BIG ASTRONOMY DEEP IN THE HEART OF TEXAS p. 36

MAY 2024

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VOL. 52, NO. 5

ON THE COVER

In this artist's rendition, an isolated black hole is relatively inactive, making it extraordinarily difficult to detect. INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA/J. DA SILVA/SPACEENGINE/M. ZAMANI

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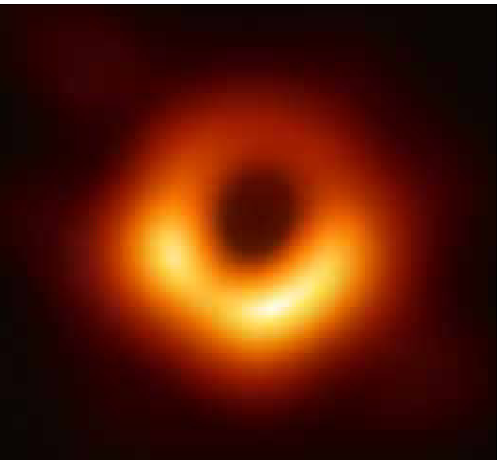
The allure of black holes



This image, produced by the Event Horizon Telescope, shows the shadow of the supermassive black hole in the giant elliptical galaxy M87 in Virgo. It has the mass of a staggering 6.5 billion Suns.
EHT COLLABORATION

Black holes are one of the greatest inventions astronomy enthusiasts have ever known. Hypothesized in 1783, not confirmed until 1990, they relentlessly teased astronomers for many decades. The idea of a region with gravity so strong that nothing, not even light, can escape, seems straightforward enough. But finding black holes is hard — really hard. They are, after all, black. And so is space.

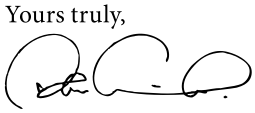
There should be many millions in our Milky Way Galaxy alone; we know of only about two dozen. Practically every large galaxy more massive than dwarfs has one in its center. Yet we didn't detect any of those until the repaired Hubble Space Telescope got going in the early 1990s. For all intents and purposes, it seems that black holes have made more appearances in movies (most of them frightfully bad) than in reality. But we know they are out there.

This month, astronomer Yvette Cendes of the University of Oregon describes the ongoing search for the nearest black holes using the Gaia satellite. This European Space Agency orbiting observatory is designed for astrometry — precise positional measurements of astronomical bodies. The ongoing mission is assembling the most voluminous three-dimensional catalog of astronomical objects ever made, totaling some 1 billion targets. That is quite a dataset.

Gaia's enormous dataset has allowed enterprising astronomers to search for anomalies in the positions of stars, recorded over spans of time. Stars that show a wobble over time but have no visible companion are promising candidates for hosting a black hole. Astronomers can even calculate the mass of the unseen companions, courtesy of our old friend Johannes Kepler. The result is an emerging list of probable black holes in our galaxy that resulted from the deaths of massive stars of about 18 times or more mass than our Sun.

The revolutionary approach demonstrates a clever technique astronomers are using to unveil new discoveries about the cosmos that surrounds us. For astronomy enthusiasts, it's a good time to be alive.

Yours truly,



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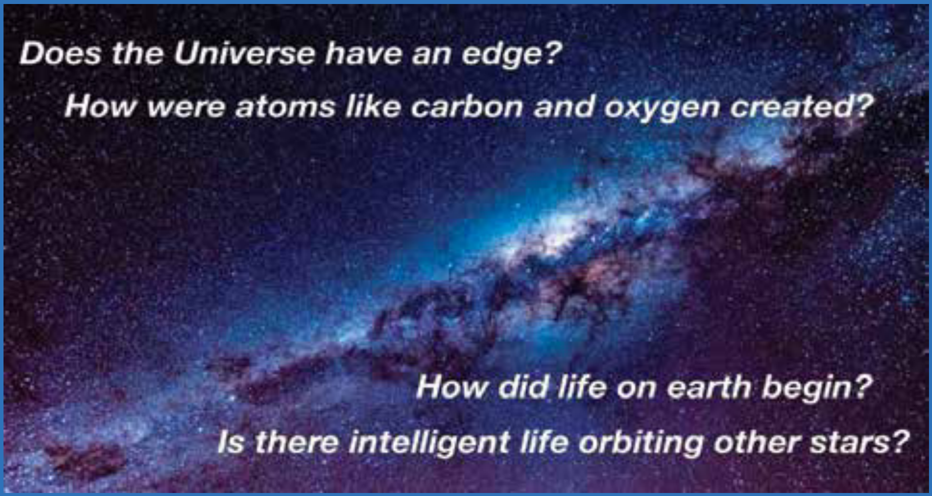

Dr. George Roush will explore

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3. The birth, evolution & death of stars
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The launch of Apollo 8 in 1968 captivated people across the U.S. NASA

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

Space Age nostalgia

I still remember watching Apollo 8's memorable Moon encounter as a 12-year-old on Christmas Eve 1968. Those who weren't around to experience the early days of the space program will never know the excitement we felt as we watched history play out on our black-and-white and, if we were lucky, color televisions. The networks would give wall-to-wall coverage to a rocket launch.

We would sit glued to the television absorbing every minute. The tumultuous times of the '60s and early '70s notwithstanding, I would love to relive those days again. **—Robert Lindner,** Oak Creek, WI

Victory and defeat

I just finished the December 2023 issue, including the article about the Civil War entitled "A dark war and a bright night sky." My only complaint is that the article wasn't long enough. I've read about the Civil War a lot and I thought I knew a lot about the war. And over the years, thanks to my telescope, books, and *Astronomy* magazine, I also thought I knew a lot about astronomy. But I never knew that people in those days, and both sides, put as much stock in the sky as they did. This is one of the best articles I have ever read in *Astronomy* magazine. Mixing astronomy with the Civil War was brilliant. **—Michael Boysuk,** Potsdam, NY

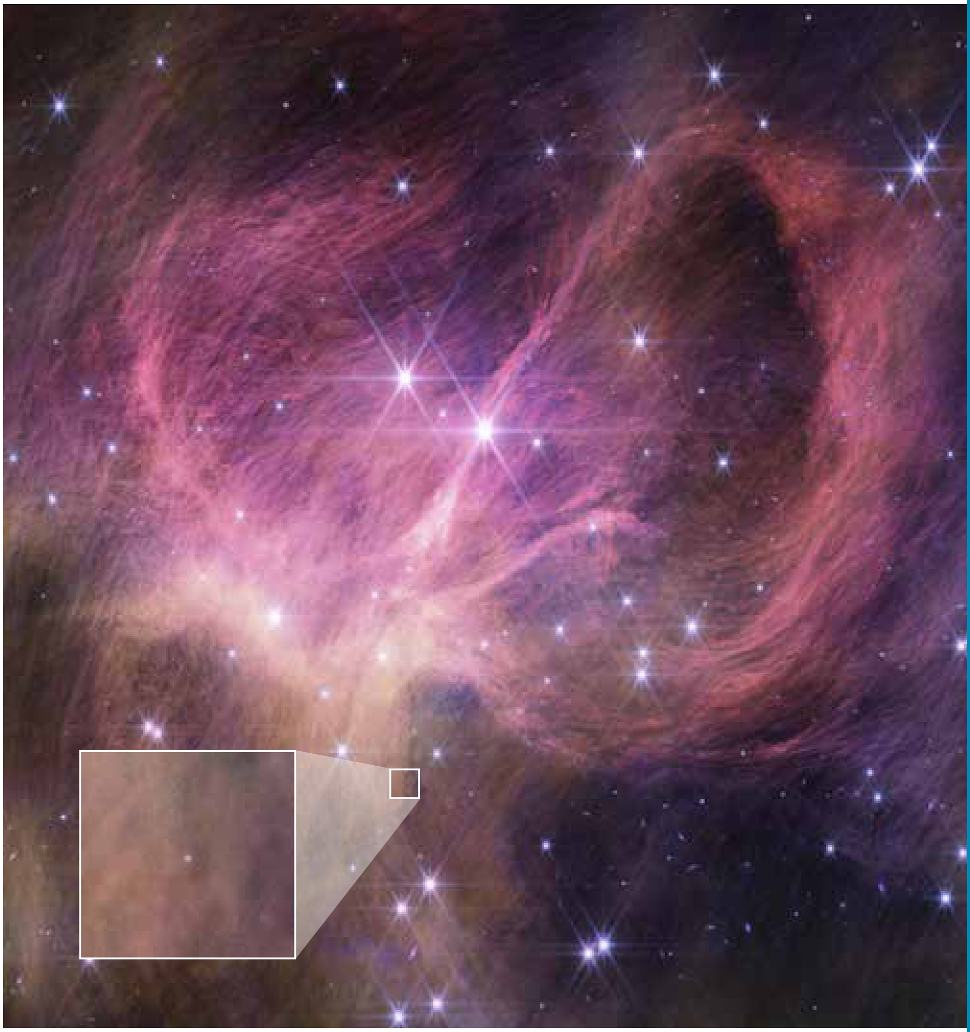
Hometown hero

Many thanks for including Ormsby MacKnight Mitchel in your "A dark war and a bright night sky" in the December 2023 issue. [Here at the Cincinnati Observatory], he is our hero. Not only is Ormsby recognized as the father of American astronomy, but he also experienced a stellar career as a Civil War general. He acquired America's first significant telescope, an 11-inch Merz and Mahler refractor, for the Cincinnati Astronomical Society (which he founded in 1842). He also served as a popularizer of astronomy with his lectures on astronomy topics in New York City and his multiple expositional astronomical publications. **—John Ventre,** historian for Cincinnati Observatory

SNAPSHOT

FEATHER-WEIGHT CHAMPION

The line between stars and planets continues to blur.

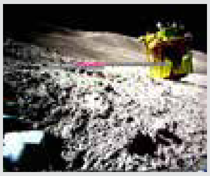


In the quest for the universe's smallest starlike objects, the James Webb Space Telescope (JWST) has identified a new record holder: a tiny, free-floating brown dwarf (inset) with a mass only three to four times that of Jupiter.

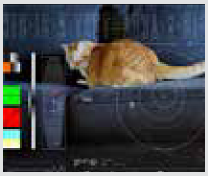
Brown dwarfs are objects that straddle the line between stars and planets. Like stars, they form from a contracting cloud of gas, but never reach the required temperature or density in their cores to begin fusing hydrogen to helium — earning them the name "failed stars."

This petite object is one of three brown dwarfs reported in December 2023 and captured by JWST's Near-Infrared Camera in its view of the young star cluster IC 348, about 1,000 light-years away in Perseus. Such clusters are ideal for hunting for these objects because newly formed brown dwarfs are still glowing in infrared light from the leftover heat of their formation. —DANIELA MATA

HOT BYTES



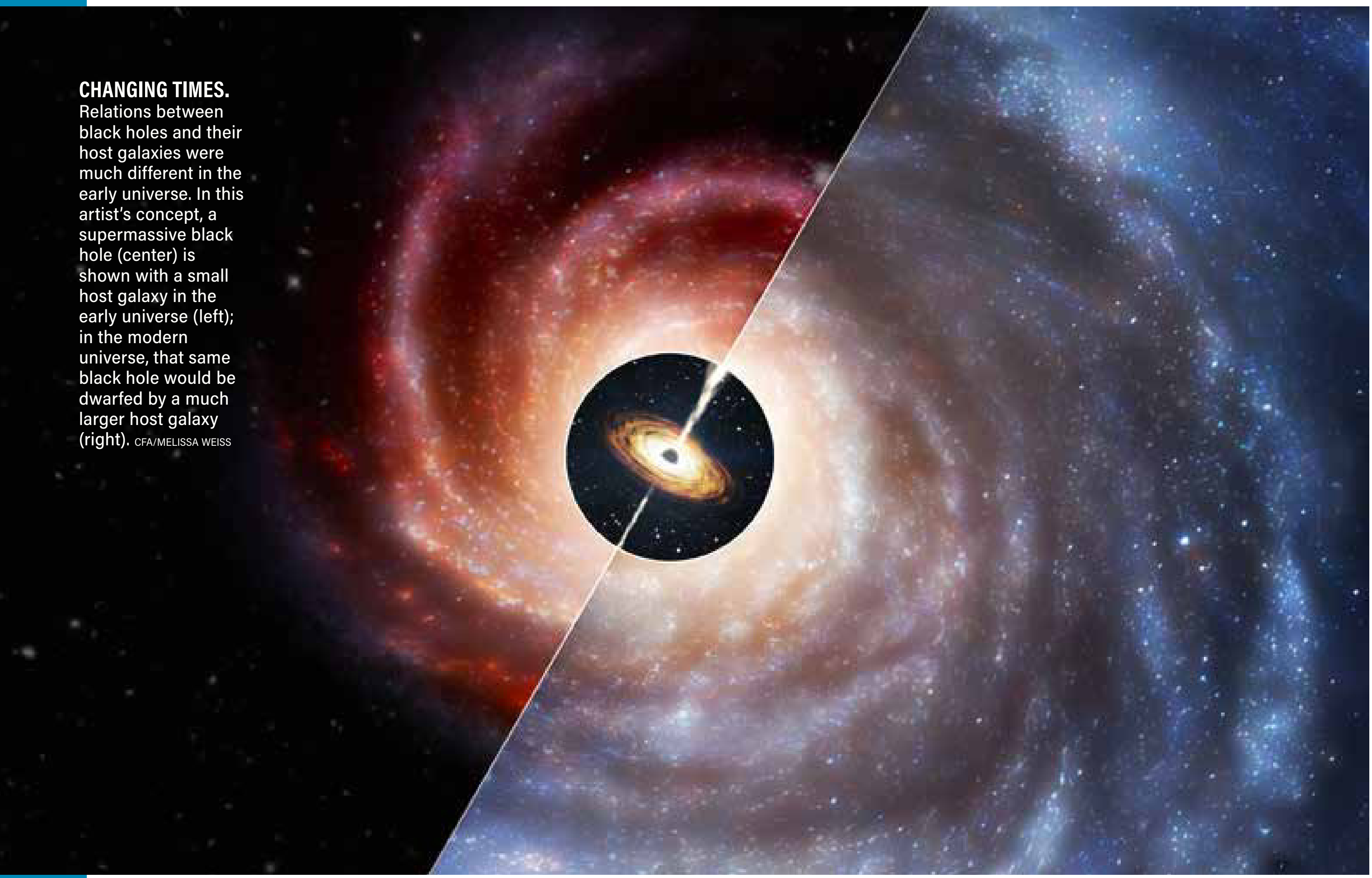
PRECISION FACEPLANT
Japan's Smart Lander for Investigating Moon (SLIM) mission made the most precise robotic lunar landing ever on Jan. 19, just 180 feet (55 m) from its intended target. However, it landed on its nose, limiting its ability to gather solar energy.



