated fact and sketch 'B' and 'C' below confirms that magnetic particles rays 'N' and 'S' has been produced from the space matter NS by the magnetic matter (Bar magnet) acting as catalyst and rays 'N' and 'S' having the property to re-unite again to form stable white matter NS.

The following sketch 'C' as understood by the Discovery Claimer also justifies repulsion and attraction to bar magnets by the magnetic rays 'S' and 'N' forming a mirror reflection image pattern.



- Electrons of an atom, lightning or of the electricity are a state of the matter, which act as energy under specific conditions. Generator generates electrons from a kind of the space's white matter along with the magnetic particle matter. In case terminals (positive/negative) of the generator are not connected to any device or to the earth; produced electrons disappear to space in the form of white matter.
- Smell/Odour particles are the chemical particles released by the decomposition of the organic/ inorganic chemical matter so smell particles are also a state of the matter.
- Gravity is not a wave or particle matter but it is directly related to the matter of any kind including white-matter.

Scientists have claimed that they have detected gravitational waves emerging from clubbing (collision) of two nearby black holes. In fact it was not the gravitational waves but were compressions and rarefactions created in the space occupied by the white matter as medium, like by the sound in air medium.

- Energy is not merely energy but it is a state of the matter (white matter), which acts as energy under specific conditions.

There is no dark energy, which is pulling the galaxies and other celestial objects towards outer space (or expanding the Universe) but it is the outwards going white matter particles and rays generated and released by the stars, planets and other objects that are pushing the celestial objects along with the galaxies towards the outer presumed end of the Universe.

Conclusion: Periodic table is for the visible states of the matter (solid, liquid and gases) but so far the World has not been able to correctly understand physical, chemical and biochemical properties of the invisible matter. Correct understanding of **true states of the matter and particularly the invisible matter** by the Discovery Claimer has resulted to conclude that Prime and only one Fundamental of the Universe for its existence, formation and working is the 'Universe is materialistic'. Already understood four fundamentals of the Universe by the World are the sub-fundamentals of it. As under the Religion belief there would be only one God (not so many). Similarly. there can't be four Fundamentals. The said discovered and claimed Prime and only one Fundamental would lead to replace all theories, postulations, hypothesises and speculations with the facts.

- Must read discovery claim advertisements over Astronomy and Light published in the magazine 'ASTRONOMY'. which appeared in the issue Feb 2020 to August 2020 (7 Nos) and over subject 'Light' (Physics) January 2021.
- Much more over the discovery claim is over the website www.newtonugeam.com under title MATERIALISTIC UNIVERSE.
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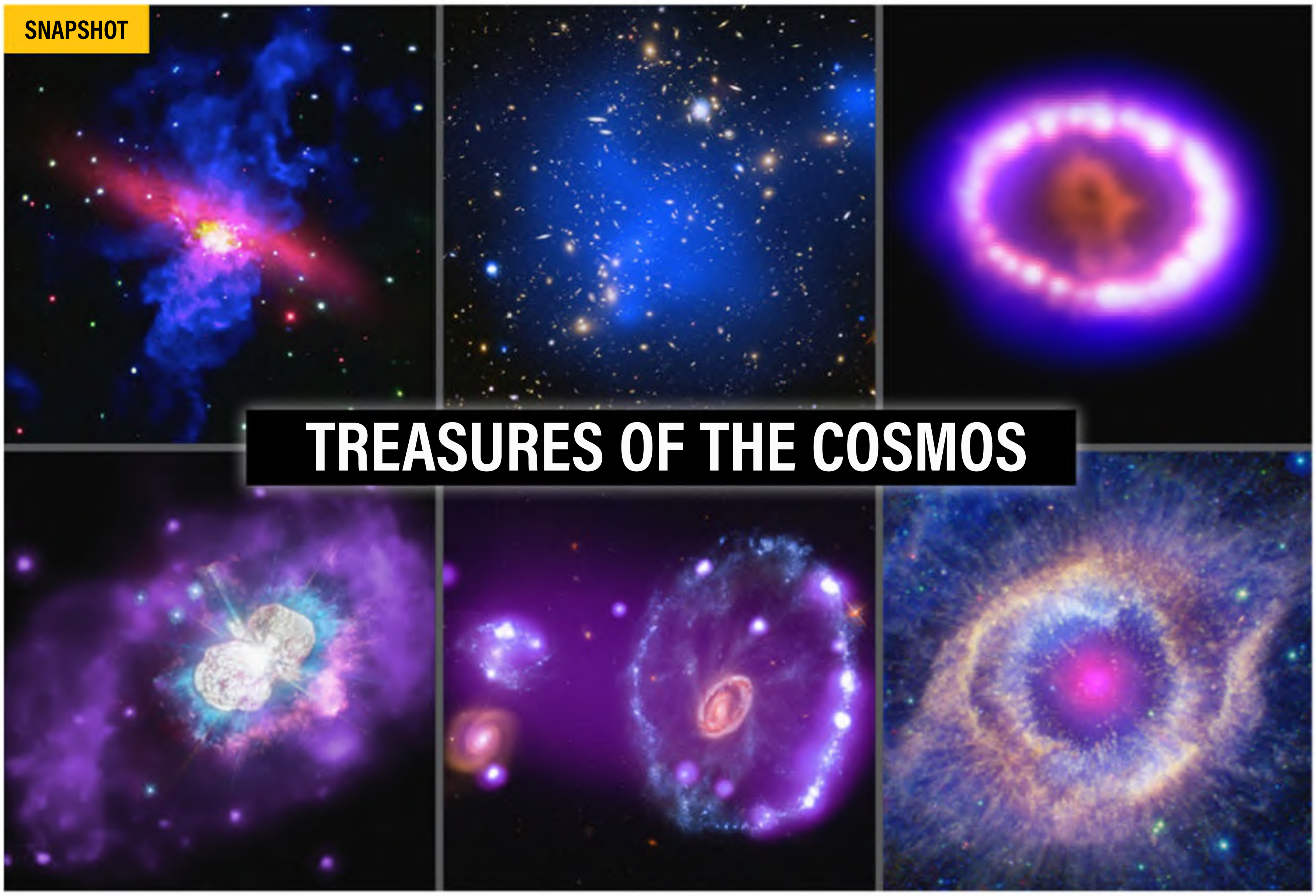
SNAPSHOT



TREASURES OF THE COSMOS

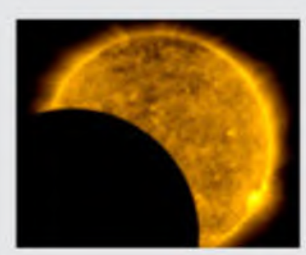
If humans could see beyond just visible light, the universe might look like these images, which combine observations from NASA's Chandra X-Ray Observatory with data from telescopes that pick up different parts of the electromagnetic spectrum. This multiwavelength approach to observing helps researchers gain a fuller understanding of how these cosmic wonders behave in the depths of space. M82 (top left) is a galaxy facing Earth edge-on, giving us a unique look at outflows of gas driven by star formation and supernovae. Abell 2744 (top center) is a galaxy cluster millions of light-years across, while SN 1987A (top right) is the remnant of a powerful supernova that exploded 160,000 years ago. On the other hand, Eta Carinae (bottom left) is a binary star system still waiting to go supernova. The Cartwheel Galaxy (bottom center) was created after one galaxy punched through another in a powerful collision. And the Helix Nebula (bottom right) is a planetary nebula, providing a glimpse at what our own Sun might look like 5 billion years in the future, after it expels its outer layers and becomes a white dwarf. —HAILEY ROSE MCLAUGHLIN

X-RAY: NASA/CXC; OPTICAL: NASA/STSCI. BOTTOM FROM LEFT: ESO/M. KORNMESSER; NOBEL MEDIA. ILL. NIKLAS ELMEHED; NASA'S GODDARD SPACE FLIGHT CENTER/SDO/JOY NG

HOT BYTES

SPAGHETTIFIED STAR
Astronomers using ESO's Very Large Telescope and New Technology Telescope got an unprecedented look at a black hole devouring a star, finding that such events send out powerful blasts of material that can obstruct our view.

NOBEL PRIZE
Three scientists whose research focuses on black holes shared the 2020 Nobel Prize in Physics. Half the award went to Roger Penrose, while the other half was jointly awarded to Reinhard Genzel and Andrea Ghez.



LUNAR PHOTOBOMB
On October 16, 2020, NASA's Solar Dynamics Observatory spacecraft tracked a stunning lunar transit. At the transit's peak, the Moon covered about 44 percent of the Sun's disk.

OSIRIS-REX OVERFLOWS WITH SAMPLES

NASA's daring asteroid mission collected so many rocks that the craft couldn't contain them all.

TOUCH AND GO. OSIRIS-REx's sample-collection mechanism makes contact with the surface of Bennu (left) and kicks up a cloud of rocks and dust (right). NASA/GODDARD/UNIVERSITY OF ARIZONA

» OSIRIS-REx is getting ready to come home — but like a lot of travelers, it has collected more souvenirs than will fit in its luggage.

This highly relatable problem is a good one to have, though. It means the spacecraft's Touch-And-Go (TAG) attempt to collect rocks and dust from the surface of asteroid Bennu October 20 was a smashing success. OSIRIS-REx — short for Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer — is now the third mission to nick rocks from an asteroid and NASA's first, following Japan's two Hayabusa missions.

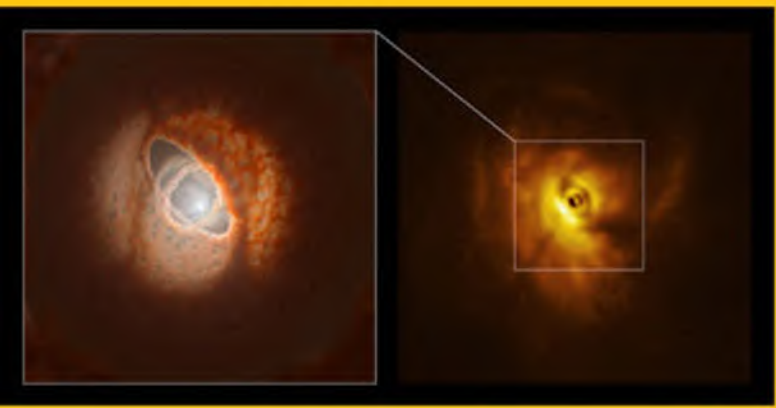
Bennu is a dark rubble pile of an asteroid more than 200 million miles (322 million kilometers) from Earth. Launched in 2016, OSIRIS-REx arrived in late 2018 and began an intensive survey of the 1,640-foot-wide (500 meters) world.

Right away, Bennu threw the mission for a loop. The team expected a smooth surface, like gravel or beach sand. Instead, the landscape was strewn with boulders, forcing a complete overhaul of the craft's landing software and a painstaking analysis of the asteroid's surface to identify a safe landing site.

Nearly two years of work came to fruition on October 20. First, OSIRIS-REx navigated down to the surface of Bennu. The spacecraft's cylindrical sample-collection head, mounted to a robotic arm, pressed into the regolith — the surface layer of dust and rocks — for six seconds. At the same time, it fired a canister of nitrogen gas, kicking up a cloud of material into a collecting area inside the rim of the sample head.

"I must have watched [the video of the TAG attempt] about 100 times last night before I finally got a little bit of shuteye," said Dante Lauretta of the University of Arizona, the mission's principal investigator, at a media briefing on October 21. "I dreamed of a wonderworld of Bennu regolith particles floating all around me."

TWISTED SOLAR SYSTEM



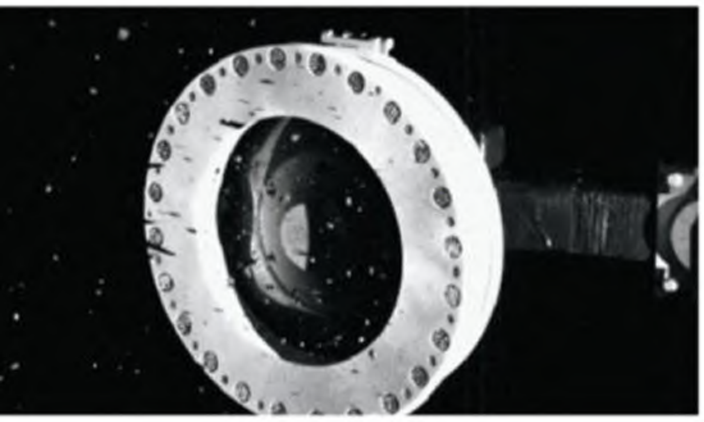
ESO/L. CALÇADA, EXETER/KRAUS ET AL.

The planets in our solar system orbit the Sun on nearly the same plane. But not every system is as harmonious. GW Orionis contains three young stars sowing chaos. Astronomers have known for more than a decade that this system (right) is surrounded by a disk of gas and dust, and new observations show that the stars' gravitational meddling has formed three distinct rings within the disk. The effects have driven the innermost ring onto a entirely different plane as the others, shown in this artist's concept (left). The disks aren't the only crooked objects — the orbits of the stars themselves are also misaligned in this skewed system. —CAITLYN BUONGIORNO

CONTINGENCY PLANS

Two days after the TAG attempt, mission engineers moved the collection head in front of the craft's cameras to evaluate their haul. Rocks were plainly visible inside the apparatus — at least 14 ounces (400 grams), they estimated.

But the team also saw something concerning: The mylar flap meant to seal in those precious rock samples was stuck open. A handful of Bennu particles just a few centimeters wide were wedged between the flap and the sample head's inner rim. Furthermore, time-lapse imagery showed some of the invaluable pebbles escaping into space. It appeared the collection head was stuffed full and literally overflowing.



RUNNETH OVER. OSIRIS-REx's sample collection head is seen here with Bennu particles wafting out. The head's mylar flap (the faint white crescent on the left side of the inner rim) is visibly wedged open. NASA

On one hand, that probably means OSIRIS-REx collected even more material than is visible — perhaps up to 4.4 pounds (2 kilograms), the researchers estimate. "It's very exciting, very surprising, but overall excellent news," Lauretta told reporters on October 23.

Still, the leaking samples injected a sense of urgency into the mission. The team cancelled further evaluations of their haul to avoid jostling more particles out of the open flap, instead opting to stow it as soon as possible to minimize losses. By October 28, the material had been secured inside the craft's sealed capsule, ready for its journey back to Earth.

The team estimates that the sample head likely bled up to a few ounces of material while it was exposed to space. But the remainder still greatly exceeds the mission's target of 2.1 ounces (60 g) and is on track to become the largest set of asteroid samples ever returned to Earth by a spacecraft.

Scientists hope scrutinizing the samples will yield insight into the formation of the solar system, as well as life on Earth. They expect to have Bennu's rocks in their labs shortly after the craft delivers on September 24, 2023. —MARK ZASTROW

QUICK TAKES

READING TEA LEAVES

Cosmonauts aboard the International Space Station tracked down a pesky minor air leak by tearing open a tea bag inside the affected module and watching the leaves drift toward the puncture.

PHOSPHINE ON VENUS?

Astronomers say they have detected phosphine in the clouds of Venus. The molecule, which is associated with biotic processes on Earth, may be produced by some unknown chemical process or even microbial life. (See "Top 10 space stories of 2020" on page 16 for more information.)

ALTERED REALITY

Paradox-free time travel is mathematically possible, University of Queensland researchers find. According to their calculations, if you traveled back in time and interacted with your past self, events would adjust themselves around you to ensure a consistent timeline.

DEARTH METAL

Astronomers have found that stars in the globular cluster RBC EXT8 in the Andromeda Galaxy have, on average, 800 times less iron than our Sun, making it the most metal-poor globular cluster known.

MAIDEN FLIGHT

China launched an experimental reusable spacecraft September 4 from the Jiuquan Satellite Launch Center. The craft, which deorbited and landed after a two-day mission shrouded in secrecy, is rumored to be a robotic spaceplane akin to the U.S. Air Force X-37B.

MAKING WAVES

In late October, the LIGO and Virgo observatories announced the discovery of 39 gravitational-wave signals caused by binary black hole or neutron star collisions. The signals, received between April and October 2019, add to 11 previous detections. —M.Z.

Tangled in a cosmic web

Astronomers have long struggled to understand how supermassive black holes could have formed in the early universe. Such cosmic goliaths must have formed quickly — less than a billion years after the Big Bang — defying our current understanding of how fast a black hole can feed and grow. Additionally, it remains unclear exactly where these giants found huge amounts of matter to gorge on.

New findings from the European Southern Observatory's Very Large Telescope, published October 1 in *Astronomy & Astrophysics*, may provide the answer.

The paper outlines six newly discovered galaxies spotted just 900 million years after the Big Bang, when the universe was only around 6 percent its current age. This is the first time such a close grouping of galaxies has been found within the cosmos' first billion years. And at the center of this galactic mosh pit lies a supermassive black hole a billion times the mass of the Sun.


ESO/L. CALÇADA

SPIDER'S WEB. This artist's concept shows six recently discovered galaxies surrounding a supermassive black hole in the early universe. It is the first such tight-knit group of galaxies seen so soon after the Big Bang.

But how did these galaxies and the supermassive black hole find enough material to grow so soon after the Big Bang? The key is likely the vast cosmic web. This universal scaffolding is woven through the entire cosmos, connecting distant galaxies, galaxy clusters, and galaxy superclusters through threads of faint gas known as filaments, which likely formed around clumps of dark matter.

The authors of the new study think the supermassive black hole and its surrounding galaxies, dubbed SDSS J1030+0524, likely fed on gas that was stockpiled in a tangled knot of cosmic web filaments.

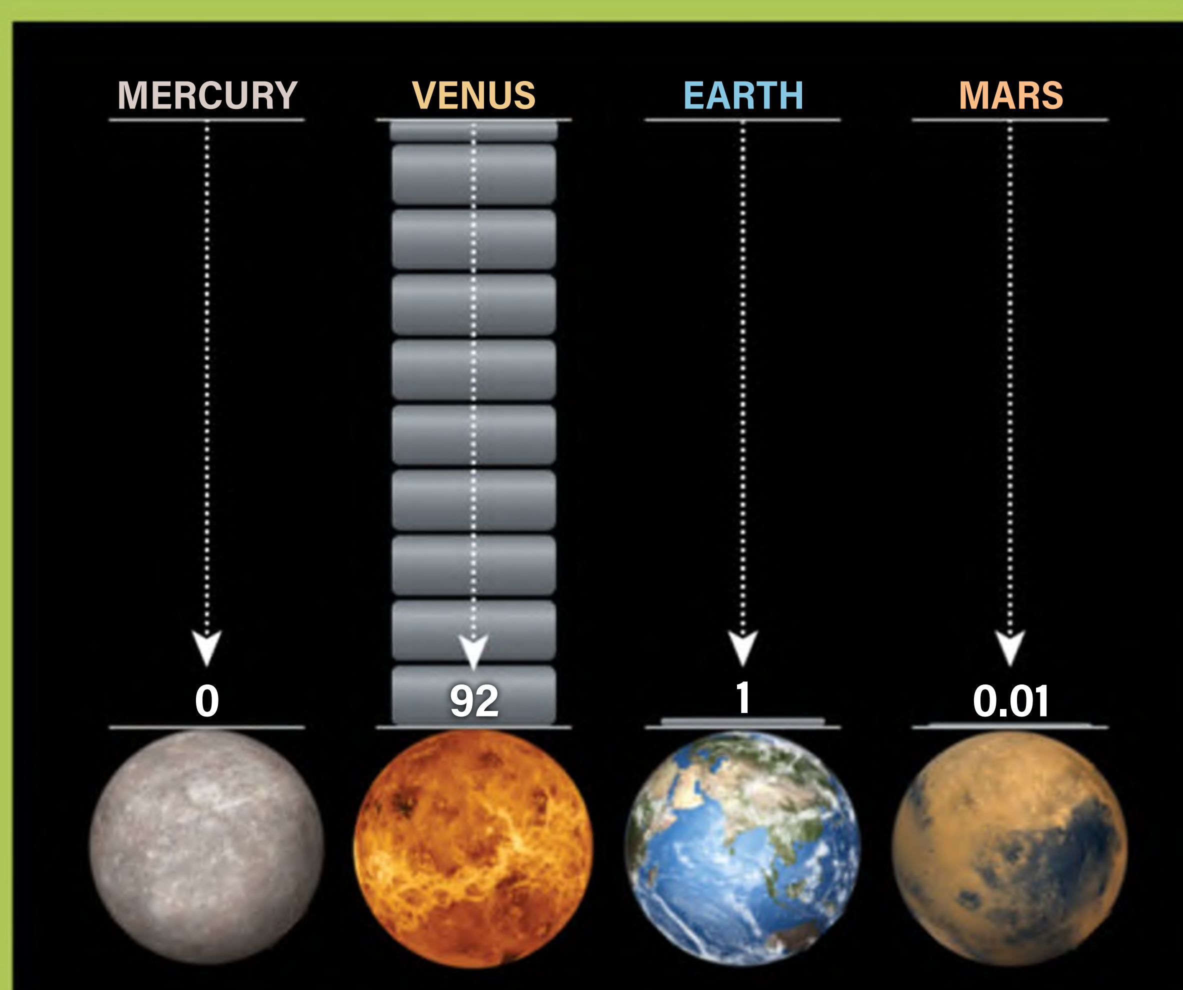
"The cosmic web filaments are like spider's web threads," said lead author Marco Mignoli in a press release. "The galaxies stand and grow where the filaments cross, and streams of gas — available to fuel both the galaxies and the central supermassive black hole — can flow along the filaments." —C.B.

PLANETARY SURFACE PRESSURES

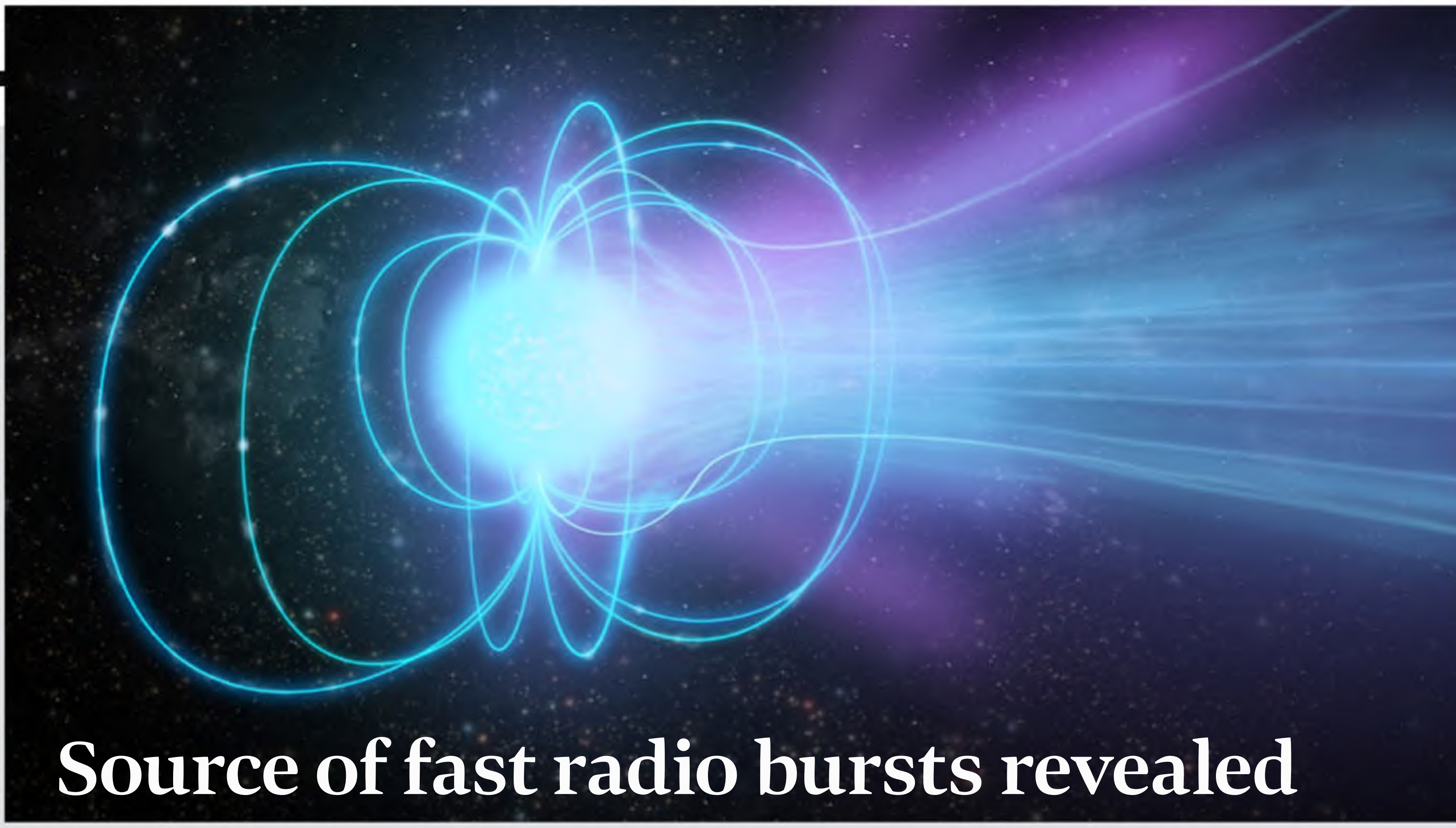
UNDER PRESSURE. Surface pressure is the pressure exerted on you by the weight of the atmosphere above your location. The composition and thickness of a planet's atmosphere affects the pressure at its surface — a thicker, heavier atmosphere translates to a higher surface pressure. On Earth, the surface pressure at sea level is 1 atmosphere, which is equivalent to 14.696 pounds per square inch (1.033 kg/cm^2). This is how the other terrestrial planets compare to our own, as a ratio of Earth's surface pressure. —ALISON KLESMAN

FAST FACT

This measurement is not possible for the outer planets, whose volumes are mostly gas and lack traditional surfaces. They do have solid cores, but these are so deep that their location is not exactly known.



ASTRONOMY: ROEN KELLY



Source of fast radio bursts revealed

SOPHIA DAGNELLO, NRAO/AUI/NSF

PENT-UP ENERGY. A magnetar emits a burst of radiation from one side of its magnetic field in this artist's concept.

1/3000

The carbon footprint of the 2020 meeting of the European Astronomical Society — held virtually due to the coronavirus pandemic — as a fraction of the carbon footprint of the previous year's in-person meeting in Lyon, France.

AFTER MORE THAN A DECADE of detective work, astronomers have found the best evidence yet for the cause of fast radio bursts, or FRBs. The culprit? Magnetars, according to three papers published in *Nature* November 4.

FRBs have become one of the most exciting enigmas in astronomy. For astronomers, the mystery began with a burst of radio waves that traveled 1.6 billion light-years and arrived at Earth on July 24, 2001. Lasting just five milliseconds, it carried as much energy in radio waves as the Sun puts out in an entire month. Incredibly, it went unnoticed until 2006, when it was discovered in archived data. Since then, radio observatories have spied dozens of FRB sources, but the nature of the objects producing them has proven elusive.

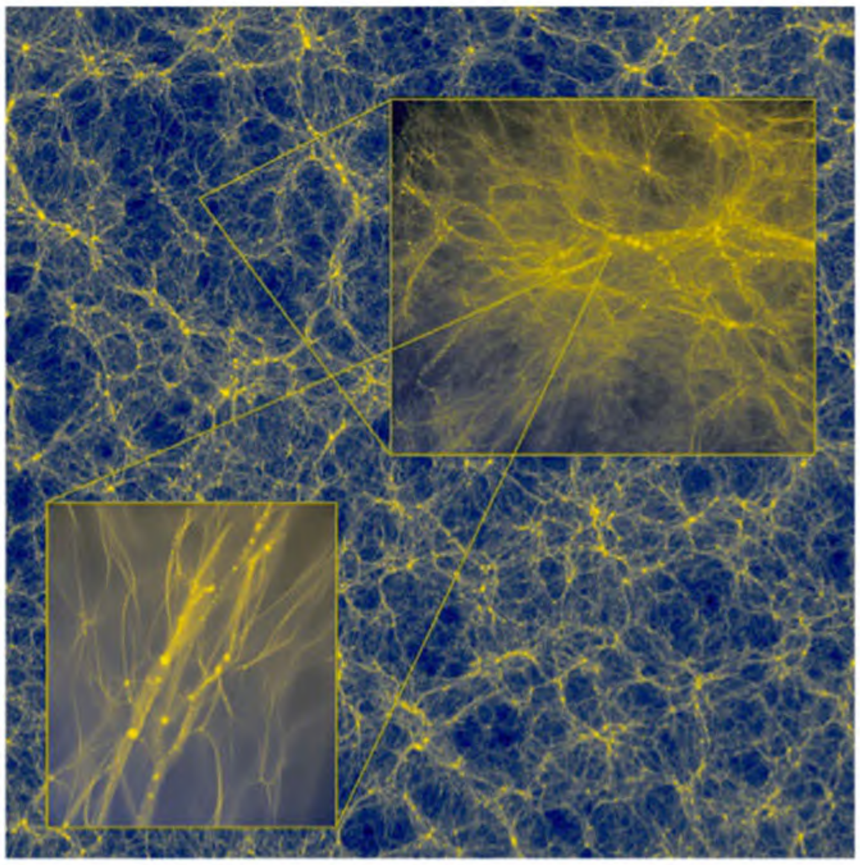
Modeling has indicated that magnetars could act as "engines" for FRBs. Magnetars, short for "magnetic stars," are highly magnetic remnants of massive dead stars. As a magnetar flares, it sends out blasts of energetic particles. Its powerful magnetic field then accelerates these particles around the star, where models suggest the particles ram into material from previous flares. Such collisions, researchers think, could trigger powerful shock waves with the stunning magnetic properties needed to produce FRBs.

However, we know of only a handful of magnetars in our Milky Way galaxy, and they all seem too tame to cause these extreme signals. To know for sure whether these stars could generate FRBs, astronomers would have to catch a Milky Way magnetar in the act.

In late April 2020, a magnetar dubbed SGR 1935+2154 began blasting out X-rays near the center of our galaxy, some 30,000 light-years away. As interest in this object built, astronomers turned ground- and space-based telescopes in its direction. They were just in time to watch the activity build to a crescendo: first X-ray bursts, then gamma rays — and eventually, the blast of a fast radio burst. It was the first FRB ever observed in our home galaxy, as well as the first FRB clearly associated with a single object.

"This discovery paints a picture that some — and perhaps most — of these fast radio bursts from other galaxies also originate from magnetars," Christopher Bochenek, a graduate student at Caltech and co-author of one of the studies, said in a press conference. —ERIC BETZ

Simulations zoom in on dark matter



J. WANG, S. BOSE/CFA

REPEATING HALOS. Inside a simulated region of the universe 2 billion light-years across, large blobs of dark matter are the size of galaxy clusters. By zooming in — the first inset is 700,000 light-years across, while the second inset is just 600 light-years across — researchers resolved clumps of dark matter roughly the size of Earth.

Dark matter is a mysterious material that makes up more than 80 percent of all matter in the universe. This strange stuff permeates and surrounds every galaxy, and clumps of dark matter, called halos, are where galaxies tend to form. Now, supercomputer simulations have found that these cosmic clumps of dark matter look surprisingly alike, no matter their size — whether they encompass monstrous galaxy clusters or are mini-blobs the size of Earth.

The results of the simulations, published September 2 in *Nature*, show some of the most detailed models constructed to date of the structure of dark matter.

The authors — a team of researchers from China, the U.S., and Germany — began by simulating a universe filled with dark matter. The result was similar to those from previous computer simulations: a cosmic web of filaments and clumps called dark matter halos.

But the team then took their simulations a step further and focused in on a small area, running the entire model again for just that region. The team repeated the process eight times, effectively zooming in each time to reveal finer and finer details.

Prior to these simulations, astronomers expected the smallest clumps of dark matter to look different from the largest halos, which may be the building blocks of some galaxy clusters. To their surprise, the filament-and-clump structure repeated itself down to the smallest scales they simulated, where the dark matter clumps are only the size of Earth.

The similarity isn't just visual: Analysis showed that the variation in density — from their center to their fringes — in small and large halos also mirrors each other.

That information could aid the search for dark matter. While dark matter does not interact with normal matter, it should give off a burst of gamma-ray light when it collides with its antimatter equivalent and the particles annihilate each other. This is most likely to happen at the centers of dark matter halos, where the density is high. The simulations' results can now help astronomers understand how much of this radiation they might be able to detect. —M.Z.

BIRTHPLACE OF THE STARS

Stars are born within enormous clouds of gas and dust. While the Orion Nebula is one of the most famous — and closest — examples, the Carina Nebula is some 500 times larger, making it another favorite for researchers. This new image from the Gemini Observatory captures the western wall of the Carina Nebula like never before, taking advantage of a technique known as adaptive optics, which allows astronomers to compensate for the effects of Earth's turbulent atmosphere. In this image, researchers have already spotted a number of unexpected structures, including a long series of parallel ridges possibly produced by a magnetic field, evidence of a strong wind blowing off fragments from the cloud, and a possible jet being ejected from a newly formed star. —C.B.

INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA ACKNOWLEDGMENT: PI: PATRICK HARTIGAN (RICE UNIVERSITY); IMAGE PROCESSING: PATRICK HARTIGAN (RICE UNIVERSITY), TRAVIS RECTOR (UNIVERSITY OF ALASKA ANCHORAGE), MAHDI ZAMANI & DAVIDE DE MARTIN

18+

WHAT IS

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AVAXHOME -

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Unlimited satisfaction one low price
Cheap constant access to piping hot media
Protect your downloadings from Big brother
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18 years of seamless operation and our users' satisfaction

All languages
Brand new content
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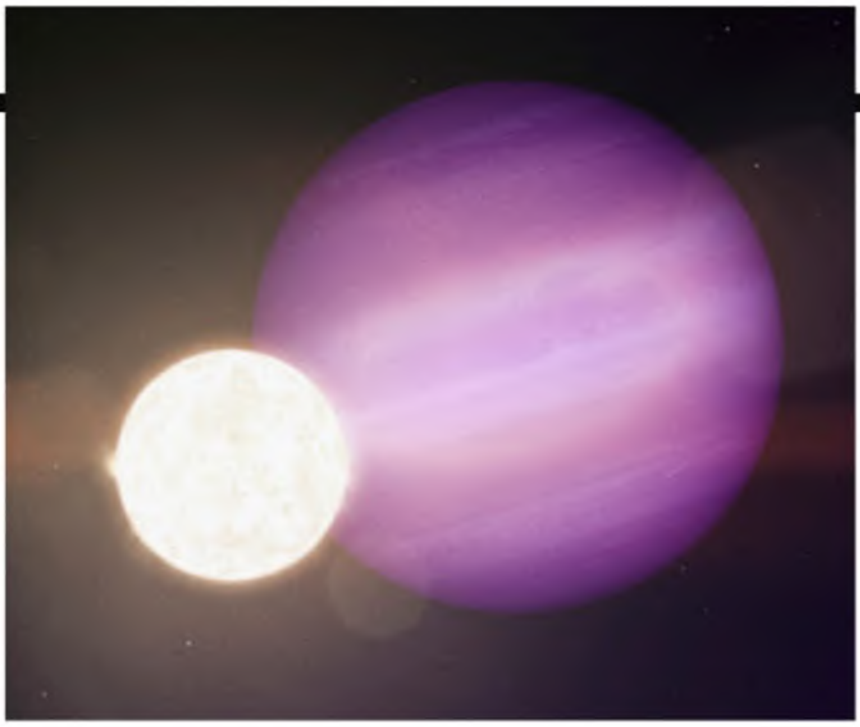
We have everything for all of your needs. Just open https://avxlive.icu

PLANET CAPTURED IN THE LIGHT OF A DYING STAR


NASA/JPL-CALTECH/GODDARD SPACE FLIGHT CENTER

RESEARCHERS HAVE FOUND a Jupiter-sized planet orbiting the remains of an exhausted star some 80 light-years away. The international team of astronomers spotted the unlikely pair using NASA's Transiting Exoplanet Survey Satellite (TESS) and data from the retired Spitzer Space Telescope.

The dead star, dubbed WD 1856+534, is a white dwarf — the stellar ember of a Sun-like star — only 40 percent the diameter of Earth. That makes it seven times smaller than the Jupiter-sized planet orbiting it, shown here in an artist's concept. The planet, WD 1856 b, speeds around its host every 34 hours. For comparison, it takes Mercury 88 days to complete a single orbit.

When a star similar to our Sun runs out of fuel, it balloons outward, forming a red giant that gobbles up any planets in its path. Eventually, the star ejects its outer layers and loses most of its mass, leaving behind a smoldering stellar core. Distant objects within a system, such as asteroids and comets, can be pulled inward by this disruptive death. But these objects are usually ripped apart by the star's gravity. This is the first time astronomers have found a planet that managed to survive with its host star, sweeping in toward the star during its final stage of life. The finding also expands the possibilities of where life could manage to take hold elsewhere in the universe. – C.B.

Sprites and elves frolic in Jupiter's skies


NASA/JPL-CALTECH/SWRI

Lightning is familiar throughout the solar system. But it isn't the only electrical outburst that can occur. Stunning, evanescent events called sprites and elves are sometimes seen prancing above thunderclouds on Earth. And NASA's Juno spacecraft appears to have also captured these flashes on Jupiter — the first time these events have been observed on another planet.

Both sprites (which stands for Stratospheric/mesospheric Perturbations Resulting from Intense Thunderstorm Electrification) and elves (Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources) are a type of transient luminous event, or TLE, lasting only milliseconds.

Sprites typically have round, blobby centers that sprout tendrils of light upward or downward. They occur when lightning bolts funnel positive charge away from a cloud, leaving it negatively charged. This triggers sprites above the storm. Elves look more like expanding doughnuts or rings and form when electromagnetic pulses released during a thunderstorm slam into the ionosphere.

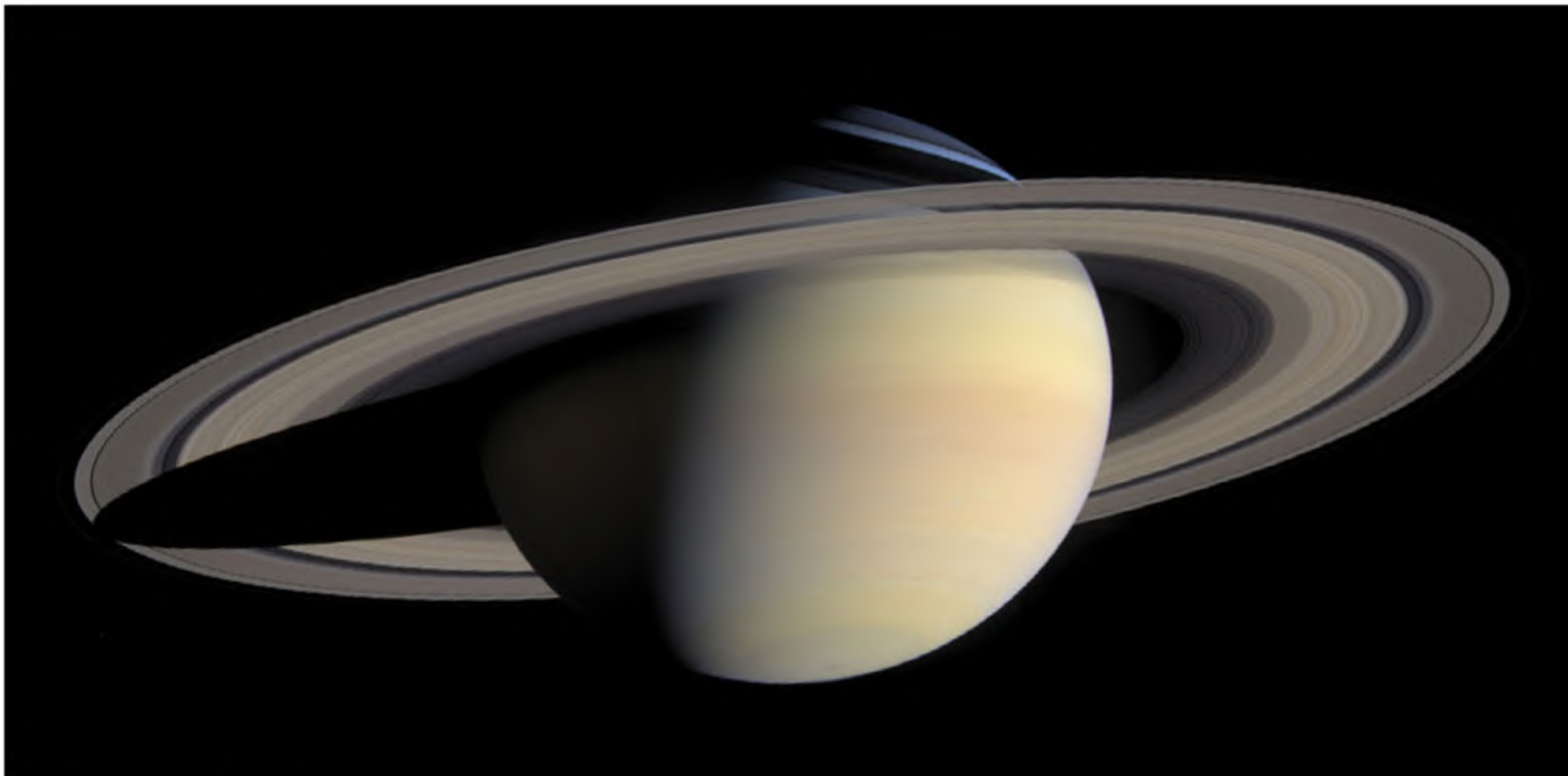
Over the past four years, Juno's Ultraviolet Spectrograph instrument captured 11 brief, bright flashes of ultraviolet (UV) light lasting between 0.1 and 2.5 milliseconds. They are the first-ever lightninglike flashes recorded on Jupiter at UV wavelengths, and also the first TLEs spotted on another world.

The flashes originated exactly where sprites and elves are assumed to form on Jupiter, above the water cloud layer where lightning is generated. Scientists aren't sure which TLEs Juno saw — sprites or elves — but now that they know what to look for, the researchers think it will be easier to spot these phenomena on Jupiter and in the clouds of other planets, too. – A.K.

CHANGING COLORS. On Earth, sprites and elves appear red, thanks to the abundance of nitrogen in our atmosphere. But in Jupiter's hydrogen-dominated atmosphere, these phenomena likely appear pink or blue, as in this artist's concept.

The devil's in the details

What should you really look for through the eyepiece?



This 2004 image of Saturn shows clearly the Cassini division — the dark gap between the planet's A and B rings. Spotting details like this is what keep us returning to the eyepiece. NASA/JPL/SPACE SCIENCE INSTITUTE

BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

You've heard the cliché about details. But it's celestially inaccurate, because details are where we usually discover the sublime — or, at least, they're what lure our attention. So, what is it that we crave to see, time and time again?

For the sake of newbies who are just starting on this epic adventure of exploring the universe, let's help whittle down the long process of deciding where to look. Our theme this month is the exquisite detail that, I guarantee, you'll keep trying to observe.

For example, everyone enjoys watching Jupiter's four big moons form a straight line with military band precision. As giant Ganymede circles back to its starting point once a week, Europa goes around exactly twice — to the second! And in that same interval, Io completes four revolutions, again with one-second accuracy. They're bright, easy to see, and unique. And no other planet with satellites shares Jupiter's lack of axial tilt. Jove's poles angle a negligible 3° from vertical. And since its satellites orbit its equator, they must line up no matter where in their orbit they happen to be.

Details are where we usually discover the sublime.

Very cool, but not a fine-detail challenge, since observing them requires no more than a $5 toy telescope. Sharp-eyed observers have even claimed to see them unaided. So if you did invest more than $5 and want to "open 'er up" to see what the 440-horsepower engine under your telescope's hood will accomplish, you'll want more of a challenge.

But first, a reminder that whatever cosmic wonder you're after, optics alone aren't enough. If someone gave you the keys to the two 6.5-meter Magellan Telescopes (along with the instruction booklet explaining how to detach all 30 cables from the echelle spectrograph and instead insert a nice 30mm visual eyepiece), you'd still need a night of good seeing, or atmospheric stillness. Fine detail always requires good seeing. Where I live, excellent seeing conditions arrive as often as magnetic pole reversals. But when they do come — heralded when stars are not twinkling in the least — we excitedly look for cool details.

On Jupiter, that starts with the Great Red Spot, the comically understated name for the universe's largest hurricane. (Official celestial names rarely serve as worthy observing suggestions.) Jupiter's coolest features may be the unnamed cloud details: Between its main dark belts, on the equator, diagonal white clouds contain breaks where one can peer deeply down and see actual blue sky, no joke. Some of us routinely seek out those amazing unnamed cobalt sky patches.

On Saturn, most observers seeking fine detail first try for the Cassini division. This inky gap between its A and B rings highlights the yawning breach separating the rings' unique, epic beauty and their names, lazily derived from the alphabet. We often give things letters, like the six stars in M42's stunning Trapezium and lunar craters around larger ones (Copernicus A, B, C, etc.). It's not a bad idea, except where exceptional beauty cries out, unanswered, to try to stir a poet on the International Astronomical Union's naming committee. As for that Cassini break, its impossibly narrow, half-arcsecond width somehow materializes whenever the air is steady. In the entire universe, no other thin dark line is more observed, sought after, or treasured.

You get the gist of my criteria. So, I'll skip any further literary flourishes and simply list 10 examples of details telescopists try for when observing various celestial objects:

1	**Mars:** The polar caps and dark surface markings
2	**Orion Nebula (M42):** Those six Trapezium stars
3	**NGC 4575:** A silhouetted black dust lane running this edgewise galaxy's entire length
4	**M51:** The galaxy's two spiral arms
5	**The Moon:** Six craterlets forming a French curve inside Clavius
6	**Sirius:** Its "Pup" companion star
7	**M87:** A single jet of near-light-speed material issuing from the galaxy's core
8	**Mercury:** The planet's Moon-like phases, slight orange color, and subtle dark surface blotch
9	**NGC 7000:** The outline of North America
10	**The Horsehead Nebula:** Anything resembling the knight from your chess set

But what about you? Is there some marvelous detail you glimpsed long ago and have sought out ever since? Some enchanting feature the rest of us should hunt for? Share it! That's the point of this column.

Let's make it a contest — the winner gets to replace the names of Saturn's A and B rings with more inspirational letters.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**

ABOVE: NGC 7000, also known as the North America Nebula, floats in the upper left corner of this image. Can you see the faint outline of the continent for which it is named? DENNIS HARPER

LEFT: M51 (on the right) is a face-on spiral galaxy with prominent arms that attentive amateurs can glimpse through the eyepiece. STEPHEN RAHN

An international fleet of spacecraft set off for Mars, Crew Dragon carried astronauts to the ISS, and a global pandemic left its mark on astronomy.

TOP 10 SPACE STORIES OF 2020

BY ALISON KLESMAN AND JAKE PARKS

2020 WAS A WILD YEAR. Astronomers kicked it off with the discovery of a distant galaxy group. Closer to home, they saw the Milky Way doing the wave and confirmed geologic activity on Mars. The star Betelgeuse underwent a strange and striking dimming event, while naked-eye Comet NEOWISE took our breath away. And a major announcement about Venus sparked intense interest; that researchers are still scrutinizing the result is a signal that science is working as it should.

In May, SpaceX's Crew Dragon capsule ferried astronauts to the International Space Station from U.S. soil, the first such trip in nearly a decade. Two months later, three new missions launched for Mars to usher in a new era of robotic exploration.

The global pandemic that defined much of the year changed how scientists worked and shuttered telescopes for months. But despite these challenges, our top 10 space stories show how we pressed on with new, innovative ways to explore our universe.

9 Mars and Venus are geologically active

ON FEBRUARY 24, 2020, researchers released the initial results of NASA's InSight lander on Mars. Covering the first 10 months of the mission, the findings included the conclusion that the Red Planet is seismically active.

Of 174 marsquakes recorded from February to September 2019, scientists traced two of the strongest to Cerberus Fossae. This young region has undergone volcanism and other geologic changes in the last 20 million to 2.5 million years, says Suzanne Smrekar, deputy principal investigator for InSight. "Mars' surface is on average several *billion* years old, so anything in the million-year range is

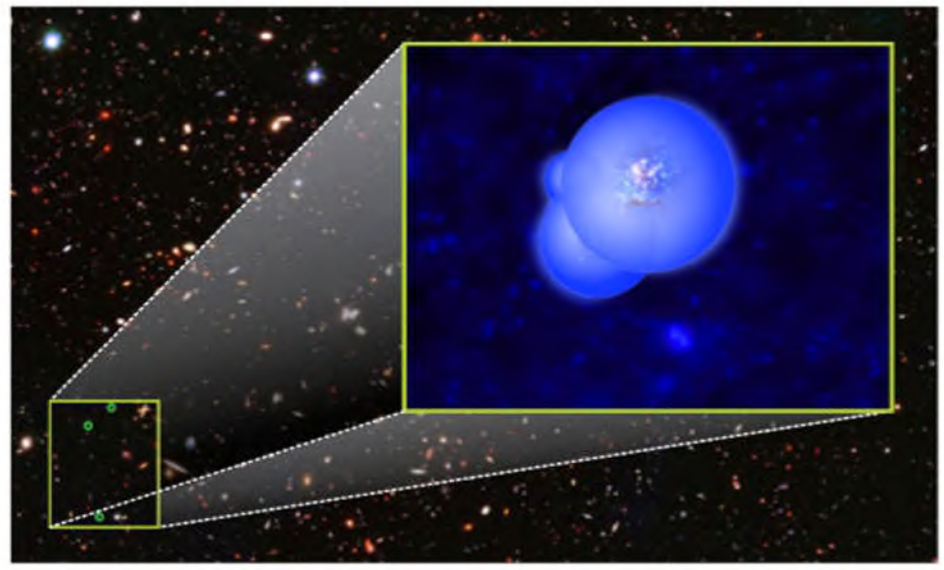
10 Earliest galaxy group found

THE COSMIC DARK AGES began 380,000 years after the Big Bang. At first, no stars or galaxies existed to emit light. But even after these objects began forming, their light remained shrouded because the universe was filled with a "fog" of neutral hydrogen atoms that absorb and scatter ultraviolet light.

Over time, energetic ultraviolet light from early objects ionized these hydrogen atoms, knocking away their electrons. This era of reionization ended 1 billion years after the Big Bang, leaving the universe transparent to light.

But astronomers aren't sure exactly what types of objects — galaxies, black holes, or stars — were responsible for clearing the fog during reionization, says Vithal Tilvi of Arizona State University, who is part of the Cosmic Deep And Wide Narrowband (Cosmic DAWN) survey seeking to understand this era. Astronomers also aren't sure how fast the transition from an opaque to a transparent universe occurred.

Then the survey found EGS77: three galaxies shining 680 million years after the Big Bang, when the universe was just 5 percent its current age. "[It's] the most distant group of galaxies — and therefore the earliest group of galaxies in the universe — we have ever seen," says Tilvi, whose team published their find February 27 in *The Astrophysical Journal Letters.*



EGS77 (circled in green) is the earliest galaxy group ever discovered. The inset artist's concept shows how these galaxies are blowing bubbles of ionized hydrogen around them during the era of reionization. NASA, ESA AND V. TILVI (ASU)

Each galaxy is generating a bubble of ionized hydrogen about 2 million to 3 million light-years across. These bubbles overlap, creating a larger, single region of space that's free of cosmic fog, allowing light to travel freely. "So far we had [seen] individual galaxies spread across the survey areas. This is the first time we have found a group of galaxies" making the universe transparent, says Tilvi. By virtue of being in a group, EGS77's combined bubbles allowed the team to spot fainter galaxies than could be seen if they were alone.

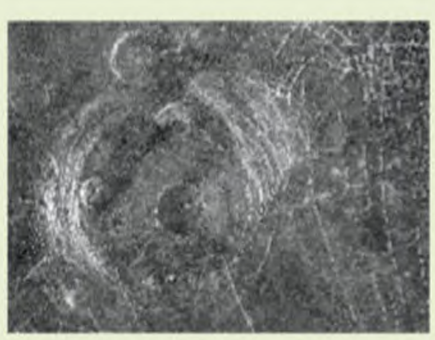
In the future, Tilvi says, using the same technique will allow researchers to discover more faint galaxies. That will ensure astronomers don't underestimate the number of dim galaxies — which we know outnumber bright ones — responsible for bringing about cosmic dawn.

super intriguing," she adds. "Where's the energy [for the activity] coming from? Why there and not elsewhere on Mars?"

By late September 2020, InSight had recorded about 500 quakes, roughly 50 of which give clues about the planet's deep interior, Smrekar says. By studying how seismic waves travel through the lower crust, scientists have learned Mars' crust is likely intact — "more like Earth's than the Moon's, where the crust has been pummeled and fragmented by impacts," she says. "Overall, we are seeing a level of seismicity within the predicted range," Smrekar concludes — except when it comes to bigger quakes, which are rarer than expected. "It may be that we just need to be patient, or maybe Mars is behaving in a way that we didn't anticipate."

But Mars isn't the only active inner planet. On July 20, a paper in *Nature Geoscience* added evidence for recent volcanic activity on Venus. Researchers led by Anna Gülcher at ETH Zürich in Switzerland looked at circular

Cerberus Fossae is a young, geologically active region of Mars responsible for at least two powerful quakes detected by NASA's InSight lander. ESA/DLR/FU BERLIN, CC BY-SA 3.0 IGO

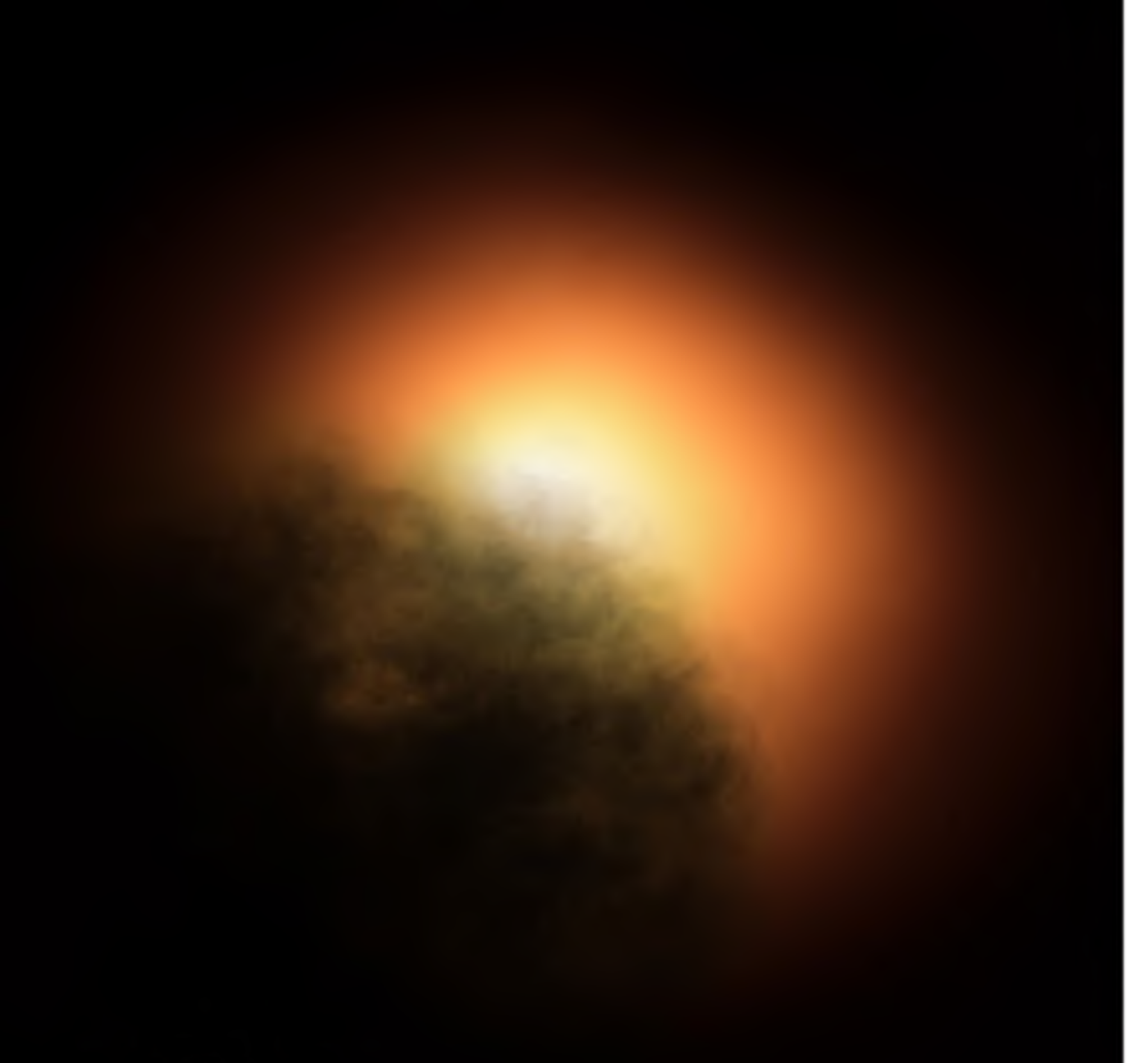


The large, circular Aine Corona dominates this Magellan radar image of Venus' surface. New research suggests dozens of these features are still active on the planet. NASA/JPL

features called coronae, which scientists think form when faults develop around areas where rising magma lifts up the surface. By comparing 3D models of how coronae form and evolve with observations of Venus' surface, the team concluded at least 37 of the planet's large coronae are still evolving — indicating the planet is geologically active.

Smrekar — who is also principal investigator of the Venus Emissivity, Radio Science, InSAR, Topography & Spectroscopy (VERITAS) mission currently under consideration for NASA funding, and who worked on the Magellan spacecraft that orbited Venus in the early 1990s — isn't surprised. Despite the fact that the idea of Venus as a geologically dead planet has persisted, she says, "There [have been] a bunch of recent studies that point to current, geologically recent activity on Venus."

And research into Venus is gaining even more momentum, as evidenced by No. 2 on this list. "I'm positive this will lead to great new science," Smrekar says.



8 Betelgeuse blows its nose in our direction

IN LATE 2019, Orion the Hunter began having shoulder problems: Betelgeuse, the red giant star that marks the figure's right shoulder, started dimming dramatically. While astronomers know the star varies regularly over time, this episode was both unexpected and unusually extreme, noticeable even to naked-eye observers. By mid-February 2020, the star was just one-third its normal brightness and the astronomical community was abuzz — could this signal an impending supernova explosion?

But, spoiler alert, Betelgeuse remains a fixture in our night sky. It's also back to normal brightness. So, what happened? An August 13, 2020, paper in *The Astrophysical Journal* provides the explanation. Based on Hubble Space Telescope observations leading up to the so-called "Great Dimming Event," the authors concluded the star "sneezed" out a cloud of hot gas from its photosphere in fall 2019. By the time it reached millions of miles from the star, the cloud had cooled and condensed into dust grains that temporarily obscured the star's southern hemisphere and made Betelgeuse appear dimmer.

According to study leader Andrea Dupree of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, events like this can show astronomers how stars like Betelgeuse lose mass — a process that is poorly understood.

In late 2019, Betelgeuse sneezed out a cloud of hot gas. Over the next few months, that gas condensed into dust that blocked a portion of the star's light, as shown in this artist's concept. ESO, ESA/HUBBLE, M. KORNMESSER

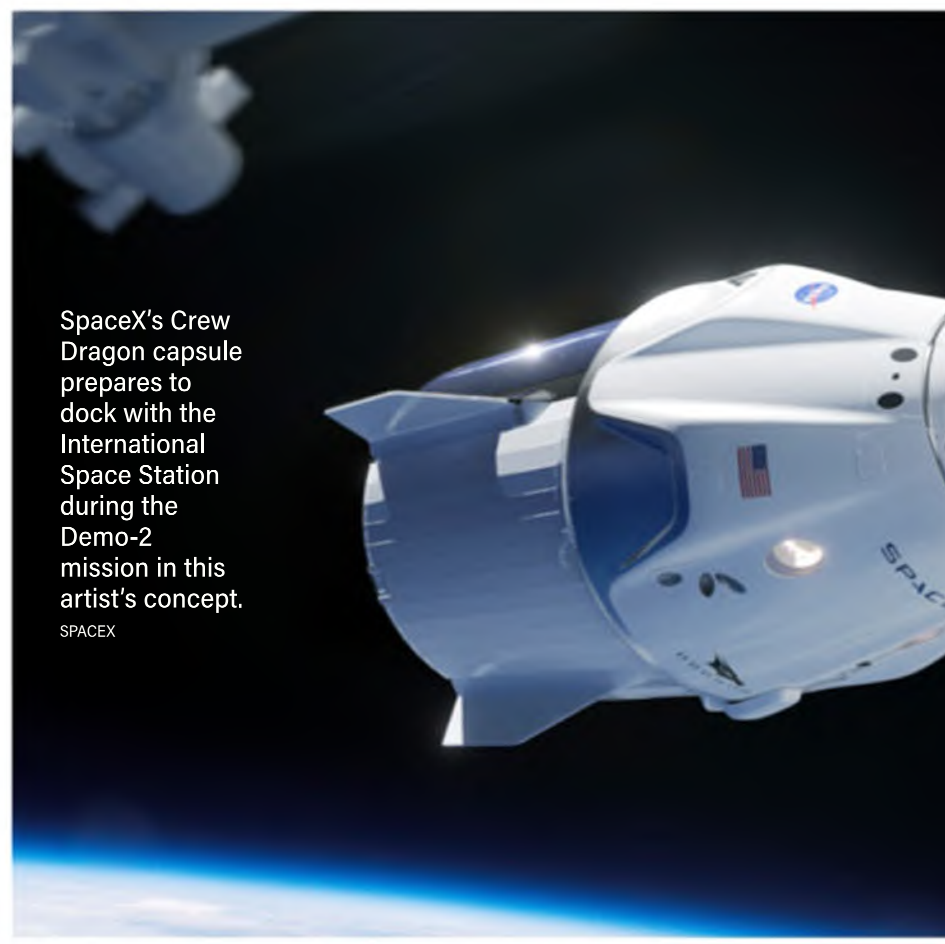
A NEARBY SUPERNOVA?

Despite its continued presence, questions still abound about what we'll see when Betelgeuse does finally end its life in a brilliant explosion. To observers on Earth, "all this brightness would be concentrated into one point," says University of California, Santa Barbara, astronomer Andy Howell, whose answer is based on simulations run by two UCSB graduate students, Jared Goldberg and Evan Bauer. "It would be this incredibly intense beacon in the sky that would cast shadows at night, and that you could see during the daytime. Everyone all over the world would be curious about it, because it would be unavoidable." *—Eric Betz, A.K.*

7 Solar science enters a golden age

ALTHOUGH THE CLOSEST STAR to Earth has been widely studied, the Sun still maintains some secrets. But perhaps not for long, as a veritable armada of solar science missions may soon unlock the last mysteries.

"In my opinion, the most interesting and significant solar discoveries have been coming from the Parker Solar Probe," says Russell Howard, head of the U.S. Naval Research Laboratory's Solar and Heliospheric Physics branch in Washington, D.C., and principal investigator for Parker's Wide-field Imager for Solar PRobe (WISPR). Parker, which launched in 2018, "has been making both *in situ* and remote sensing observations from … much closer to the Sun than ever before." Recently, the probe revealed that the Sun's magnetic field is surprisingly complex far from the star. The simple dipole (like a bar magnet) structure researchers expected is there,



SpaceX's Crew Dragon capsule prepares to dock with the International Space Station during the Demo-2 mission in this artist's concept. SPACEX

SOLAR ORBITER/EUI TEAM/ESA & NASA; CSL, IAS, MPS, PMOD/WRC, ROB, UCL/MSSL

Solar Orbiter snapped this ultraviolet image of the Sun from halfway between Earth and our star. It is the closest photo of the Sun ever taken.

Howard says, but overlaid with other structures as well, which scientists are now modeling to better understand.

Soon to observe in tandem with Parker is the European Space Agency/NASA Solar Orbiter spacecraft. After launching February 9, 2020, the probe made its first close pass of the Sun in mid-June. Its 10 instruments are working as expected — or better, says Howard, who is also principal investigator of the Solar Orbiter Heliospheric Imager (SoloHI).

SoloHI appears less affected by stray light than estimated and the magnetometer observed the signs of a coronal mass ejection event. Ultraviolet images show never-before-seen bright spots on the Sun. Small and ubiquitous, each is about a millionth to a billionth the size of a traditional solar flare. Researchers have christened them "campfires," and suspect they are either miniature solar flares or perhaps related to nanoflares, which are thought to heat the Sun's outer atmosphere, the corona.

The more sensors in the solar wind, the better, Howard says, because that gives scientists a more comprehensive view. Parker and Solar Orbiter are also joined by the Solar and Heliospheric Observatory, the two Solar Terrestrial Relations Observatory probes, the BepiColombo mission, and the ground-based Daniel K. Inouye Solar Telescope. "I am extremely excited about this 'golden age' of solar observations from five different space probes and the ground-based observations," Howard says.

6 Crew Dragon ferries astronauts, a first

SINCE THE RETIREMENT of the Space Shuttle Program in 2011, NASA astronauts have depended on Russia for rides to the International Space Station (ISS). But that's not the case anymore. In a historic first, the private spaceflight company SpaceX launched two American astronauts into orbit May 30 as part of the Crew Dragon Demo-2 mission.

The launch, which was streamed online and aired by all major TV news networks, was viewed live by some 10 million people. The following day, the spacecraft docked with the ISS and its passengers, astronauts Doug Hurley and Robert Behnken, migrated to the orbiting research lab, where they spent the next two months testing Crew Dragon and carrying out science experiments.

Once their stint on the ISS concluded, the pair hopped back into Crew Dragon and set course for home. Shortly after 1:48 P.M. CDT on August 2, Hurley and Behnken splashed down in the Gulf of Mexico. The capsule was plucked from the water by the recovery ship *Go Navigator* shortly thereafter. Out of an abundance of caution, the astronauts' departure from Crew Dragon was delayed due to the detection of low levels of a potentially toxic propellant called nitrogen tetroxide. After it was purged from the spacecraft, the astronauts safely exited the sealed crew cabin, proving the privately built capsule's worth.

NASA/JSC

On November 15, the first *official* Crew Dragon mission, dubbed Crew-1, blasted off for the ISS. After docking with the space station the next day, NASA astronauts Michael Hopkins, Victor Glover, and Shannon Walker, as well as JAXA astronaut Soichi Noguchi, boarded the ISS, where, as of the time of this writing, they continue to work.

Now that two Crew Dragon spacecraft have successfully delivered astronauts to the ISS, the future once again looks bright for American crewed spaceflight.

LEFT: Comet NEOWISE's twin tails spread across the sky over West Texas. Now on its way back to the outer solar system, NEOWISE won't return for nearly 7,000 years. JAMES LOWREY

Our solar system's second identified extrasolar visitor, Comet Borisov, appeared much more cometlike than 'Oumuamua. This Hubble image was snapped shortly after Borisov made its closest approach to the Sun in December 2019. NASA, ESA AND D. JEWITT (UCLA)

5 A triple comet surprise

WHEN IT WAS DISCOVERED August 30, 2019, the second-known interstellar visitor to our solar system, Comet 2I/Borisov, hadn't yet made its closest pass to the Sun (called perihelion). Unlike 1I/2017 U1 'Oumuamua, which was spotted only after it had already rounded our star, astronomers were able to watch Borisov before, during, and after its December 8, 2019, perihelion pass.

John Noonan of the Lunar and Planetary Laboratory at the University of Arizona, Tucson, was part of a team that observed Borisov with the Hubble Space Telescope in late December and early January. They looked for carbon monoxide (CO) sublimating, or turning directly from solid ice to gas, off the surface. "[CO] sublimates at very low temperatures. So, if you see carbon monoxide, that tells you something has been cold for a very long time," he says.

On Borisov, "there was more carbon monoxide than there was water, which is pretty much unheard of" for comets in our own solar system, Noonan says. The out-of-whack ratio means Borisov "very clearly formed in a system … very different than our own." That place could have been around a red dwarf star — stars smaller and cooler than our Sun, and commonplace throughout the galaxy.

As Borisov faded from headlines, comet enthusiasts eagerly awaited C/2019 Y4 (ATLAS), whose mid-May glow astronomers predicted would be rivaled only by Venus. But on April 11, amateur astronomer Jose de Queiroz snapped a photo that showed the comet breaking up. Hubble images on April 20 and 23 confirmed the comet had fragmented into several pieces — an interesting turn of events for researchers, but one that quashed any chances of ATLAS achieving "great comet" status.

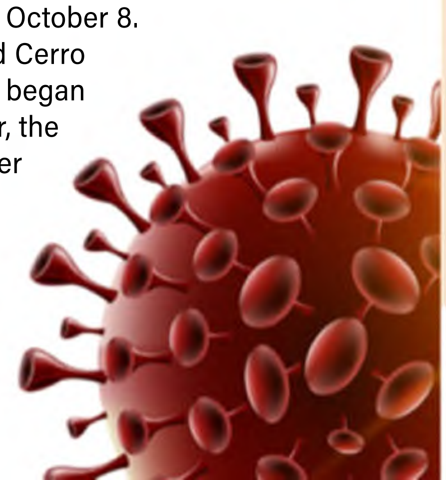
Fortunately, C/2020 F3 (NEOWISE) stepped up. It flared to naked-eye visibility between magnitude 1 and 2 after rounding the Sun on July 3, just over three months after its discovery. The comet quickly developed a picturesque pair of gas and dust tails that ultimately stretched more than 30° across the sky and offered an ideal target for astrophotographers.

NEOWISE spent several weeks delighting skywatchers as the brightest Northern Hemisphere comet since C/1995 O1 (Hale-Bopp). "What a great little comet!" astrophotographer John Chumack wrote in an email on July 29 to *Astronomy*. By then, the comet was a 4th-magnitude target low in the northern sky. "Over the last few weeks, NEOWISE put on a nice show for us Northern Hemisphere observers. Some of my astronomy friends in the Southern Hemisphere have now got to glimpse it and they are reporting it still fading," he said.

THE COVID-19 PANDEMIC

The coronavirus pandemic impacted astronomy in 2020 in many ways, from major observatories shuttering their scopes to mass transitions to remote work. More than 100 of Earth's largest telescopes closed at some point during the year. Jet Propulsion Laboratory engineers, unable to take their high-performance computers and virtual reality setups out of the lab, drove Curiosity on Mars from home using plastic red-blue 3D glasses to visualize the rover's complex environment. And scientists launching missions such as Solar Orbiter and Mars 2020 faced unique challenges imposed by travel restrictions to reduce the spread of disease.