COSMIC CAT VIDEO
An ultra-high-definition video of an orange tabby cat named Taters chasing a laser pointer across a couch was streamed from NASA's Psyche mission to Earth at a distance of 19 million miles (31 million km) via laser transmitter Dec. 11, serving as a demo for high-bandwidth deep-space communications.

BETA CAT
JWST has revealed that the debris disk around the young star Beta Pictoris — famously, the first such disk directly imaged, in 1984 — has a previously unseen curved feature, dubbed the "cat's tail." The trail of dust may have been caused by a collision of planetary objects.

NASA, ESA, CSA, STSCI, AND K. LUHMAN (PENN STATE UNIVERSITY) AND C. ALVES DE OLIVEIRA (EUROPEAN SPACE AGENCY). BOTTOM FROM LEFT: JAXA/TAKARA TOMY/SONY GROUP CORPORATION/DOSHISHA UNIVERSITY; NASA/JPL-CALTECH; NASA, ESA, CSA, STSCI, C. STARK AND K. LAWSON (NASA GSFC), J. KAMMERER (ESO), AND M. PERRIN (STSCI)



CHANGING TIMES. Relations between black holes and their host galaxies were much different in the early universe. In this artist's concept, a supermassive black hole (center) is shown with a small host galaxy in the early universe (left); in the modern universe, that same black hole would be dwarfed by a much larger host galaxy (right). CFA/MELISSA WEISS

JWST SEES STRANGE BLACK HOLES IN THE EARLY UNIVERSE

Astronomers are winding back the clock to discover how the first black holes formed.

» Since its launch, astronomers have been using the James Webb Space Telescope (JWST) to peer back to a time when the first stars and galaxies were forming. Not only is JWST showing us that early galaxies are different than anticipated, it's also revealing that black holes in the early universe are behaving unexpectedly as well.

YOUNG HEAVYWEIGHTS

"In the local universe there is a supermassive black hole at the center of every massive galaxy," Fabio Pacucci, a Center for Astrophysics | Harvard & Smithsonian researcher, says. These black holes are millions to billions of times the mass of the Sun. "And there are pretty tight correlations between the mass of the black hole and many properties of the host galaxy."

But according to Pacucci and colleagues' research, published in *The Astrophysical Journal Letters* and presented Jan. 9 at the winter meeting of the American Astronomical Society, that correlation seems to break down at early times.

Typically, a supermassive black hole now is about 0.1 percent the total mass of its host galaxy. But galaxies early in the universe's history, such as those in the study between 700 million and 1.5 billion years after the Big Bang, have black holes often between 1 percent and 10 percent the mass of the galaxy.

While there had been hints

of such a trend, Pacucci's study looks at as many high-redshift galaxies as possible from JWST. And "every single supermassive black hole studied by JWST up to that point was very over-massive with respect to stellar mass of the galaxies," he says.

STARTING LARGE

Some theories posit that early supermassive black holes formed from mergers of smaller black hole "seeds" left behind when the first stars exploded. But in that case, astronomers aren't sure how to explain the appearance of supermassive black holes in the early universe, when there wasn't yet time to build them up.

A theory called heavy seeding attempts to solve this. In the early universe, there could have been gas clouds so huge and dense they couldn't form stars, instead collapsing right into black holes 10,000 times the mass of the Sun or more. In this way, heavy seeding creates small supermassive black holes from the outset, no mergers required.

A galaxy with such a black hole in the center would have found star formation difficult, if not impossible — which makes heavy seeding an even more likely culprit for the galaxies Pacucci's team saw. "The over-massive black hole is really injecting a lot of energy into the system," Pacucci says. "It's heating up the gas. And once the gas is heated up, it's very hard to form stars." He says it likely wasn't until about 2 billion or 3 billion years after the Big Bang that the material outside the black hole started to take on a larger percentage of the galaxy's mass.

Subsequent work could help piece together the steps between massive seeds and more massive galaxies, as well as whether the find is truly representative of the conditions of the early universe.

HUNGRY BLACK HOLES

In a paper published Jan. 17 in *Nature*, another group seeking to understand how the first black holes formed used JWST to identify the oldest known supermassive black hole just 400 million years after the Big Bang. It is a few million times the mass of the Sun and lies at the center of the galaxy GN-z11.

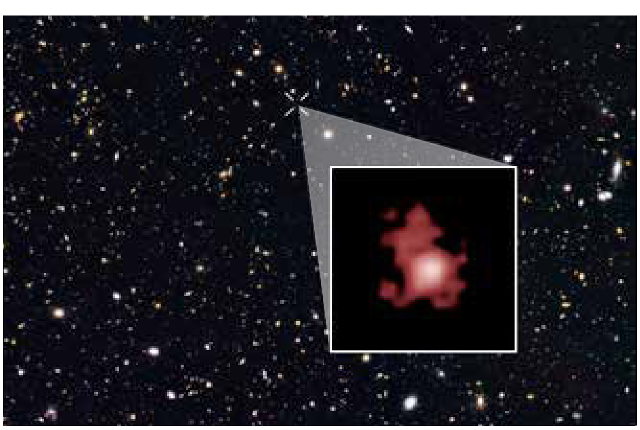
Normally, such a large black hole should have taken a billion years to form. Instead, the team says, it's gotten so large by eating away at its surroundings much faster than predicted.

Black holes grow by pulling in material like dust and gas. The infalling matter creates a glowing accretion disk. But there is a theoretical limit to how fast a black hole can eat, called the Eddington rate. If it tries to eat faster, the accretion disk heats up and radiates so powerfully that it blows itself away, escaping as a wind of energetic particles and limiting the black hole's growth.

But astronomers have observed black holes occasionally exceeding the Eddington rate without losing their disks. This seems to be happening within GN-z11: Its black hole is eating at five times the Eddington rate. So, GN-z11 seems to show that supermassive black holes can go through short episodes of super-Eddington accretion before calming down again.

The team can't determine whether GN-z11's black hole started as a lower-mass black hole or a heavy seed created through direct collapse. But each new black hole that JWST finds helps researchers to piece together the puzzle of how supermassive black holes form.

— JOHN WENZ, ELIZABETH GAMILLO



QUICK EATER. The galaxy GN-z11 (inset), seen here in a Hubble Space Telescope image, seems to have a black hole gobbling up material faster than the Eddington limit predicts. NASA, ESA, AND P. OESCH (YALE UNIVERSITY)

QUICK TAKES

DESTROYER OF WORLDS

The star J0931+0038 has an unusual composition with heavy elements that no known model of nucleosynthesis can explain. Astronomers think it formed from the remains of an exploded star at least 50 to 80 times more massive the Sun, which they've dubbed the "Barbenheimer Star."

CMB CO-DISCOVERER DIES

Cosmologist Arno Penzias, who shared one half of the 1978 Nobel Prize in Physics with Robert Wilson for codiscovering the cosmic microwave background, died Jan. 22 at the age of 90.

CLIMATE CRISIS CONTINUES

A NASA analysis concluded that 2023 was the warmest year on record, with an average surface temperature 2.1 F (1.2 C) higher than a baseline period from 1951–1980.

INTERGALACTIC SURVIVOR

A 10-billion-year-old star found orbiting the Milky Way's central supermassive black hole at a distance of just 0.04 light-year is similar in composition to stars in the small galaxies surrounding the Milky Way. Astronomers think this star was born in a now-extinct dwarf galaxy that was absorbed by our own.

VIBE KALE-ER

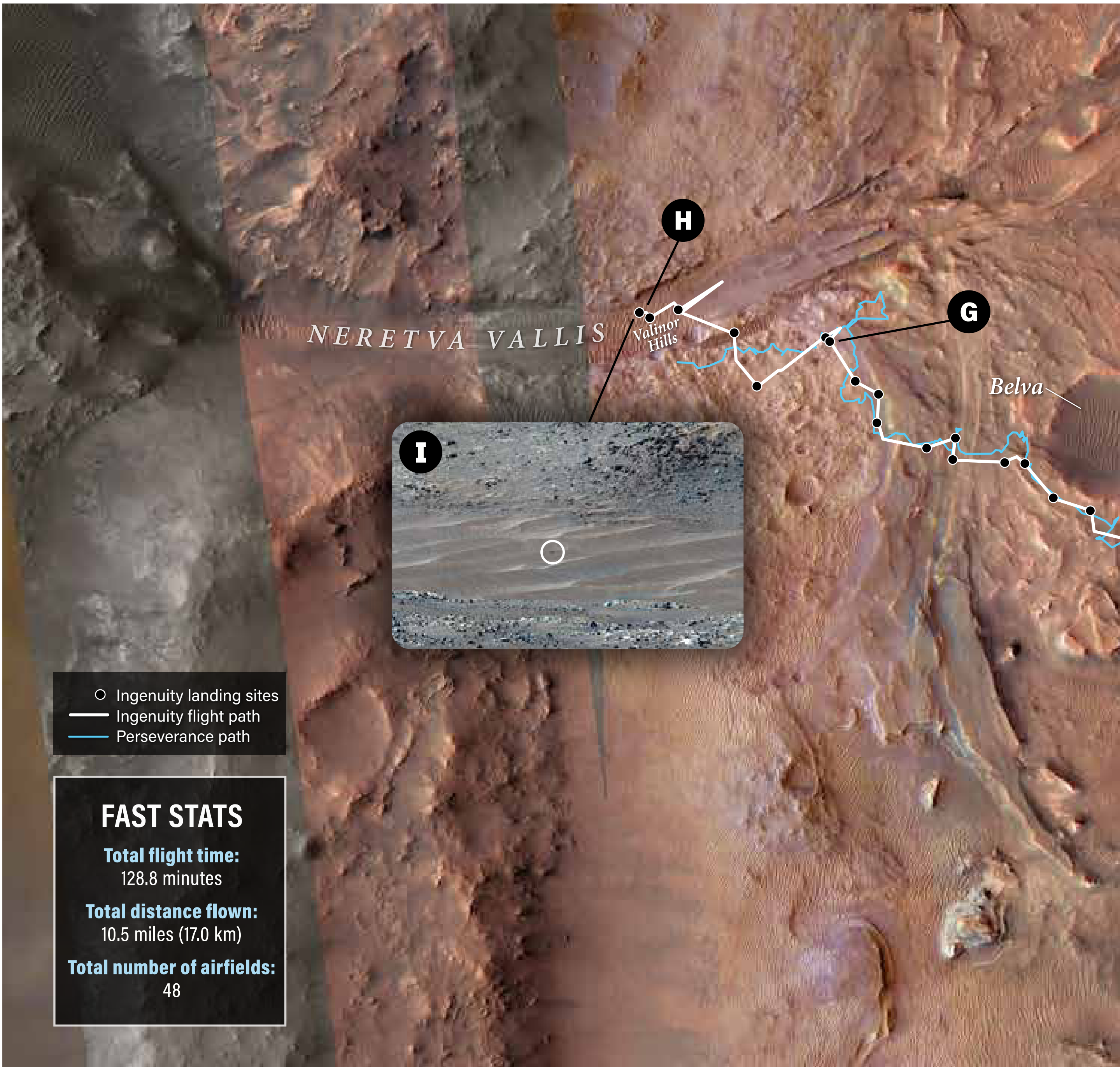
Lettuce grown in simulated microgravity is more prone to salmonella infections, lab tests find. The weaker gravity seems to confuse the leafy greens, leaving its pores open to pathogens that could threaten a mission crew that grows food in space.

— MARK ZASTROW

INGENUITY'S FLIGHT LOG

When NASA's Perseverance rover landed in Mars' Jezero Crater on Feb. 18, 2021, it carried a small companion: the helicopter drone Ingenuity. The twin-rotor craft was originally conceived as a technology demonstration with the goal of making a handful of flights to show that powered flight in Mars' thin air was possible.