Fall 2020 saw a rash of telescope reopenings as conditions in some locations improved. The Very Energetic Radiation Imaging Telescope Array System in Arizona and the Las Campanas Observatory in Chile had reopened by October 8. Telescopes at Kitt Peak in Arizona, and Cerro Pachón and Cerro Tololo in Chile, also began reopening at that time. By late October, the Atacama Large Millimeter/submillimeter Array was also readying for reopening and a new round of South Pole Telescope observers had gone into quarantine to prevent carrying the virus to Antarctica. —*A.K., E.B.*



SARAYUT THANEERAT/DREAMSTIME

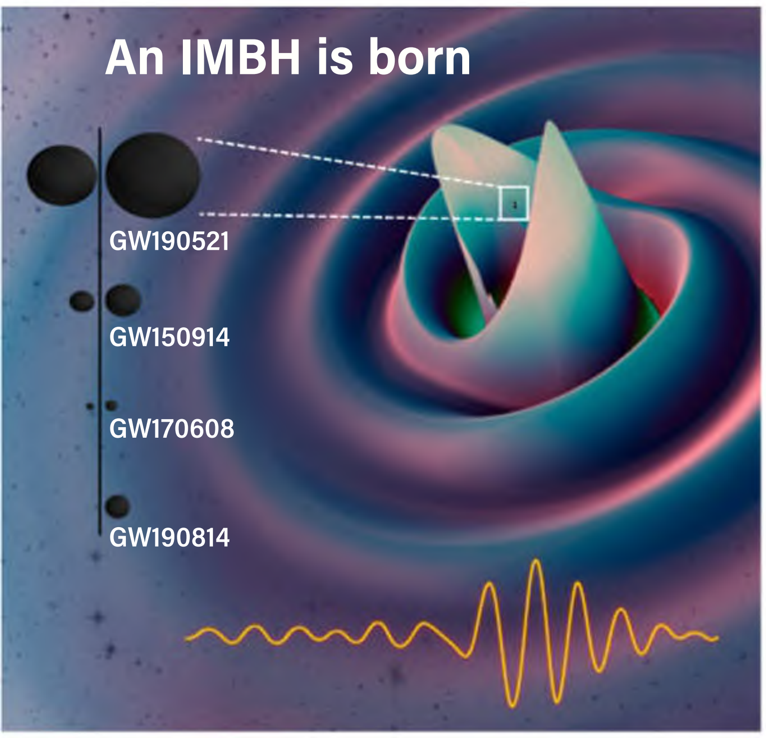
4 First midsized black hole detected

BLACK HOLES COME in a variety of sizes, ranging from a few to billions of times the mass of the Sun. Although there is ample evidence for stellar-mass and supermassive black holes, there is surprisingly little proof of their middleweight brethren. But on May 21, 2019, scientists at the Laser Interferometer Gravitational-wave Observatory (LIGO) and the partnering Virgo site received the first convincing sign: gravitational waves that point to the violent birth of an intermediate-mass black hole (IMBH).

After spending more than a year scrutinizing the signal (called GW190521), which lasted just a tenth of a second, on September 2, 2020, an international team of researchers released two papers detailing their results: The gravitational waves originated halfway across the universe and were produced when two hefty black holes merged to create an IMBH about 142 times the mass of the Sun. Their collision also released a stupendous amount of energy, equivalent to roughly eight solar masses, as gravitational waves.

Although this detection confirms that IMBHs exist, it also raises questions. The progenitor black holes weigh in at 66 and 85 solar masses, so the larger one firmly falls in the "pair-instability mass gap." When most massive stars die, they leave behind a black hole. But when a star weighs 130 to 200 solar masses, photons in its core become so energetic they morph into electron-antielectron pairs, which can't fully combat gravity. The star becomes extremely unstable and, after going supernova, leaves nothing behind.

"This event opens more questions than it provides answers," LIGO member Alan Weinstein, professor of physics at Caltech, said in a press release. "From the perspective of discovery and physics, it's a very exciting thing."



GW190521 signaled the birth of an intermediate-mass black hole. But it didn't sound like a typical "chirp" — it was more like a "bang." D. FERGUSON, K. JANI, D. SHOEMAKER, P. LAGUNA, GEORGIA TECH, MAYA COLLABORATION

FAST FACTS

Stellar-mass black holes:
a few to 100 solar masses

Intermediate-mass black holes:
100 to 1 million solar masses

Supermassive black holes:
millions to billions of solar masses

3 The Milky Way does the wave

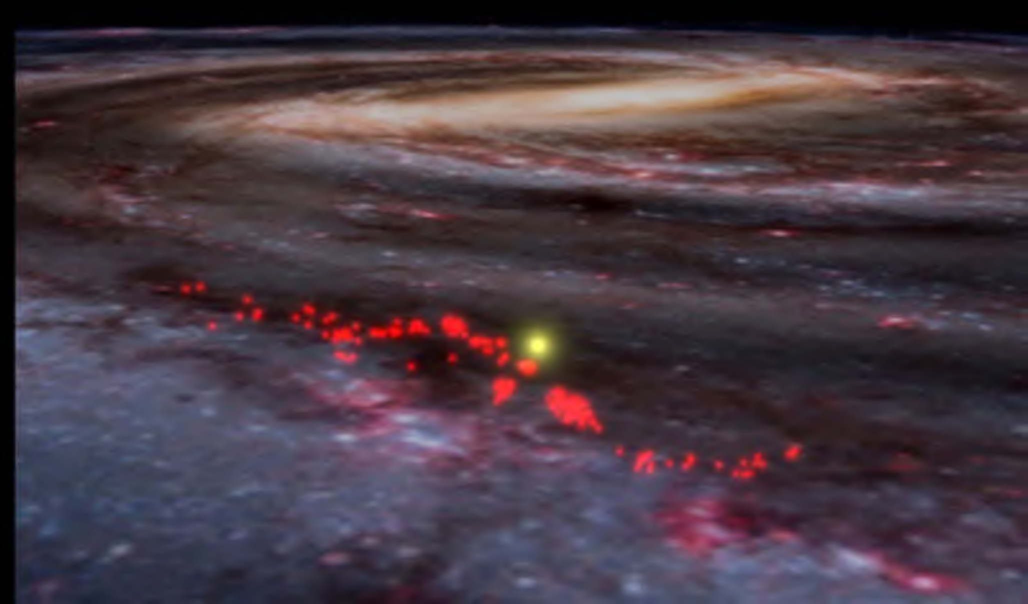
BECAUSE WE ARE EMBEDDED within the Milky Way Galaxy, mapping its large-scale structure is challenging. That is especially the case for galactic star-forming regions, huge clouds of gas and dust whose distance is difficult to measure because they aren't points like single stars. But new work by Harvard University astronomers published January 7, 2020, in *Nature* dramatically increased the accuracy of distance measurements to nearby star-forming regions. It also uncovered something unexpected: the Radcliffe Wave.

Nearly 9,000 light-years long and 400 light-years wide, this snaking line of interconnected star-forming regions rises above and dips below the plane of our galaxy. It lies less than 500 light-years from Earth at its nearest point and connects molecular clouds in Orion, Taurus, Perseus, Cepheus, and Cygnus.

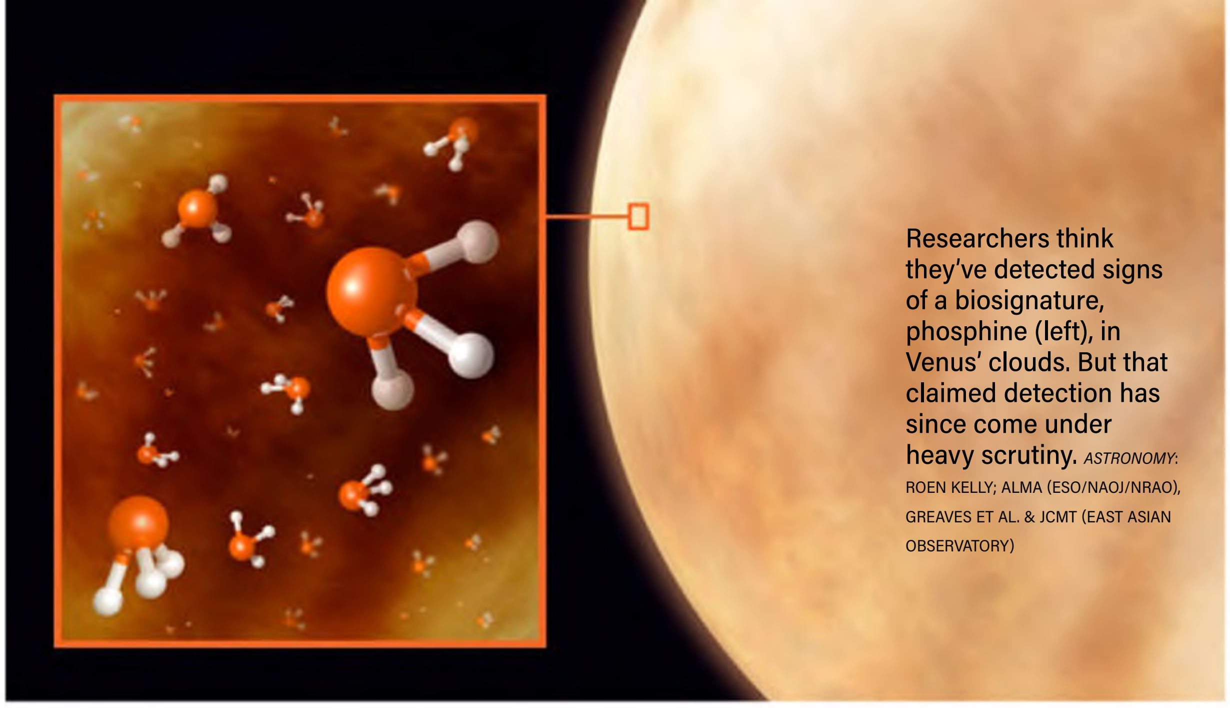
"Prior to the discovery of the Radcliffe Wave, star-forming regions were studied in relative isolation. The Radcliffe Wave showed that all these regions are connected on the grandest of scales, via tendrils of filamentary gas, which is something we never knew before," says Catherine Zucker, whose Ph.D. work at Harvard led the effort to pin down distances to the star-forming regions that make up the Wave. That work involved combining observations of the way intervening dust and gas makes starlight appear redder with accurate distance measurements to those stars from ESA's Gaia spacecraft.

"Since this effect [reddening] is observable throughout our solar neighborhood, it allowed us to determine the distances to a huge sample of star-forming regions, using the same technique, for the first time," Zucker says. "Previous distance techniques were piecemeal, obtained inhomogeneously on a cloud-by-cloud basis."

Her technique revealed, to a factor of five times better than previous measurements, the distances to nearby star-forming regions — and the Radcliffe Wave. "In the future, this will force us to reframe our understanding of star formation on small scales (i.e., within individual molecular clouds) in a larger galactic context," she says.



The Radcliffe Wave (shown in red; the location of our Sun appears in yellow) is a sinuous structure thousands of light-years long and hundreds of light-years wide. It connects several star-forming regions and likely forms the densest part of the spiral arm in which the Sun resides. IMAGE FROM THE WORLDWIDE TELESCOPE, COURTESY OF ALYSSA GOODMAN



Researchers think they've detected signs of a biosignature, phosphine (left), in Venus' clouds. But that claimed detection has since come under heavy scrutiny. *ASTRONOMY:* ROEN KELLY; ALMA (ESO/NAOJ/NRAO), GREAVES ET AL. & JCMT (EAST ASIAN OBSERVATORY)

2 Astronomers spy phosphine on Venus

VENUS IS A SIZZLING world thought by many to be inhospitable to life. Surface temperatures are hot enough to melt lead — almost 900 degrees Fahrenheit (480 degrees Celsius) — while the pressure at ground level is more than 90 times that of Earth at sea level. But that hasn't stopped some, including Carl Sagan, from proposing that life could exist in the more temperate clouds of our sister planet. And now, there could be evidence to support that hypothesis — albeit controversial evidence.

In a paper published September 14 in *Nature Astronomy*, researchers presented observations of an inexplicable surplus of the rancid gas phosphine in the clouds of Venus. On Earth, microbes produce most phosphine, though it can also be created abiotically under great temperatures and pressures. Measured at a level of some 20 parts per billion, the researchers behind the new paper say no known geological activity or exotic catalysts — such as lightning or meteorites — can explain the strength of their observed signal.

"We are *not* claiming we have found life on Venus," said co-author Sara Seager, an MIT planetary scientist, in a press conference. However, she added, they can't explain the phosphine's origin.

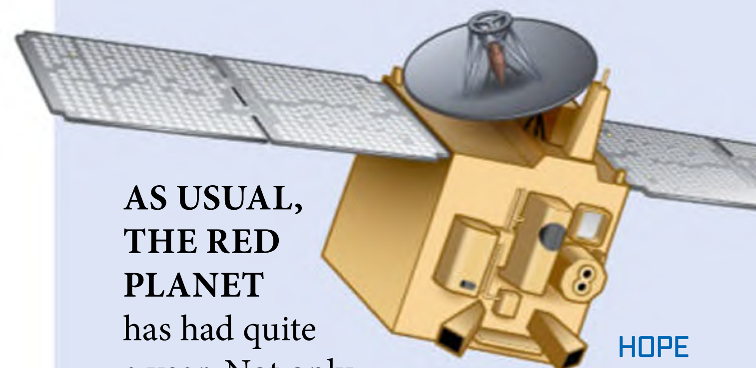
Many find the unexplained biosignature, or potential evidence for past or present life, tantalizing. However, others remain skeptical. Chemical compounds each have a unique spectrum, or fingerprint, that depends on the wavelengths of light they absorb. Although the researchers detected this fingerprint of phosphine with two independent telescopes at different times, they only saw it at a single wavelength — one that sulfur dioxide happens to absorb as well.

"As a geochemist, I always worry about detection from one peak," says Justin Filiberto of the Lunar and Planetary Institute. "A single line is a coincidence, not a detection," adds astrobiologist Kevin Zahnle of NASA Ames Research Center in California. Still others are concerned about the quality of the noisy data itself, which means many groups are already reanalyzing it.

But if the detection holds up, "it demands follow-up," says Bethany Ehlmann, a planetary scientist at Caltech who was not part of the discovery team. "The top three destinations to look for life in the solar system are Mars, Enceladus, and Europa — and now we should perhaps add Venus to the list."

Alison Klesman *and* **Jake Parks** *are associate editors of* Astronomy. *They sure hope 2021 is better than 2020.*

1 Missions to MARS



HOPE

AS USUAL, THE RED PLANET has had quite a year. Not only did NASA's InSight lander detect hundreds of marsquakes shaking the planet, but ESA's Mars Express orbiter found more signs that the world has several underground saltwater lakes buried beneath its south pole. Perhaps most importantly, however, 2020 saw three new spacecraft set forth for the Red Planet, taking advantage of a once-every-26-months alignment that shortens the time and distance required to get from Earth to Mars.

As its first interplanetary mission, the United Arab Emirates launched an orbiter named al-Amal (meaning "Hope") July 19. The craft is equipped with both an infrared and ultraviolet spectrometer — the former meant to investigate dust,

Stories to watch for in 2021

The missions that left Earth for Mars in 2020 — the UAE's Hope, China's Tianwen-1, and NASA's Perseverance — will all reach the Red Planet in February 2021.

NASA's Double Asteroid Redirection Test, or DART mission, will launch July 22, 2021, to binary asteroids Didymos and Dimorphos. The agency's Lucy spacecraft is scheduled to launch October 16, 2021 — the first mission to Jupiter's Trojan asteroids.

Because of technical difficulties and the ongoing coronavirus pandemic, NASA has updated its target launch date for the James Webb Space Telescope to October 31, 2021.

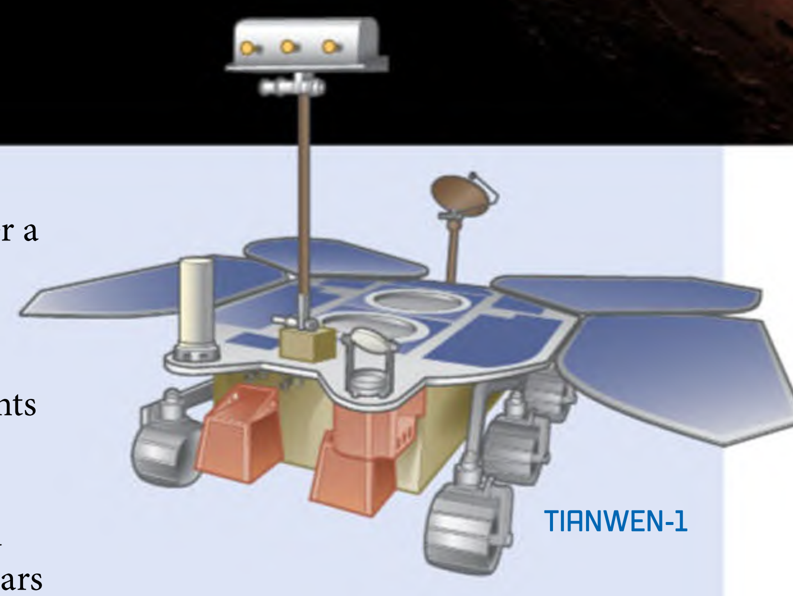
Three Mars missions from three different countries took advantage of an alignment between Earth and the Red Planet in 2020. The missions will teach us more about Mars' atmosphere, seek out signs of past and present life, and even cache rock samples for their future return to Earth. NASA/JPL-CALTECH

water, and ice in Mars' lower atmosphere and the latter meant to study oxygen and carbon monoxide in the upper atmosphere. Additionally, the craft carries a multiband camera that can achieve resolutions better than 5 miles (8 kilometers) per pixel. Altogether, Hope aims to paint a more comprehensive picture of the Red Planet's atmosphere.

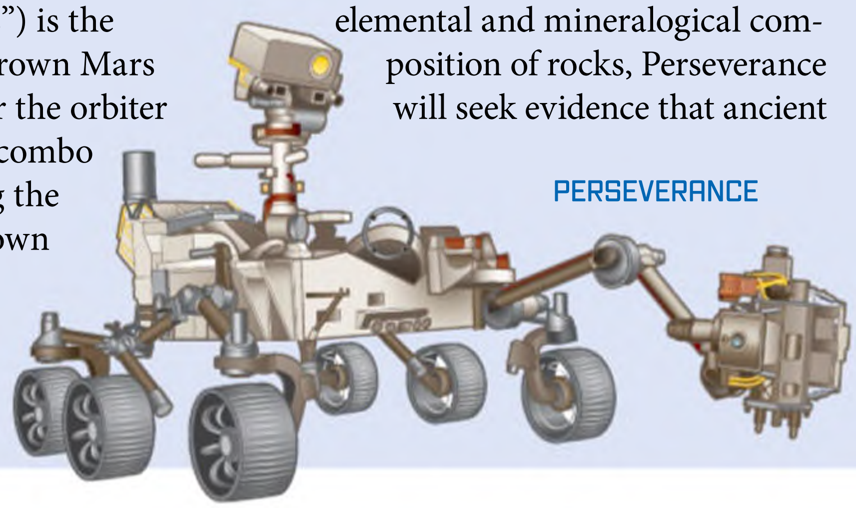
China jumped into the fray next, launching an orbiter, lander, and rover trio to Mars July 23. Tianwen-1 (which means "heavenly questions") is the country's first fully homegrown Mars mission. Engineers plan for the orbiter to release the lander/rover combo after a few months orbiting the Red Planet. It will touch down near Utopia Planitia in the northern hemisphere to seek signs of past or present life. Then the orbiter will enter a polar elliptical orbit around Mars. There, it will serve as a communication relay for the rover and lander, as well as use its seven science instruments to remotely study Mars' environment and map its surface.

Finally, on July 30, NASA launched the Perseverance rover as part of its Mars 2020 mission. This car-sized rover, based largely on Curiosity's design, has ambitious plans. Equipped with instruments that can create spatial maps showing the elemental and mineralogical composition of rocks, Perseverance will seek evidence that ancient life once existed in Mars' Jezero Crater. The rover also comes with a few proof-of-concept experiments: an oxygen-production device called MOXIE and a solar-powered helicopter named Ingenuity. Last but not least, Perseverance plans to find, collect, and seal rock and soil samples that will ultimately be returned to Earth for closer inspection with sophisticated lab equipment.

With all these missions expected to reach the Red Planet in February, 2021 is bound to be a big year for Mars.



TIANWEN-1



PERSEVERANCE

ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

- Also delayed due to coronavirus, the Indian Space Research Organisation's Chandrayaan-3 mission, which comprises a lander and rover, is now scheduled to launch for the Moon in late 2021.
- The ESA and Roscosmos' robotic Luna-25 lander aims to put Russia back on the Moon with an anticipated launch date in October 2021.
- First light for the 8.4-meter Simonyi Survey Telescope at the Vera C. Rubin Observatory in Chile is expected in October 2021.
- Both the Parker Solar Probe and Solar Orbiter will make flybys of Venus in 2021: Parker will make two, Solar Orbiter will make one.
- The uncrewed Artemis I mission, the first in NASA's plan to return humans to the Moon, is scheduled to launch in 2021. This first mission will combine the new Space Launch System rocket and Orion crew capsule.

NEW MARS ROVER begins its mission

Perseverance is more than just Curiosity's double — it will hunt for ancient life, cache samples, and pave the way for human explorers. BY JIM BELL

EVERY 10 YEARS, planetary scientists put their collective minds together to develop mission recommendations for the decade ahead. The most recent of these decadal surveys, published in 2011, had a clear top priority for NASA: to collect samples from the surface of Mars and return them to Earth.

The concept of returning samples from Mars has been something of a holy grail for planetary scientists. As intrepid as NASA's previous robotic explorers have been, their analyses of the rock and soil they rove have always been limited by the equipment they carry. When you ship a rover to Mars, the cost of every extra ounce is colossal. And rover instruments — marvels of engineering though they are — are no substitute for a fully equipped laboratory on Earth.

That's why, in the 2011 Decadal Survey, scientists recommended NASA design a flagship mission to "collect, document, and package samples for future collection and return to Earth." In other words, the community strongly recommended that NASA finally greenlight a set of missions collectively known as Mars Sample Return.

Now, nine years later, that ambitious journey is about to begin. The Mars 2020 mission launched from Cape Canaveral on July 30, 2020, and is scheduled to land in Jezero Crater on February 18, 2021. If all goes well, the rover will embark on a mission lasting at least a full martian year (equivalent to 687 days on Earth). In addition to its own explorations, it will also collect and cache samples that will later be returned to Earth — revealing the mysteries of that once-habitable place on Mars.

A clone is born

In December 2012, just four months after the Curiosity rover landed on Mars, NASA announced a new wheeled explorer that would address the top goal of the most recent decadal. It was scheduled to launch during a favorable Earth–Mars alignment in 2020. This Mars 2020 rover would be designed and built by a team at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California — a team that included many of the engineers, managers, and others who had built Curiosity, as well as previous Mars rovers Sojourner, Spirit, and Opportunity.

To fit NASA's tight budget and reduce the mission's complexity, 90 percent of the Mars 2020 rover, cruise stage, and sky crane landing system would be built from spare parts left over from Curiosity. Mars 2020

The Perseverance rover is NASA's follow-up to the successful Curiosity rover and will rove Jezero Crater in search of chemical or textural evidence of past microbial life. NASA/JPL-CALTECH

Perseverance takes its first driving test on December 17, 2019, in a clean room at NASA's Jet Propulsion Laboratory in Pasadena, California. NASA/JPL-CALTECH

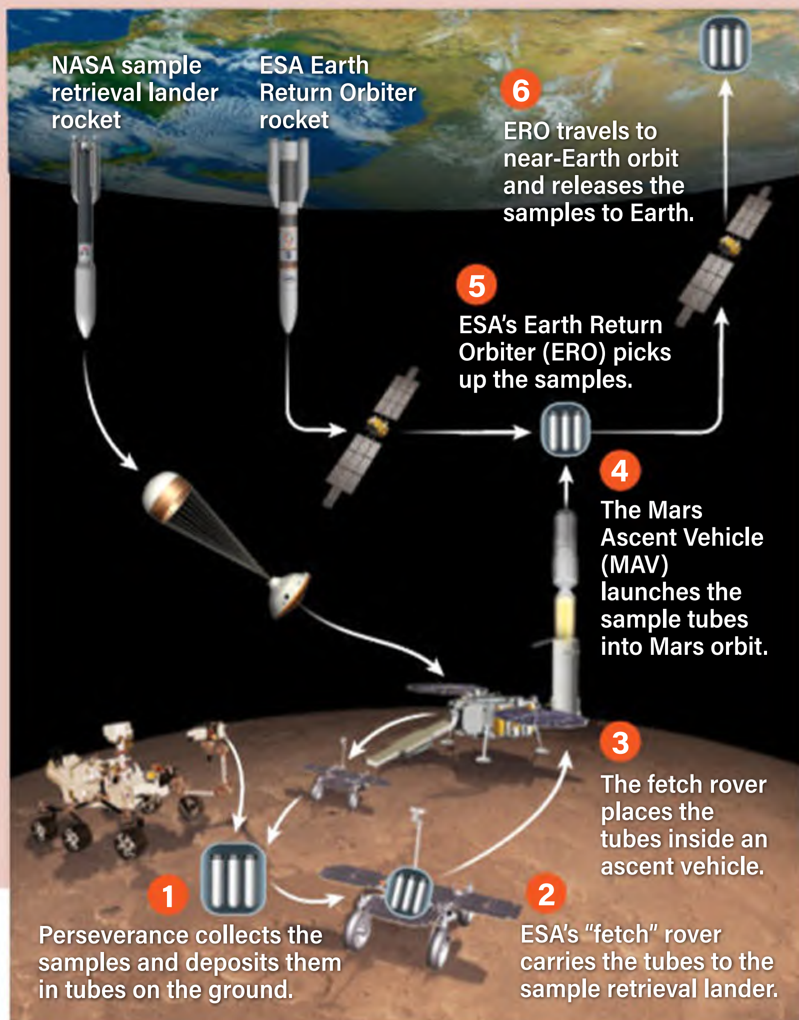
Perseverance lifts off on July 30, 2020, atop a United Launch Alliance Atlas V rocket at the Space Launch Complex-41 on Cape Canaveral. UNITED LAUNCH ALLIANCE

With social distancing in effect, senior engineers in Southern California conducted their final inspections remotely via a video feed from a smartphone at the Kennedy Space Center in Florida. NASA/JPL-CALTECH

MARS SAMPLE RETURN

WHILE NO MISSIONS have yet been approved or funded, several space agencies around the world are deep in the planning stages for a Mars sample-return mission. For example, NASA and the European Space Agency (ESA) are discussing a concept for joint missions that would find, collect, and return the samples cached by the Perseverance rover. And the Chinese National Space Agency is looking into potential robotic sample-return missions as follow-ons to their Tianwen-1 mission, which launched July 23, 2020, and will land a rover in the Utopia Planitia region of Mars in February 2021.

The NASA/ESA plan as currently envisioned would involve the launch of two missions in 2026. The first is a dedicated NASA lander carrying an ESA-built "fetch" rover and a small rocket known as the Mars Ascent Vehicle (MAV). The fetch rover would collect the cached sample tubes left by Perseverance on Mars' surface and bring them back to the MAV, placing them inside a soccer ball-sized sample capsule. The MAV would then launch them into Mars orbit, where an ESA Earth-return orbiter — the second launch of 2026 — would be waiting to capture the sample capsule. That orbiter would then depart Mars and return to Earth, jettisoning the capsule for a parachute-assisted landing in the Utah desert in 2031. —*J.B.*



ASTRONOMY: ROEN KELLY. SPACECRAFT MODELS: NASA, ESA

A ROVER'S JOURNEY

This map shows a hypothetical course that Perseverance might take, based on scenarios plotted by mission scientists. The actual route will of course differ, depending on where Perseverance happens to touch down within the landing ellipse. The prime mission is to explore Jezero Crater; if the rover survives to tackle an extended mission, it may trek up and out of the crater west to another site, dubbed Midway.

ASTRONOMY: ROEN KELLY. BASE MAP IMAGE: ESA/FU-BERLIN; ROVER PATH (PRIME MISSION): SANJEEV GUPTA AND BRIONY HORGAN; ROVER PATH (EXTENDED MISSION): RICHARD OTERO, ERISA STILLEY, NATHAN WILLIAMS, ALLEN CHEN, ET AL.

would thus be a clone, of sorts — looking a lot like Curiosity on the outside, but costing at least $700 million less than Curiosity's $2.8 billion price tag.

On the inside, however, the Mars 2020 rover would sport some entirely new equipment to help it carry out the sample-caching job the decadal had outlined. The mission's announcement kicked off what NASA Associate Administrator for Science John Grunsfeld called "seven years of innovation" to develop that equipment, along with some completely new tools. In early 2020, nearing the end of the seven-year sprint, the rover finally received its name: Perseverance.

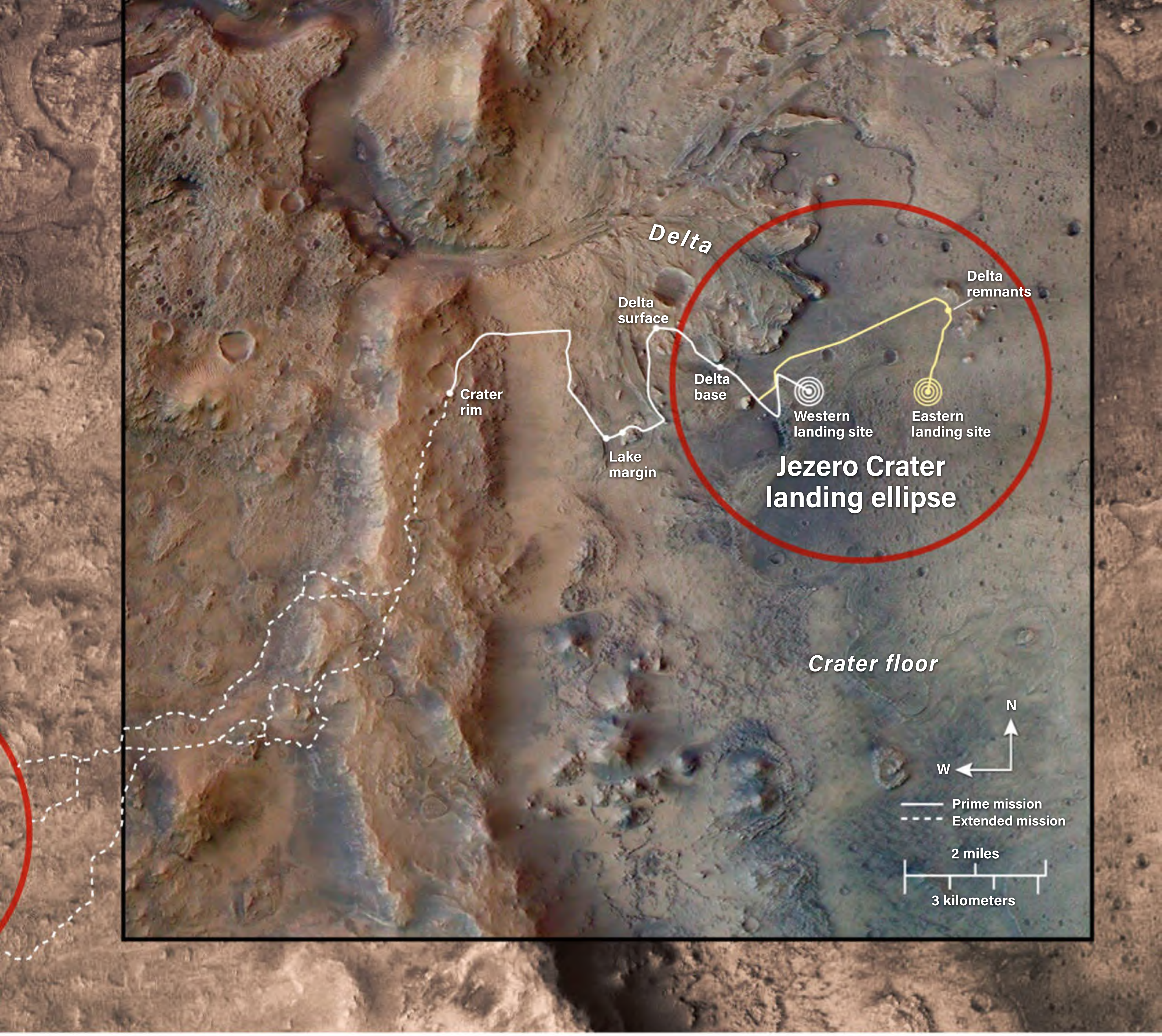
In search of ancient life

Many of the Mars 2020 mission's goals are similar to those of previous Mars rover missions, like studying the geology and weather of its field site. However, Perseverance also has a number of new and unique objectives. Perhaps the most important is to seek the signs of ancient life.

Ancient means not focusing on any potential living organisms on the surface of Mars today (which are highly unlikely to exist, given the harsh radiation, low surface pressure, and frigid temperature). Instead, Perseverance will seek evidence of organisms that may have lived billions of years ago, during a time early in Mars' history when the surface environment was a lot more like Earth's.

These signs could come in the form of preserved physical or chemical evidence, or textures left imprinted on rocks. Finding these biomarkers, however, is no small task. Geologists have a similar struggle on Earth: Though life began on our planet some 3 billion to 4 billion years ago, back in the Precambrian era, organisms didn't develop shells or skeletons that could easily leave behind fossil remains until about 550 million years ago.

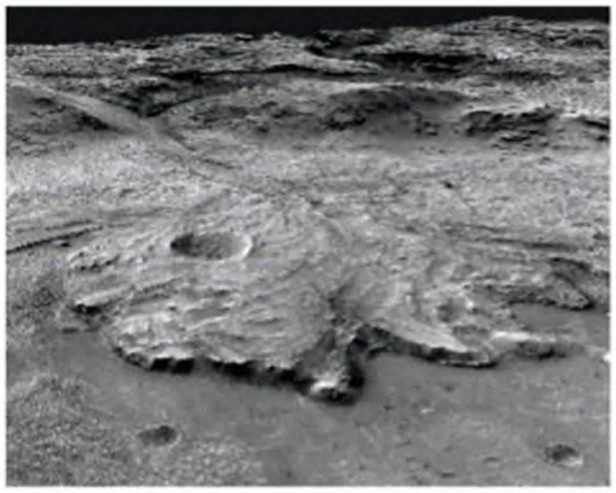
Among the prime examples of ancient biomarkers on Earth are stromatolites,



which are rock and mineral structures built up by coordinated groups of simple single-celled organisms, especially cyanobacteria (formerly called blue-green algae). Finding structures like those in ancient rocks on Mars would be an exciting and potentially profound discovery.

But definitively confirming these structures will be difficult with Perseverance's toolkit alone. Taking a cue from terrestrial geologists, planetary scientists have realized that equipment used in the field often cannot tease out whether the samples truly provide evidence of biological action, or only geological or geochemical processes. Rather, samples must often be taken back into sophisticated laboratories with the most advanced equipment that exists.

This is one of the main motivations for making Mars 2020 the first step of an international Mars sample-return program. Barring the unambiguous (and unlikely) discovery of biomarkers like fossils, the only way to confirm signs of life might be to bring those samples back to Earth so they can be studied in much greater detail. As Carl Sagan famously noted, "extraordinary claims require extraordinary evidence."



This reconstructed mosaic view of Jezero Crater's magnificent river delta from above looks west, out to the crater rim. The steep slopes of the delta in the foreground stand up to 350 feet (107 m) above the crater floor. NASA/MSSS/USGS

On September 4, while Perseverance was en route to Mars, JPL moved the rover's twin — a full-scale engineering model dubbed OPTIMISM (Operational Perseverance Twin for Integration of Mechanisms and Instruments Sent to Mars) — to its "Mars Yard" test area. Engineers can test rover commands and operations using OPTIMISM in an environment that simulates the Red Planet to better understand what Perseverance is experiencing on Mars. NASA/JPL-CALTECH

Mars 2020 also has a number of new experiments that are designed to help engineers develop technology for future robotic and human Mars missions. For example, the rover carries a device designed to extract small amounts of oxygen (O2) by splitting carbon dioxide (CO2) molecules with electricity. Larger systems based on this technology could generate oxygen for future human crews on Mars.

Perhaps Perseverance's most famous tech demo is a small four-blade helicopter drone named Ingenuity. Early in the mission, engineers will program it to conduct three to five test flights to learn more about operating drones on Mars. On future missions, such drones could serve as scouts or sample delivery systems.

Choosing a target

From 2014 to 2018, NASA and the planetary science community carefully studied options for where to land Perseverance. Just as for previous NASA rover missions, a series of open community workshops brought together scientists, JPL mission engineers, technology experts, and even members of the general public to discuss and debate which site would offer the best chance of accomplishing the mission's goals.

By the time of the fourth workshop in October 2018, the competition had boiled down to four sites. One option was a return to the Columbia Hills in Gusev Crater, where the Spirit rover had uncovered outcrop rocks with interesting silica-bearing minerals and nodular shapes a decade earlier; some researchers think these are potential biosignatures, as similar features can be found in some places on Earth.