Ingenuity passed this test with flying colors — and then kept flying, surviving the harsh martian winter. It become a key part of Perseverance's mission, acting as an aerial scout for the rover as it



FAST STATS

Total flight time: 128.8 minutes

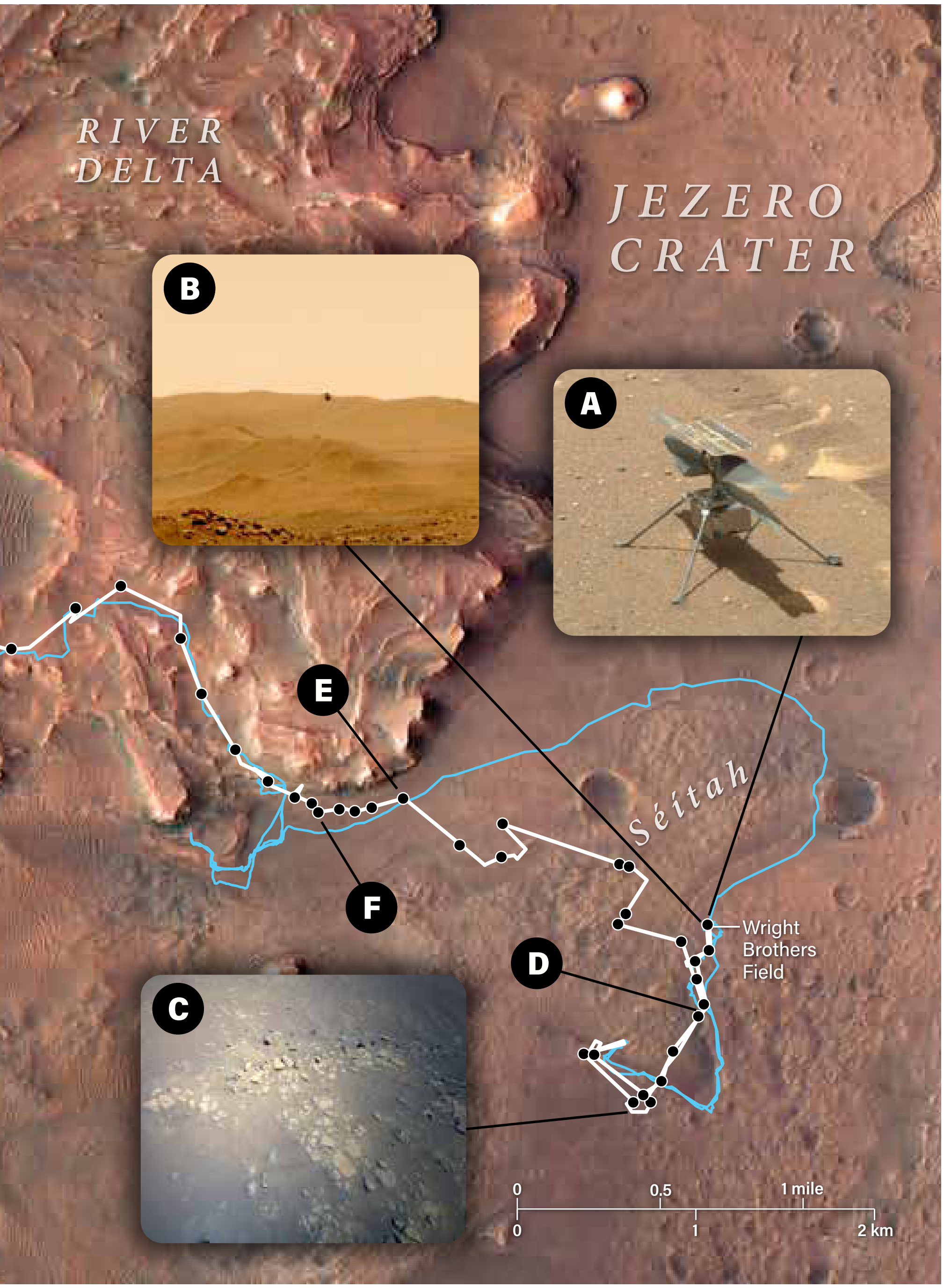
Total distance flown: 10.5 miles (17.0 km)

Total number of airfields: 48

* Some landing sites for flights that returned to nearly the same location have been removed for legibility.

traversed dunes and explored an ancient river delta, looking for samples to cache.

NASA announced Jan. 25 that Ingenuity was being retired due to a damaged rotor. But its performance and longevity were impressive enough to convince the agency to rework its plans for its Mars Sample Return mission, which will send a rover to return Perseverance's cached samples to Earth. The new plans also call for a pair of drones that will carry on Ingenuity's legacy with the capability to buzz around Jezero Crater and retrieve the samples. — M.Z.



INSET I: NASA/JPL-CALTECH/ASU/MSSS; ALL OTHER IMAGES: NASA/JPL-CALTECH

MISSION MILESTONES

A. FLIGHT 1
April 19, 2021
Ingenuity successfully takes off, reaching an altitude of 33 feet (10 m) and hovering for 30 seconds.

B. FLIGHT 5
May 7, 2021
Ingenuity completes its tech demo phase and departs its first airfield, dubbed Wright Brothers Field, heading south to begin exploring Jezero Crater.

C. FLIGHT 10
July 24, 2021
Ingenuity makes its first official scouting flight, taking aerial images of surface fractures and ridges on the crater floor.

D. FLIGHT 19
scheduled Jan. 5, 2022; departed Feb. 7, 2022
An unexpected dust storm causes the first-ever weather delay to a flight on another planet. After wiggling its rotors to shake off settled dust, Ingenuity finally takes off over a month later.

E. FLIGHT 29
June 11, 2022
A low battery due to approaching winter forces a change to operations, with Ingenuity hibernating during martian nights to conserve power.

F. FLIGHT 34
Nov. 23, 2022
Ingenuity gets a navigation software update with better terrain awareness, enabling it to scout ahead of Perseverance as it climbs through a canyon on its way up the steep slopes of the river delta.

G. FLIGHTS 61 AND 62
Oct. 5 and 12, 2023
Ingenuity sets new records for maximum altitude (79 feet [24 m]) and ground speed (22.4 mph [36.0 km/h]).

H. FLIGHT 71
Jan. 6, 2024
Ingenuity cuts short its scheduled flight plan and makes an emergency landing.

I. FLIGHT 72
Jan. 18, 2024
A flight intended to check Ingenuity's systems is the helicopter's last. Images reveal damage to one of its rotor blades, permanently grounding it. The mission team nicknames the craft's final airfield Valinor Hills after the western realm of the immortals in J.R.R. Tolkien's *The Lord of the Rings*.

A GALAXY NOT YET BORN

ASTRONOMERS MAY HAVE FOUND a dark, primordial galaxy — an enormous, undisturbed mass of cold hydrogen gas that has yet to form any stars — sitting in the modern-day universe.

If confirmed, the object could offer astronomers a look at an early stage of galactic evolution. "I've been in this field for quite a few decades, and we've wanted to find something like this for a very long time," study leader Karen O'Neil, an astronomer at the Green Bank Observatory in West Virginia, tells *Astronomy*.

The first hint of something unusual was a discrepancy between observations made by the Green Bank Telescope (GBT) and the Nançay Radio Telescope in France as part of a coordinated survey of faint galaxies. Though they were supposed to be looking at the same patch of sky, the 100-meter-wide GBT was seeing something that Nançay wasn't.

"Upon looking a little bit closer at it and spending far too much time, we discovered that we had actually mistyped the coordinates in the GBT catalog," O'Neil said Jan. 8 at a press conference at the winter meeting of the American Astronomical Society in New Orleans. "This is something, unfortunately, astronomers do occasionally late at night."

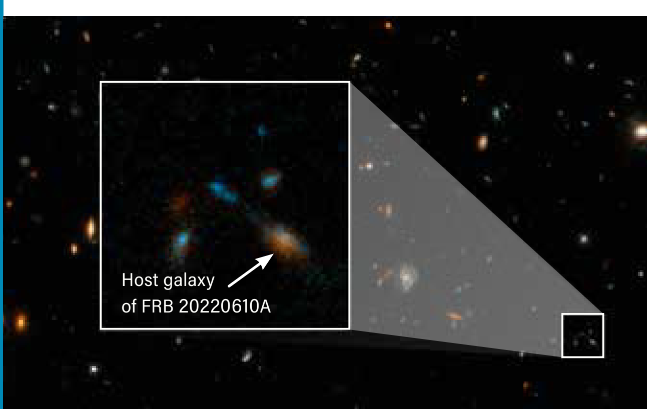
The GBT's radio observations indicated there was a spiral-galaxy-sized cloud of gas — a couple of billion Suns' worth — rotating at about the same speed as the Milky Way. But surveys in visible light showed nothing. "So that means what we might have here — *might* — is the discovery of a primordial galaxy," a galaxy of gas that is too spread out for its gravity to pull stars together, said O'Neil. The galaxy, dubbed J0613+52 and located roughly 270 million light-years away, is also isolated from any other galaxies that might disturb it or trigger it to clump up and begin forming stars.

Primordial galaxies must be rare, says O'Neil. Otherwise, surveys of neutral hydrogen by the now-defunct Arecibo Observatory in Puerto Rico would have uncovered some before.

To confirm the galaxy's primordial nature, the team will seek approval to aim a large optical telescope at it for tens of hours — ironically, in the hopes of seeing nothing at all. "Even if we can detect it, it's still going to be insanely low surface brightness, and it's still going to be really exciting," says O'Neil. "If we can't detect it, that's going to be pretty fascinating, too." –M.Z.

NOTHING TO SEE. The colors in this image are an artist's depiction of the rotation of the hydrogen in galaxy J0613+52, as detected by the Green Bank Telescope. Red is gas moving away from us and blue is gas moving toward us. STSCI POSS-II WITH ADDITIONAL ILLUSTRATION BY NSF/GBO/P.VOSTEEN

A burst from a 'blob'



THE BLOB REVEALED. The Hubble Space Telescope showed the source of FRB 20220610A to be a dwarf galaxy (indicated by the arrow) interacting with six smaller dwarf galaxies. NASA, ESA, STSCI, ALEXA GORDON (NORTHWESTERN)

FAST RADIO BURSTS (FRBs) were first discovered in 2007 and have vexed astronomers ever since. As the name implies, they're fast (on the order of a millisecond) flashes of energy observed in radio waves. Now, a recently described FRB that lies 9 billion light-years away could give astronomers an assist in tracing their origins.

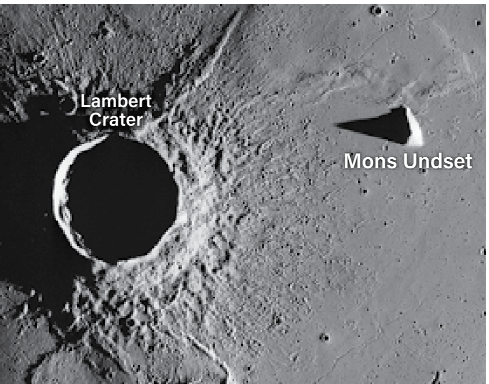
Not only is it the farthest FRB spotted to date, but it's one of the most unusual. That's because the Very Large Telescope in Chile showed not a well-defined host galaxy, but a blob. "We had never seen something that was so blobby looking," says Northwestern University graduate student and study leader Alexa Gordon, who presented the work Jan. 9 at the winter meeting of the American Astronomical Society in New Orleans. "We weren't sure if this was just a really sort of amorphous bizarre galaxy or if there were maybe multiple galaxies, interacting or merging."

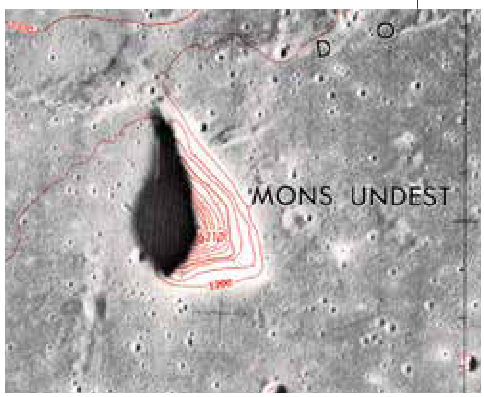
The team was awarded observing time on the Hubble Space Telescope. This revealed that the blob consists of one large dwarf galaxy surrounded by six smaller dwarf galaxies, all packed into a space the size of the Milky Way and likely to merge into one galaxy. The FRB, named FRB 20220610A, is the first to have been found in such a compact group of merging galaxies.

The find gives a boost to the leading theory to explain FRBs, which is that they come from magnetars — highly magnetic, fast-spinning neutron stars. A neutron star is the ultra-compact husk of a large star that exploded into a supernova. "If we think FRBs come from magnetars, they should be connected to recent star formation," Gordon says. And merging galaxies trigger star formation, giving the idea credence. –J.W.

Undset's forgotten mountain

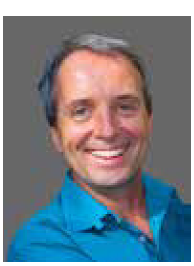
This nameless lunar feature has many names.





LEFT TO RIGHT: An Apollo 15 image of Lambert Crater with Mons Undset to its west (right), casting a pyramidal shadow. Mons Undset was named for novelist Sigrid Undset (whose portrait is at the center of this page). NASA; FRANKFURTER BUCHMESSE 2019

This section of image 40B4 from the 1973 *Lunar Topographic Orthophotomap Series* displays Mons Undset misspelled as "Mons Undest." NASA



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

On the evening of Sept. 23, 2023, I was training my 3-inch Tele Vue refractor on the Moon to catch sunrise over Lambert Crater when a brilliant pyramid of light just to the east of the crater grabbed my attention instead. This isolated peak was the brightest feature to emerge from the lunar twilight that night. At high power, the mountain's sharply cut facets reflected the rising Sun's rays in the most alluring manner. I immediately had to know the mountain's name, only to discover … it has none.

But it did once! I'll explain.

In 1973, Lambert γ was renamed Mons Undset.

The next morning, I checked NASA's online Scientific Visualization Studio's Moon Phase and Libration (which displays the Moon on any chosen date with countless labels), as well as the Lunar Reconnaissance Orbiter Camera ACT-REACT QuickMap, but neither site identified this peak. Nor was the mountain listed in the International Astronomical Union's (IAU) Gazetteer of Planetary Nomenclature for the Moon.

Doubtful that such a bright feature went unnamed, I went back in time to the 1913 *Collated List of Lunar Formations*. Sanctioned by the International Association of Academies, this work was the first attempt to remedy the unsatisfactory state of lunar nomenclature of the day. (At that time, the Moon's most prominent features were known by at least three different names, depending on the source.) I was not disappointed: *The Collated List* provides us with the first official mention of our target mountain's name: Lambert Gamma (Γ).

German astronomer Johann Henrich Mädler assigned that name to the mountain in his and Wilhelm Beer's *Mappa Selenographica* (1836), which was then the universally accepted standard in selenography. Mädler's convention was to name isolated lunar peaks wtih the name of a nearby crater followed by a Greek letter. In his 1876 book *The Moon and the Condition and Configurations of Its Surface*, Edmund Neison gives a wonderful description of Lambert Γ: "Owing to its curved form, the mountain Γ … appears at times like a crater … Occasionally this peak glitters on the terminator in a very striking manner."

Lambert Γ's uppercase Gamma was changed to the lowercase Lambert γ in the 1935 *Named Lunar Formations*, the first official list of IAU nomenclature. When the IAU discontinued the use of Greek letters for elevated features in 1973, Lambert γ was renamed Mons Undset, in honor of Sigrid Undset, a Danish-born Norwegian novelist who won the 1928 Nobel Prize in literature.

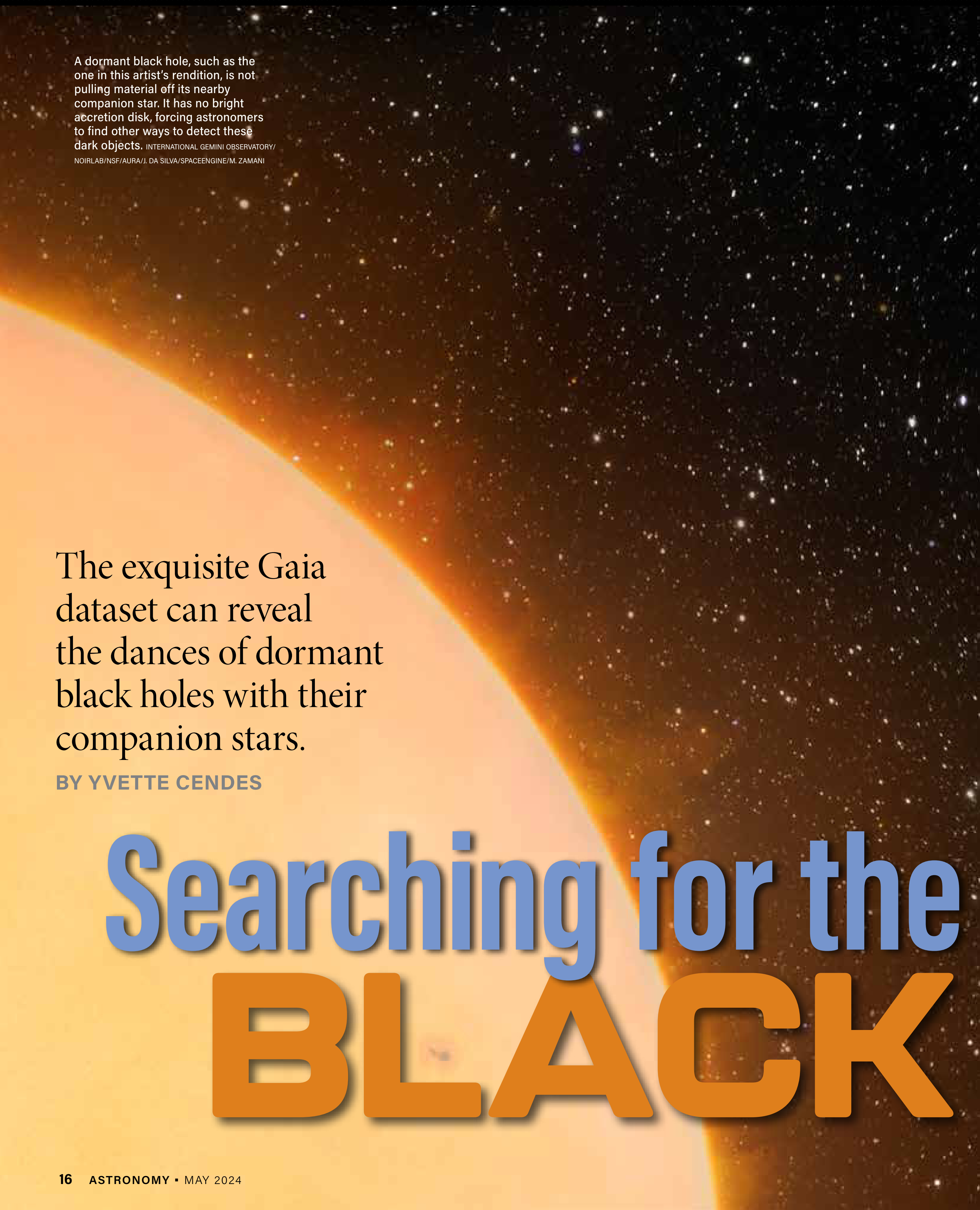
Unfortunately, when Undset's name was applied to her lunar mountain in the 1973 *Lunar Topographic Orthophotomap Series* — the first comprehensive and continuous mapping based on photographs from Apollo 15, 16, and 17 — her name was misspelled "Undest." Rather than fixing the mistake, the IAU stripped the mountain of its name, leaving it in nomenclature limbo.

Most references today lean toward unofficially renaming the mountain Lambert γ, but why take away an honor bestowed upon a great woman just because of a typo? (For what it's worth, in 1985 the IAU named a crater on Venus in Undset's honor — but we cannot visually admire this sight.)

My observation of Mons Undset occurred at lunar colongitude 18.3°, which must have been one of the occasions Neison mentioned, when the mountain appears as a striking site near the terminator. But Mons Undset is so unusual at times that observers have mistaken it for a lunar transient phenomenon. So, it's a sight worth pursuing — and remembering.

In her book *Christmas and Twelfth Night*, Undset writes, "Let us remember that He has given us the sun and the moon and the stars." And lest we forget, we gave her a mountain on the Moon. As always, send your thoughts to sjomeara31@gmail.com.

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

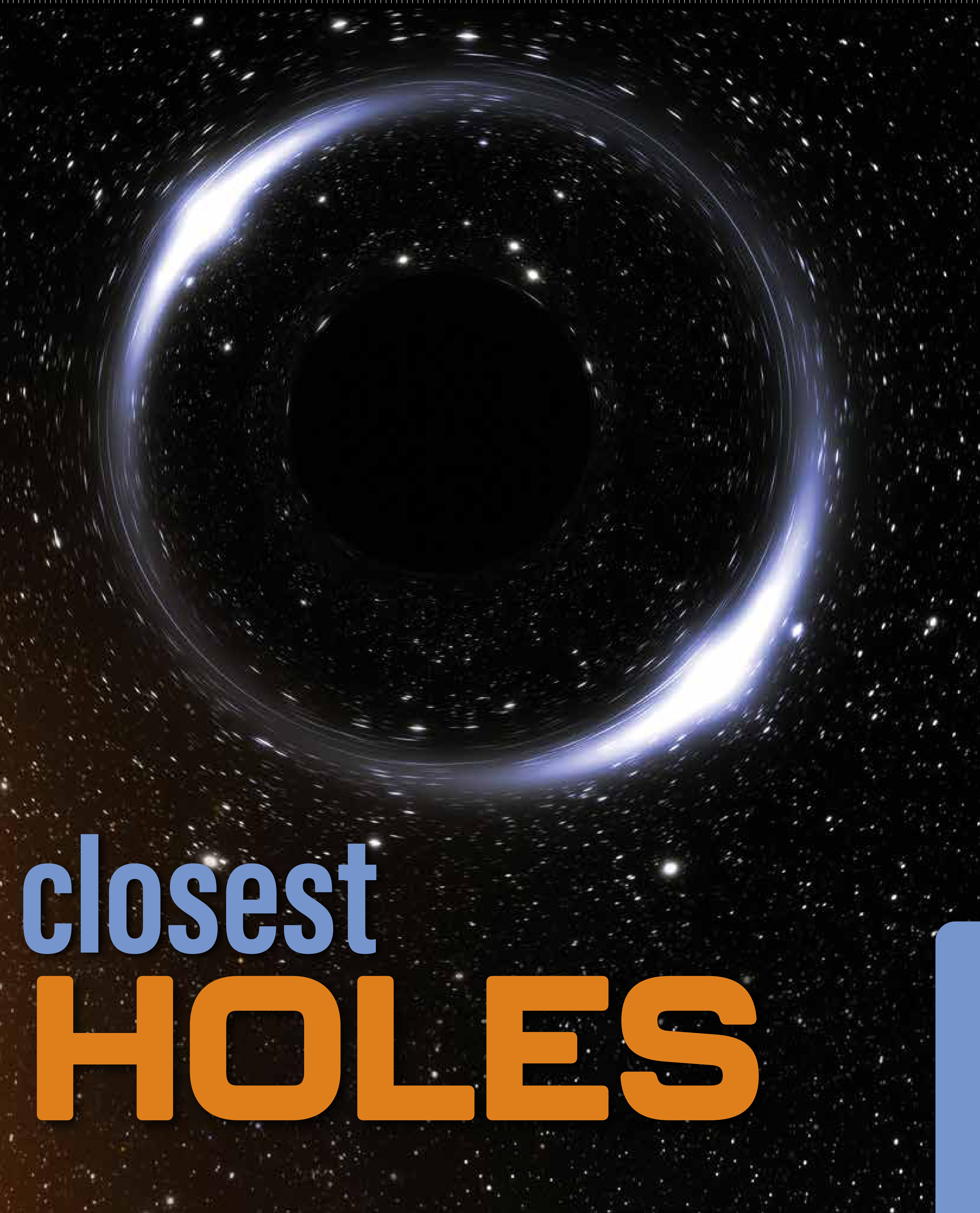


A dormant black hole, such as the one in this artist's rendition, is not pulling material off its nearby companion star. It has no bright accretion disk, forcing astronomers to find other ways to detect these dark objects. INTERNATIONAL GEMINI OBSERVATORY/NOIRLAB/NSF/AURA/J. DA SILVA/SPACEENGINE/M. ZAMANI

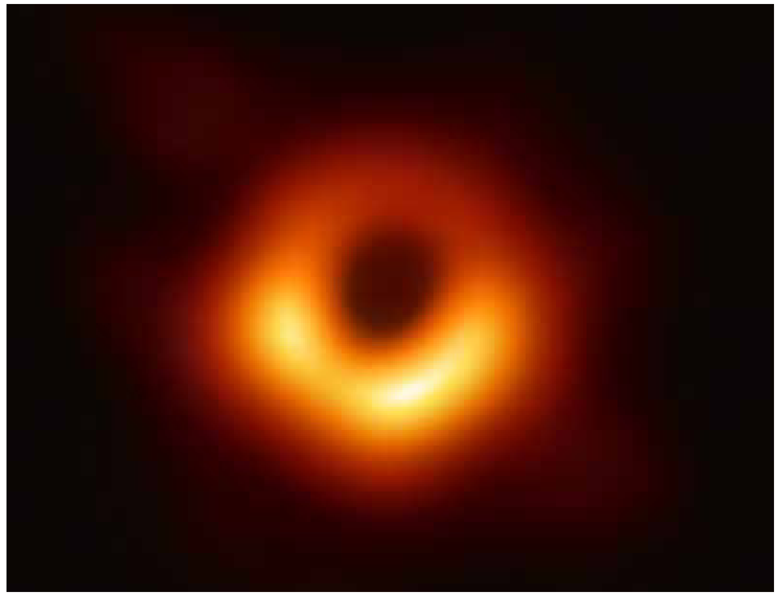
Searching for the BLACK

The exquisite Gaia dataset can reveal the dances of dormant black holes with their companion stars.

BY YVETTE CENDES



closest HOLES



After two years of dedicated work, the Event Horizon Telescope team produced the remarkable, first-ever image of the black hole at the center of galaxy M87 in 2019. The black hole weighs about 6.5 billion solar masses and feeds on a swirling disk of glowing matter — the bright region encircling the dark center. EVENT HORIZON TELESCOPE

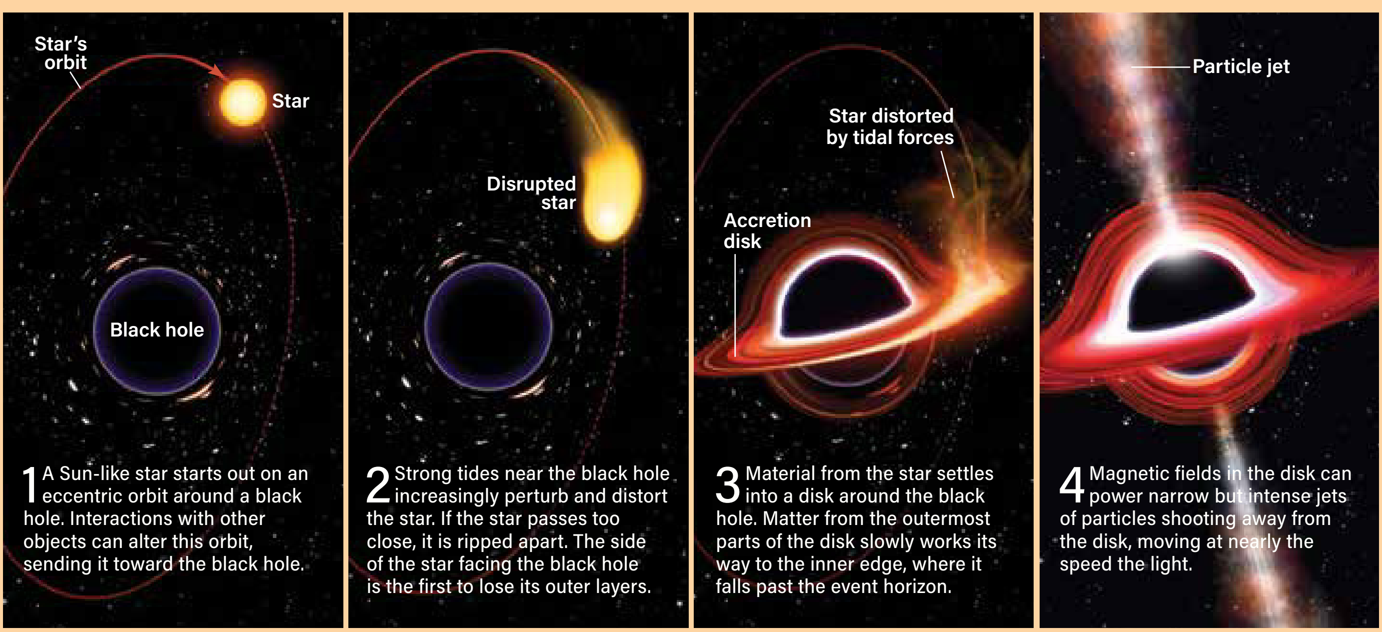
IN A UNIVERSE FULL of fascinating and exotic phenomena, few objects challenge the imagination quite like black holes.