The other three sites all sat within less than 100 kilometers of each other. Two of them, near the famous dark region Syrtis Major, had abundant deposits of clay and carbonate minerals, potentially indicating an ancient habitable environment. The final option was Jezero, a 31-mile-wide (50 kilometers) impact crater on the western margin of Isidis Planitia that hosts clays, carbonates, and a well-exposed ancient river delta.

The workshop participants and Mars 2020 science team ultimately recommended Jezero — named after a small town in the Balkan nation of Bosnia-Herzegovina — as their top choice, and NASA officially chose the site as the winner in November 2018.

Jezero will be among the most challenging martian terrains that NASA has yet attempted to land on. All rover landings sites have to meet certain engineering requirements: close enough to the equator to avoid extreme cold; low enough in elevation that a descending rover's parachute has thick enough air to grasp; and free enough of large rocks, slopes, and other potential obstacles to avoid crashing into them.

But sites with large rocks and slopes are often some of the most scientifically rewarding landscapes. So, clever engineers from JPL and elsewhere have worked to develop more intelligent software to guide Perseverance's landing stage to a touchdown in Jezero Crater. One upgrade makes the descent stage more aware of when and where to deploy its parachute. And once the parachute is jettisoned and the rover and descent stage are in powered retrorocket flight, a new hazard-avoidance system helps avoid rocks and other large obstacles, guiding the rover to a height of about 25 feet (7.6 meters) over a safe landing site. Then, the sky crane system — pioneered by Curiosity — lowers the rover to the ground via cables for a soft touchdown.

Jezero will be among the most challenging martian terrains that NASA has yet attempted to land on.

The experimental helicopter drone Ingenuity will become the first aircraft to take powered flight on another world. Though it won't be able to wander far — it will stay less than 0.6 mile (1 km) from the Perseverance rover to remain in wireless communication (right) — future drones could serve as more capable scouts. At left, Ingenuity receives its final inspection at the Kennedy Space Center in Florida before being mounted to Perseverance for its journey to Mars. NASA/JPL-CALTECH

A crater to explore

When Perseverance takes in the landscape inside Jezero Crater for the first time, it will send back images that show the hills of the crater rim rising 2000 feet above the crater floor. If the rover lands close enough to it, early images could also show the 150- to 350-foot-tall edge of one of the most exciting aspects of Jezero: its beautiful western river delta.

On Earth, deltas are fan-shaped splays of sediments where rivers gently deposit sand and silt, forming layers of sandstone and mudstone that can trap and preserve organic materials. Jezero Crater preserves several deltas along its inner rim, showing that it was clearly a shallow crater lake sometime early in Mars' history. If life emerged on Mars long ago, evidence of it might be preserved in those delta sediments.

What that lake looked like billions of years ago remains unknown, but there are many possibilities. Perhaps waves were lapping at its shores, around what is now the crater rim. Or, if the climate was too cold for surface water, Jezero may have been a vast frozen expanse, with all the river and delta-building action happening below. It's tempting to speculate, but instead of making wild guesses, the best recourse is to go there and find out.

In the spring of 2020, as the COVID-19 pandemic took hold around the world, mission staff persevered and adapted to working from home in the runup to the Mars 2020 launch on July 17. Clockwise from upper left: lead mobility systems engineer Rich Rieber (with son Ben); deputy project scientist Katie Stack Morgan; mission system verification and validation supervisor Ruth Fragoso; mission design and navigation manager Fernando Abilleira (below mission logo); staff assistant Monica Hopper; systems engineer Heather Bottom; project chief engineer Adam Steltzner; guidance and control systems engineer Swati Mohan; Entry, Descent and Landing phase lead Al Chen (with son Max); project manager John McNamee; and Entry, Descent and Landing systems engineer Cj Giovingo. NASA/JPL-CALTECH

A major goal of the mission is to drive the rover up to and perhaps even onto that delta, to search for geologic, mineralogic, and chemical evidence of its past environs. On Earth, different kinds of traces of life can appear in different areas of a river delta depending on the speed of the water that deposits the sediment, the size of the grain particles, and how quickly the sediment builds up. The rover team could try to systematically explore the equivalent of these different zones on Jezero. This strategy could maximize the chances of finding regions where potential biosignatures might be preserved.

After exploring and sampling the delta, the team might drive the rover to the foothills at the boundary of the crater floor and rim, where orbital measurements show a "bathtub ring" of clay and carbonate minerals — indicators of a past watery environment that dried out as the lake waters receded. From there, the team might drive the rover up the crater rim — charting a course along the safest slopes — to more closely explore the original ancient rocks from which the delta sediments originated.

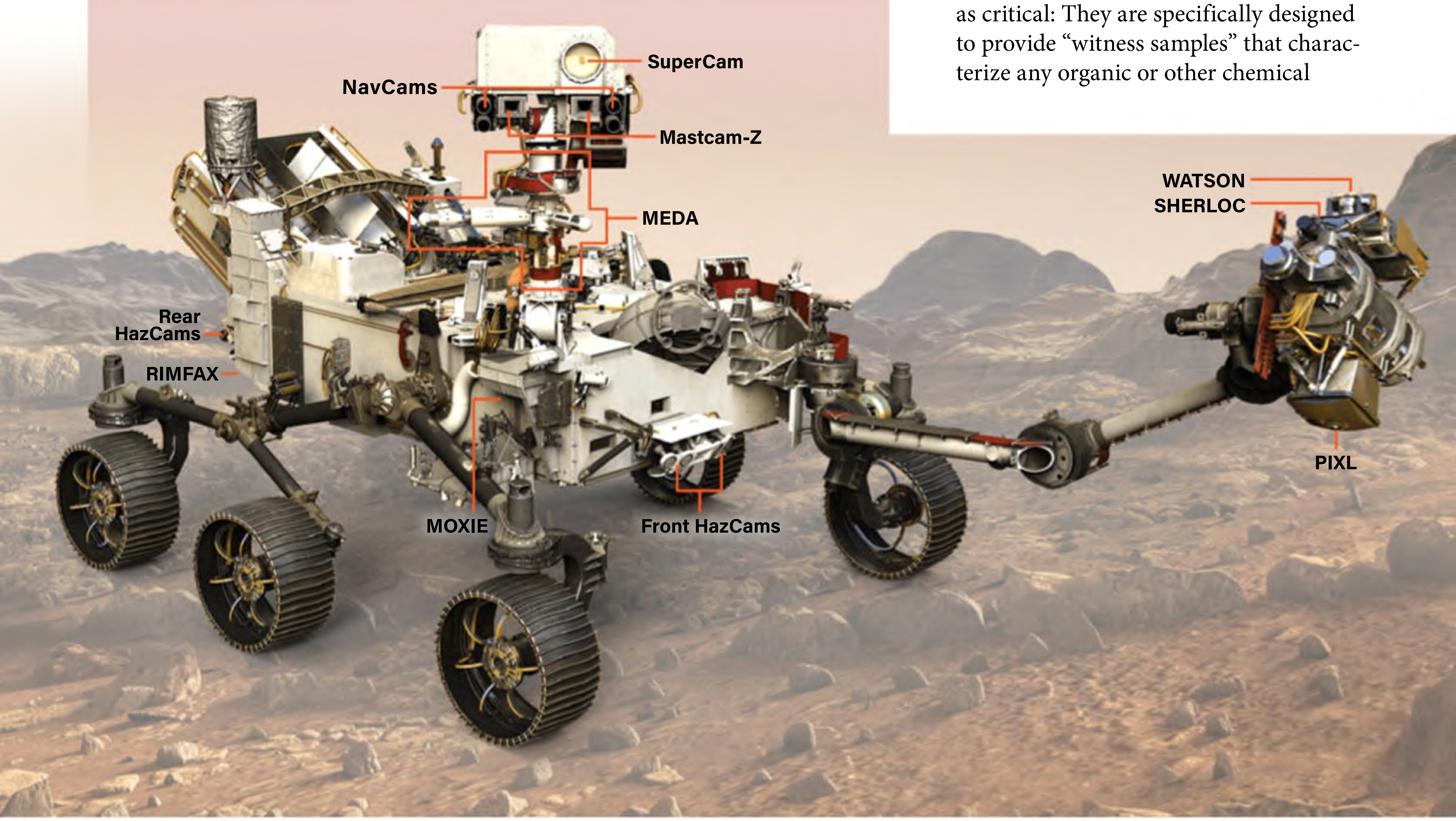
If the rover team can successfully get Perseverance completely out of Jezero Crater, just 10 miles (16 kilometers) beyond the western rim lies one of the rejected landing sites, dubbed Midway. It's also rich with ancient clay and carbonates, but many of those mineral deposits could have been created by groundwater coursing through the rocks, rather than surface water. The chance to explore a very different, but also potentially once very habitable, ancient martian environment as part of an extended mission is an exciting prospect.

PERSEVERANCE'S TOOLKIT

NASA SELECTED PERSEVERANCE'S scientific payload of six instrument systems in a competition between dozens of proposals that researchers submitted in 2014. The winners include three instruments on the rover's mast: a pair of panoramic, zoomable 3D cameras called Mastcam-Z; a camera and spectrometer called SuperCam that zaps rocks and soil with a laser to analyze their chemical makeup; and a weather-monitoring station called the Mars Environmental Dynamics Analyzer (MEDA). For the most part, these are enhanced versions of systems on the Curiosity rover. However, in a first, SuperCam includes a high-fidelity microphone designed to record sounds on Mars — either from the instrument and other rover subsystems, or potentially from the winds of Mars itself.

The rover carries three new science investigations as well. A ground-penetrating radar system called the Radar Imager for Mars' Subsurface Exploration (RIMFAX) will probe underground layers of rock — and potentially water ice. The Planetary Instrument for X-ray Lithochemistry (PIXL) will analyze samples on microscopic scales by focusing a beam of X-rays and taking images of the resulting glow. And an instrument called Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) will put samples under a magnifying glass, so to speak, with a microscopic imaging subsystem called Wide Angle Topographic Sensor for Operations and eNgineering (WATSON). Together, the pair of devices will use an ultraviolet laser and spectrometer to search for biomarkers in organics and minerals. PIXL, SHERLOC, and WATSON are all mounted on the rover's hefty robotic arm; RIMFAX is mounted to the rover's lower aft deck.

In addition to its science instruments, Perseverance is outfitted with engineering-focused cameras and other subsystems. These include cameras for basic navigation, as well as front- and rear-mounted cameras for avoiding hazards. There are also seven simple, largely "off-the-shelf" cameras mounted on the rover and the spacecraft stages that will carry it to the surface. These will record images and video of the landing process. And, for the first time, there will be sound to go with it — a microphone will be recording audio during the landing. In all, Perseverance, its descent stage, and the Ingenuity helicopter are loaded with 25 cameras, making it the most photo-capable spacecraft ever sent to the Red Planet. *—J.B.*



NASA/JPL-CALTECH; *ASTRONOMY:* ROEN KELLY

Caching the samples

Of course, Perseverance's scientific legacy will also depend on the samples it collects for return to Earth. To perform this task, the rover's designers carved out a significant amount of space for the Sampling and Caching Subsystem (SCS). The SCS drill, mounted on the rover's arm, will take core samples of martian rock and soil. Its carousel of bits includes six bits for drilling rock core samples, one "regolith" bit for collecting soil, and two abrading bits for grinding rocks or other surfaces for analysis with the rover's instruments. There's also a tool that can blow puffs of nitrogen gas onto a sample to remove dust or drill tailings.

The rover also houses a tiny robotic arm that can capture samples delivered into the rover's body, document them, seal them in titanium tubes, and then drop them onto the surface for later collection and return to Earth. Perseverance is carrying a total of 43 of these dry-erase-marker-sized tubes to Jezero. During the prime mission, the science team hopes to fill up to 38 of them with the most compelling and potentially revealing rock and soil samples as possible.

However, the remaining five are just as critical: They are specifically designed to provide "witness samples" that characterize any organic or other chemical contaminants that might have been brought to Mars from Earth, despite the team's best efforts at sterilizing the sample tubes. Instead of being filled with samples, they will go through a full "mock coring" process and be handled and sealed by the rover's SCS systems just like the actual samples. This provides a way to check whether any organic materials or other contaminants coming from the rover itself have been able to sneak into the actual Mars samples, too.

Ready to rove

After several years of design, the rover instruments and subsystems finally began taking shape in 2016. Engineers at JPL assembled the rover in 2019 and put it through extensive tests through the first half of 2020, simulating the harsh thermal conditions on Mars and the vacuum of space.

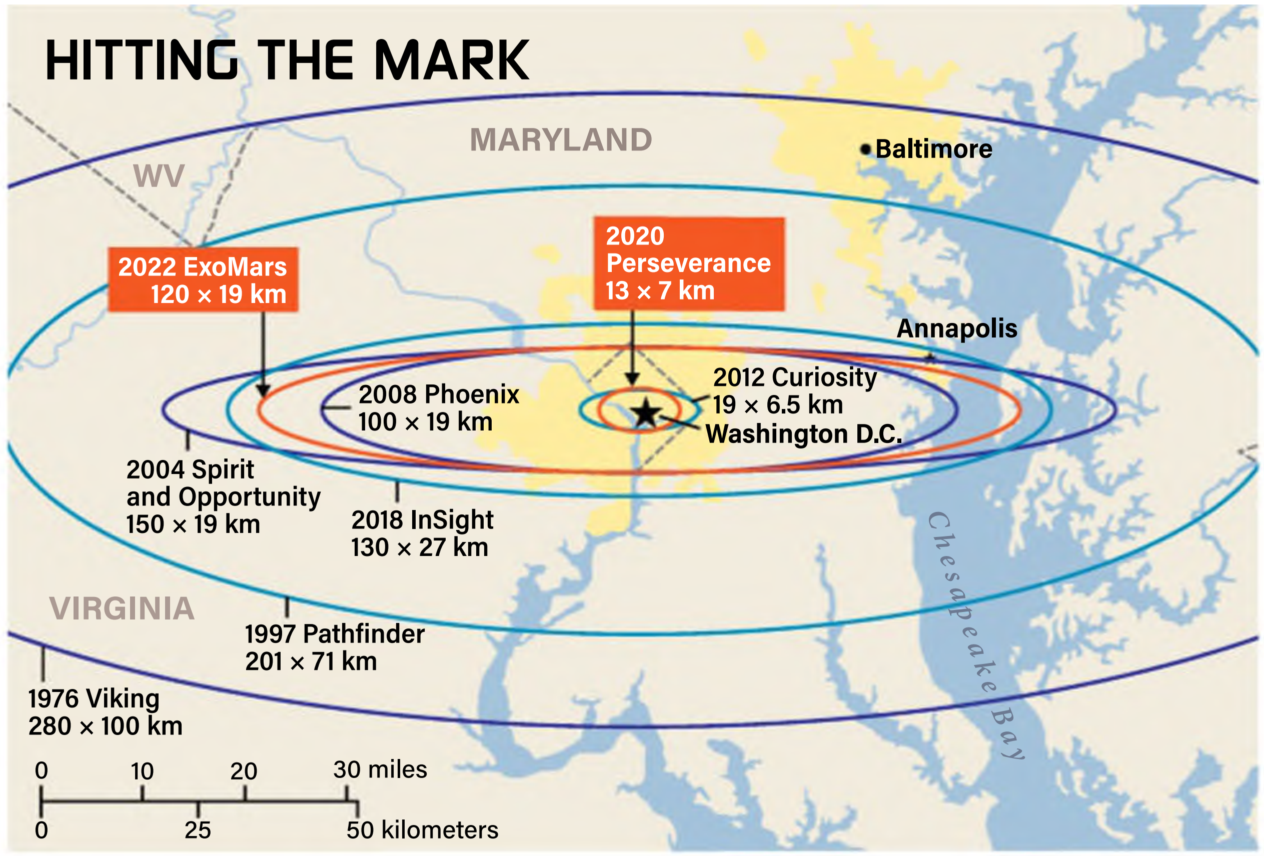
The final stages of assembly, testing, and installing the craft atop the launch vehicle occurred in the midst of the COVID-19 pandemic. By mid-April, 90 percent of the team at JPL was working from home, but mission-critical personnel were still needed to at the Kennedy Space Center in Florida to prep the rover itself.

Following clean protocols was not a challenge for the team, as those are necessary for preparing any lander to avoid contaminating the worlds they visit. But they improvised to minimize the number of people needed inside the clean room itself. For instance, the final "walkdown" inspection of the spacecraft — in which experts in each spacecraft system give the rover one last check — took place remotely, with a technician in Florida using a smartphone to send a video feed to senior engineers at their homes.

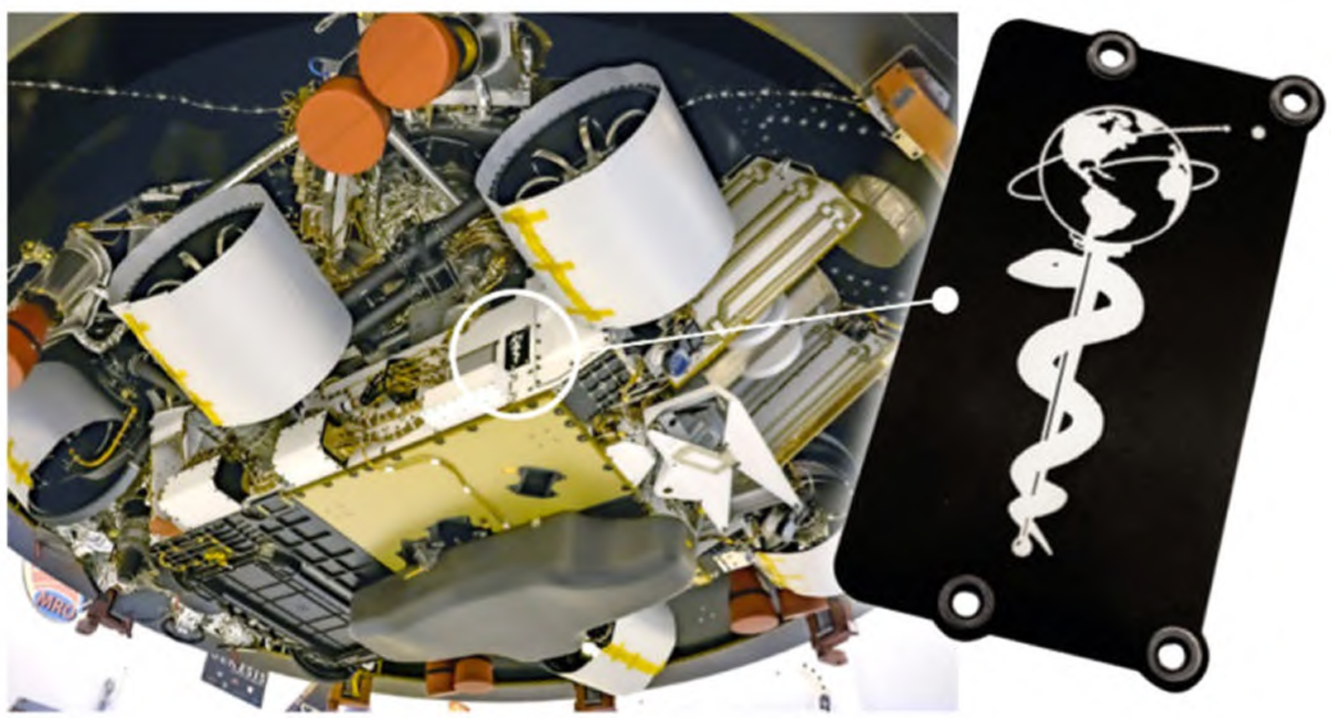
The window for Mars 2020 to actually launch in 2020 ran from July 17 through August 15. If the mission missed that window, it would have had to wait until September 2022. The challenges that the coronavirus presented made the efforts of all involved — including at JPL, NASA's Kennedy Space Center, United Launch Alliance (the manufacturers of the Atlas V rocket), and other NASA and subcontractor facilities — to make the launch window especially impressive.

The ambitious rover did go over its original 2012 budget — but only by around 12 percent, partly due to delays and issues related to COVID-19. Considering the cost overruns that have plagued many past NASA flagship-class missions, a 12-percent overrun could be considered something of a minor victory.

Now, the anticipation is building. Who knows what discoveries await us all in Jezero, what new secrets about Mars will be revealed by the images and other data the rover will collect. Everyone involved is extremely excited about what we will learn from the rover's mission on Mars. And many of us are eagerly looking forward to the day when we can see those rover-collected samples — not just through the lenses of our sophisticated robotic avatar, but with our own human eyes.



The landing ellipse is the area in which mission planners estimate a lander could touch down — i.e., the margin of error they must account for. Improvements to Perseverance's landing system make its landing ellipse smaller and allow engineers to consider targeting more challenging and scientifically interesting terrain. This figure compares the landing ellipses of several Mars missions plotted over the more familiar territory of Washington, D.C. *ASTRONOMY*: ROEN KELLY, AFTER PAJOLA ET AL. (2019)



This aluminum plate bearing the staff of Asclepius — the Greek deity of healing and medicine — was installed on the rover to commemorate the impact of the COVID-19 pandemic and to pay tribute to health care workers. NASA/JPL-CALTECH

***Jim Bell** leads the Mastcam-Z camera team on the Mars 2020 mission's Perseverance rover. He is an astronomer and planetary scientist at Arizona State University and president of The Planetary Society.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

This month you'll find several planets hiding in twilight. Careful observers can even follow Venus (pictured here) and Jupiter into daylight. JAMIE COOPER

FEBRUARY 2021

Twilight planets delight

Be ready to catch the early morning appearance of four planets: Mercury, Venus, Jupiter, and Saturn. They appear in the brightening morning twilight and some are challenging. Jupiter passed Saturn last December and now stands to its east. Both gas giants rise earlier each morning as they increase their elongation from the Sun, preparing for a fine spring lineup before dawn. Venus is heading to superior conjunction with the Sun and is briefly visible in the dawn sky. Mercury is near the end of its morning apparition.

The evening skies of February carry the distant giants Neptune and Uranus — Neptune is lost quickly in twilight, but Uranus lingers a while. Mars dominates the evening sky and enters Taurus this month. Although distant from Earth and showing a tiny disk, it will remain in our evening skies for a long while yet.

Attentive observers may catch **Mercury** February 1 in bright twilight after sunset. It's a challenging view now, following its greatest eastern elongation late last month. Begin your attempt 30 minutes after sunset. Can you spot the magnitude 0.9 planet 6° high in the western sky? Watch with binoculars for 15 to 20 minutes as the sky darkens and Mercury dips lower. The planet descends quickly and 15 minutes before it's gone, it stands 2° high — tough to spot at such a faint magnitude, but some observers with clear skies may have good luck. Locations with the best chance are those with fine atmospheric transparency offered by a high altitude and a clear view to the west.

Morning triad

Early risers can catch Mercury forming the apex of a triangle with Saturn and Jupiter shortly before sunrise on February 20. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Mercury passes through inferior conjunction February 8 and springs into the dawn sky

OBSERVING HIGHLIGHT

MERCURY, SATURN, and **JUPITER** share the dawn sky this month. Catch them February 20, forming a triangle a mere 30 minutes before sunrise.

along with Jupiter — more on that later.

Neptune makes a brief appearance early in February as a binocular object in Aquarius. It lies less than 20° high once the sky is dark. The magnitude 7.8 planet lies slightly less than 2° northeast of Phi (ϕ) Aquarii, a dim 4th-magnitude star, on February 1. The pair's angular separation increases as the month progresses. By mid-month, the planet is too low to find, and it's telescopically disappointing due to turbulence in our atmosphere muddying the view. It will reappear in the morning sky later in the spring.

Mars and Uranus begin the month about 6.5° apart in the constellation Aries the Ram. **Uranus** is only visible with binoculars for most observers. At magnitude 5.8, it may be visible to the naked eye under exceptionally clear sky conditions. It lies 10.5° south of Hamal, the brightest star in Aries. A waxing crescent Moon lies within 5° of Uranus on February 17 and skips next door to sit 4° south of Mars on the 18th.

Through a telescope, Uranus displays a fine 3.5"-wide disk with a greenish hue on nights when stars are not twinkling badly — a sure sign of good seeing conditions.

Mars shines as a brilliant beacon among the faint stars of

— Continued on page 38

RISING MOON | Lunar strongmen

PROMINENTLY PAIRED CRATERS Atlas and Hercules rule the lunar northeast. Without compare in strength, these mythological musclemen have appropriately striking features named after them.

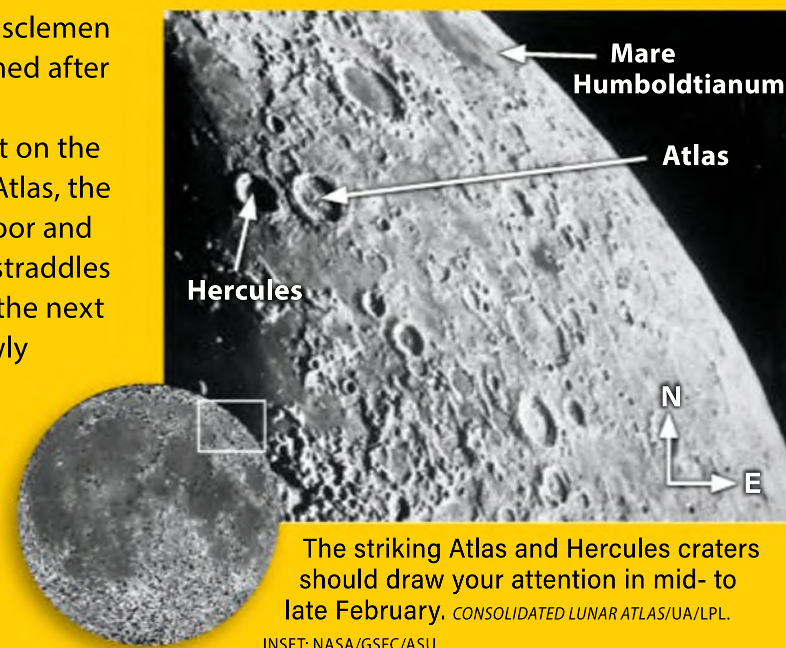
Their chiseled forms seem to pop out on the 16th, lit by a rising Sun in the lunar sky. Atlas, the one closer to the limb, sports a rough floor and central peak. Just to the west, Hercules straddles the day-night line, the terminator. Over the next few hours, watch the long shadows slowly retreat. The western inner walls face the brilliant Sun, while their eastern sides remain dark. Return on the 17th to see the floor of Hercules — surprise! It's a pool of frozen lava with the barest hint of a central peak and a sharp crater just off the bull's-eye.

Each bowl is surrounded by an apron of debris. Under the low Sun angle, can you tell which one drapes over the other? Researchers disagree over which formed first. It may help to look with reversed lighting, when the setting Sun illuminates the craters' eastern flanks on March 1, a few days after Full.

Luna slowly turns its nose up at us beginning on the 17th. Key in on the limb northeast of Hercules and watch the dark floor of Mare Humboldtianum shift out of sight from night to night. The Moon's axis does not actually tilt — as it bobs up and down in its orbit around Earth, we see it from slightly different points of view. Astronomers call this apparent nodding motion of our satellite libration.

Any time after First Quarter (the 19th), we're close to lunar high noon for both Atlas and Hercules. Without the shadows, Atlas practically disappears. In contrast, Hercules's lava lake stands out well against its neighboring light-hued crater. Pay close attention — Luna reveals a different face every night.

Hercules and Atlas



The striking Atlas and Hercules craters should draw your attention in mid- to late February. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | A dim, dusty glow

WITH NO MAJOR SHOWERS, February is traditionally a quiet month for meteors. The average sporadic (random) rate for meteors is seven per hour and there are occasional fireballs — meteors that break up and achieve a brilliance of Venus or greater. These are, of course, rare, but worth spending time under a night sky ready for their appearance.

The zodiacal light begins to make an appearance during moonless nights in February, March, and April. The evening view of this subtle glow, which arises from the meteoritic dust that fills the plane of our solar system, gets better as the ecliptic becomes more steeply inclined to the horizon. The first two weeks of February are favorable, with the Moon in the morning sky. As soon as the Milky Way becomes visible — arching from high up in Perseus through Orion and toward the southern horizon — look for a faint, cone-shaped glow of light reaching up from the western horizon through Pisces, Aries, and into Taurus at its narrowest. The zodiacal light is never seen from cities or towns, but is visible from country locations with dark skies to the west.

False dusk

Moonless February evenings are perfect for spotting the glow of the zodiacal light from a dark location. BARRY BURGESS

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. February 1
9 P.M. February 15
8 P.M. February 28

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.**

FEBRUARY 2021

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						

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

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

CALENDAR OF EVENTS

2 Asteroid Melpomene is at opposition, 2 A.M. EST

3 The Moon is at perigee (229,980 miles from Earth), 2:03 P.M. EST

4 Last Quarter Moon occurs at 12:37 P.M. EST

8 Mercury is in inferior conjunction, 9 A.M. EST

9 Asteroid Pallas is in conjunction with the Sun, 3 P.M. EST

10 The Moon passes 3° south of Saturn, 6 A.M. EST

The Moon passes 3° south of Venus, 3 P.M. EST

11 Venus passes 0.4° south of Jupiter, 7 A.M. EST

New Moon occurs at 2:06 P.M. EST

13 The Moon passes 4° south of Neptune, noon EST

Mercury passes 4° north of Jupiter, 2 P.M. EST

17 The Moon passes 3° south of Uranus, 11 A.M. EST

18 The Moon is at apogee (251,324 miles from Earth), 5:22 A.M. EST

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

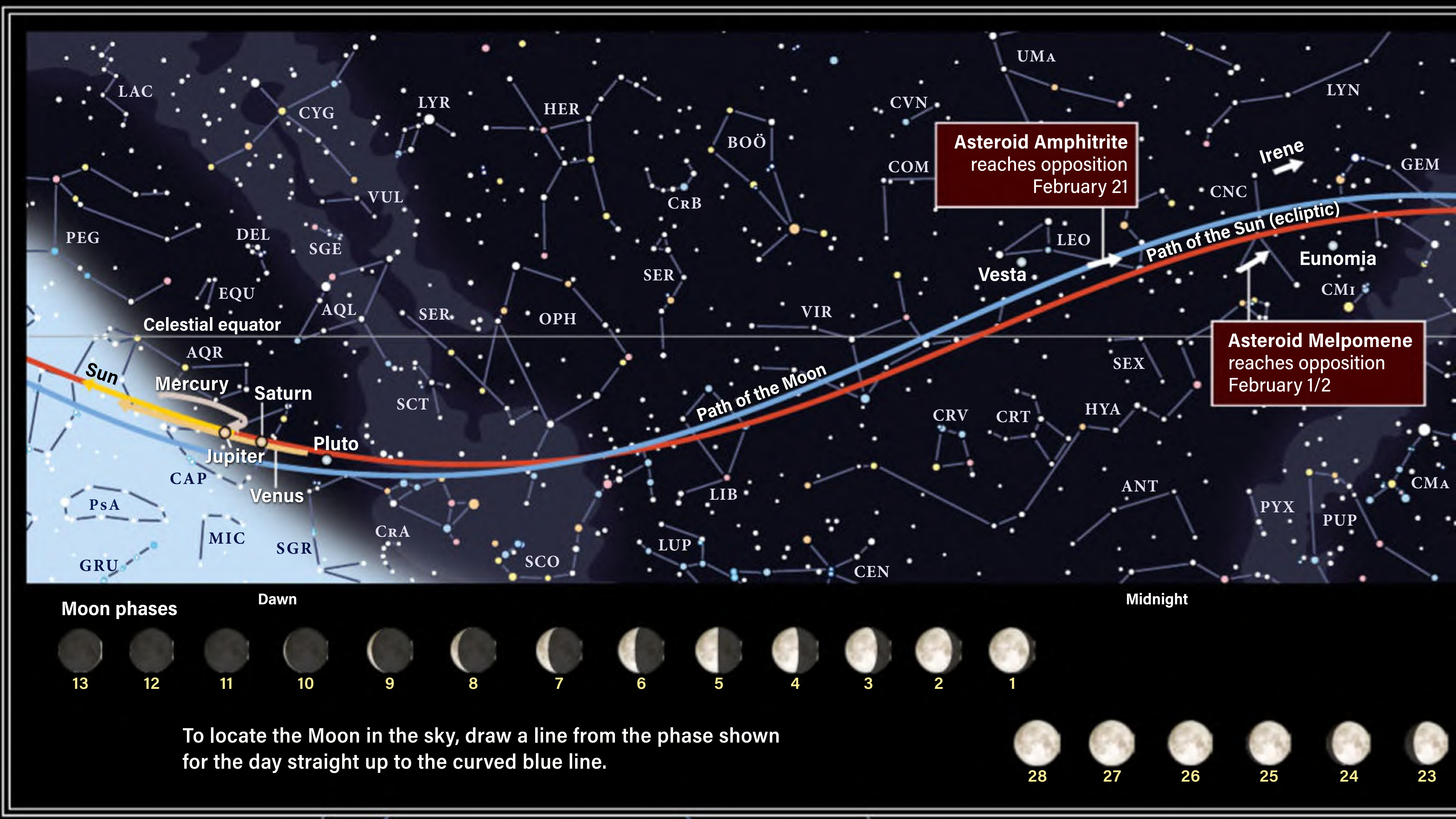
19 First Quarter Moon occurs at 1:47 P.M. EST

20 Mercury is stationary, 8 A.M. EST

21 Asteroid Amphitrite is at opposition, 11 P.M. EST

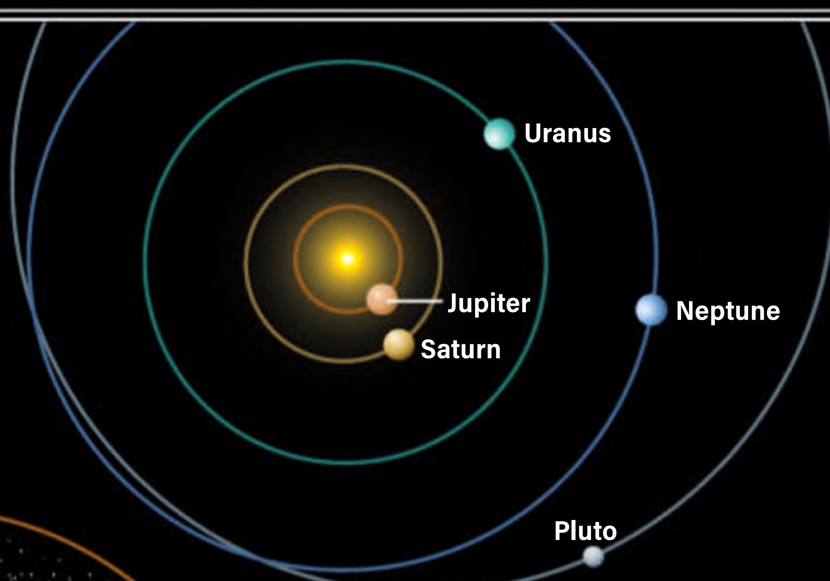
27 Full Moon occurs at 3:17 A.M. EST

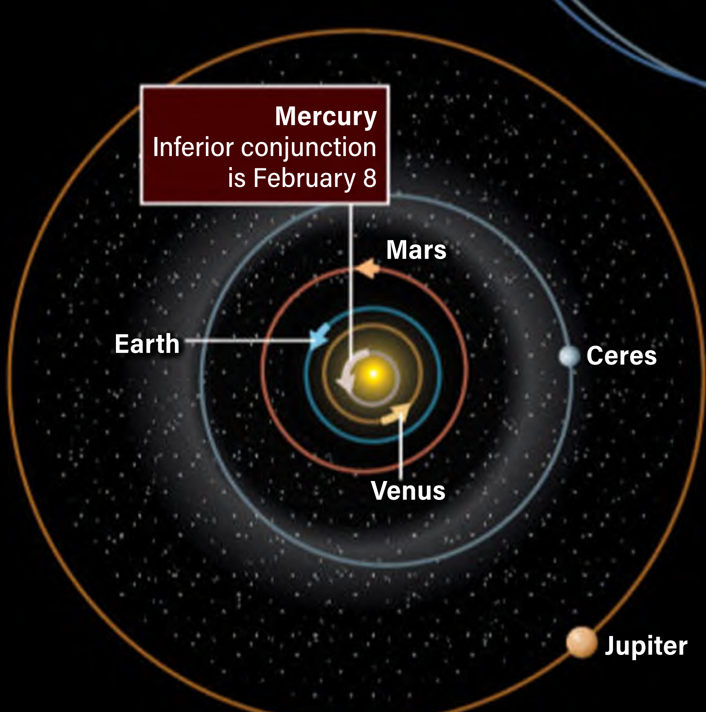
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

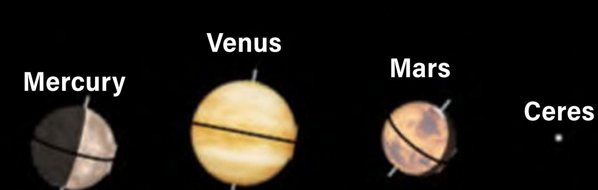
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

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



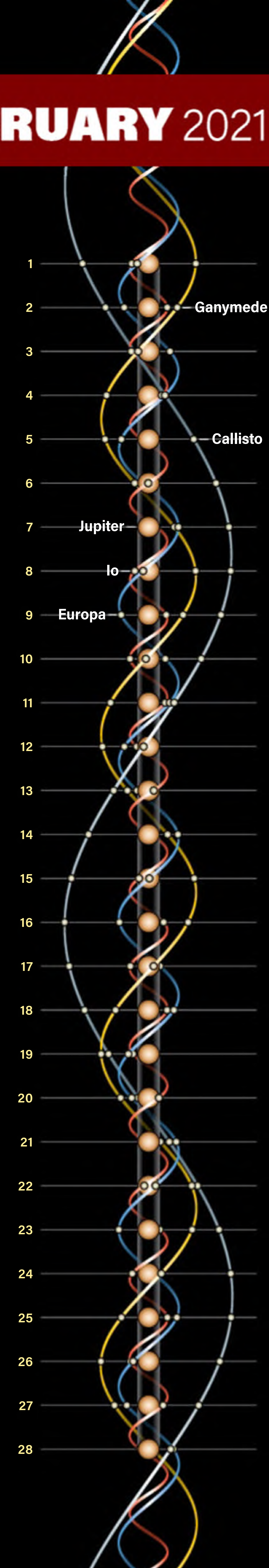
PLANETS	MERCURY	VENUS
Date	Feb. 28	Feb. 1
Magnitude	0.3	–3.9
Angular size	8.0"	10.1"
Illumination	45%	98%
Distance (AU) from Earth	0.843	1.652
Distance (AU) from Sun	0.440	0.728
Right ascension (2000.0)	21h01.6m	20h05.0m
Declination (2000.0)	–16°12'	–20°58'

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.

FEBRUARY 2021

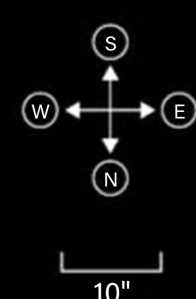
JUPITER'S MOONS

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



Jupiter

Saturn



MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Feb. 15	Feb. 15	Feb. 28	Feb. 28	Feb. 15	Feb. 15	Feb. 15
0.7	9.3	–2.0	0.6	5.8	7.8	15.1
7.0"	0.4"	33.0"	15.4"	3.5"	2.2"	0.1"
89%	99%	100%	100%	100%	100%	100%
1.329	3.732	5.972	10.811	20.072	30.831	35.065
1.567	2.941	5.076	9.978	19.766	29.926	34.221
3h08.4m	0h03.1m	21h14.9m	20h42.5m	2h18.7m	23h22.9m	19h50.3m
19°03'	–8°21'	–16°34'	–18°41'	13°24'	–5°09'	–22°18'

Although no meteor showers take place in February, keep your eyes on the sky for sporadic meteors, including the occasional fireball. MIKE LEWINSKI

Aries, beginning the month at magnitude 0.5 and dipping to 0.9 by the end of February. The Red Planet this month has competition from Aldebaran, the brightest star in Taurus the Bull, which glows at magnitude 0.8. Can you tell which night they are both equal brightness?

Mars moves into Taurus February 23 and ends the month nearly 14° northwest of Aldebaran and nicely placed about 3° southwest of the contrasting blue stars of the Pleiades (M45).

The Red Planet presents a tiny disk through telescopes as its distance from Earth continues to increase apace. Its gibbous phase is a distinctive 90 percent lit. On February 1, it's already 1.2 astronomical units from Earth (1 astronomical unit, or AU, is the average Earth-Sun distance). That distance increases to nearly 1.5 AU by February 28. The disk's angular size shrinks from nearly 8" to 6.4" over the course of the month.

Features so familiar during Mars' opposition late last year are now tougher to spot. During the first five days of February, the darkest — Syrtis Major — swings into view in the evening between sunset and local midnight for most observers in the U.S. The lack of albedo features is apparent during mid-February, as desert regions transit the martian disk during our evenings. Solis Lacus and Sinus Meridiani, two distinctive dark features, are on view in the last week of the month, but the tiny disk makes them hard to spot except under optimum seeing conditions. Skilled observers who practiced video capture during last year's opposition can still bring them out if conditions cooperate.

Four planets congregate in the dawn twilight this month. Some events are difficult to catch due to their proximity to the Sun. For example, on February 6, **Venus** stands less than a Moon's-width southeast of Saturn, but they rise only half an hour before the Sun. Even at magnitude –3.9, Venus will be hard to see. Saturn is not visible at a much dimmer magnitude of 0.6.

Venus, on its way to a late March superior conjunction, passes 26' due south of Jupiter February 11. They're located just 10.5° east of the Sun. **Jupiter** shines at magnitude –2; the pair

WHEN TO VIEW THE PLANETS

EVENING SKY
Mars (southwest)
Uranus (southwest)
Neptune (west)

MIDNIGHT
Mars (west)

MORNING SKY
Mercury (east)
Venus (east)
Jupiter (east)
Saturn (east)

0.3 Between February 1 and 28, Mars retreats nearly 0.3 AU from Earth.

COMET SEARCH | Challenge versus chance

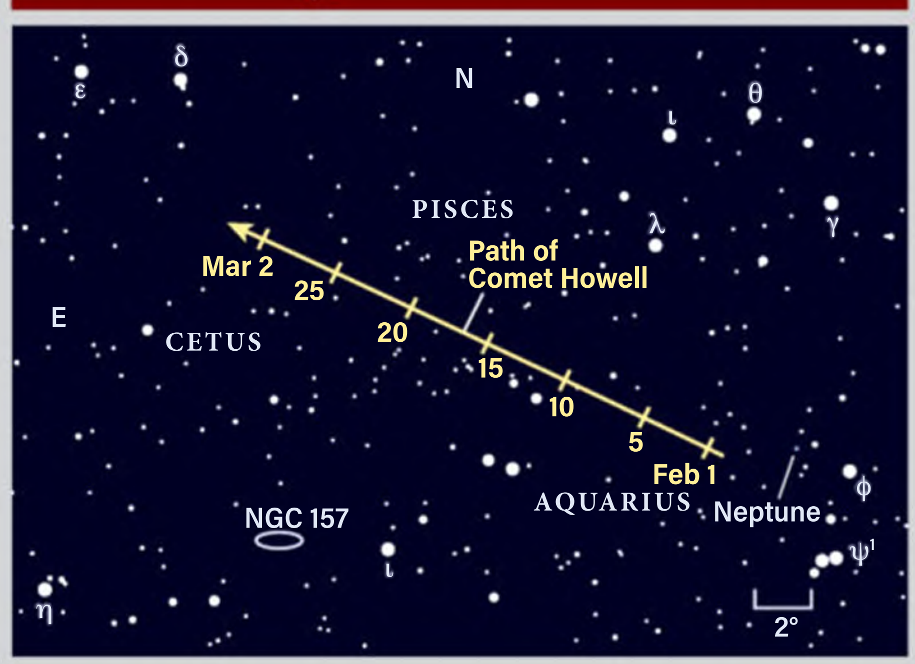
COMET ENTHUSIASTS are used to excitement, disappointment, and satisfaction all in one month. No one can be sure which it will be this spring. As Earth circles the inner solar system, some comets coincidentally arc behind the Sun, popping into visibility with only three months' notice before they peak, missing our publication deadline.

Surprising us twice since its discovery, 17P/Holmes has outburst to 2nd magnitude. Cruising in front of the circlet of Pisces, will it shine anew? Meanwhile, as 141P/Machholz 2 sails from Cetus to Orion, its last fragment might flare up to 10th magnitude for a final show.

With great but not absolute confidence, we expect Comet 88P/Howell to present a challenge for an 8-inch scope under a dark sky. Once you've confirmed the starfield is right, pump up the magnification to about 200x. Get comfortable, dark adapt as much as possible, and patiently scan for a very small fuzz — picture a 13th-magnitude elliptical galaxy. Tapping the scope gently can leverage our eyes' low-light motion-detector system, while also suppressing "phantom galaxies" produced by a noisy visual cortex.

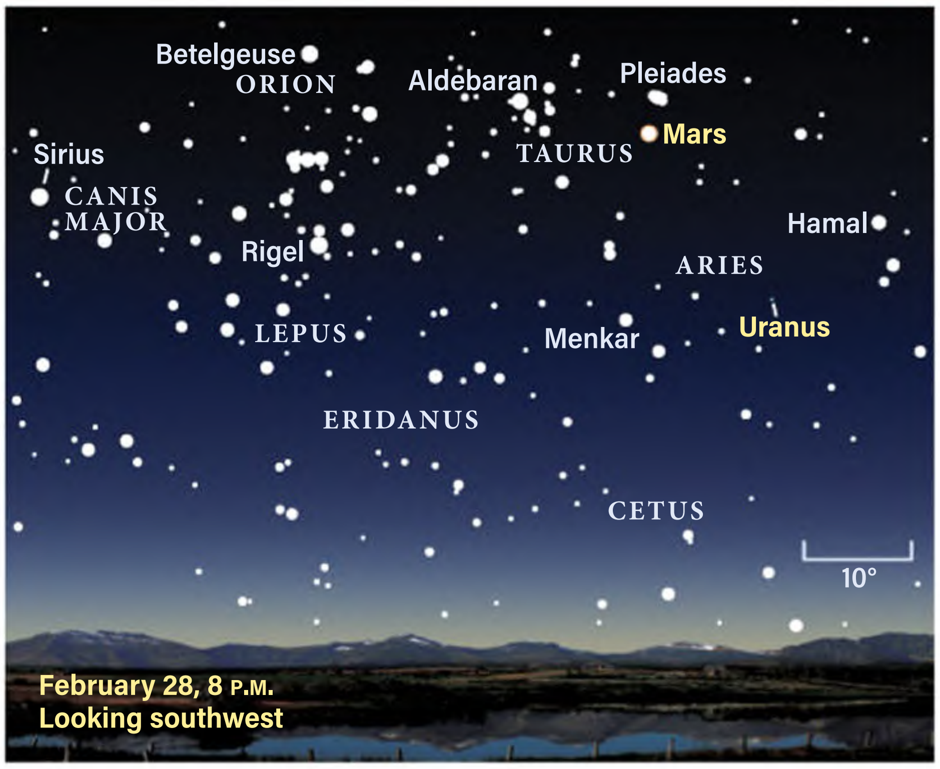
The best comet hunting this month is during the moonless first half of February.

Comet 88P/Howell



A challenging 88P/Howell skims through Pisces on its way from Aquarius to Cetus this month. The location of Neptune is shown on February 7. Should they flare up, 17P/Holmes is west of this field and 141P/Machholz 2 is east.

Bull crossing



Mars crosses into Taurus February 23 and ends the month beneath the Pleiades (M45). Uranus floats nearby in Aries and is visible with binoculars or a telescope.

may be seen in binoculars 20 minutes or so before sunrise, but will be very challenging. Observers, be very cautious — you can easily lose track of time as the Sun comes up. Protect yourself by setting an alarm to go off several minutes before sunrise. Never scan the skies after sunrise, because an accidental view of the Sun through binoculars will cause lasting damage to your eyes!

Observers with clear, transparent daytime skies and an accurately aligned telescope on February 11 can use their go-to device to find Venus and Jupiter in daylight.

On February 15, **Saturn** and **Mercury** rise together in the eastern sky, but remain difficult objects due to their relative faintness in twilight. By February 18, they stand roughly 3° high 45 minutes before sunrise. Mercury has brightened to magnitude 1.2, while Saturn remains easier at magnitude 0.6. The two planets' visibility improves each consecutive morning.

Try on the morning of Saturday, February 20, to spot all three planets in a triangle: Saturn and Mercury rise together 4.4° apart around 5:40 A.M. local time, followed by Jupiter 7° east of Saturn about 22 minutes later.

Mercury and Saturn match in magnitude February 22, when they stand almost 5° high 40 minutes before sunrise. Jupiter stands less than 1° high, but its brilliance makes it more easily visible. It lies about 5° east (lower left) of Mercury, while Saturn stands 4° to Mercury's southwest (right).

The triangle formed by this trio of planets flattens as Mercury drops in declination in late February, brightening as it does so. On February 28, it shines at magnitude 0.3 and stands only 3° west of Jupiter, with Saturn 5.5° to Mercury's west. It's amazing to get this view across the solar system — all three planets are currently on the far side of the Sun. Mercury is closest to Earth at 0.85 AU, while Jupiter is at 6 AU and Saturn is a distant 10.8 AU away.

If you're able to swing a telescope towards these planets, you're in for a visual — though short-lived — treat, since twilight is advancing quickly. Mercury displays a 46-percent-lit disk spanning 8", whereas both Jupiter and Saturn are full. Jupiter spans 33" and is accompanied by its four Galilean moons, just visible in the shimmering haze. Saturn's disk is 15" wide and its bright ring system spans 34" at its widest.

Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

Buzzing the Crab

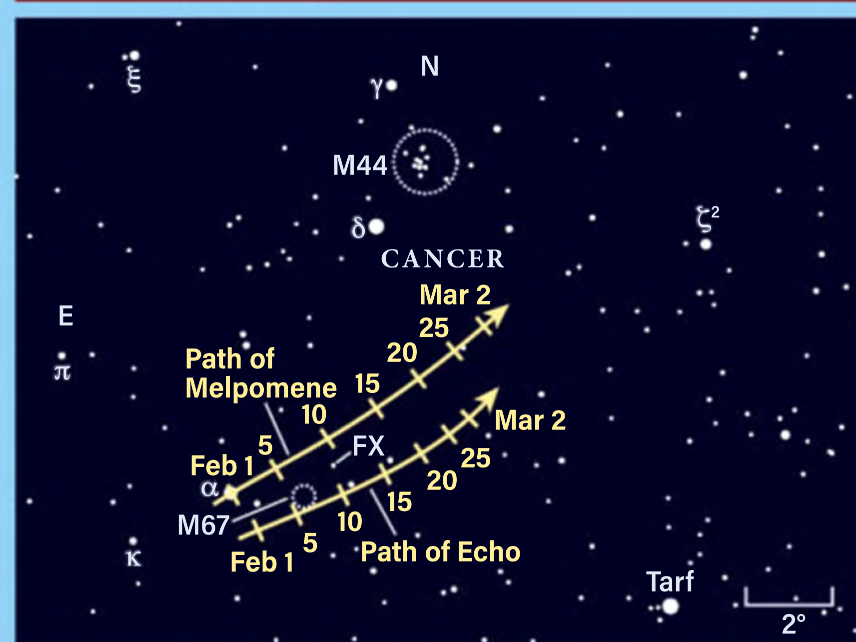
IT'S TWO-FOR-ONE asteroids this month. Floating only one field apart, 18 Melpomene and 60 Echo track across southern Cancer. The celestial crab is well placed one-third of the way up the eastern sky once darkness sets in. This aquatic constellation boasts the splashy Beehive Cluster (M44); start with this showpiece, then shift a few degrees south to Alpha (α) Cancri and M67.

From the 5th to the 8th, magnitude 10 Echo shares the medium-power field with the well-studied cluster M67. Melpomene is just over 1° to the north and is a bit brighter at magnitude 9.5. Crank the power to the max on M67 and test your limiting magnitude against the chart in the Royal Astronomy Society of Canada's *Observer's Handbook* or one generated online at the American Association of Variable Star Observers' website, www.aavso.org.

Until much brighter 4 Vesta arrives in spring, we must be meticulous in our identification of these main-belt asteroids. Starhop carefully, sketch a field in the expected area, then come back a night or two later to see which dot has moved. The orange star FX Cancri varies only slightly from magnitude 6.7, making a nice reference in the same field.

Thanks to the longer nights of February, you might be able to see these small worlds move slightly over a four-hour session.

Double feature



Asteroids Melpomene and Echo travel together this month through Cancer. Close by is the sparkling Beehive Cluster (M44).

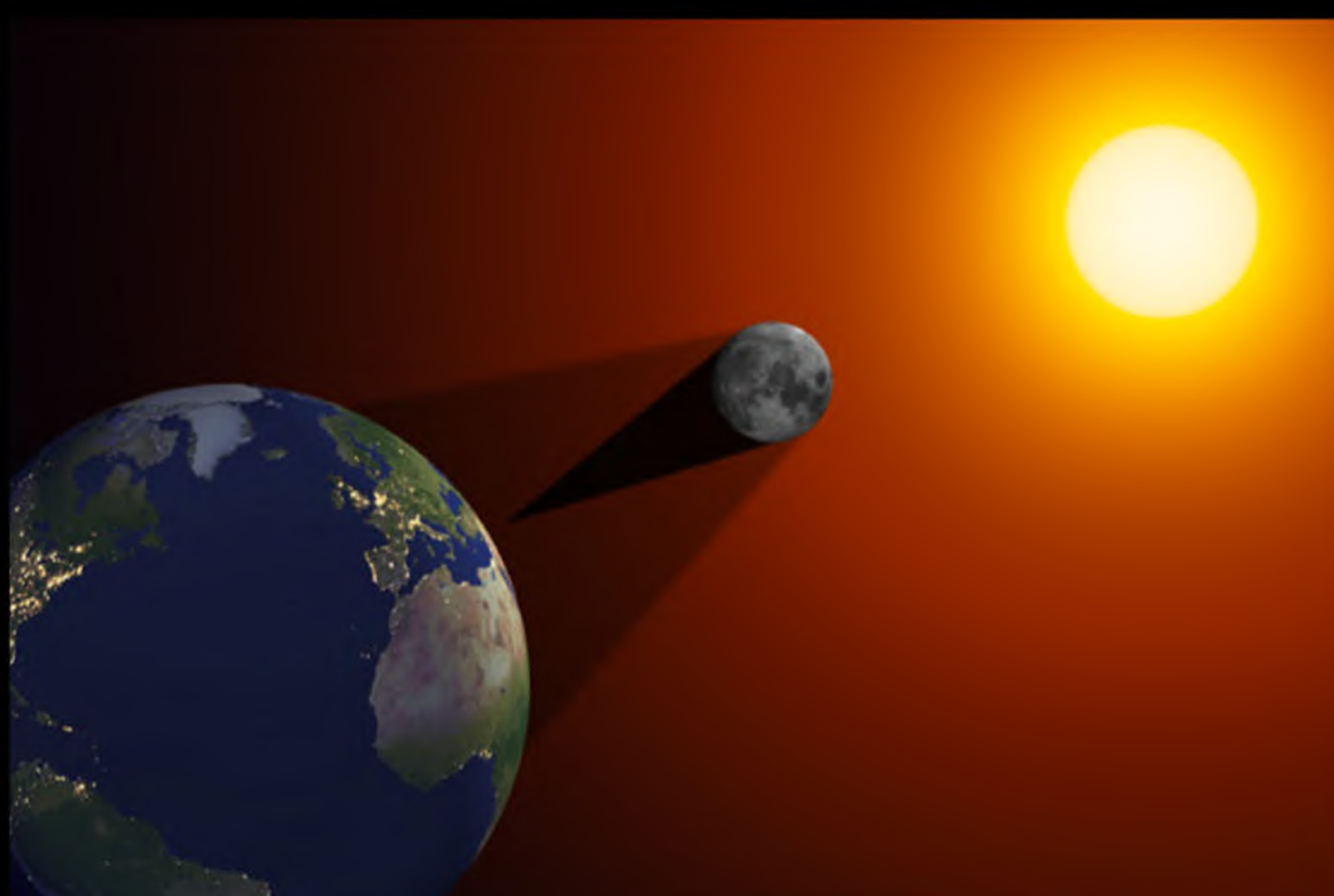
GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

Corona light

Missed last year's annular eclipse? We've got you covered with some of the best shots out there.

BY JAY PASACHOFF

BACKGROUND: The Mango Education Group experienced annularity during clear weather from Dehradun, which is the most populous city in the Indian state of Uttarakhand. That fortunate weather allowed them to capture this crisp shot of the thin circle created by the Sun's disk stretching out just beyond the Moon's silhouette. HARINDRA BARAIYA (WILDLIFE INSTITUTE OF INDIA/MANGO ASTRONOMY CLUB); IMAGE FORWARDED BY STEPHEN INBANATHAN (AMERICAN COLLEGE IN MADURAI)



RIGHT: On June 21, the Moon was relatively far from Earth thanks to its slightly elliptical orbit. That meant its angular size was smaller than usual. Therefore, it couldn't fully block the solar disk when the Sun, Moon, and Earth aligned, or entered syzygy, as shown in this artist's illustration. *ASTRONOMY*: ROEN KELLY AFTER ERNEST T. WRIGHT (NASA'S SCIENTIFIC VISUALIZATION STUDIO)

The wild year of 2020 boasted two solar eclipses: an annular eclipse on June 21 and a total solar eclipse on December 14. Travel restrictions prevented North Americans, as well as many others in the Western Hemisphere, from viewing the path of annularity that stretched from Africa through the Middle East to Pakistan, India, mainland China, and Taiwan. Fortunately, local eclipse viewers who managed to get beneath the Moon's shadow captured wonderful images of the breathtaking event.

The following is a smattering of shots from last June's annular eclipse, which I monitored into the wee hours of the morning with the help of email, the web, and livestreams from the Middle East and Asia. My decades-long interest in eclipses, and the resulting expeditions I have taken to view them, have allowed me to meet many fascinating people whom I never would have otherwise. And although I don't keep in constant contact with every one of them, when an eclipse passes overhead anywhere in the world, I have a good chance of hearing from some of my old friends who are eager to share their new pictures.

At the time of this writing, the next solar eclipse to be seen from Earth will be total, with its peak occurring near the border of Argentina and Chile on December 14, 2020. Be sure to keep an eye out for images of December's total solar eclipse in future issues of *Astronomy*.

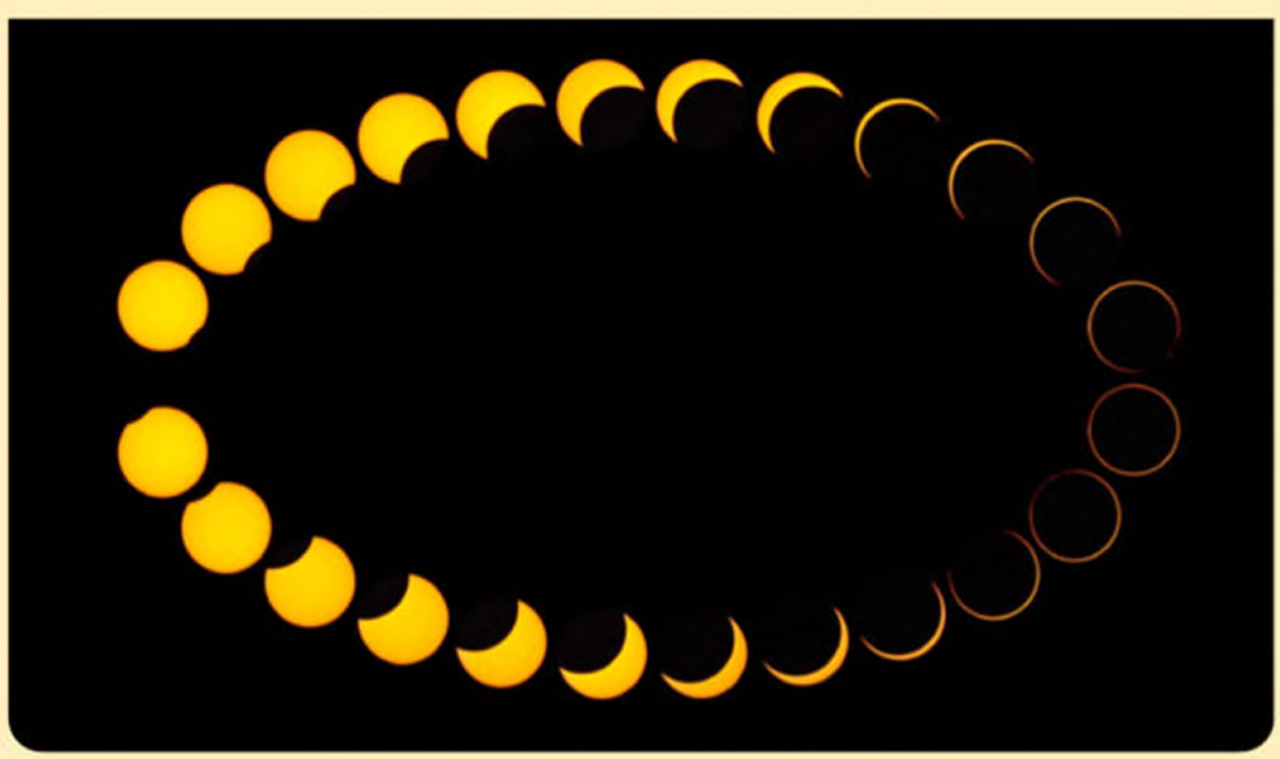
Meanwhile, the next annular eclipse will be on June 10, 2021. Its path will trek from southern Canada over the North Pole and down to the Russian Far East. Observers in the northeastern United States will be happy to learn that partial phases of this annular eclipse will be visible to them in the early morning. So, make sure to get your filtered solar eclipse glasses now, available at MyScienceShop.com.

And don't forget: Share what you see!

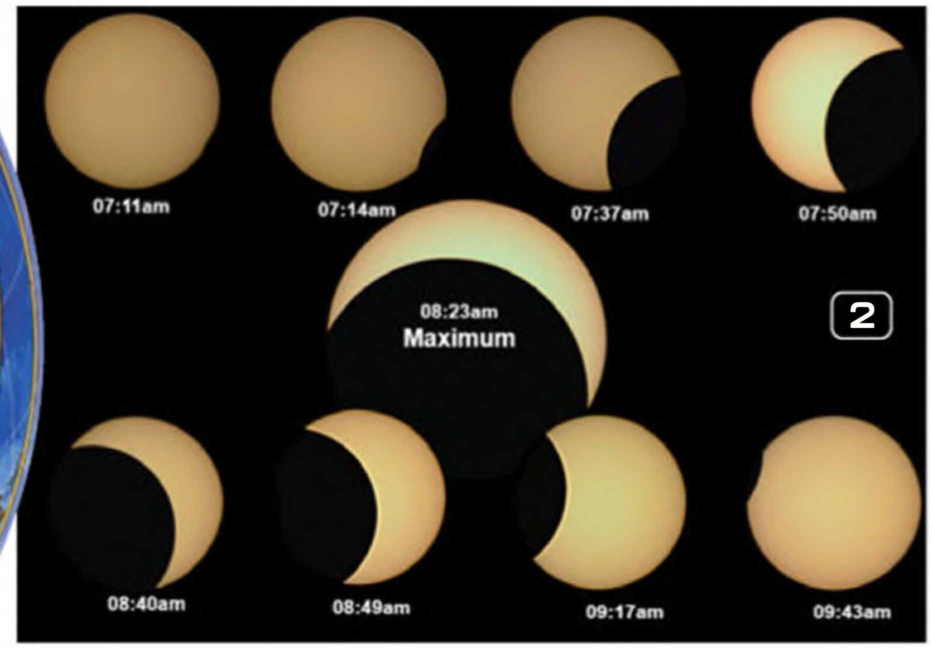
A RINGED ECLIPSE

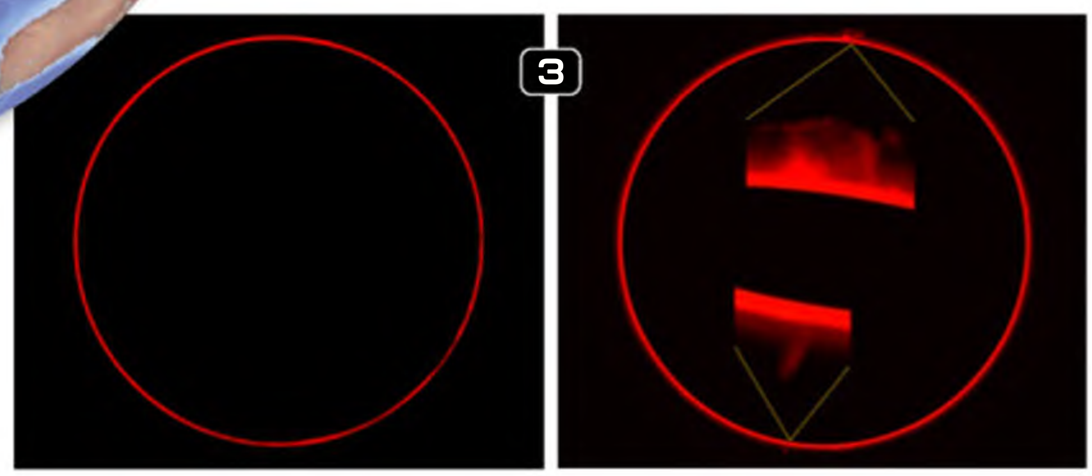
The word *annular* comes from *annulus*, which means "ring." So, when the Moon is just far enough away from Earth that it leaves the outer perimeter of the Sun's disk unobscured, the result is often referred to as a "ring-of-fire" eclipse. At maximum coverage, this outer band of sunlight is up to a few percent of the solar disk's diameter. So, technically, it could be called a "ring-of-photosphere" or a "ring-of-sunlight" eclipse.

The term "ring-of-fire" has murky origins dating back at least 150 years, but its modern usage in reference to annular eclipses has been around for at least a few decades, when it started popping up in various publications. However, "ring-of-fire" is somewhat misleading terminology, and it is disliked by many professional and amateur astronomers, or so-called umbraphiles (the umbra is the dark part of a shadow). Contrary to common conception, there is no chemical fire on the Sun. Rather, we owe the warmth and light we receive from the Sun to the clean thermonuclear fusion of hydrogen gas safely occurring some 93 million miles (150 million kilometers) away.



IMAGES: JAY PASACHOFF. COMPOSITE: MUZHOU LU



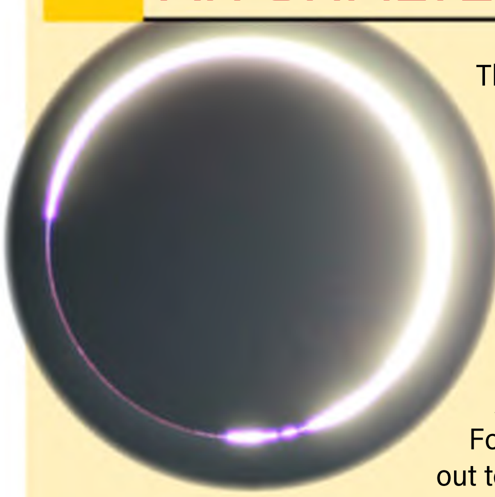


1 The Moon's shadow first touched the Republic of Congo during the June 21 annular eclipse. After it departed Africa, it went through the Middle East, then passed through southern Pakistan, northern India, mainland China, and Taiwan before vanishing southeast of Guam. The annular eclipse path, which stretched 9,058 miles (14,578 km), was just 13 miles (21 km) wide and maximum eclipse (99 percent) lasted only 38 seconds. MICHAEL ZEILER

2 The path of annularity also grazed Saudi Arabia, resulting in a partial eclipse for many. Abouazza Elhamdi of the Astronomy and Physics Department of King Saud University captured this sequence of partial phases in the early morning from Riyadh. I am working with Abouazza, Marcos Peñaloza-Murillo of Venezuela, and Michael Roman of England to analyze how eclipse darkening impacts the local temperature and humidity in desert climates. ABOUAZZA ELMHAMDI

3 **LEFT:** Unlike central Saudi Arabia, observers in Izki, Oman, did see annularity. Alaa Ibrahim and Zach Ioannou of the Astronomy Group in the Department of Physics at Sultan Qaboos University captured a series of images with the aid of a hydrogen-alpha filter, including this single short exposure. **RIGHT:** Made by stacking 210 images, this view reveals solar prominences, or bright tendrils of chromospheric-temperature plasma that extend into the corona. During the event, the observers tracked changes in ambient temperature and humidity. Before the eclipse, it was 113 degrees Fahrenheit (45 degrees Celsius), which caused some equipment to overheat. But as the Moon blotted out most of the Sun's disk, the temperature dropped down to 90 F (32 C). LEFT: A.I. IBRAHIM. RIGHT: A.I. IBRAHIM/I.A. ALSHAIKH

AN UNFILTERED VIEW LEADS TO A REVISION



The June 21 annular eclipse also traced a path through Pakistan, where the cloud-cover forecast was not as favorable as in the lower Arabian Peninsula. Fortunately, it turned out to be very clear.

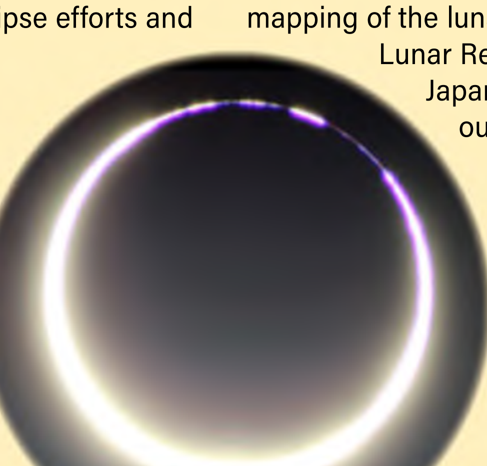
From Sukkur — a city in the Pakistani province of Sindh — Talha Moon Zia, who is a research astronomer at Pakistan's National Center for Big Data and Cloud Computing/NED University of Engineering & Technology, obtained these wonderful unfiltered views of the annular eclipse. The shots were created by stacking several short-exposure images and were taken under the guidance of Michael Kentrianakis, the former project manager of the American Astronomical Society's 2017 U.S. eclipse efforts and a member of our International Astronomical Union's (IAU) Working Group on Solar Eclipses.

Our IAU group focuses on being a central resource for anyone looking to find out more about past or upcoming solar eclipses. To do this, we maintain a website at the easiest possible address to remember: eclipses.info. The working group also serves as a clearinghouse for professionals pursuing international eclipse expeditions, coordinating such matters as visas, customs, and the shipping of equipment.