Discovering new black holes, however, is no easy feat — where do you even begin to look for them? Recent research has found a new category that includes the closest black holes we know of.

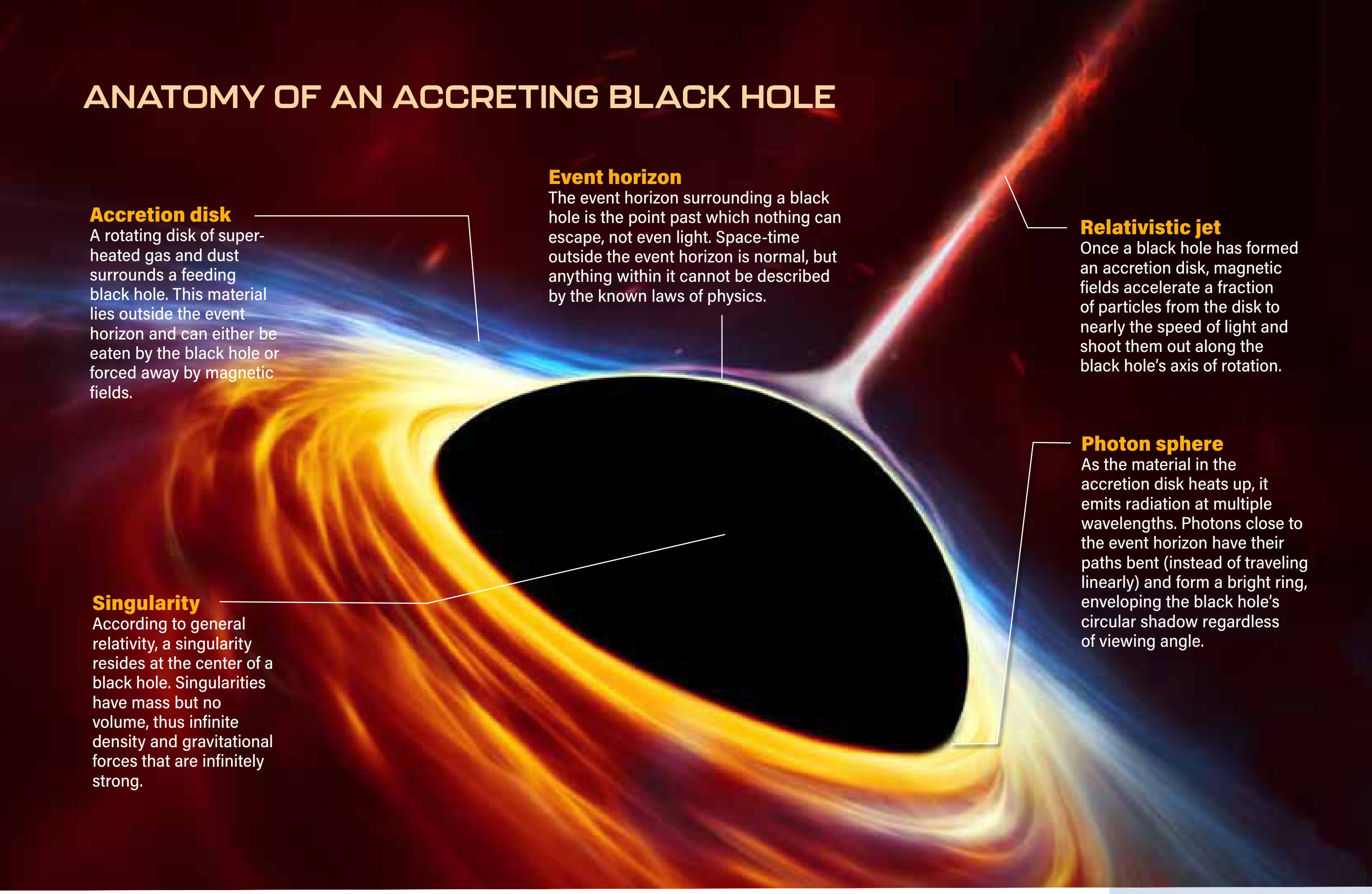
As an astronomer, I have studied black holes for many years, and know firsthand that finding new ones isn't as simple as one would like. The first thing to consider is that, well, they're *black*: Their gravity is so strong that even light — the fastest thing in the universe — cannot escape the event horizon, or point of no return. This means astronomers can only detect black holes through their interactions with other nearby objects. For example, we know a supermassive black hole called Sagittarius A* (Sgr A*) lurks in the center of our Milky Way Galaxy, weighing more than 4 million times the mass of the Sun. Astronomers first got an idea of the black hole's existence by watching stars zooming around an invisible object there — a result striking enough to win the 2020 Nobel Prize in physics. Two years later, in May 2022, members of the Event Horizon Telescope announced they had successfully linked radio telescopes around the globe to photograph Sgr A*. The picture shows a spectacular ring of hot plasma just outside the event horizon itself, created by

FORMING AN ACCRETION DISK

Accretion disks are hot, bright disks of swirling gas and dust surrounding black holes. They emit across the electromagnetic spectrum — from high-energy gamma rays and X-rays, through visible and infrared light, to radio waves — and give off the light we see from black holes. Astronomers study accretion disks in order to understand more about black holes themselves, as well as their environments.



ASTRONOMY: ROEN KELLY



Black holes are among the most mysterious objects in the universe, but researchers have determined some of the main components that make up an accreting black hole. EUROPEAN SOUTHERN OBSERVATORY

the black hole accreting stray gas that wanders too close.

Black holes are the worst hosts

But while our galaxy contains just one supermassive black hole, it plays host to numerous smaller black holes, formed after massive stars (over 18 times the mass of our Sun) collapse at the end of their lives and explode in a supernova. We know of several such black holes specifically in binary systems, thanks to the dance their stellar companions perform. The most famous is the black hole Cygnus X-1 (Cyg X-1), one of the brightest X-ray sources in the sky despite its location some 7,000 light-years away. Cyg X-1 was the first source widely accepted to be a black hole — in fact, astrophysicists Kip Thorne and Stephen Hawking famously made a wager in the 1970s over whether Cyg X-1 was a black hole or not. Thorne was in favor of a black hole and Hawking against. Hawking was happy to concede in the early 1990s once the evidence was clear.

Today, astronomers know Cyg X-1 is a black hole about 21 times the Sun's mass, accompanied by a blue supergiant star orbiting it at just 20 percent the distance between Earth and the Sun. (Astronomers call the average Earth-Sun distance an astronomical unit, or AU.) The blue supergiant has a mass between 20 and 40 solar masses — it, too, will become a black hole someday — and its stellar wind sends a steady stream of particles falling onto Cyg X-1, a process called accretion. It is this process that fuels the bright X-ray emission we see. Several other black holes (and even neutron stars) have also been discovered this way, as material from a close companion accretes onto the compact object, creating a class of objects called X-ray binaries.

X-ray binaries are a special, atypical kind of system. The black hole and the star must be very close for the emission to be detectable. So, what about the binary systems with greater distances between the two objects? And what about the black holes with no companion and thus nothing nearby to accrete? Is there a way to find black holes such as these?

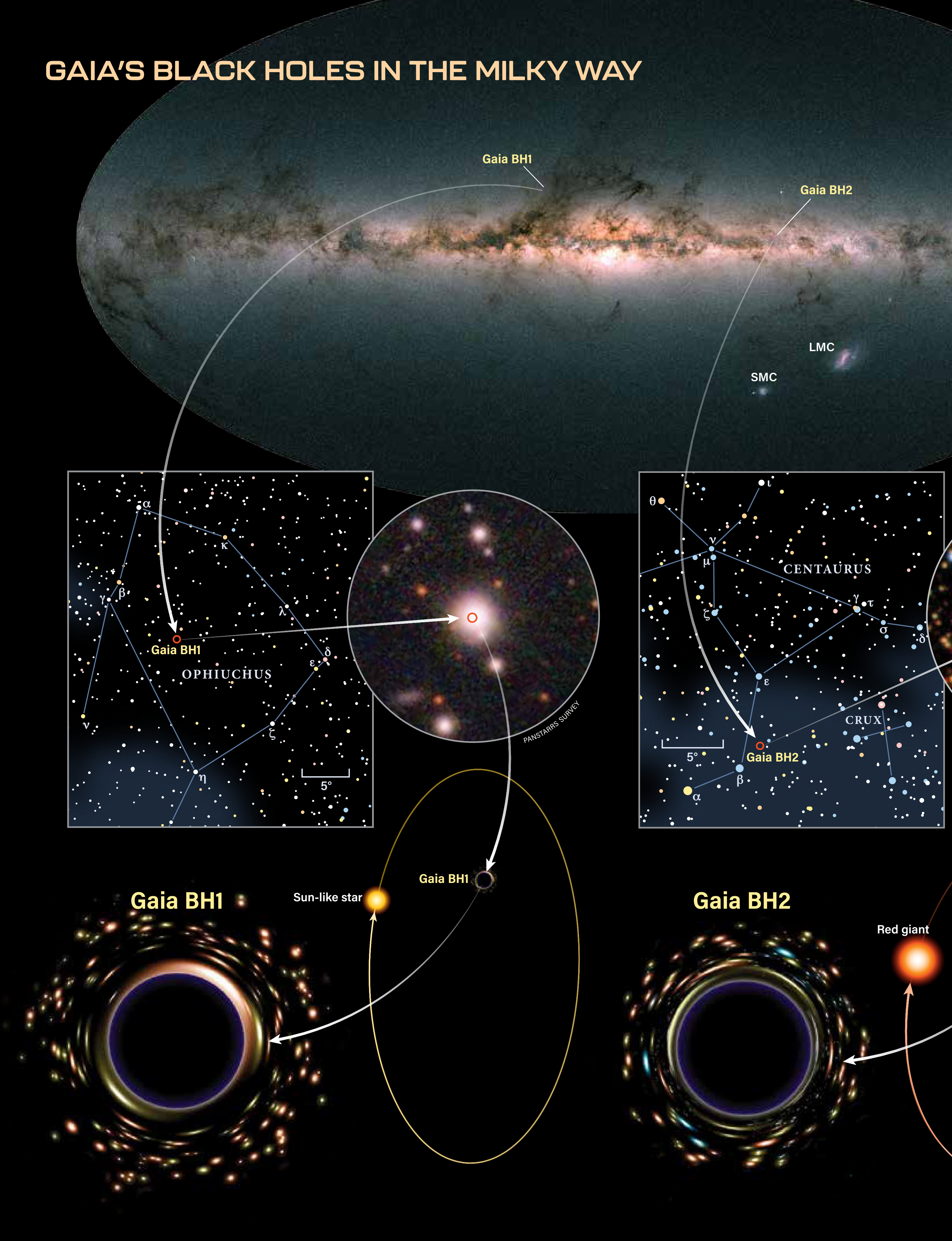
Historically, the answer was no. Lone black holes are, as I said, black. But a few months ago, that answer changed due to the efforts of the European Space Agency (ESA) mission Gaia and an astronomer named Kareem El-Badry.

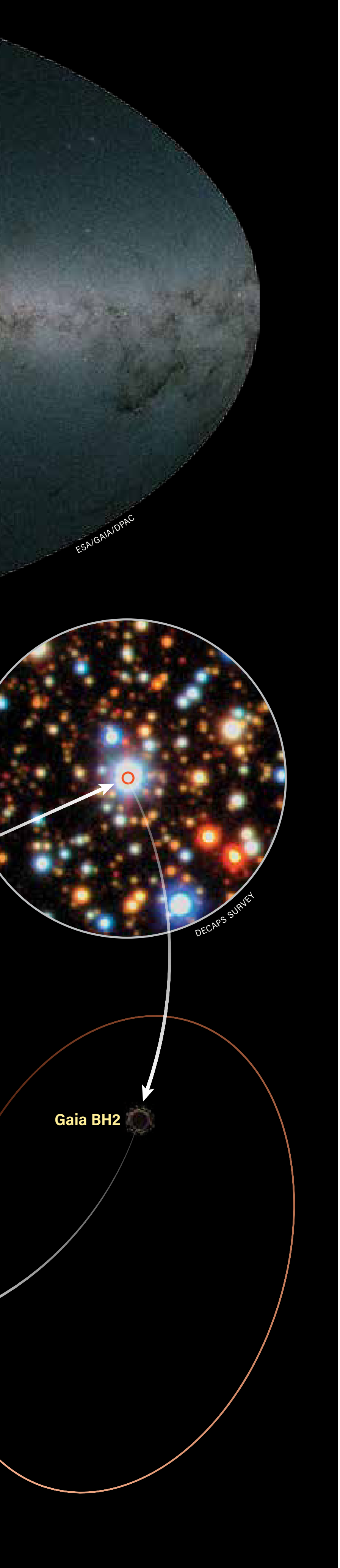
Gaia: Mother of life and precise data

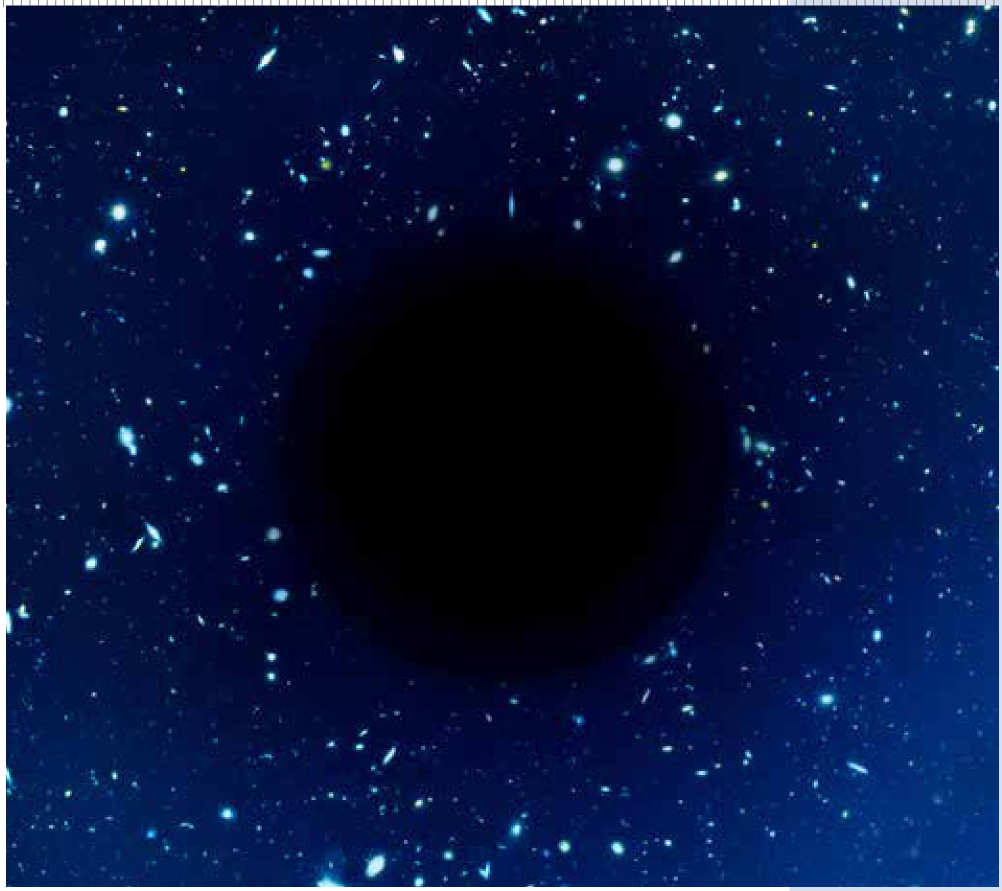
Kareem is currently an assistant professor of astronomy at