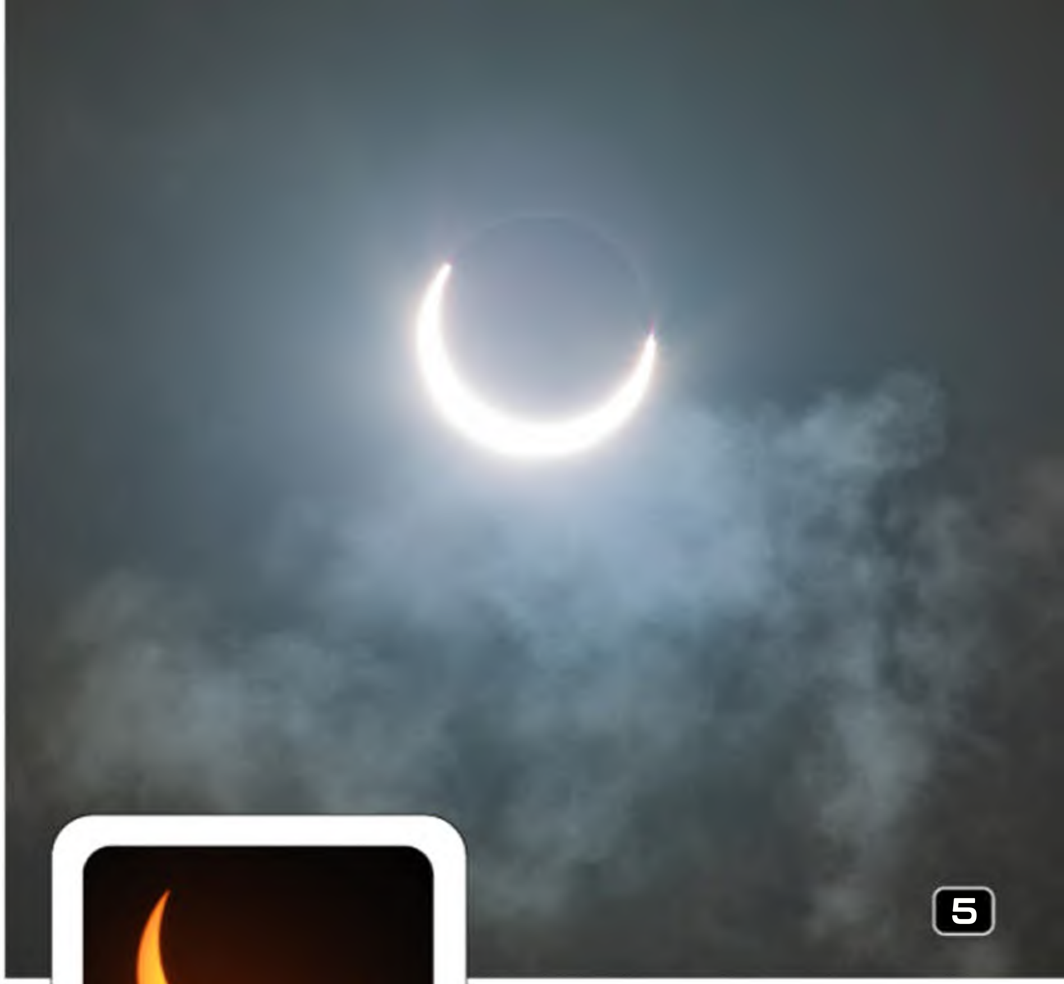
For these images, Zia and Kentrianakis forwent filters in order to capture detailed views of Baily's beads, which occur when sunlight peeks through valleys along the lunar limb. This allowed them to successfully detect the solar chromosphere, and even the inner solar corona.

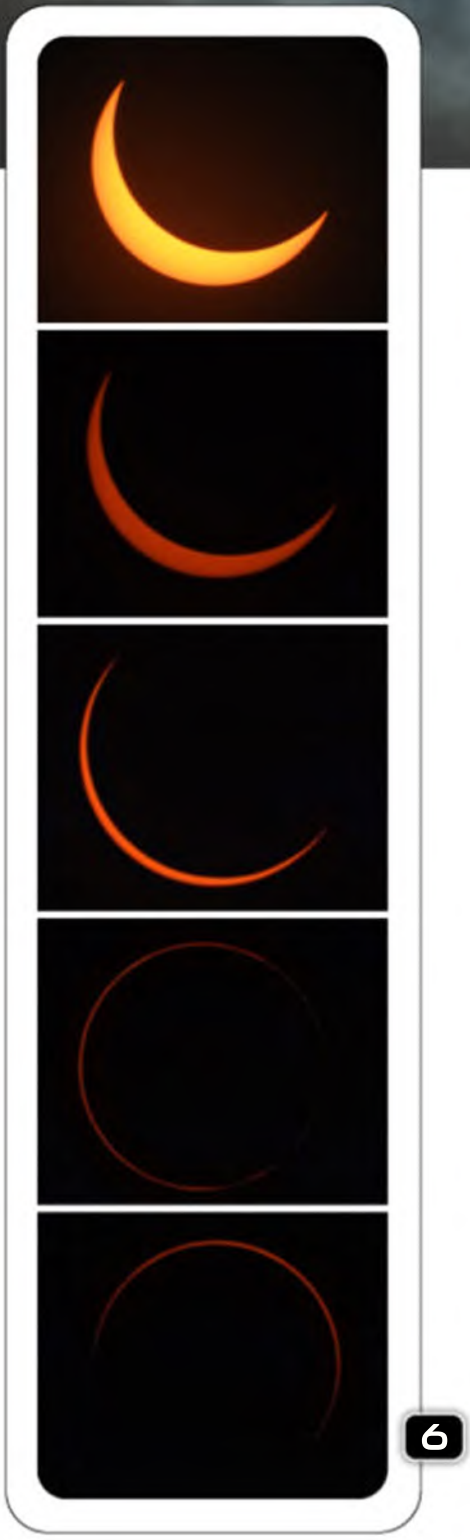
Prior imaging of Baily's beads taken during previous total solar eclipses led to discussions between me, Xavier Jubier, and Ernest T. Wright of NASA's Scientific Visualization Studio. We concluded that the IAU's nominal solar diameter — the defined size of the Sun's photosphere, which is used for predicting the length of eclipse totalities down to a fraction of a second — needed a minor revision. By comparing our observations to simulations by Jubier of the expected Baily's beads for this eclipse, which were based on high-resolution 3D mapping of the lunar surface obtained by NASA's Lunar Reconnaissance Orbiter and the Japanese Kaguya mission, we found our suspicions were confirmed.

Zia's observations, as well as Jubier's simulations, show the true size of the Sun's photosphere is slightly larger than previously thought.



BOTH IMAGES: NCBC-NEDUET





4 Rafay Kazmi, a student at Williams College in Williamstown, Massachusetts, observed a partial eclipse from his home in Islamabad, Pakistan. Here, he and his sister are seen viewing the eclipse through special solar filters, one of thousands left over from the 2017 Great American Eclipse and available through Astronomers Without Borders. RAFAY KAZMI

5 Clouds only served to add mystique to this view of the eclipse from the city of Sirsa in the northern Indian state of Haryana, taken by Neelam and Ajay Talwar. NEELAM & AJAY TALWAR

6 This series of images, showing the partial eclipse as seen from Coimbatore, a city in the south Indian state of Tamil Nadu, was captured by members of the Mango Astronomy Club. OBULI CHANDRAN

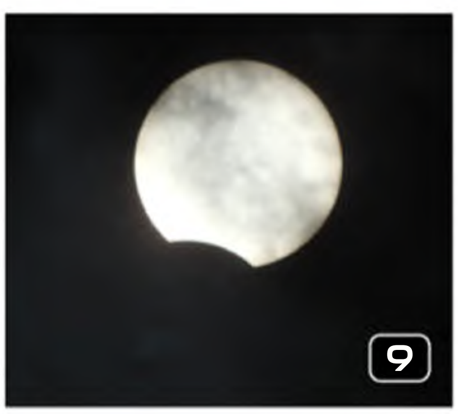
7 The Talwar team also captured this series of images tracking the progress of the annular eclipse over Sirsa. Even through the clouds, one can identify Baily's beads, the solar chromosphere, and, perhaps, even the solar corona. NEELAM & AJAY TALWAR

ECLIPSE RESOURCES

Many observers who were unable to personally see the annular eclipse dim the skies during the daytime instead opted to monitor images and livestreams of the event aired during the middle of their local night — an option not available to eclipse enthusiasts just a few decades ago.

Now, worldwide communication and online eclipse-mapping tools, like those from Xavier Jubier of France (http://xjubier.free.fr/ase2020map) and retired astrophysicist Fred Espenak (EclipseWise.com), provide detailed eclipse data for any location on Earth. Additionally, cartographer Michael Zeiler of New Mexico has meticulously created high-quality eclipse maps, while cloudiness statistics over the decades have been gleaned and put into context by Jay Anderson of Canada. (Anderson and I jointly authored the *Peterson Field Guide to Weather*, which is being published in summer 2021.)

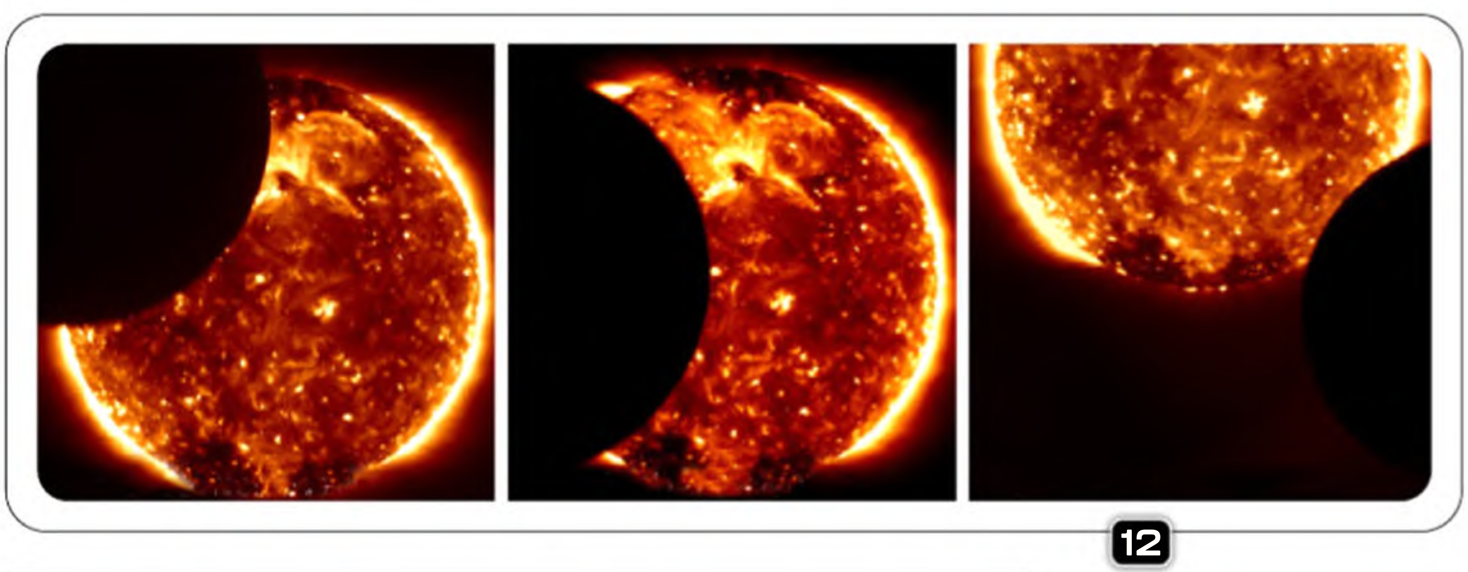
All of these resources are linked on the website for the International Astronomical Union's Working Group on Solar Eclipses (http://eclipses.info), which I chair. Additionally, observations of the 75 or so solar eclipses I worked on in the past are posted to the Williams College Eclipse Expeditions website (https://sites.williams.edu/eclipse).

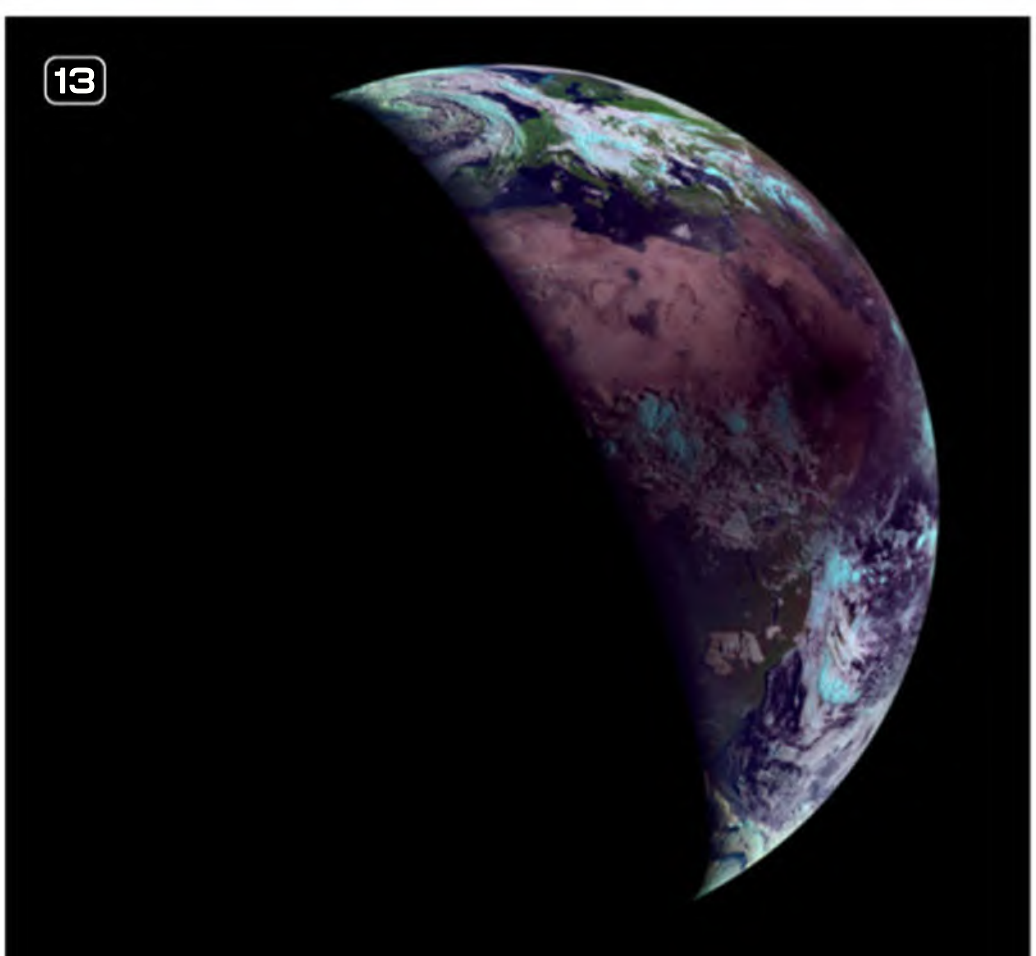


8 Amateur astronomer Zhou Guanhuai (left), with whom I have previously corresponded about earlier eclipses, sent an image of the partial eclipse (right) as seen from Jinan, Shandong province, China. Here, the partial eclipse reached its greatest coverage at 15:55 local time with 67 percent of the Sun's disk blocked. ZHOU GUANHUAI

9 Due to travel restrictions related to the COVID-19 pandemic, I was unable to venture to Europe. This image, however, came from Thessoliniki, Greece. It was captured by Aris Voulgaris, with whom I closely work on total solar eclipses. ARIS VOULGARIS

10 Near the end of the path of annularity in Guam, the eclipse was visible with 97 percent coverage, as seen in this eerie shot. The path of annularity continued about 50 miles (80 km) out to sea — briefly tempting me to fly to the U.S. territory for a quarantined glimpse from a boat. DEAN PATRICK SERVITO





Jay Pasachoff is Field Memorial Professor of Astronomy at Williams College in Williamstown, Massachusetts, and chair of the International Astronomical Union's Working Group on Solar Eclipses. He has worked on 75 solar eclipses and written about the Sun for Astronomy *since its very first issue. His research is sponsored by the NSF.*

11 A camera mounted to the outside of the International Space Station captured this shot of the Moon's shadow racing across Earth (near the border of Kazakhstan and China) during the June 21 annular eclipse. In the foreground, a Japanese cargo spacecraft is visible. NASA/ISS EXPEDITION 63

12 The X-ray telescope on the Japanese Hinode spacecraft captured this series of shots, which have been rescaled and colored, showing the Moon blocking the Sun's disk during the June eclipse. Astronomer Taro Sakao of the Japan Aerospace Exploration Agency (JAXA) took advantage of Hinode's vantage point to observe how plasma moves within the high-speed solar wind stream, using the lunar silhouette for calibration of stray light. JAXA/HINODE (THANKS TO ALPHONSE STERLING OF NASA'S MARSHALL SPACE FLIGHT CENTER, AND KATHY REEVES AND LUCAS GULIANO OF THE HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS)

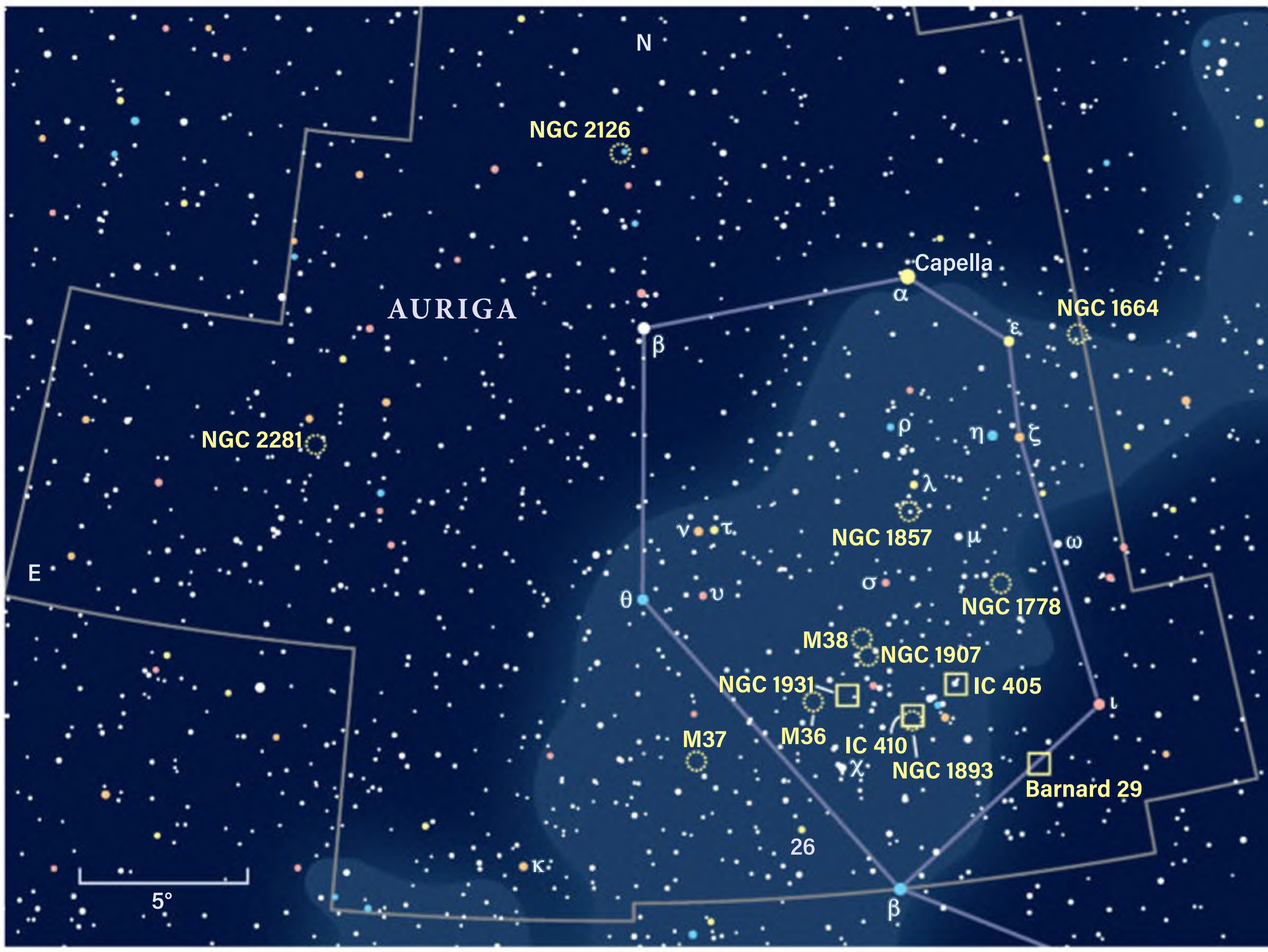
13 The passage of the Moon's shadow across Earth's surface was also tracked by the European Meteosat-8 and the Japanese Himawari-8 spacecraft. Here we see a Meteosat view of Moon's shadow over northeast Africa, the Red Sea, and the Arabian Peninsula. The next annular solar eclipse will occur June 10, 2021. EUMETSAT

SPEND SOME TIME

With three Messier objects and loads of other bright targets, the Charioteer has a lot to offer. // BY MICHAEL E. BAKICH

The constellation Auriga (pronounced or-EYE-guh) the Charioteer, a star pattern known by this name for several thousand years, is easy to recognize primarily because of its brightest star, Capella (Alpha [α] Aurigae). This luminary is the sixth-brightest nighttime star and shines with an intense yellow light. The constellation's Beta star, magnitude 1.9 Menkalinan, is 40th brightest.

The Charioteer is visible in the evening from mid-autumn through winter in the Northern Hemisphere. Its center lies at R.A. 6h01m and Dec. 42° north. Auriga ranks 21st in size out of the 88 constellations, covering 657.44 square degrees (1.59 percent) of the sky. Its size is a bit of a hindrance to its visibility, however. It lies in the middle of the constellation ladder (43rd) in terms of overall brightness.



ASTRONOMY: RICHARD TALCOTT AND ROEN KELLY

The best date each year to see Auriga is December 21, when it stands opposite the Sun in the sky and reaches its highest point at local midnight. With respect to visibility, anyone living north of latitude 34° south can see the entire figure at some time during the year. And it's completely invisible only to those who live at latitudes south of 62° south.

Auriga contains three Messier objects (all open clusters) and several other open clusters and emission nebulae. Because it lies along the Milky Way, it doesn't contain any galaxies. As you can see, however, lots of targets lie within its borders for you to point a telescope at. Good luck!

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

1 Open cluster NGC 2281 glows at magnitude 5.4 and measures 14' across. It lies 0.8° south-southwest of magnitude 5.0 Psi[7] (ψ^7) Aurigae. Through a 4-inch scope at 100x, you'll spot two dozen stars. Four stars forming a parallelogram sit at the center of the cluster. ANTHONY AYIOMAMITIS

2 NGC 1664 is an attractive open cluster 2° west of magnitude 3.0 Epsilon (ε) Aurigae. It glows at magnitude 7.6 and spans 18'. A 4-inch scope at 100x reveals three dozen stars. The background star field is rich, but you'll have no trouble picking out the cluster. JASPAL CHADHA

IN AURIGA

3 NGC 1778 is a magnitude 7.7 open cluster with a diameter of 8'. You'll find it 2° east-southeast of magnitude 5.1 Omega (ω) Aurigae. Through a 4-inch scope, you'll see two dozen stars unevenly spread across this cluster's face. Double the aperture to 8 inches, and you'll raise that star count to 50. MARTIN C. GERMANO

4 Barnard 29 is a dark nebula that lies 2.4° southeast of magnitude 2.7 Iota (ι) Aurigae. Through a 12-inch scope, B29 appears as a gray, mottled region that blends gradually into its starry surroundings. The darkest area appears 15' across. MARTIN C. GERMANO

5 The Flaming Star Nebula (IC 405) appears as a dim 30' by 20' wisp of light. To observe it, first find AE Aurigae, which lies 4.2° east-northeast of Iota. Through a 6-inch scope, the nebula appears triangular. ALISTAIR SYMON

6 Open cluster NGC 1857 sits 0.8° south-southeast of magnitude 4.7 Lambda (λ) Aurigae. It glows at magnitude 7.0 and measures 5'. Through an 8-inch scope, you'll see 25 stars around 13th magnitude. The exception is SAO 57903, a magnitude 7.4 yellow star at the center. MARTIN C. GERMANO

7 IC 410 is a large (40' by 30') emission nebula 2.4° west-northwest of magnitude 4.7 Chi (χ) Aurigae. The nebulosity glows brightest in an area 5' in diameter on the northwestern edge. Use a 12-inch scope with an Oxygen-III filter and this object will knock your socks off. MARK HANSON

8 NGC 1907 is a magnitude 8.2 open cluster that spans 6'. A 4-inch scope at 100x shows about a dozen stars. Use a low-power eyepiece and you'll sweep up an even-brighter open cluster: M38, 0.5° to the north-northeast. MARTIN C. GERMANO

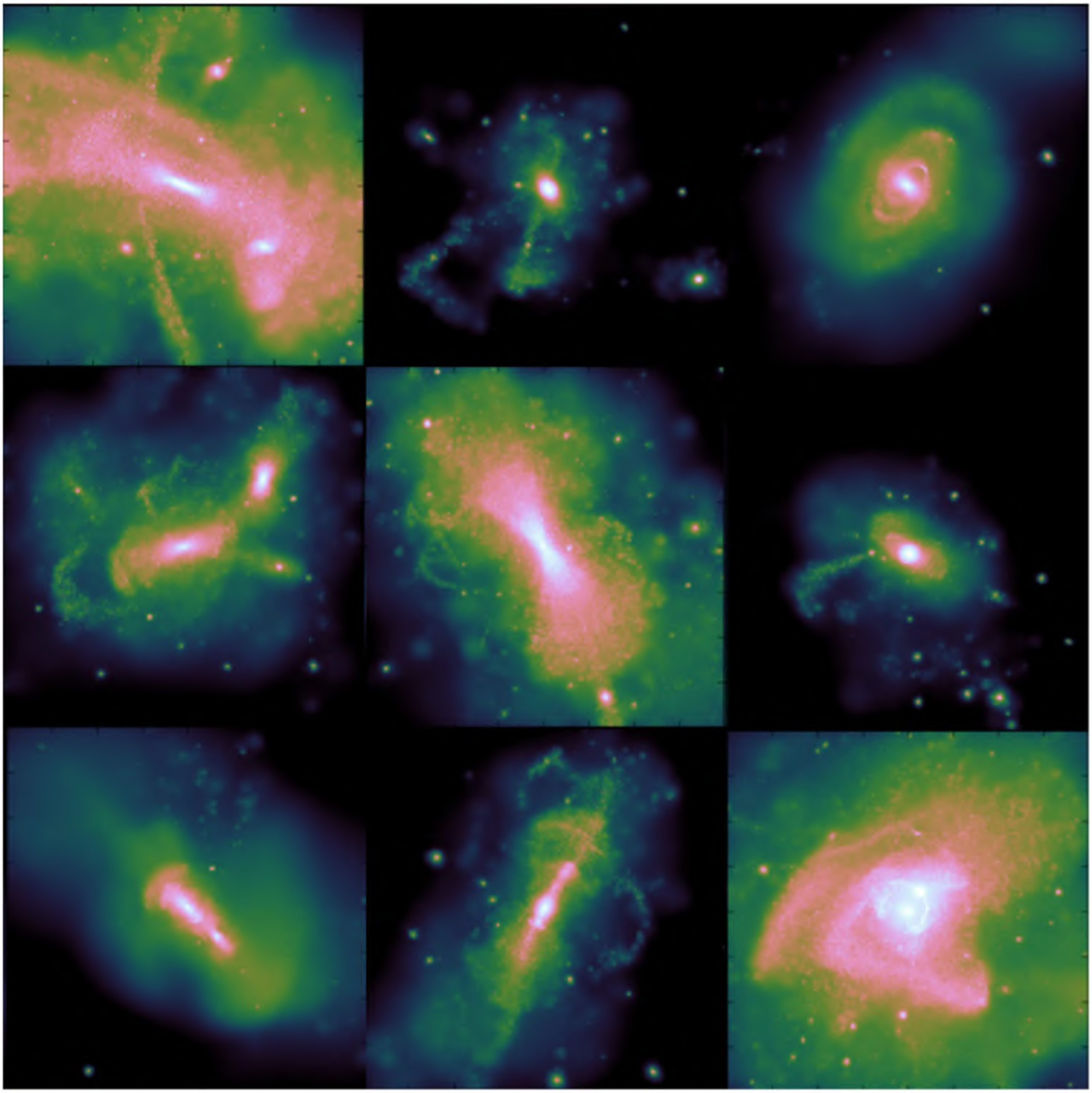
9 The Starfish Cluster (M38) is the westernmost and faintest (magnitude 6.4) of the three Messier open clusters in this constellation. A 4-inch scope will reveal three dozen stars in an area 20' across.
ANTHONY AYIOMAMITIS

10 Emission nebula NGC 1931 sits 0.8° east-southeast of magnitude 5.1 Phi (ϕ) Aurigae. An 8-inch scope at 200x shows the nebula, which spans 4'. It orients northeast to southwest and shows non-uniform brightness across its face. AL AND ANDY FERAYOMI/ADAM BLOCK/NOAO/AURA/NSF

11 The Pinwheel Cluster (M36) is the least spectacular of the Messier trio in Auriga. At magnitude 6.0, however, it still outshines 99.99 percent of the sky's star clusters. Through a 4-inch scope, you'll see several dozen stars strewn across an area 12' wide. ANTHONY AYIOMAMITIS

12 The Salt and Pepper Cluster (M37) displays an even distribution of stars — a rarity in open clusters. A 3-inch scope reveals 50 stars. Through a 10-inch scope, you'll count 200, and a 16-inch will reveal 500. M37 glows at magnitude 5.6 and is 20' across. ANTHONY AYIOMAMITIS

13 NGC 2126 lies midway between magnitude 1.9 Menkalinan (Beta [β] Aurigae) and magnitude 3.7 Delta (δ) Aurigae. It glows at magnitude 10.2 and spans 6'. Through a 6-inch telescope, you'll see about 20 stars. The magnitude 6.0 star SAO 40801 lies 3' northeast of the cluster.
MARTIN C. GERMANO



These computer-generated images from the Copernicus Complexio cosmological simulation show stellar halos of Milky Way-like galaxies. The visible streams result from tidally disrupted satellite galaxies. A.P. COOPER (NATIONAL TSING HUA UNIVERSITY, TAIWAN)/W. HELLWING AND THE VIRGO CONSORTIUM

This discovery image of a giant, low-surface-brightness, looplike stellar structure around edge-on spiral NGC 4013 was obtained with a 20-inch amateur telescope. The marked redder color of the stream material compared to the outer parts of the disk suggests that this loop did not originate from the disk itself, but rather is the tidal stream of a dwarf galaxy being destroyed by its interaction with NGC 4013. R. JAY GABANY

STUDYING GALAXIES with amateur images

Advances in our understanding of galaxy formation aren't just coming from large, professional telescopes.

BY DAVID MARTÍNEZ-DELGADO AND R. JAY GABANY

FROM THE TIME Galileo first peered into his telescope until the middle of the 19th century, professional telescopes required the observer to look through an eyepiece. As a result, astronomers manually logged mountains of information and telescopic drawings in journals.

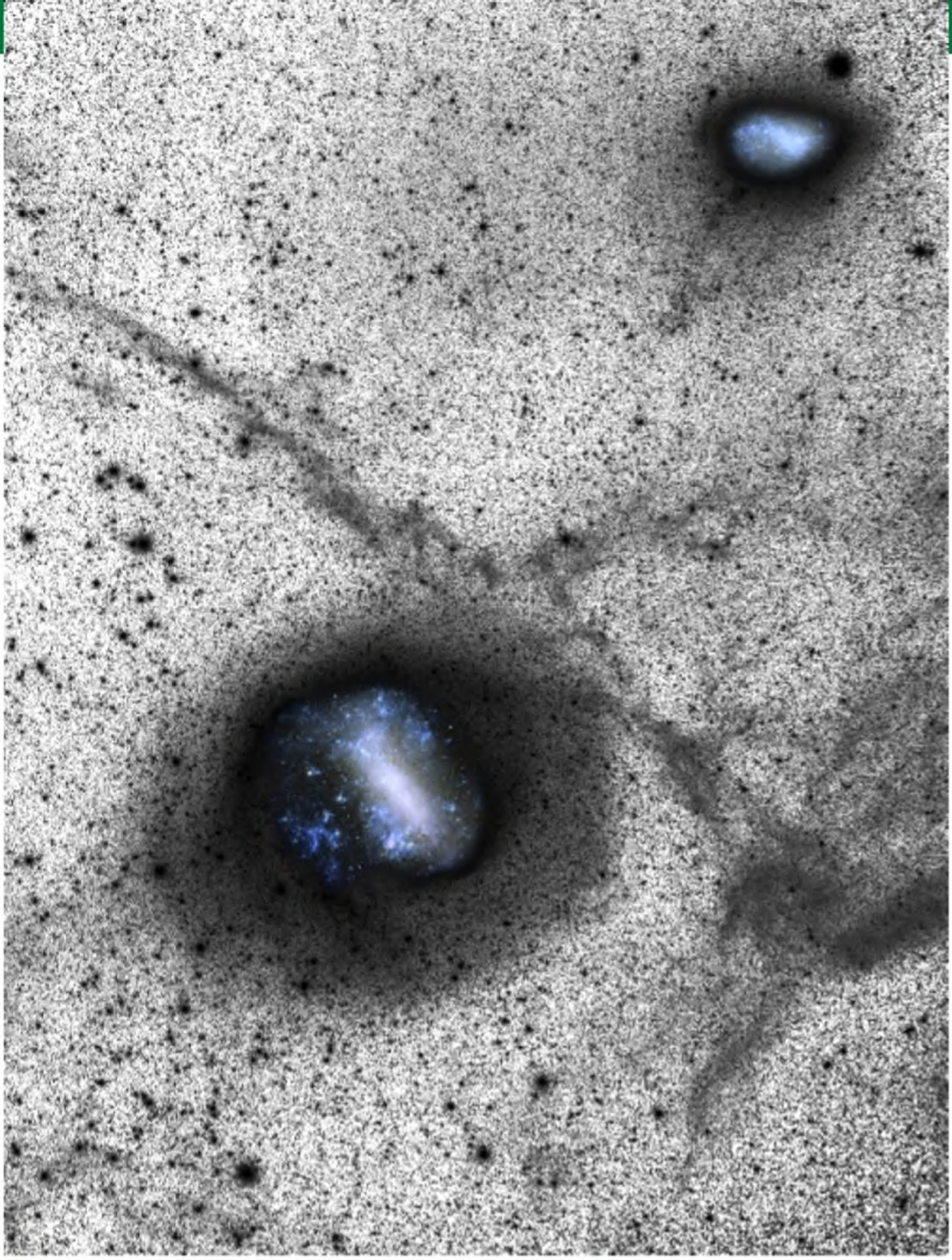
Then came photography. Almost from its inception, photography offered the tantalizing prospect of serving as a tool to discover and document new, hitherto-unseen phenomena. In fact, by the beginning of the 20th century, advancements in photography enabled career astronomers to lay down their pencils and trade their telescope eyepieces for glass plates coated with photographic emulsions.

In addition to appealing to professional astronomers, this potential captured the imagination of resourceful amateur astronomers equipped with modest instruments as well. One such amateur was sanitary engineer Andrew Common. In 1883, he took the first photograph of faint structures in the Orion Nebula (M42) that were not visible through an eyepiece. Others, photographing a plethora of objects, quickly followed.

Paving the way

As the 21st century dawned, the digital imaging technology that had already replaced chemical photography at professional observatories began to trickle down into consumer products. This enabled amateur astronomers to purchase, at a reasonable cost, computer-controlled charge-coupled device (CCD) cameras expressly designed for use with small telescopes. At the same time, motorized mounts

Dwarf galaxy Donatiello I was captured through a Takahashi FSQ-106 refractor at f/3.6 and a commercial CCD camera at the Avalon Merlino, the personal remote observatory of Avalon Instruments. The total exposure time was 24,300 seconds through a luminance filter. The zoomed-in panel shows a red-filtered image of Donatiello I from the 10.4-meter Gran Telescopio Canarias in La Palma, Spain. G. DONATIELLO



driven by electronic maps of the sky enabled amateurs to place any celestial object at the center of an electronic imaging chip and track it with high precision.

As a result, modest equipment became a tool for obtaining ultra-deep images that could capture the outskirts of nearby massive galaxies and survey vast areas of the sky with unprecedented depth. This enabled a new type of collaboration between world-class amateur astroimagers and international teams of professional astronomers exploring one of the fundamental questions in modern astrophysics: How did massive galaxies like our Milky Way come to be?

The standard model of the universe's formation predicts that the elegant galactic spirals we see today, including our own Milky Way, arose hierarchically. They did this by capturing much smaller galaxies, some only composed of dark matter. State-of-the-art computer models indicate the Local Group and its neighbors should still contain evidence of this ancient galactic cannibalism.

During the last decade, amateur telescopes have revealed, in many cases for the first time, an assortment of large-scale tidal structures around nearby massive galaxies. They also have imaged formerly unknown nearby low-surface-brightness star systems. And amateurs using telephoto lenses have traced interactions between the Magellanic Clouds and other Milky Way satellite galaxies. All of these amazing images have provided evidence to support our understanding of galactic evolution as predicted by current simulations.

This wide-field mosaic of the Magellanic Clouds was taken through a Canon EF 50mm f/1.4 USM prime lens from La Silla Observatory, Chile.
YURI BELETSKY

The Small Magellanic Cloud shows a lot of detail through a Canon EF 200mm f/2.8L lens from Hacienda Las Condes, Chile. A faint, shell-like structure composed of young stars is visible on the northeast side (upper left in this image) of the galaxy.
YURI BELETSKY/FABIAN NEYER/BERNHARD HUBL

Amateurs at work

Ultra-deep observations of nearby spiral galaxies and regions around them have been obtained by world-class American, European, and Chilean amateur astroimagers. They operate privately owned observatories that use high-quality apochromatic and Ritchey-Chrétien telescopes with apertures between 4 and 32 inches (0.1 and 0.8 meter). Each observing location features spectacularly dark, clear skies with typical seeing less than 1.5".

These modest telescopes — and, in some cases, telephoto lenses — are coupled with off-the-shelf CCD cameras equipped with the latest generation of imaging chips. They can probe vast sky areas with unprecedented depth — approximately three magnitudes fainter than either classic photographic plate surveys like the Palomar Observatory Sky Survey or more recent digital surveys like the Sloan Digital Sky Survey (SDSS).

Camera sensitivity, fast operation, and lack of the competition for observing time typical of professional observatories places these low-cost robotic amateur facilities at the front line of ultra-deep imaging. They allow high-impact research of structures in nearby low-surface-brightness galaxies. Doing so requires multiple seven- and eight-hour exposures of each galactic target using high-throughput luminance (clear) filters for visible-light imaging. To capture fuzzy emission line structures in galactic halos, imagers use narrowband Hydrogen-alpha filters.

These observations demonstrate in several ways the feasibility of smaller telescopes to detect very faint diffuse structures in large fields around nearby galaxies. First, small short-focal-length telescopes combined with single-chip cameras cover a larger field of view. Second, the use of single-chip detectors also makes it easier to flatten the external regions around galaxies in comparison to standard multi-chip detector arrays used with professional telescopes. Finally, observations with large telescopes are sometimes subject to glare from nearby bright stars and significant sky background variations from different sources. These artifacts complicate or mask the detection of faint structures, and their correction adds significant observing time overhead to the data-gathering process.

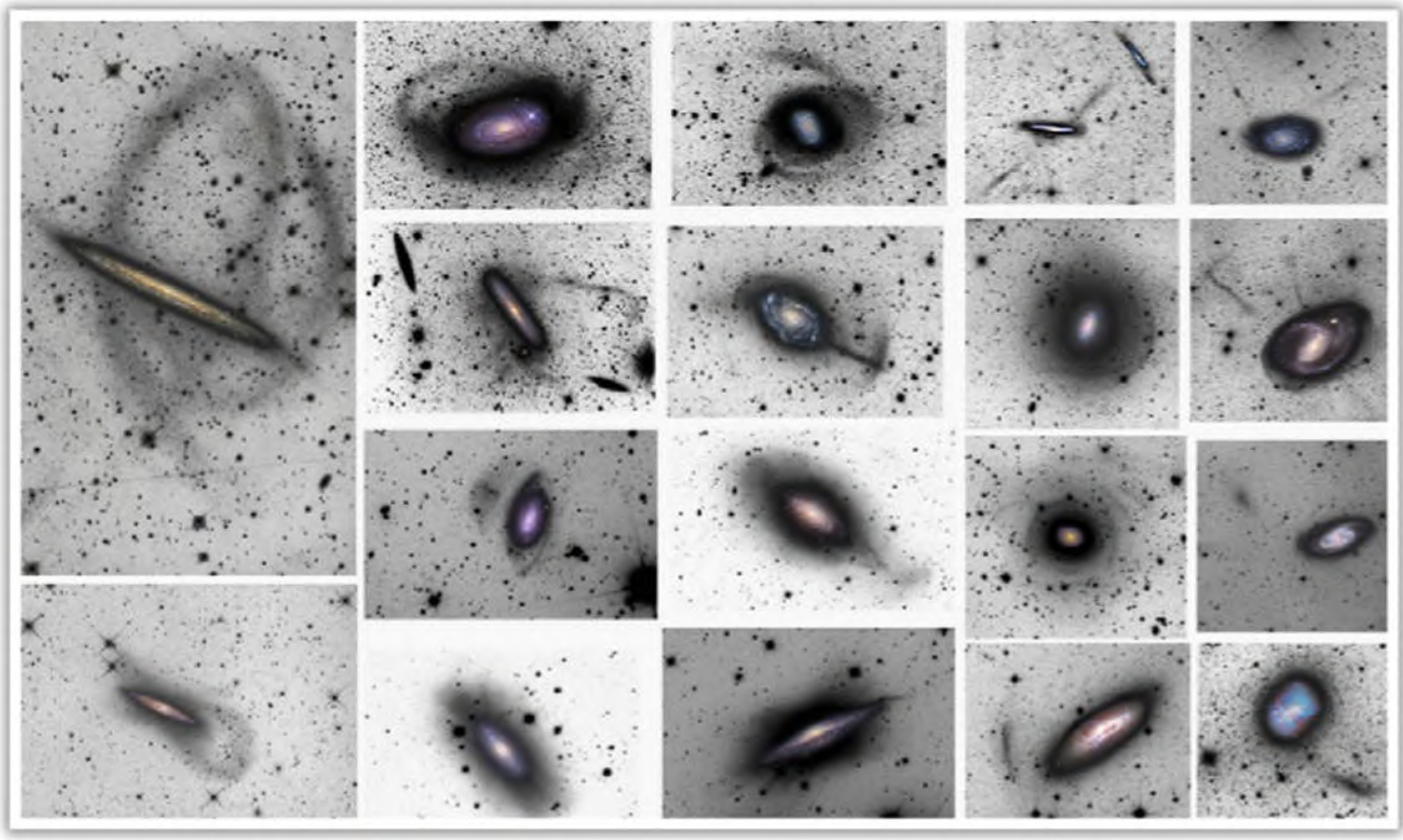
THE STANDARD MODEL OF THE UNIVERSE'S FORMATION PREDICTS THAT THE ELEGANT GALACTIC SPIRALS WE SEE TODAY, INCLUDING OUR OWN MILKY WAY, AROSE HIERARCHICALLY.

This discovery image of a stellar stream in the halo of the nearby dwarf starburst galaxy NGC 4449, located 12 million light-years away in the constellation Canes Venatici, was detected with deep, integrated-light images from a 20-inch amateur telescope. R. JAY GABANY

Stellar streams around M63 are the remnants of a satellite galaxy that was disrupted by the large spiral. Their presence was confirmed in this image, taken with a 20-inch amateur telescope located high in the Sacramento Mountains of New Mexico. R. JAY GABANY

Searching for stellar streams

Computer simulations predict that the stellar halos of massive galaxies contain an



These clear luminance filter images of nearby galaxies from the Stellar Tidal Stream Survey show large, diffuse light structures in their outskirts. A color inset of the disk of each galaxy has been over-plotted for reference. D. MARTÍNEZ-DELGADO/R.J. GABANY/K. CRAWFORD/K. TEUWEN/A. BLOCK/J. SCHEDLER/M. HANSON

Located in the constellation Leo, extensive debris shells from the accretion of one or more long-gone satellite galaxies encompass spiral galaxy NGC 3521 like a bubble. Data for this image were collected through a 20-inch amateur telescope. R. JAY GABANY

assortment of tidal debris streams that long exposures should reveal. The most spectacular examples are those that wrap around the host galaxy and roughly trace the orbit of the progenitor satellite galaxy that created them.

These streams cannot be resolved into individual stars and thus appear as elongated, diffuse light features with an angular extent of several arcminutes. Detecting them requires long-exposure, wide-field images encompassing the outskirts of the host galaxies. Working with amateur astroimagers over the last decade, we have imaged nearby spiral galaxies as part of the Stellar Tidal Stream Survey.

This observational effort has discovered almost 50 previously undetected tidal streams around our targets. The extraordinary variety of faint structures is compelling evidence that supports the hierarchical nature of galaxy formation predicted by the standard cosmological model.

In addition to circular features similar to the Sagittarius stream surrounding the Milky Way, our data have revealed enormous structures resembling open umbrellas with long, narrow shafts. These terminate in a giant shell of debris extending many thousands of light-years into space, often on both sides of the host galaxy.

We have also found isolated shells, giant clouds of debris floating within halos, jetlike spikes emerging from galactic disks, giant plumes, and large-scale diffuse structures. All of these are possibly related to the remnants of ancient satellites that are now thoroughly disrupted.

One important highlight of this survey was the discovery of a stellar stream around NGC 4449, an isolated irregular galaxy similar to the Large Magellanic Cloud. This is the lowest-mass galaxy with a verified stellar stream. Such a discovery suggests satellite accretion also can play a significant role in building up stellar halos around low-mass galaxies as well as possibly triggering starbursts.

Discovering satellite galaxies

Searching for stellar streams with deep amateur images has also led to the discovery of numerous faint dwarf satellite galaxies around a handful of nearby spirals. This is intriguing because sophisticated computer simulations predict a large number of small dark matter halos in the local universe. But our theory of galaxy formation is still unclear as to how many of these are in the form of luminous star systems. Therefore, astronomers want to conduct a full inventory of dwarf galaxies, both those orbiting as satellites and isolated dwarfs that are in the vicinity of nearby massive galaxies. The only way to detect them is by surveying vast regions with deep images.

Only a few organized astroimaging groups are searching for low-surface-brightness satellite galaxies. Some members of the Stellar Tidal Stream Survey are also involved in the Dwarf Galaxy Survey with Amateur Telescopes. Additionally, the Tief Belichtete (Very Long Exposed) Galaxies project is run by German and Austrian imagers. These groups look for dwarf galaxies in long-exposure images using software that searches for likely candidates and then extracts their photometric and structural characteristics.

This image presents in outstanding detail an extended stellar tidal stream wrapping around the edge-on spiral galaxy NGC 5907, located about 53 million light-years away in the constellation Draco the Dragon. This picture shows how the accretion of a low-mass satellite galaxy can produce an interwoven, rosettelike structure of debris dispersed in the halo of its host galaxy. R. JAY GABANY

ISOLATED DWARF SPHEROIDAL GALAXIES ARE MADE EXCLUSIVELY OF OLD STARS WITH LITTLE GAS TO FUEL STAR FORMATION.

Isolated dwarf spheroidal galaxies are made exclusively of old stars with little gas to fuel star formation. These distant star systems are of huge interest because they act as laboratories where astronomers can study why they stopped forming stars about 10 billion years ago. For example, Donatiello I is a dwarf spheroidal galaxy discovered by Italian astroimager Giuseppe Donatiello during a visual inspection of a deep image produced with a 5-inch refractor. The discovery was subsequently confirmed with SDSS images and follow-up observations by the 3.6-meter Galileo and the 10.4-meter Gran TeCan telescopes, both located in the Canary Islands. This low-surface-brightness stellar system, located about 1° from Mirach (Beta [β] Andromedae), is suspected to be the most isolated dwarf galaxy in the Local Group.

Magellanic Cloud interactions

Another important approach to understanding the formation and evolution of dwarf galaxies is studying the Milky Way's two largest galactic satellites, the Magellanic Clouds, through mapping their outskirts. These regions should still contain clues about past interactions between the Clouds that left visible imprints such as distortions, clumps, arcs, and dense stellar areas.

With that purpose in mind, we performed a deep, wide-field imaging survey of the periphery of the Magellanic Clouds. Inspired by the photographic plate work of French astronomer Gérard de Vaucouleurs in the '50s, this modern project used low-cost telephoto lenses to obtain deep images of the Clouds. One panoramic view revealed a never-before-seen, dense, shell-like area of stars in the outskirts of the Small Magellanic Cloud.

Research using photometric observations from the Survey of the Magellanic Stellar History revealed the shell is mainly composed of young stars. It suggests the structure resulted from a star-formation event, likely triggered by gravitational interaction with the Large Magellanic Cloud and/or the Milky Way about 150 million years ago. Recent studies with the Hubble Space Telescope found the two Magellanic Clouds had a head-on collision about the same time.

Can amateurs contribute?

Based on these results, it's clear that advances in our understanding of galaxy formation needn't be obtained only by large, professional instruments. Important scientific results that further our understanding of how the universe formed can be obtained when amateurs with modest telescopes collaborate with professionals with big objectives.

David Martínez-Delgado *is an astrophysicist at the Instituto de Astrofisica de Andalucia in Spain who detects galactic fossils around nearby galaxies.* **R. Jay GaBany** *is an award-winning California astroimager.*

We review

Celestron's 60th

WHEN I WAS A TEENAGER, new to observing the sky, I spent a year wandering across the Milky Way armed with nothing more than a pair of 7x50 binoculars. Then a miracle happened: I received a Celestron 8, 1976 vintage, as a birthday present. It changed my universe forever.

From the cornfield behind our Ohio subdivision, the telescope opened up completely new vistas — star clusters, nebulae, and galaxies. Not only could I see hundreds of spectacular sky objects, but I was seeing things like the Veil Nebula, which the old-fashioned literature of the time contended was beyond the reach of an 8-inch scope.

Now I feel like I have undergone another telescope revolution. Last year Celestron celebrated its 60th anniversary. As part of their festivities, they produced a new 8-inch Schmidt-Cassegrain Telescope (SCT), one that rolls all of the company's fanciest features into one package.

With a built-in wide-field camera, it aligns itself in a matter of minutes, requiring

▲ The telescope's carbon-fiber tube is both lightweight and very strong, giving this model a high-tech appearance.

◀ Celestron's most sophisticated 8-inch SCT ever features a revolutionary system that aligns itself so that users can simply punch in object names and designations on a keypad and slew to thousands of targets.

The NexStar Evolution 8HD With StarSense, a limited-edition telescope, combines all of Celestron's fanciest trappings to produce a superb, top-of-the-line instrument. **BY DAVID J. EICHER // IMAGES BY CELESTRON**

anniversary C8

minimal knowledge on the part of the user. It then slews to any of 40,000 targets within its onboard computer's database. Its multicoated optics are of the highest caliber, and the three included eyepieces are sensational. This is the ultimate 8-inch SCT of its time, and I was happy to be able to put it through its paces over the past few weeks.

Setup and inspection

Assembly was relatively straightforward, and a helpful booklet walks owners through the process. I went slowly, read everything carefully, and within an hour had everything set up in my living room for inspection, charging of the onboard battery, and preparation for a night of observing.

With the telescope assembled, I couldn't help but be struck by its quality and elegance. It features a carbon-fiber tube; multicoated, high-transmission optics (what Celestron calls "Edge HD"); a sturdy single-arm mount; and, of course, the alt-azimuth mounting enabled by the computer control of the scope. The company seemingly spared no details: The machining is top-notch and the hardware is solid, a 2" focuser and star diagonal came along with the package, and the tripod is heavy duty. The onboard battery holds a charge for more than 10 hours at a time. The included eyepieces are very nice, with a 2" 32mm "porthole" for deep-sky observing and higher-power 1¼" eyepieces of 15mm and 9mm focal lengths.

The StarSense system was really what intrigued me. I am an old-school, star-hopping guy who has taken great pride in learning the sky and finding objects manually for years. Would this computer-controlled system with its database of tens of thousands of objects — which it would apparently use to align itself before hopping between galaxies — win me over?

PRODUCT INFORMATION

Celestron Limited-Edition NexStar Evolution 8HD Telescope With StarSense, 60th Anniversary Edition

Type: Schmidt-Cassegrain reflector
Aperture: 8 inches (203 mm)
Focal length: 2,032 mm
Focal ratio: f/10
Optical tube length: 17 inches (43.2 cm)
Weight: 42 pounds (19 kg) fully assembled
Price: $2,599
Contact: Celestron
2835 Columbia St.
Torrance, CA 90503
310.328.9560
www.celestron.com

▲ Celestron supplies an array of accessories with this scope, allowing users to enjoy a luxurious telescopic experience.

Out under the stars

The first thing you need to do with this scope is set it up on level ground and run a program that enables the StarSense unit to calibrate itself. Included instructions and a link to an online video tutorial make that very simple. That first night I was in a hurry, so I set it up on my driveway to give it a quick run-through. Although a portion of the sky was blocked by a tree and the house, I was curious to see what would happen.

So began my adventure with StarSense Autoalign. The camera mounts atop the scope's tube with a heavy bracket and plugs into a port on the mount. To begin the calibration procedure, you start with the scope's tube positioned horizontally. A hand controller allows you to input choices and, once the scope is aligned, target countless objects. I uncorked the scope's mirror, the StarSense camera's cover, and the diagonal's cover before plopping a very nice E-lux 32mm Celestron eyepiece into the diagonal.

I powered the scope on, chose "Align" on the hand controller, set the time, date, and time zone, then stepped back and watched. Over the course of about 10 minutes, the scope slewed to and fro and occasionally noted on the controller that it had imaged a certain number of stars. Would this work with the handicap I gave it in my rush to test the scope? After a short time, "Alignment complete" came up on the controller.

Next, I followed the protocol by calibrating on a known star. I punched in "Vega" and the scope immediately slewed upward, capturing Vega's position. When I peered into the eyepiece — low power, no doubt — the star was dead center. The final step is a calibration on the star itself (Vega in my case), and this can be done with a high-power eyepiece to maximize precision. You can then realign the StarSense and, in another few minutes, the mount is ready to use all night; you can simply punch in targets and let the scope slew to them.

This full calibration procedure needs to be performed only once, when the StarSense Autoalign is first attached to the telescope's tube. From there, a full calibration is not needed unless the StarSense is bumped or the bracket removed.

Wow. Here is the kind of telescope that could revolutionize astronomy. This is a telescope that anyone can use without any knowledge of old-style polar alignment. It is really quite amazing to see this work just as magically as is advertised, with objects showing up dead-centered, just as requested from the database.

Computer-controlled heavens

I gave this telescope a more thorough test run from my backyard in Wisconsin, where I can see the Milky Way and a good smattering of faint stars. The telescope performed most impressively. I can't wait to get it underneath a really prime sky like that of southern Arizona.

I commenced my journey with Jupiter and Saturn, each looking really fine, with nice cloud details, even at low power. All the moons that should have been present were, and the higher-power eyepieces provided a splendid view early on, even though the seeing had not fully settled down for the evening.

But I was eager to tour deep-sky objects and so I plopped the 32mm eyepiece back in and went to work. Everything I looked at showcased the quality of the telescope's optics — the views were crisp and well defined, and I saw all the details in clusters, nebulae, and galaxies that I would expect to see from a suburban site. The 32mm eyepiece provides a sharp, flat field, yielding crisp stars all across the view.

▲ Celestron's StarSense system uses a remarkable wide-field camera to image star patterns around the sky, allowing the telescope to understand where it is and how it's aligned before automatically slewing to a target.

▲ The scope's standard visual back employs a 2" star diagonal and can accommodate both 2" and 1¼" eyepieces.

The Lagoon Nebula did not disappoint, with its gauzy areas of bright gray-green nebulosity and the sparkly, well-populated star cluster NGC 6530. For a time, I walked up the line of bright clusters and nebulae in Sagittarius and Serpens. Only needing to input the numbers of Messier and NGC objects makes one spoiled quickly. There was the Trifid, glowing faintly; the unmistakably bright Omega Nebula popped fiercely, and the delicate light of the Eagle Nebula appeared well defined. The computer-controlled database makes punching in some of the lesser-known objects like clusters M23, M25, and NGC 6603 easy. I worked my way up to M11, which was incredible, and then viewed some globulars — M22 in particular was a killer, looking quite photographic.

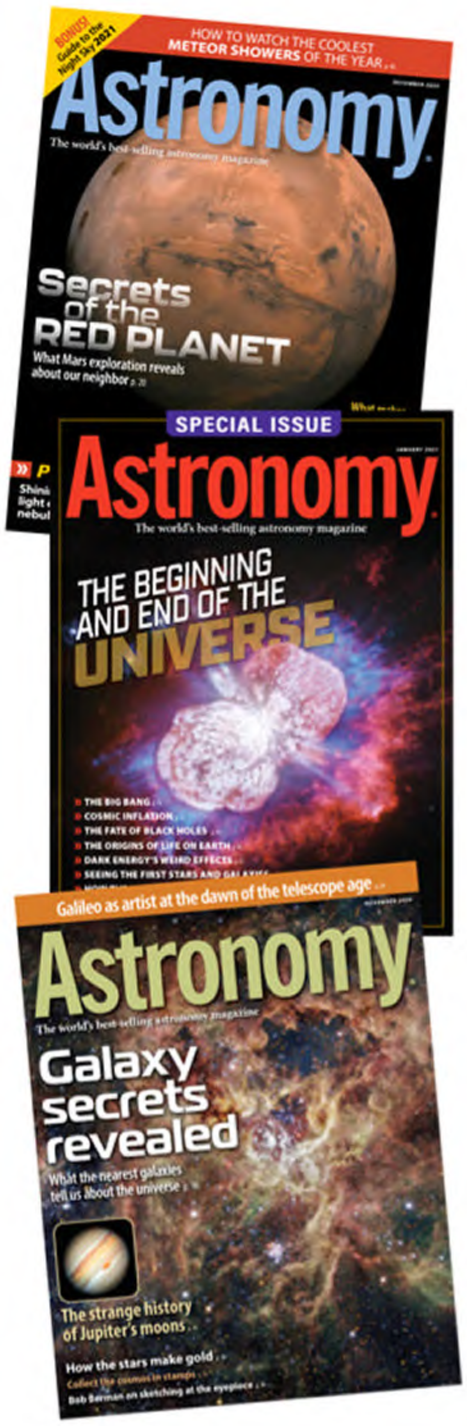
I turned toward some favorite planetary nebulae I hadn't viewed in a while. The Dumbbell Nebula, high in the sky, knocked my socks off — it looked like a glowing photo in a rich starfield of colorful suns. What incredible beauty. But Cygnus and Aquila had many other treasures, and I viewed NGC 6781, NGC 6894, NGC 7008, and NGC 6826 (just to name a few). They all appeared quite well defined, with the blue-green colors showing well, and were visible at low powers, growing more spectacular as I increased magnification.

I then took a shot at some widely scattered objects just to see the range of views the telescope could provide. The Andromeda Galaxy appeared bright and oval, with well-defined dust lanes close to the nucleus. The Owl Cluster in Cassiopeia, with its bright deep yellow chief sun, was an old friend I revisited. Double stars like Mizar and Albireo were simply stunning, set in black starfields, and galaxies like M81 and M82 floated majestically in space.

As the night went on, I found this telescope to deliver on everything I had hoped for: The optics are sharp, the accessories luxurious, the tripod overbuilt and very stable, the craftsmanship of the optical tube and the electronics first-rate. I have a soft spot for the old 1976 Celestron 8, with which I made my initial thousands of observations, and which is now in my basement. But there's a new Celestron in town, and this magnificent model is going to be hard for any such portable instrument to overcome. This is a telescope for a new age of amateur astronomy.

At press time, Celestron had announced that they have sold out of this exclusive anniversary model. However, almost exactly the same telescope — without the carbon-fiber tube and a few bells and whistles — is available. The Celestron NexStar Evolution 8HD With StarSense functions in exactly the same way as the anniversary edition. You can find out more about it here: www.celestron.com/products/nexstar-evolution-8-hd-telescope-with-starsense.

David J. Eicher *is editor of* Astronomy *and has been using telescopes for more than 40 years.*



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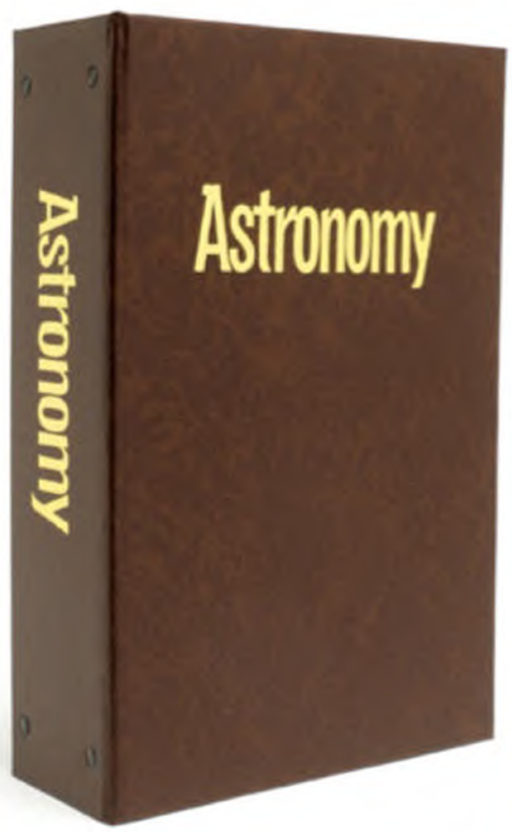

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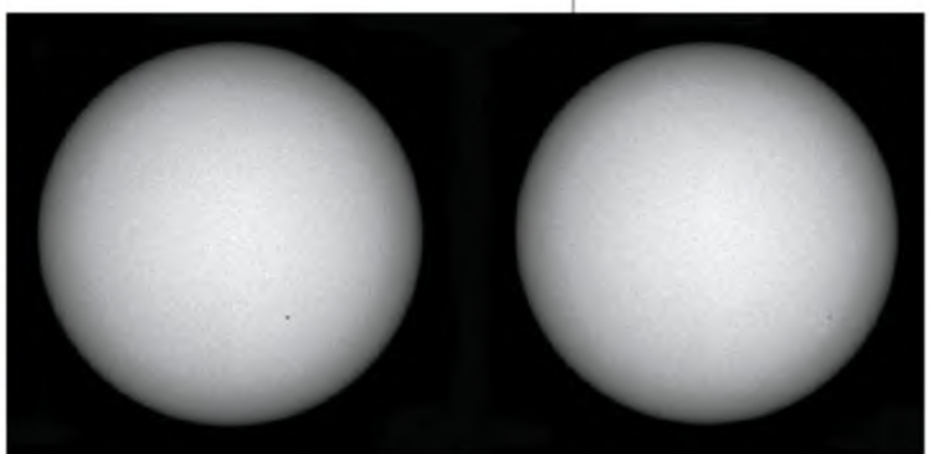

LEFT: On June 10, 2020, an Earth-sized sunspot, AR 2765, from brewing solar cycle 25 could be seen through handheld 8x42 binoculars. RIGHT: Two days later, when the spot's umbra was smaller and less apparent, it was difficult to see, even when the author braced the binoculars. North is up and east to the left. SDO/HMI

The long-awaited next solar cycle is showing signs of awakening, and so is the time for observers to search for naked-eye sunspots.

But at the beginning of a new cycle, the first spots to appear are generally too small to be detected without optical aid. Using safe solar filters in front of binoculars will help bring some of these devilishly delightful spots into view. Unfortunately, the task is not easy.

Cycle 25 brewing?

In their February 2020 article in *Research Notes of the American Astronomical Society*, Dibyendu Nandy from the Center of Excellence in Space Sciences India and his colleagues argue that solar cycle 25 may be dawning. No one knows exactly how a new solar cycle starts, but it's thought to be based in a complex interaction of ionized gas and the Sun's magnetic field. We do know that spots in a new cycle will have their magnetic poles reversed from those in the last cycle — in this case, cycle 24, which ended around December 2019.

Since November 2019, solar astronomers have been observing new sunspots with reversed polarity around 25° north and south latitudes. And this happens to be exactly where they expected new spots from solar cycle 25 to appear. Seeing such spots is a positive sign that a new solar cycle is in the making.

The binocular challenge

Before we get into viewing cycle 25 sunspots, two definitions. A sunspot's *umbra* is the dark inner part. Its *penumbra* is the lighter outer region. Currently, the stammering start of cycle 25 has been creating three types of spots: Short-lived naked cores, which are state-sized dark spots without any penumbra; partially dressed proto-sunspots, which are Moon-sized marks with only a partial penumbra that doesn't completely surround the core; and fully dressed sunspots, which are Earth-sized and feature a dark core, an umbra, and a penumbra.

I began systematically observing the Sun on June 10, 2020. That day, I used handheld 8x42 binoculars to see without difficulty a fully dressed Earth-sized sunspot labeled AR 2765. (AR stands for active region.) The evolved spot was in the Sun's southern hemisphere and had already sailed past the central meridian.

Two days later, the foreshortened spot appeared both smaller and less apparent, making it more difficult to detect. Only when I braced the binoculars against a wooden post could I resolve the spot, which looked more smoky gray than black.

A similar situation occurred July 25, when another Earth-sized sunspot (AR 2767) appeared in the Sun's southern hemisphere. As for AR 2765, handheld 8x42 binoculars easily brought it into view. It remained visible until July 31, when the spot's highly foreshortened umbra diminished in apparent size enough that it became a challenge to see through the binoculars. It vanished from view the next day.

By August 5, a more challenging spot (AR 2770) in the Sun's northern hemisphere had slid into binocular view. That day, the foreshortened spot was difficult to see even with braced 10x50 binoculars. I had to know exactly where to look to pick it out. Sighting AR 2770 was similar to spotting Venus in the daytime — if you look away for an instant, it's gone.

Two days later, however, the Earth-sized spot was a cinch through handheld binoculars. I finally lost sight of it on August 11, the day after an enigmatic light bridge had split the spot in two, and before it had dwindled into a naked pore.

Observe in sunlight

By the time you read this, other Earth-sized spots may be moving across the Sun. Each offers you a chance to test your direct vision through filtered binoculars. I want to learn how small of a sunspot you can see, especially if you use tripod-mounted binoculars or those larger than 10x50. Good luck, and, as always, send what you see and don't see to sjomeara31@gmail.com.

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

BY STEPHEN JAMES O'MEARA

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

Bound across the sky

Lepus the Hare offers some less-explored celestial sights.

Through binoculars, M79 (NGC 1904), a collection of 100,000 stars, appears as a single, fuzzy star.
ADAM BLOCK/NOAO/AURA/NSF

At this time of year, all eyes are on Orion, Taurus, Canis Major, Gemini, and Auriga, with their bevy of stellar and deep-sky treasures. But that leaves other constellations to pass by unnoticed and underappreciated. This month and next, let's explore the rest of the winter sky.

South of Orion's knees, marked by Rigel (Beta [β] Orionis) and Saiph (Kappa [κ] Orionis), are a half-dozen or so fainter stars that form the constellation Lepus the Hare.

Even though its brightest star shines no better than magnitude 2.6, Lepus is apparent in suburban backyards if there is a good view to the south. Directly below the imaginary line connecting Rigel and Saiph lie four of the Hare's brightest stars, set in a distinctive trapezoid. Beginning at the northernmost of the four and moving clockwise, there's Alpha (α), Beta (β), Gamma (γ), and Delta (δ) Leporis. All fit comfortably into a 7° field of view through binoculars.

Of the four, **Gamma** will immediately catch your eye. That's because it has a friend, a 6th-magnitude star 97" to its north. The 4th-magnitude star you see by eye alone is known as Gamma A, while its fainter companion is Gamma B. The Gamma system lies 29 light-years away, with the stars separated from each other by an estimated 870 astronomical units — where 1 astronomical unit, or AU, is the average distance between Earth and the Sun. Together, they create one of the most striking binocular binaries in the entire sky. Each is bright enough and separated far enough from the other that any binocular can resolve them. When I study them closely, Gamma A impresses me as yellow-white, although some report it as greenish. Gamma B is a subtle orange. Defocusing your binoculars slightly will help enhance the delicate colors.

This month and next, let's explore the rest of the winter sky.

Next, shift your attention diagonally across the Lepus trapezoid to **Alpha Leporis,** also known by the proper name Arneb. The Hare's brightest star, Arneb is an F-type supergiant 1,300 light-years away. It makes the perfect jumping-off point to find an object in celestial limbo.

Glance 1.5° due east of Arneb. Can you make out a misty knot of four faint stars? That's **NGC 2017**. Originally classified as an open cluster, we now know that NGC 2017 is an asterism that happens to also include the multiple-star system h3780. With most binoculars, we can see that the system's brightest star, at 6th magnitude, is framed by a tight triad of 8th-magnitude attendants.

Lepus contains a single entry in Charles Messier's famous catalog: **M79**, an out-of-the-way globular cluster. To find it, bunny-hop 3° from Arneb southwestward to Beta Leporis (also known by the proper name Nihal), and then repeat the leap, continuing in the same direction. Most globular clusters swarm around the center of our galaxy, placing them in our summer sky. But a few, like M79, lie in the opposite direction. M79 sits 60,000 light-years from the galactic center, about 10,000 light-years farther than our solar system. Some believe that this points to an extragalactic origin — that M79 was once affiliated with a tidally disrupted dwarf galaxy known as the Canis Major Dwarf.

Through binoculars, M79 appears much like Messier himself described it in December 1780, two months after his contemporary, Pierre Méchain, discovered it: "Nebula without a star; the center bright; the nebulosity a little diffuse." In reality, of course, M79 is a spherical collection of about 100,000 stars. You will find this fuzzy little patch of light just northeast of a 5.5-magnitude star, SAO 170351.

Lastly, we come to a challenging treasure, the tiny but colorful planetary nebula **IC 418**, better known as the Spirograph Nebula (thanks to a famous image from the Hubble Space Telescope). I received a note last winter from reader Scott Harrington (no relation) reminding me just how bright this planetary nebula is, and yet how few of us have ever seen it. Although many sources list it as photographic magnitude 10.7, it appears much brighter by eye, bringing it well within the limits of most binoculars. IC 418 is sometimes called the Raspberry Nebula, for its prominent pinkish color through giant backyard telescopes. With most binoculars, however, it appears grayish, with possibly a blue or green tinge. Try it for yourself and let me know what you see.

Questions, comments, suggestions? Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

BROWSE THE "BINOCULAR UNIVERSE" ARCHIVE AT **www.Astronomy.com/Harrington**

Observe Orion with ease

Even a small scope reveals this timeless winter treat.

Orion holds a plethora of beautiful celestial sights you can explore, and many of them are accessible using a small telescope.
ASTRONOMY: ROEN KELLY

A year ago, I received an email from Joe McCoubrey, a 13-year-old astronomy enthusiast from Bennett, Colorado, who asked me for a list of the best winter sky targets for small telescopes. The request reminded me that I hadn't made a small-scope voyage into the winter skies for years. To remedy this oversight, I decided to take out my small scope (a 60mm refractor) and explore a classic winter constellation: Orion.

I began with Rigel. This 0.1 magnitude blue giant was a dazzling sight in the little scope. That's especially true at a magnification of 117x, where it flickered like a diamond under somewhat turbulent skies. I used this high magnification (around the upper limit for a 60mm scope) in a vain attempt to see Rigel's 7th-magnitude companion, located about 10" away. Theoretically, a 60mm refractor should be able to split double stars as close as 1.9", but that's only if the component stars are relatively bright and similar in magnitude. Rigel's companion is 400 times fainter, so it's easily lost in the bright star's glare. I chose to save Rigel and its partner for a night with a steadier atmosphere.

If Rigel was a diamond, Betelgeuse was sparkling like a yellow-orange topaz.

Next up was the red supergiant Betelgeuse. The color contrast between ruddy Betelgeuse and blue-white Rigel was striking. If Rigel was a diamond, Betelgeuse was sparkling like a yellow-orange topaz. Betelgeuse wasn't alone, either. Just 20' to its south stood the pretty double star Struve 817 (magnitudes 8.7 and 8.9, separation 18.6"). This delicate little duo humbly shining next to brash Betelgeuse was a captivating sight!

Looking for more doubles, I moved to Mintaka (Delta [δ] Orionis), the most westerly of Orion's Belt stars. This 2nd-magnitude blue giant is accompanied by a much fainter partner (magnitude 6.8, to be exact). Fortunately, the lesser star is 56" away. Both were well seen at 70x.