FUNNEL AT FAR LEFT: PETER HERMES FURIAN/DREAMSTIME.COM

GAIA'S BLACK HOLES IN THE MILKY WAY







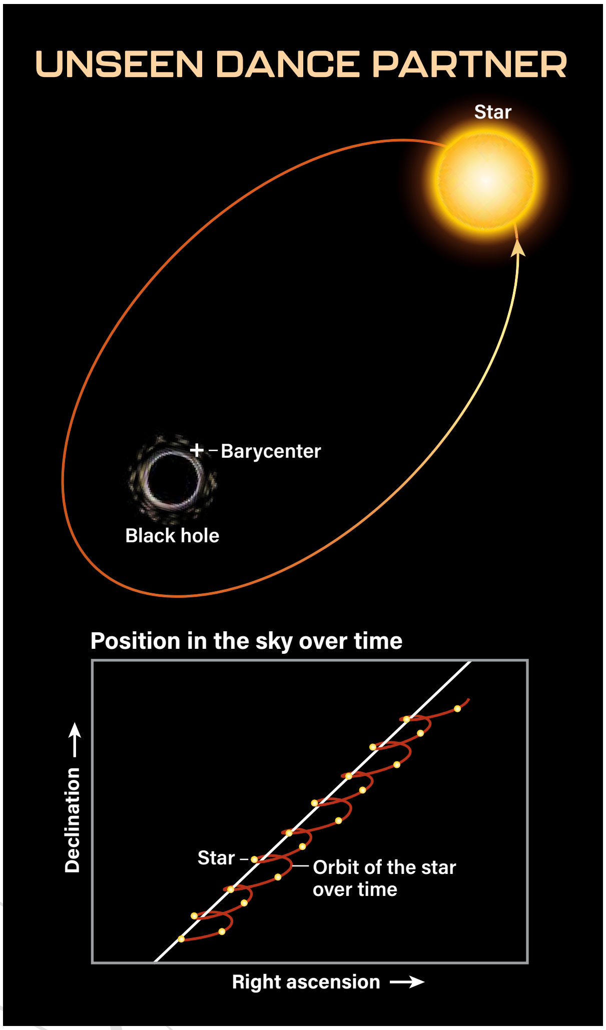
Isolated black holes without accretion disks, like the one in this artist's rendition, lie scattered invisibly throughout the universe. SCALIGER/DREAMSTIME.COM & NASA

Gaia BH1 and Gaia BH2 are the first known members of a new family of dormant black holes. Both objects were detected by the observed "wobble" of their single companion star (each with a different mass) as they orbited an unseen object. *ASTRONOMY:* ROEN KELLY

Caltech. He set out to find black holes while in graduate school at the University of California, Berkeley. "I spent a lot of time during my Ph.D. trying to find nonaccreting black holes, unsuccessfully," he recalls. I first met Kareem when we were both astronomy postdocs at Harvard University, when he already held a reputation in the field as "the black hole debunker" — though this wasn't his intention. This was because Kareem devoted time to confirming allegedly discovered black holes in papers published by other astronomers. But when he examined the data, he found no black holes — in other words, what Kareem did find was that none of these black hole candidates stood up to scrutiny. "They just weren't there, and also the methods [used to identify candidates] weren't optimal," he says.

However, one potential method used for finding black holes *did* catch Kareem's attention. It involved the Gaia satellite. Launched in 2013, Gaia is designed for astrometry, meaning it collects the precise locations of millions of stars. Gaia achieves this by carefully measuring a star's position in the sky every several months. As more time passes, the more precise the data for each star become. Every few years, a new Gaia data release updates previous catalogs to great fanfare from researchers.

When the latest Gaia data release occurred in June 2022 (named Gaia DR3), Kareem was ready: He ran a computer script on the massive new catalog within five minutes of its release. He was looking specifically for stars with a "wobble" in their orbit, caused by an unseen black hole companion. When a star is in a gravitationally bound system with another object, the two (or three, or however many) objects orbit a common center of mass, called the barycenter. Even if the



A star in a binary system with an invisible black hole exhibits an apparent wobble in space if observed long enough. Gaia measures this wobble by continuously scanning in two directions simultaneously, to measure each star's position with an accuracy of about 20 microarcseconds. *ASTRONOMY:* ROEN KELLY

second object is unseen, the star will appear to move back and forth from our point of view on Earth. Once its orbit is established, astronomers can apply Kepler's laws of planetary motion to find the mass of the companion. Astronomers often use this technique to discover exoplanets; however, before Gaia the data weren't nearly precise enough to go after black holes. Today, the precision of Gaia allows astronomers to check the positions of suspected X-ray binary activity for such wobbles, as well as find wobbling stars to investigate as potential X-ray binaries.

Now, with Gaia DR3 in Kareem's capable hands, two stars stood out among the millions of others in the database. And with all the analyses complete, it turns out they are orbiting the two closest black holes to Earth.

Does this puzzle piece belong?

The first star in question is about as Sun-like as they get. It's about the same size and mass as the Sun, lying 1,560 light-years away. The star is bright enough to be easily spotted by a professional telescope. However, the similarities end there. Unlike our Sun, this star is orbiting an invisible, massive companion every six months, at roughly the distance between Mars and the Sun. Follow-up observations to confirm the orbit indicated the unseen object was 10 times the mass of the Sun, making it much more massive than the visible star. And it couldn't be another star because one *that* massive would be brighter and more easily spotted than the first star — plus, nothing else known can be as weighty and yet still dark. The simple process of elimination led to the conclusion that the invisible companion must be a black hole. Kareem named it Gaia BH1: the closest known black hole to Earth.

The discovery made headlines and rocked the astronomical world. Not only is Gaia BH1 three times closer than the now-outranked closest black hole, V616 Monocerotis, but it's a *dormant* black hole, which means that it doesn't pull material from its companion to form an accretion disk. Such an object had never been discovered before. "Because the orbit's as wide as it is, we can look at the evolution of the black hole itself," explains Katie Brevik, an astronomer at Carnegie Mellon University who studies how stars and black holes evolve. "This thing is an amazing gold mine for studying how black holes form."

One unknown factor is how the system formed in the first place. "Binary interactions shrink orbits over time," says Brevik, "and at present we basically think it's impossible to create a black hole like this in isolation." In other words, we don't understand how the Gaia BH1 system (with its black hole and its Sun-like star) came to be because all previously known black holes in binary systems likely evolved by sharing material with their companion while both were still stars. What's more, the Sun-like companion appears completely untouched, with no evidence of any previous close interactions with another star or black hole. "That's a puzzle," Brevik says.

There are a few possibilities on the table: for example, if this were originally a triple system, where one companion was either ejected or swallowed by the black hole. But confirming such a history would be extremely difficult. Alternatively, perhaps the Sun-like star and the star that eventually became Gaia BH1 were both born in the same crowded cluster of stars and got nudged into a common orbit. That's also a tough scenario to prove at this stage, millions of years later.

The discovery led to other

questions as well: Was Gaia BH1 truly dormant? Was it the only object like it out there? That's where I came in.

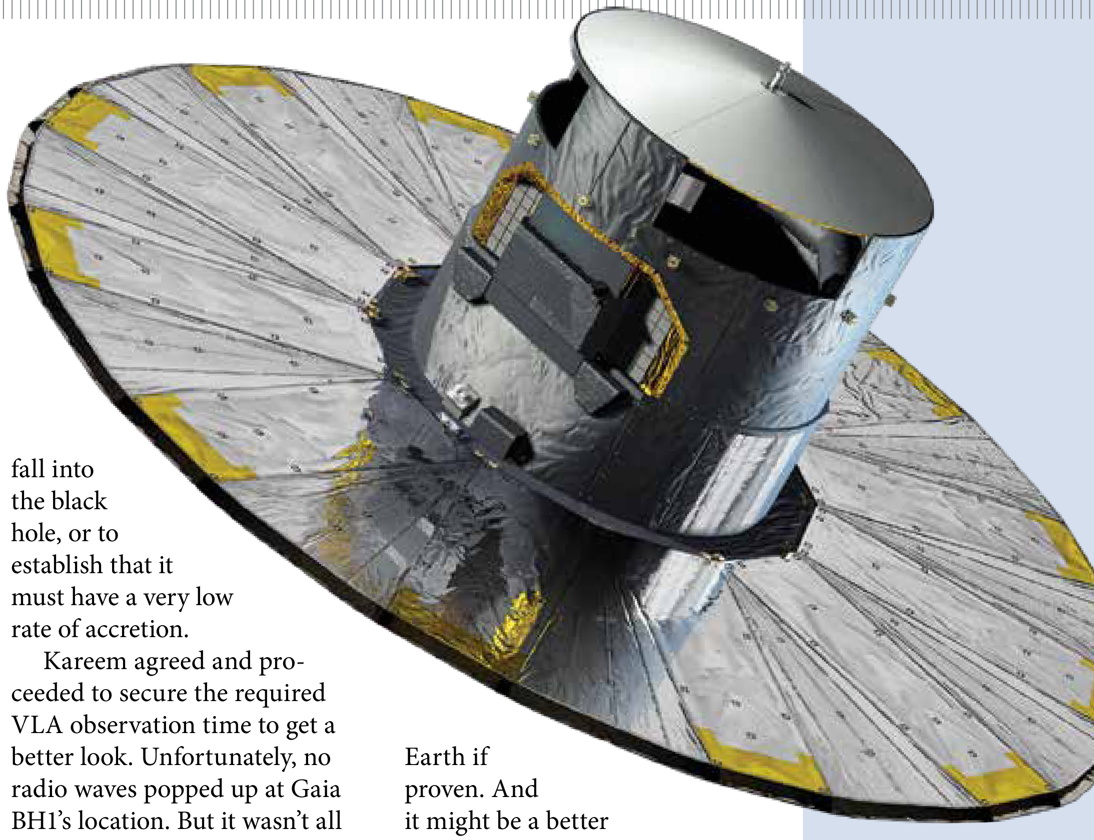
To detect, or not to detect

If Kareem's scientific reputation lies in debunking (and sometimes finding) black holes, my own lies in detecting radio emission from black holes, usually as they tear stars apart and eat them. (See my story in the December 2021 issue, "How to swallow a star.") When the news of Gaia BH1 came out in late 2022, my office at Harvard was down the hall from Kareem's, so I had to run in and ask: Had he or his colleagues considered a dedicated observation of the source with the Very Large Array (VLA) in New Mexico? After all, that Sun-like star has a solar wind of particles, just like that of our own Sun. And at such a "close" distance to us, a few hours of VLA time would likely be enough to either detect emission as these particles fall into the black hole, or to establish that it must have a very low rate of accretion.

Kareem agreed and proceeded to secure the required VLA observation time to get a better look. Unfortunately, no radio waves popped up at Gaia BH1's location. But it wasn't all bad news — a few days later, while commiserating the result, Kareem mentioned: "You know, I have a second candidate in the Gaia data, which would be the second-closest black hole to Earth if proven. And it might be a better bet for detecting radio emission, but it's in the Southern Hemisphere. Interested?"

I don't think anyone who becomes an astronomer would say no to an opportunity like

Follow-up observations to confirm the orbit indicated the unseen object was 10 times the mass of the Sun, making it much more massive than the visible star.



ESA's Gaia mission kicked off a new era of precise measurements for the positions of millions of stars with its first data release in September 2016. Gaia contains two optical telescopes that work with three different instruments to continuously take wide-angle observations. ESA–D. DUCROS, 2013

This vibrant artist's portrayal shows the interaction between the two objects in the Cygnus X-1 X-ray binary system. The black hole (at left) weighs in at 21 solar masses, while its blue supergiant companion star (right) has a mass between 20 and 40 solar masses. NASA/CXC/M.WEISS

BLACK HOLES DON'T SUCK!

One common misconception about black holes is the idea that they are similar to cosmic vacuum cleaners, sucking in and swallowing in everything near them. However, this is not the case: While a black hole contains a lot of mass in a very small space, it doesn't exert any extra force beyond the same gravitation that the Sun, Earth, or any other object with mass has in the universe.