A degree southwest of Alnitak (Zeta [ζ] Orionis), the easternmost Belt star, is the multiple star Sigma (σ) Orionis. In the 60mm refractor at 117x, Sigma was a triple: the 4th magnitude primary accompanied by two 6th-magnitude stars on one side separated from the main star by 13" and 42". I then pointed my scope north to Lambda (λ) Orionis, brightest of the triangle of stars that forms Orion's head. This eye-pleasing duo (magnitudes 3.5 and 5.5, separation 4.3") was split with 117x.

Turning to deep-sky objects, I made my way northeast towards Xi (ξ) and Nu (ν) Orionis, and the nearby open cluster NGC 2169, sometimes called the 37 Cluster. NGC 2169 is comprised of two stellar groups — each forming one of the numbers. Just 7' in apparent diameter and comprised of a little more than a dozen stars, the 37 Cluster was best seen at 117x. Unfortunately, my scope was equipped with a standard star diagonal, which produced a mirror image of the 37.

From NGC 2169, I moved past Betelgeuse and traveled an equal distance beyond to the reflection nebula, M78. Similar in size to NGC 2169 and just 8th magnitude, it required a patient, minutes-long search with low magnification (23x) before a rather faint puffball appeared in the field. I tried higher magnifications, but 70x seemed to offer the best view.

I completed my journey at Orion's Sword and the constellation's pièce de résistance: the Orion Nebula (M42/43). A magnification of 23x brought the entire Sword into view, from the loose open star cluster NGC 1981 near the north end down to Iota (ι) Orionis and the wide double star Struve 747 near the south. Since Iota is double and too close for a low-power split (the magnitude 7.7 companion is 12.5" from the magnitude 2.8 main star), I quickly switched to 117x for a clean split.

The Orion Nebula was a magnificent sight in the little refractor, especially at 70x — a magnification that captured the expanse of the nebula while still resolving the four brightest members of its embedded multiple star Theta^1 (θ^1), the Trapezium. It would take an entire column to do justice to this region, as it's one of the finest deep-sky targets in the entire sky. (In fact, I did that in my February 2019 column, "Experience the Orion Nebula.")

And although everything described in this article can be viewed through large-aperture instruments, there's a sense of accomplishment that comes with snagging a good look through a modest instrument like a 60mm refractor. So, if you own one, take it out for a night under the Orion sky.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: more observer's lists. Clear skies!

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

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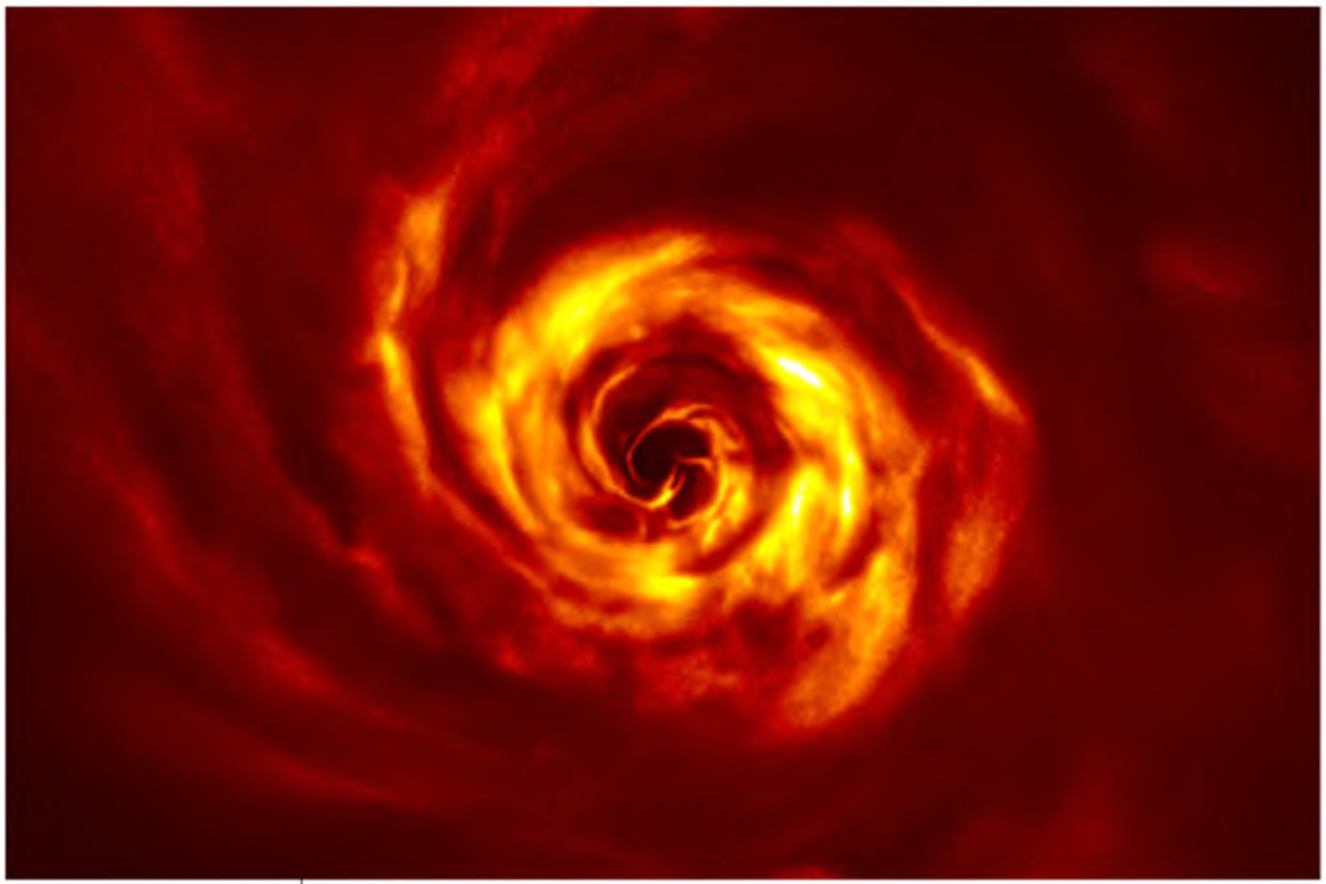


Some 520 light-years away lies AB Aurigae, which has a twisted planetary disk. The spirals around AB Aurigae are likely caused by baby planets coalescing in the dust surrounding the young star. ESO/BOCCALETTI ET AL.

Galactic traffic jam

Q | WHAT CAUSES THE FORMATION OF SPIRAL ARMS IN GALAXIES? DO SPIRAL ARMS FORM IN OTHER FLATTENED GROUPS OF ORBITING OBJECTS, LIKE PLANETARY RINGS AND PROTOSTELLAR DISKS?

Robert Harrison
Albuquerque, New Mexico

A | Spiral arms in galaxies can form by a combination of processes. In a spiral galaxy, everything orbits at the same speed, meaning stars and gas near the center of the galaxy complete an orbit in less time than objects farther out. This effect is referred to as differential rotation. So, in the time it takes an inner star to complete one revolution around its galaxy, an outer star might have only finished half a revolution.

Differential rotation naturally generates spirals as the galaxy rotates. Galaxies like the Milky Way have rotated a few dozen times — it typically takes 200 million years for the entire galaxy to complete a revolution. If differential rotation were the only process involved in generating spirals, we would expect to see many tightly wrapped spiral arms, like a wound coil. But most spiral galaxies have only two to four main arms.

Spiral arms show the same structure whether composed of billion-year-old stars or million-year-old stars. This indicates that the arms are the result of a persistent pattern of stars rather than particular stars causing the structures.

That pattern is caused by a density (pressure) wave that spirals from the edge of the disk to the center and back out again, creating the visible spiral arms of the galaxy. Essentially, as stars and gas move through the pattern, they bunch up in the wave crests, like a stellar traffic jam, and then eventually break past the crest and continue on their orbit.

Both planetary rings and protoplanetary disks can have density waves and spiral structure. Planetary rings are made of small amounts of debris trapped in a particular orbit. Sometimes they are perturbed by moons that cause waves. According to computer simulations, observed spirals in protostellar disks are from density waves driven by planets forming in the disk.

Debra Elmegreen
Professor of Astronomy on the Maria Mitchell Chair, Vassar College, Poughkeepsie, New York

Q | SINCE NEW HORIZONS' FLYBY OF ARROKOTH IN JANUARY 2019, IS THE SPACECRAFT ZOOMING TOWARD A NEW TARGET? IS NEW HORIZONS ABLE TO SEARCH FOR PLANET NINE?

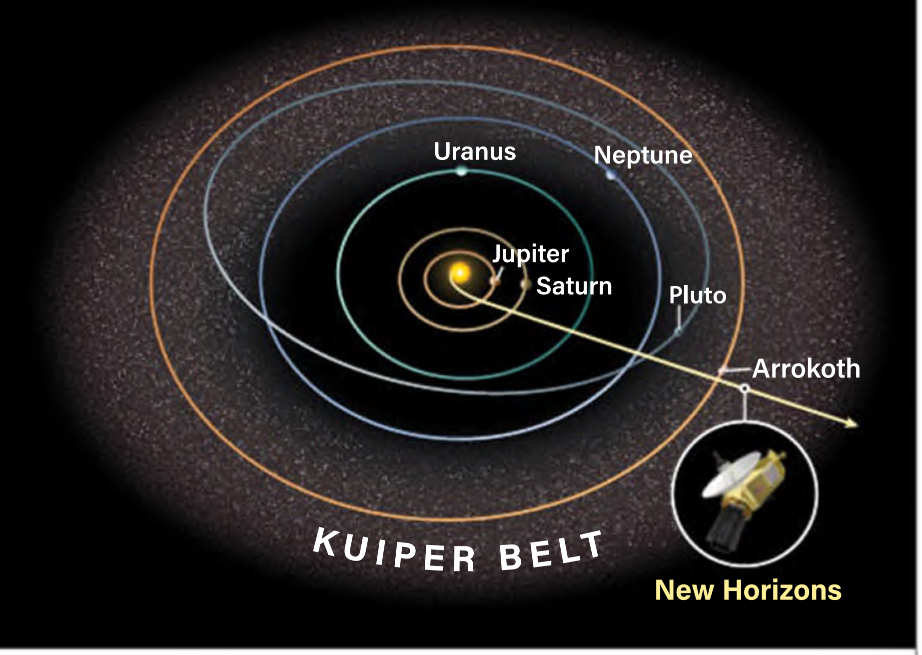
Douglas Kaupa
Council Bluffs, Iowa

A | New Horizons is healthy and routinely studying the Kuiper Belt environment and Kuiper Belt objects (KBOs) it passes in the distance. For the next year or so, the New Horizons team is using the largest telescopes on Earth — such as the Subaru telescope in Hawaii — to find more KBO targets. From there, we can determine if New Horizons has the fuel to perform a flyby.

We should know the results of our first search by fall or early winter 2020, and we will observe again using ground-based telescopes between April and September 2021. If either search succeeds in finding a potential target, we would seek NASA's permission to burn our engines to conduct another flyby.

I personally consider Pluto to be the solar system's ninth planet to honor its discoverer Clyde Tombaugh and his contributions to planetary science. So, I call

WHERE NEW HORIZONS IS NOW



New Horizons is currently deep within the Kuiper Belt, about 48 astronomical units (AU) from the Sun, where 1 AU is the average Earth-Sun distance. After passing Arrokoth, New Horizons is on the hunt for a new Kuiper Belt object to fly by.
ASTRONOMY: ROEN KELLY

Pluto planet nine. With regard to the hypothetical object Konstantin Batygin and Michael E. Brown believe causes the perturbations of KBOs' orbits, the jury is still out on whether it is real. Scientists have looked for such a planet for many years and have not been able to find it.

While it would be fun to look for new planets with New Horizons, large telescopes on Earth do a much better job than the smaller telescopes New Horizons is equipped with. New Horizons also has no internal reaction wheels and relies on its thrusters to orient itself, so slewing the spacecraft around to search for planets would waste precious fuel we could use for another flyby farther out in the Kuiper Belt.

S. Alan Stern
Principal Investigator for New Horizons, Southwest Research Institute, Boulder, Colorado

Q | WHAT WILL HAPPEN TO THE STARS IN THE GALAXY 3C186, NOW THAT THE CENTRAL SUPERMASSIVE BLACK HOLE HAS BEEN EJECTED FROM THE GALACTIC CENTER? WILL THEY SLOWLY DRIFT APART, OR WILL THEIR COLLECTIVE MASS HOLD THEM TOGETHER FOR A WHILE?

Dennis Moore
Houston, Texas

A | Located 8 billion light-years away, the galaxy 3C186 is home to an extremely bright galactic nucleus — the signature of an active supermassive black hole (SMBH). But this SMBH is about 35,000 light-years from the center of the galaxy, suggesting it was kicked out of the galactic center.

As to what happens to the rest of 3C186, the short answer is that the galaxy will remain as it is. A galaxy is held together by the collective mass of its stars, gas, and dark matter, and any gravitational effects of the central SMBH are negligible with respect to that of the whole galaxy. For example, the SMBH at the center of our own Milky Way — Sagittarius A* (Sgr A*) — has a mass only one-millionth the total mass of the galaxy. So, Sgr A* only dominates the motions of the stars and gas in a very small central volume and not of the galaxy as a whole.

When two galaxies merge, their SMBHs will eventually coalesce into a new SMBH. In the case of 3C186, this new black hole likely received a "kick" from the gravitational waves emitted during the SMBH merger, acquiring velocities up to several thousand miles per second.

As a result of this kick, 3C186's SMBH's orbit began to oscillate around the galaxy's core. Nearby stars and gas were pulled along with it, in principle creating observable effects such as distortions in the morphology and dynamics of the galaxy. However, since the SMBH's sphere of influence is very limited, the entire galaxy will not suffer major disruptions, even if the black hole is completely ejected.

But this does not mean that the overall influence of the central SMBH on the host galaxy is negligible! There are a number of extremely close relations between the mass of the SMBH and the properties of its host galaxy, known as scaling relations. These mean the host galaxy and its SMBH essentially grow together. But, as we have seen, this cannot be due to the gravitational influence of the SMBH. There must be something else causing this relationship.

Stefano Bianchi
Associate Professor, Università degli Studi Roma Tre, Rome, Italy

SEND US YOUR QUESTIONS

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The galaxy 3C186 — itself the likely result of a previous galaxy merger — hosted the merger of two supermassive black holes. The resulting gravitational waves are believed to have "kicked out" the newly created supermassive black hole from the center of the galaxy.
NASA, ESA, AND M. CHIABERGE (STSCI/ESA)

Cosmic portraits

1. HAWTHORNE'S A
The Scarlet Letter (Sharpless 2–96) is an emission nebula in the constellation Cygnus the Swan. Astronomers suspect that it is part of supernova remnant SNR 65.2+05.7.
· *Jerry Yesavage*

2. AWAY IT GOES
An occultation is the temporary disappearance of a celestial body due to the passage of another in front of it, from a certain point of view. The Moon occulted Mars on August 9, 2020.
· *Ricardo José Vas Tolentino*

3. BLUE BEAUTY
Abell 72 is a planetary nebula in the constellation Delphinus the Dolphin. This glowing shell of gas expanding outward from a dying Sun-like star spans 2 light-years. This image combines 18.6 hours of exposures.
· *Douglas J. Struble*


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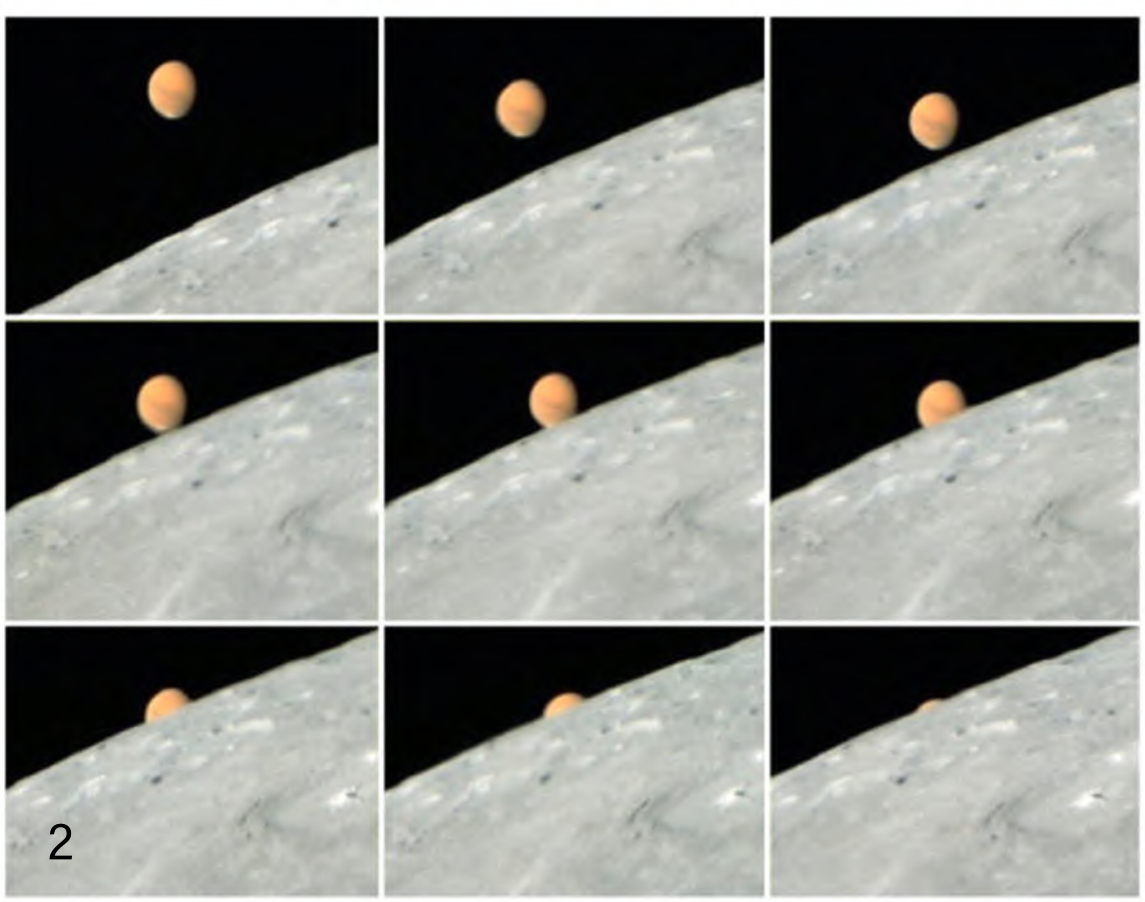
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4. FULL CIRCLE
This 360° panorama shows the entire sky above Black Canyon of the Gunnison National Park in Colorado. The two-row composite has one row for the sky and one for the landscape, which was shot without tracking before it was completely dark, in order to retain detail. The image includes the Milky Way and lots of colorful airglow.
▪ *Vince Farnsworth*

5. WAGGING ITS TAIL
The tail of Comet C/2019 U6 (Lemmon) appears to touch open cluster M41 in Canis Major on May 27, 2020, from Tivoli — Southern Sky Guest Farm in Namibia. At the time, the comet stood a mere 20° above the horizon. **▪ *Gerald Rhemann***

6. SOUTHERN BRILLIANCE
The Southern Pleiades goes by several other names, including Caldwell 102, IC 2602, Collinder 229, and the Theta Carinae Cluster. But its resemblance to the Pleiades (M45) makes "the Southern Pleiades" the name that resonates most with observers. Because it glows at magnitude 1.9, this cluster is easy to spot without optics. **▪ *Nicholas Clarke***

7. FLASH FORWARD
The green flash happens when long-wavelength light (red, orange, yellow) from the setting Sun is bent away from our eyes. These three exposures were captured a few seconds apart March 29, 2020, from Siesta Key, Florida. **▪ *Tom Fazekas***

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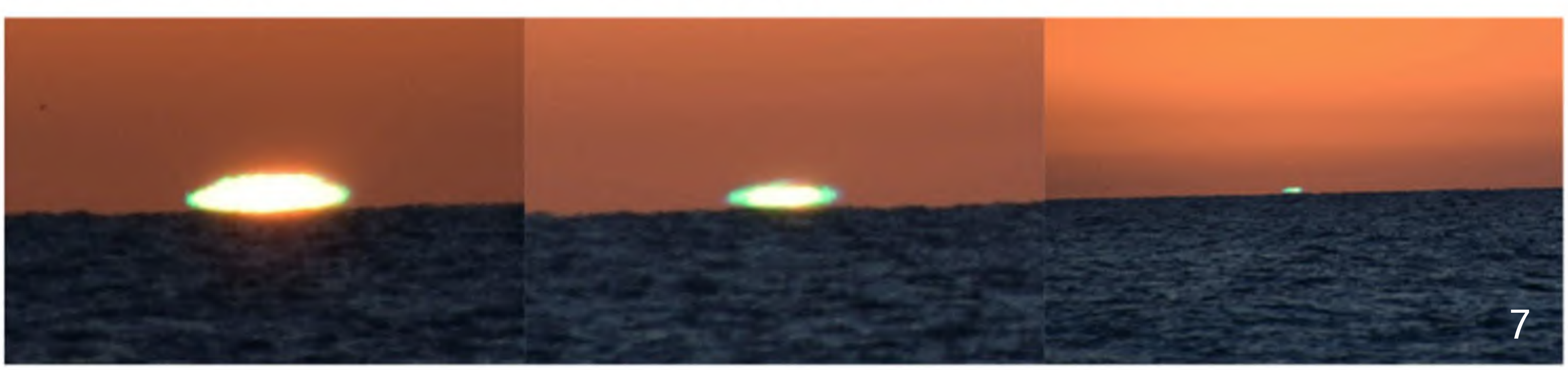
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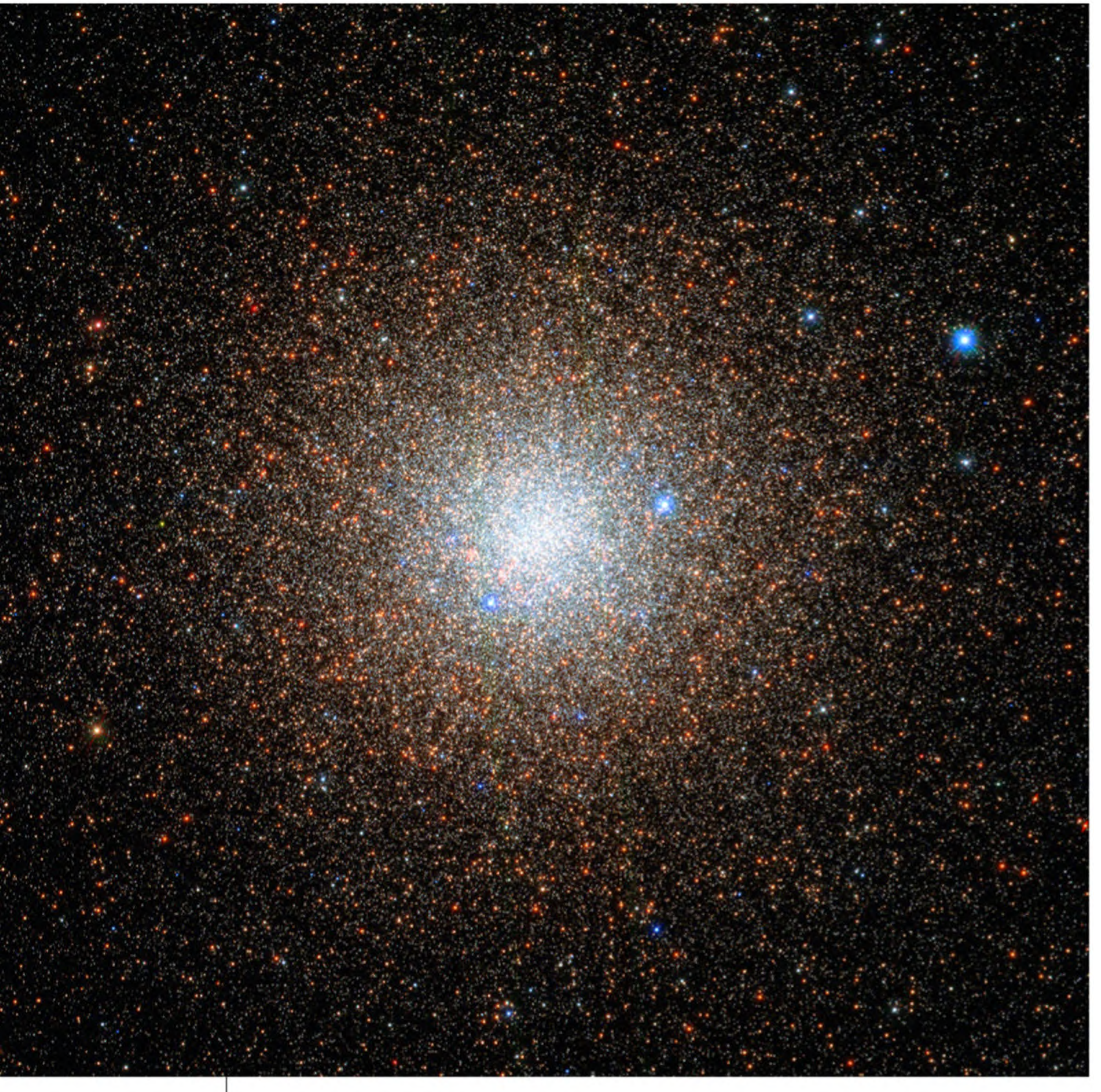

HEAVY METAL STAR ATTRACTION

Globular cluster NGC 6441 doesn't get a lot of respect from amateur astronomers. Maybe its location in southern Scorpius, which keeps it low in the sky from midnorthern latitudes, tips the scales against it. And its great distance of roughly 40,000 light-years doesn't help. Yet NGC 6441 stands out among the Milky Way's approximately 150 globular clusters. It ranks among our galaxy's most massive and most luminous globulars, weighing some 1.6 million solar masses and shining with the light of 600,000 Suns. It also contains more metals — astro-speak for elements heavier than helium — than most globulars. Perhaps this stunning Hubble Space Telescope portrait will help NGC 6441 gain the respect it deserves. ESA/HUBBLE AND NASA/G. PIOTTO

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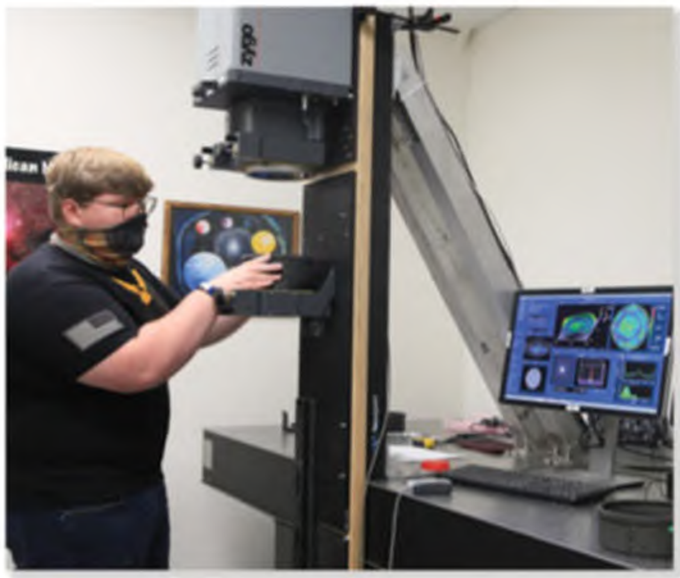

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April 2021

Mars hangs on at dusk

With autumn now in full swing, skygazers have their first opportunity of the year for early evening observing. For solar system enthusiasts, however, only one naked-eye planet graces the evening sky. You can find **Mars** low in the northwest after darkness falls. The Red Planet lies against the backdrop of Taurus in early April, to the right and a bit below the Bull's luminary, Aldebaran. The red giant star, which shines at magnitude 1.0, appears slightly brighter than the magnitude 1.3 planet.

Mars heads eastward relative to the background stars this month, crossing the invisible border between Taurus and Gemini on April 24. Three nights later, on the 27th, the planet passes just north of the 5th-magnitude open star cluster M35. Plan to view this conjunction through binoculars or a telescope, but don't expect to see any detail on the planet's 5"-diameter disk.

A waxing crescent Moon passes in front of Mars on April 17. The best views in the Southern Hemisphere come from Indonesia. In Jakarta, for example, the planet disappears behind the Moon's dark limb at 13h32m UT and reappears from behind the bright limb at 14h29m UT.

You'll have to wait until after midnight to see another planet. **Saturn** rises shortly after 2 A.M. local time in early April and nearly two hours earlier by month's end. The ringed planet shines at magnitude 0.6 among the stars of north-central Capricornus the Sea Goat.

For the best views of Saturn through a telescope, wait until it climbs high in the sky an hour or two before twilight begins. You won't be disappointed. On April 15, the planet's disk measures 16" across while the spectacular ring system spans 37" and tilts 17° to our line of sight. Any scope also shows the 8th-magnitude moon Titan, which circles Saturn once every 16 days. A 10-centimeter instrument gathers enough extra light to reveal three or four additional satellites.

About an hour after Saturn rises, **Jupiter** pokes above the eastern horizon. You won't mistake the Sun's largest planet for any other object — at magnitude –2.1, it shines brighter than any other planet or star visible this month. Jupiter spends most of April in Capricornus, but it pushes across the border into Aquarius the Water-bearer during the month's final week.

As with Saturn, you'll want to wait until dawn approaches before targeting Jupiter through your telescope. That's because higher altitudes deliver sharper views of the giant planet and its dynamic atmosphere. Jupiter shows an alternating series of bright zones and darker belts on a disk that spans 36" in mid-April. During moments of good seeing, finer details pop into view. Also keep an eye out for the planet's four bright moons — Io, Europa, Ganymede, and Callisto — which appear obvious through any scope.

Mercury remains prominent during morning twilight in early April. It rises about 80 minutes before the Sun on the 1st, when it glows at magnitude –0.5 and is the brightest object between Jupiter and the eastern horizon. It disappears in the Sun's glare during April's second week on its way to superior conjunction on the 19th.

Although **Venus** typically appears brighter than any other point of light in the sky, it remains out of sight this month as it tracks across the sky with the Sun. It will return to view after sunset in May.

The starry sky

Once darkness falls during April, Crux the Cross appears prominent about halfway from the southeastern horizon to the zenith. The unmistakable constellation is tipped on its side, with the base of the Cross — Acrux (Alpha [α] Crucis) — farthest to the right. Acrux also ranks as the constellation's brightest star.

But for those who prefer to explore the night sky through a telescope, Acrux stands out most because it is a fine double star. In fact, for the past several years, it has rivaled its better-known cousin Alpha Centauri in neighboring Centaurus. That's because the separation between the main stars in Alpha Cen is now near a minimum, so that pair looks less spectacular than usual.

Acrux's two main components shine at magnitudes 1.3 and 1.8 and stand some 4" apart. That is plenty wide enough for any telescope to split them. The view through a high-quality refractor is particularly impressive. The brighter component is also a spectroscopic binary, meaning that the two suns lie so close to each other that they can't be split at the eyepiece, but a spectrum reveals their mutual orbital motions.

A fourth component of the multistar system shows up easily through binoculars. Look for a 5th-magnitude star positioned about 90" south of the main pair.

James Dunlop of the Parramatta Observatory in New South Wales first cataloged Acrux as a double star in the 1820s. He wasn't the first to notice its duplicity, however. Jean de Fontenay and Guy Tachard observed the star from the Cape of Good Hope in 1685 while they were making their way to the Far East. In his account of the trip, Tachard described viewing Acrux through the telescope: "Two bright stars distant from one another about their own diameter only." Tachard also recorded the third, distant component. How do your observations compare when pointing a telescope at Acrux?

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. April 1
8 P.M. April 15
7 P.M. April 30

Planets are shown at midmonth

MAP SYMBOLS

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

STAR MAGNITUDES

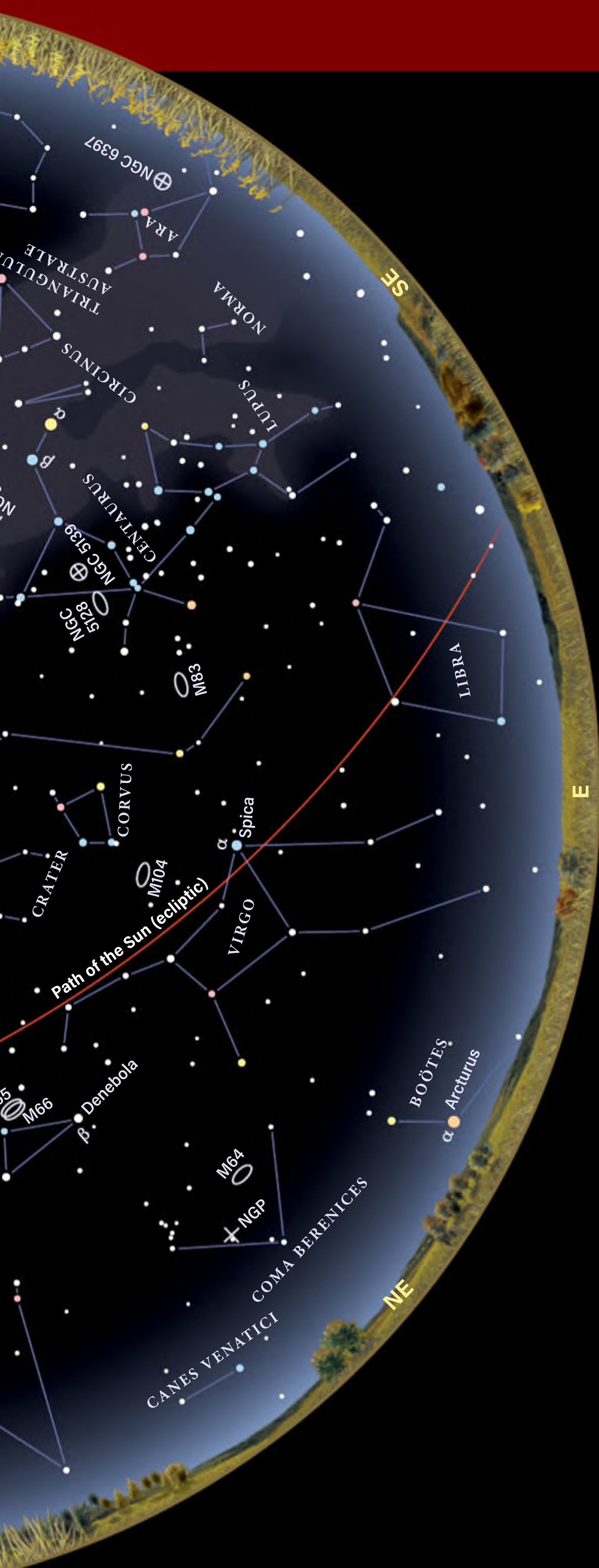
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

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.**



APRIL 2021

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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

CALENDAR OF EVENTS

4 Last Quarter Moon occurs at 10h02m UT

Asteroid Metis is at opposition, 12h UT

6 The Moon passes 4° south of Saturn, 8h UT

7 Dwarf planet Ceres is in conjunction with the Sun, 7h UT

The Moon passes 4° south of Jupiter, 7h UT

9 The Moon passes 4° south of Neptune, 11h UT

12 New Moon occurs at 2h31m UT

13 Asteroid Juno is stationary, 2h UT

The Moon passes 2° south of Uranus, 12h UT

14 The Moon is at apogee (406,119 kilometers from Earth), 17h46m UT

17 The Moon passes 0.1° south of Mars, 12h UT

19 Mercury is in superior conjunction, 2h UT

20 First Quarter Moon occurs at 6h59m UT

22 Asteroid Vesta is stationary, 18h UT

27 Full Moon occurs at 3h32m UT

The Moon is at perigee (357,378 kilometers from Earth), 15h22m UT

28 Pluto is stationary, 19h UT

30 Uranus is in conjunction with the Sun, 20h UT