As an example, imagine if the Sun immediately collapsed into a black hole. Our new "black hole Sun" would be the same mass, but just a mile (1.6 kilometers) or so in radius. Amazingly, Earth and all the planets would continue to orbit on the same trajectories as before, undisturbed. It's only if you traveled too close to the black hole that you'd be ripped apart, just as the Sun currently rips apart comets that wander too near. But if you kept your distance there'd be no danger of getting sucked in. *—Y.C.*

NASA/CXC/M. WEISS

The National Radio Astronomy Observatory's VLA is located in the Plains of San Agustin in New Mexico. It is composed of 27 active antennas that can gather cosmic radio waves billions of times fainter than radio broadcast waves on Earth.
BETTYMAYA FOOTT, NRAO/AUI/NSF

FLORIS LOOIJESTEIJN

SARA TABIN

Yvette Cendes (top) is a postdoctoral fellow specializing in supernovae and TDEs. Kareem El-Badry (bottom) is an assistant professor of astronomy at Caltech studying binary stars. They met while at the Center for Astrophysics | Harvard & Smithsonian in Cambridge, Massachusetts.

that. Kareem filled me in on the details: At 3,800 light-years away, Gaia BH2 is farther than Gaia BH1. It lies 5 AU from its binary star companion (roughly the distance from the Sun to Jupiter), which means one orbit takes 3.5 years to complete. However, as luck would have it, the pair would approach each other most closely (known as periastron) in February 2023. And what's more, the star in this case is a red giant. Our own Sun will someday become a red giant as it begins to run out of hydrogen in its core, swelling up, cooling off (which turns it red), and developing a much stronger stellar wind. So, Gaia BH2 might be farther from Earth than Gaia BH1, but the star's stronger stream of particles made it a far better bet that we'd detect emission from accretion onto the black hole. And if we still didn't detect anything, it would mean we'd confirmed a new category of black holes that we have no chance of observing directly with current technology.

Emergency observing proposals were written and approved for the MeerKAT telescope in South Africa and our observation was scheduled for periastron. Before I knew it, it was a snowy winter weekend in New England and I woke up to an email saying the observation had been successful. Now the *real* fun could begin!

There are several reasons I chose to become an astronomer. But each time I get a fresh observation, only one dominates my mind: that instant where, after impatiently waiting for a data transfer from halfway around the world, it finishes and you're briefly the only person in the world who knows something new about the cosmos. How do you describe such a significant, soul-filling feeling, especially when the topic is whether we can detect a new type of black hole? It's addictive, I can tell you that much!

When the blank, black patch of pixels showed up on my screen, I wasn't really surprised that it wouldn't be that easy. Not detecting something is never quite as exciting as detecting it, but this time the absence of emission filled me with a wonder on its own. Based on our understanding of black holes and stellar environments, we really should have seen radio emission. The fact that we didn't indicates those stellar wind particles never get close enough to Gaia BH2's event horizon to accrete and generate radio waves, which possibly means something is stopping them. Maybe a strong wind near the event horizon, blowing them away? I excitedly began imagining all the possible reasons for the nondetection.

My mind strayed for a moment to a hypothesized family of black holes we have never directly detected, called isolated, or rogue, black holes. These have no companion at all and an estimated 100 million are thought to silently roam our Milky Way. Might we detect them as they interact with the occasional stray gas and dust? Based on the results from Gaia BH2, not a chance. Deep space is

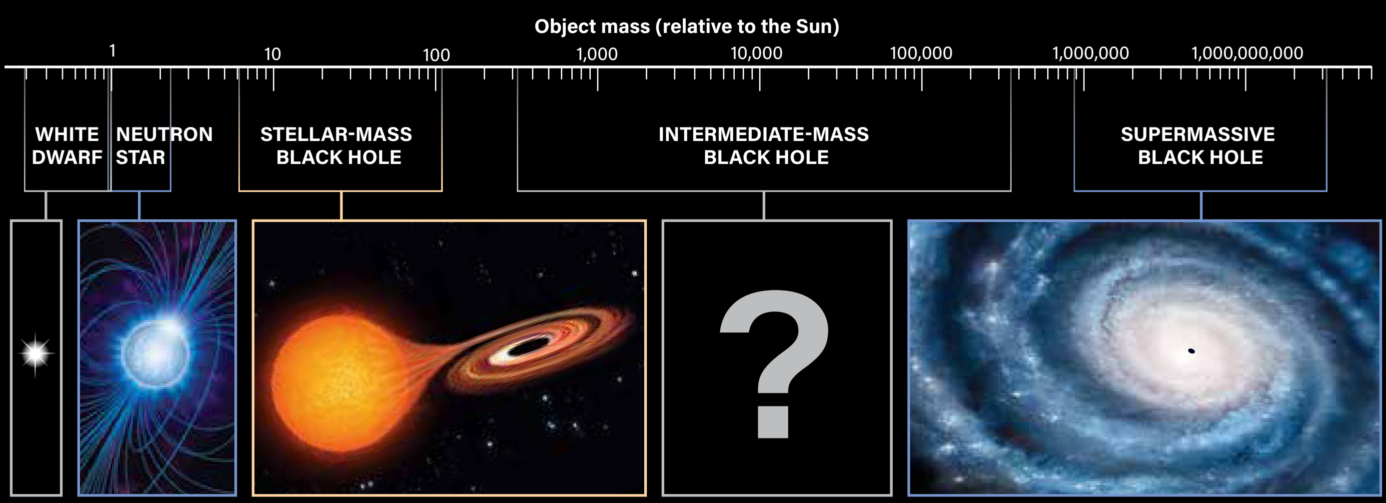
not a perfect vacuum, but it's *far* emptier than the space where the Gaia black holes live. If a black hole is isolated, the lack of emission from Gaia BH1 and BH2 insinuates it's not possible to detect rogue black holes electromagnetically from their accretion and that we still need quite some time until we can confirm their existence, given today's technology. It's a fascinating and terrifying thought straight out of a science-fiction story and brought to life by my radio data.

This new family of black holes may be the darkest we've directly detected yet without seeing X-rays or gravitational waves, but the exciting news is that our studies of them are just the beginning. Gaia's mission isn't nearly over and ESA plans to collect data for ever-more-precise measurements on millions of objects until 2030. In its next data release, scheduled for 2025, we expect dozens more members of this new black hole family to be in the catalog, waiting to be found. And when that does happen, we'll be ready.

Yvette Cendes *is a radio astronomer and will begin as an assistant professor of physics at the University of Oregon in summer 2024. You can visit her website at yvettecendes.com.*

The masses of the densest cosmic objects range from white dwarfs to supermassive black holes. The new class of dormant black holes is believed to lie mostly within the range of stellar-mass black holes. *ASTRONOMY:* ROEN KELLY

MASS IS JUST A NUMBER



A HERO'S

BURIED TREASURE

JWST shows Herbig-Haro 797 to be twice the object astronomers expected. BY RICHARD TALCOTT

WHEN THE JAMES WEBB SPACE TELESCOPE (JWST) opened its eye to the universe in 2022, scientists anticipated getting a whole new view of star formation. The instrument's ability to see infrared light not only would help pierce the dusty veil that too often hides star birth from optical astronomers, but it also would reveal emission from many of the simple molecules that populate stellar nurseries.

Now researchers have harnessed both of these powers to reveal the inner workings of Herbig-Haro object 797 (HH 797), the outflow from a protostar still condensing from the interstellar medium. JWST's exquisite resolution shows that what astronomers previously thought was a single protostar with oppositely directed outflows is actually two protostars, each with its own pair of outflows.

THE LOWDOWN ON HH 797

JWST's target lies in the southwestern corner of open star cluster IC 348. This stellar group, still immersed in its natal cocoon, started forming 2 million to 3 million years ago near the eastern edge of the Perseus molecular cloud complex. The region lies roughly 1,000 light-years from Earth, providing astronomers with a closer look than they can get at most other star-forming regions.

A protostar like the two at the heart of HH 797 has only just begun its journey to stardom. It continues to pull in nearby gas and dust, which forms an accretion disk that lies in the rotating object's equatorial plane. If it eats too much of this material too quickly, the developing star spews the excess out in two jets aligned with the protostar's rotational axis. These outflows carry away angular momentum, slowing the star's spin rate and helping to keep it from flying apart.

The jets themselves travel at hundreds of thousands of miles per hour. When they collide with their surroundings, they create shock waves that excite the interstellar molecules and cause them to emit infrared light. JWST is particularly attuned to picking up radiation from molecular hydrogen and carbon monoxide, creating the glorious details seen in the large image at right.

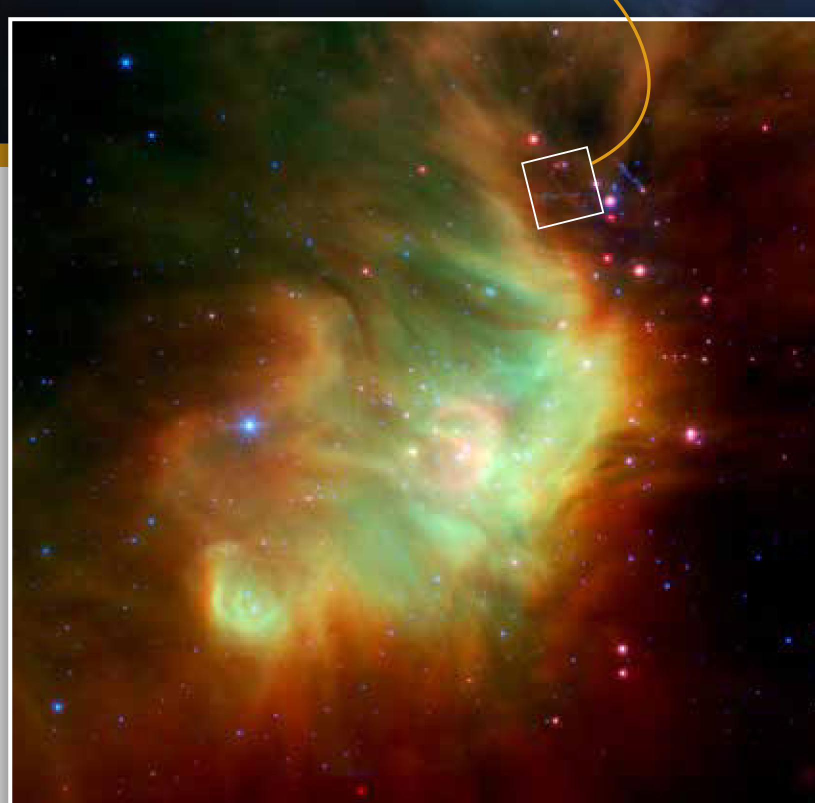
A DEEP DIVE INTO HH 797

The luminous jets from HH 797 dominate the bottom half of the new JWST photograph. Although previous ground-based observations showed little of this detail, they were able to describe the velocities of the molecular gas. The material on the south (right) side moves away from us while that on the north (left) side approaches. Even more intriguing, earlier studies suggested that the jets were rotating, with the west (top) side spinning toward us and the east (bottom) side receding.

JWST revealed the truth: HH 797 comprises two sets of jets that run nearly parallel to one another. Each has its own set of shock waves moving at slightly different speeds, mimicking a single rotating outflow. The jets arise from a double star embedded in the dark gap located about one-third of the way from the right edge to the left edge of the jet. Astronomers estimate that each of these

The exquisite resolution of JWST shows the dual nature of the jets in Herbig-Haro 797 (bottom) along with the fan-shaped nebula LRLL 54361 (top). ESA/WEBB, NASA & CSA, T. RAY (DUBLIN INSTITUTE FOR ADVANCED STUDIES)

INSET: NASA's Spitzer Space Telescope captured this wide-field infrared image of open cluster IC 348 and its related nebulosity. HH 797 lies at the object's southwestern corner. NASA/ESA/J. MUZEROLLE (STSCI)/E. FURLAN (NOAO AND CALTECH)/K. FLAHERTY (UNIVERSITY OF ARIZONA/STEWARD OBSERVATORY)/Z. BALOG (MAX PLANCK INSTITUTE FOR ASTRONOMY)/R. GUTERMUTH (UNIVERSITY OF MASSACHUSETTS, AMHERST)



protostars is only a few thousand years old and eventually will become stars similar to the Sun.

Adding to the JWST scene is the enigmatic object LRLL 54361 near the top of the image. Although this fan-shaped emission nebula also seems to be the creation of a protostar pair, this one releases a burst of light that propagates through the surrounding dust cloud approximately every 25 days.

Contributing Editor **Richard Talcott** *described how to view the Great American Eclipse, part 2, in the April issue.*

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

MAY 2024

Early risers win out

The planetary action moves to the morning sky this month, with several planets lining up. Here, (from bottom left) Mercury, Mars, Jupiter, and Venus stand in line in late 2015; the planetary players this May are Mercury, Mars, Neptune, and Saturn. ALAN DYER

The evening sky loses its last planet early in May, shifting the attention of planetary observers to the morning. Try to glimpse Jupiter before it's lost in the Sun's glow soon after sunset. Meanwhile, Mercury, Mars, Saturn, and Neptune are up before sunrise. A waning crescent Moon joins the group twice during May, adding beauty to the scene.

Jupiter sets within an hour of the Sun on May 1 and earlier each successive evening, limiting its observability. On the 1st it shines at magnitude –2, bright enough to be visible in early twilight. At the onset of civil twilight, when the Sun is 6° below the horizon, Jupiter stands 4.5° high. It's not a great altitude to see visible details on the cloud tops, but for eager

OBSERVING HIGHLIGHT

NEPTUNE and **MARS** start the month just 1.7° apart on May 1.

followers of the solar system's largest planet, twilight is still a nice time to view it. The Galilean moons will be visible, although from time to time one or two are hidden behind the planet or transiting in front.

Jupiter is lost quickly and reaches conjunction with the Sun May 18. The gas giant will reappear in the morning sky next month.

Moving to the pre-dawn sky, first up is **Saturn**, rising before

— Continued on page 34

RISING MOON | Building by pounding

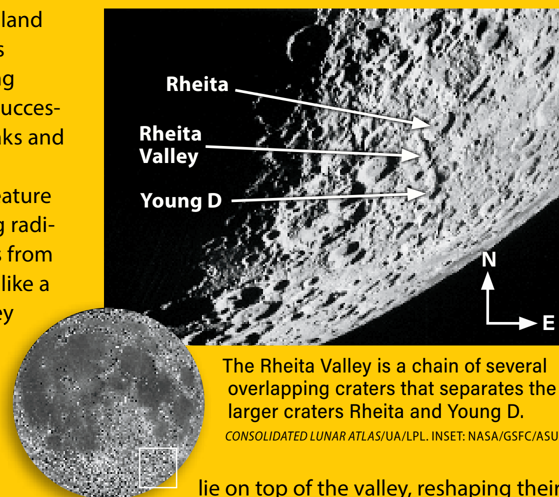
SECOND ON LISTS of lunar valleys is Rheita. The more famous Alpine Valley was created when the crust pulled apart, allowing the land to collapse. In contrast, the Rheita Valley is understood to be a nice line of overlapping craters where each impactor fell in rapid succession, obliterating the standard central peaks and rims of the ones formed just before.

Around any young and large impact feature you can find several crater chains pointing radially away from its center, formed as debris from the excavation shoots out in linear sprays like a spoke on a bicycle wheel. The Rheita Valley is the widest such chain, implying that the original impact must have been rather large. It was: Mare Nectaris lies not far to the north.

With a bit of practice and an eye for detail, you can tell that the Rheita Valley is neither the freshest nor oldest feature in the southeastern quadrant of the Moon. On the northeastern flank, note a couple of chopped-off circles. Those must have come before — an idea confirmed by the worn-down appearance of their rims and floors, a consequence of long-term pounding. And Rheita Crater to the northeast and Young D at the south end obviously arrived later because their forms are sharper and lie on top of the valley, reshaping their parts of it.

Sunrise over the Rheita Valley has occurred by the 11th, but the view on the 12th will be closer to that in the accompanying image. Take another look on the 24th and 25th, when the lighting will be reversed under a setting Sun. This is when you can readily see that the valley points right back to its origin at Mare Nectaris, the Sea of Nectar — a fanciful name for a lake of lava!

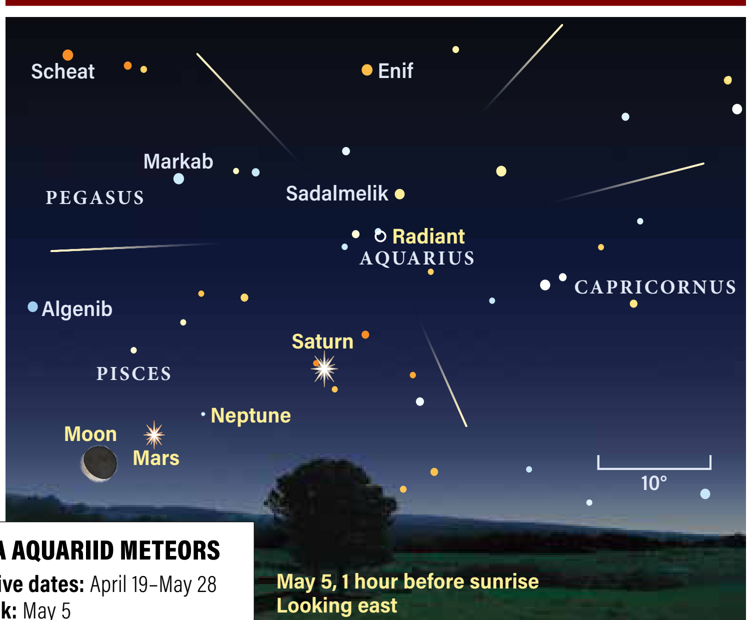
Vallis Rheita



The Rheita Valley is a chain of several overlapping craters that separates the larger craters Rheita and Young D. *CONSOLIDATED LUNAR ATLAS*/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Improved prospects

Eta Aquariid meteor shower



The Eta Aquariids may give us a small burst of activity this year on May 3. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

ETA AQUARIID METEORS

Active dates: April 19–May 28
Peak: May 5
Moon at peak: Waning crescent
Maximum rate at peak: 50 meteors/hour

THIS IS THE YEAR to watch the Eta Aquariid meteor shower. In addition to a favorable Moon (New Moon occurs May 7), Earth passes very close to a stream of debris ejected by Halley's Comet (the shower's parent object) about 3,000 years ago.

The shower is active from April 19 through May 28 and peaks on May 5. The radiant lies near Zeta (ζ) Aquarii and rises at 2:30 A.M. local daylight time in the continental U.S., reaching an altitude of 20° two hours later. This gives most observers a fine opportunity to watch for an hour or two before morning twilight. The predicted peak zenithal hourly rate is 50 meteors per hour but since the radiant is not overhead, observed rates are normally a dozen per hour.

However, this year could see an increase in rates the morning of May 3. Material left by Halley's Comet is affected by various gravitational resonances and the threads of debris wander like a silk scarf in a breeze. On the 3rd, Earth passes through a thread left by the comet in 985 B.C.E., potentially leading to more and brighter meteors. But like predicting the number of snowflakes in a snowstorm, such calculations are difficult and reality can vary greatly. One thing is for sure: It's worth observing a few days prior to the peak. If you do see a rise in the number of meteors, you're seeing the result of a passage of Halley's Comet some 3,000 years ago. How cool would that be?

STAR DOME

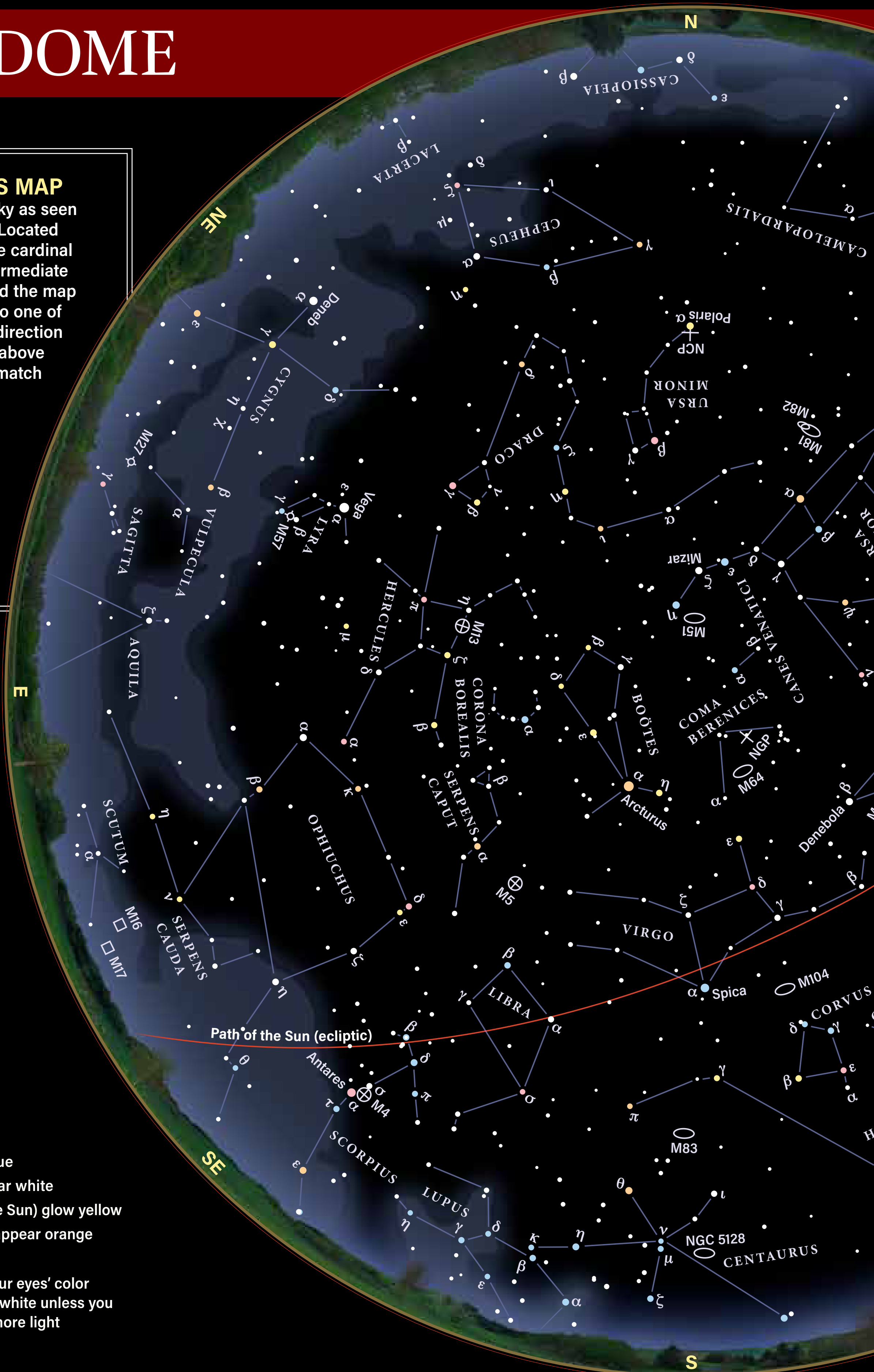
HOW TO USE THIS MAP

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:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth



MAP SYMBOLS

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

STAR MAGNITUDES

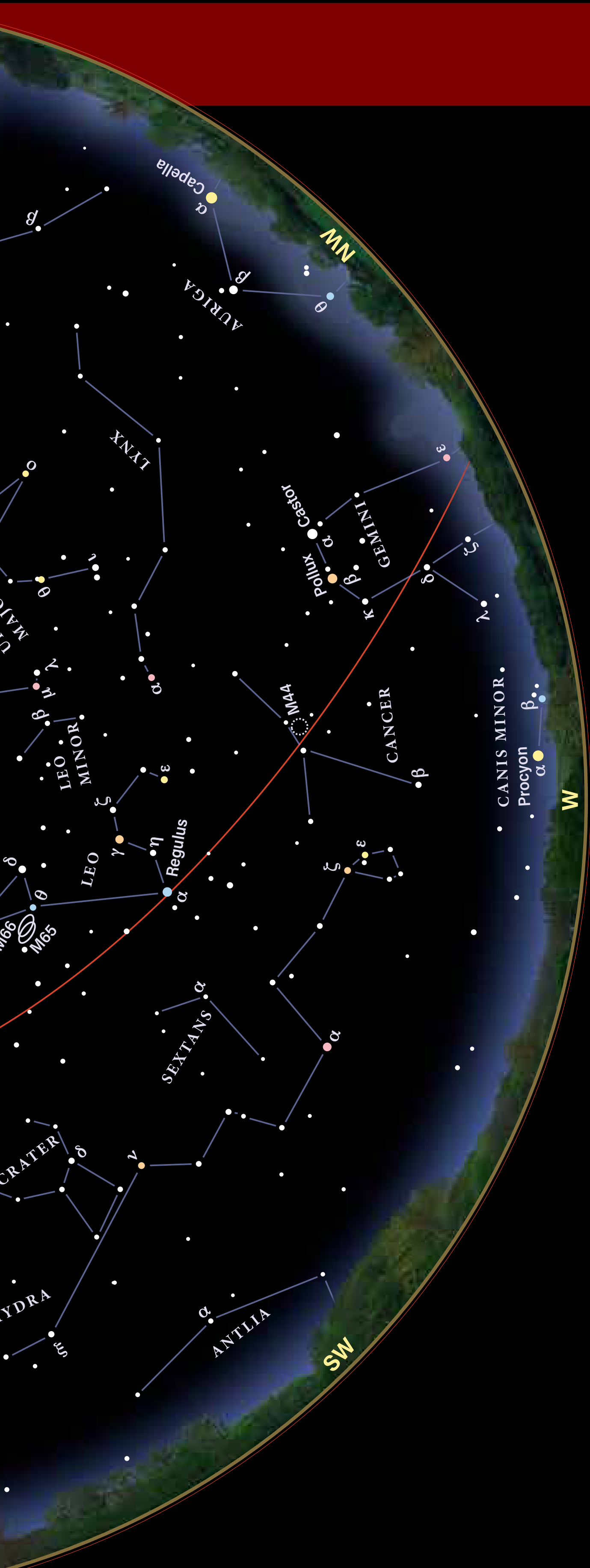
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

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

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



MAY 2024

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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

CALENDAR OF EVENTS

1 Last Quarter Moon occurs at 7:27 A.M. EDT

3 The Moon passes 0.8° south of Saturn, 7 P.M. EDT

Pluto is stationary, 11 P.M. EDT

4 The Moon passes 0.3° south of Neptune, 3 P.M. EDT

The Moon passes 0.2° north of Mars, 10 P.M. EDT

5 Eta Aquariid meteor shower peaks

The Moon is at perigee (225,659 miles from Earth), 6:04 P.M. EDT

6 The Moon passes 4° north of Mercury, 4 A.M. EDT

7 New Moon occurs at 11:22 P.M. EDT

8 Mars is at perihelion (128.4 million miles from the Sun), 7 A.M. EDT

9 Mercury is at greatest western elongation (26°), 6 P.M. EDT

13 Uranus is in conjunction with the Sun, 5 A.M. EDT

15 First Quarter Moon occurs at 7:48 A.M. EDT

16 The Moon passes 1.1° north of asteroid Juno, 9 A.M. EDT

Dwarf planet Ceres is stationary, 7 P.M. EDT

17 The Moon is at apogee (251,432 miles from Earth), 2:59 P.M. EDT

18 Jupiter is in conjunction with the Sun, 3 P.M. EDT

19 Asteroid Pallas is at opposition, 11 A.M. EDT

23 Full Moon occurs at 9:53 A.M. EDT

The Moon passes 0.4° north of Antares, 11 P.M. EDT

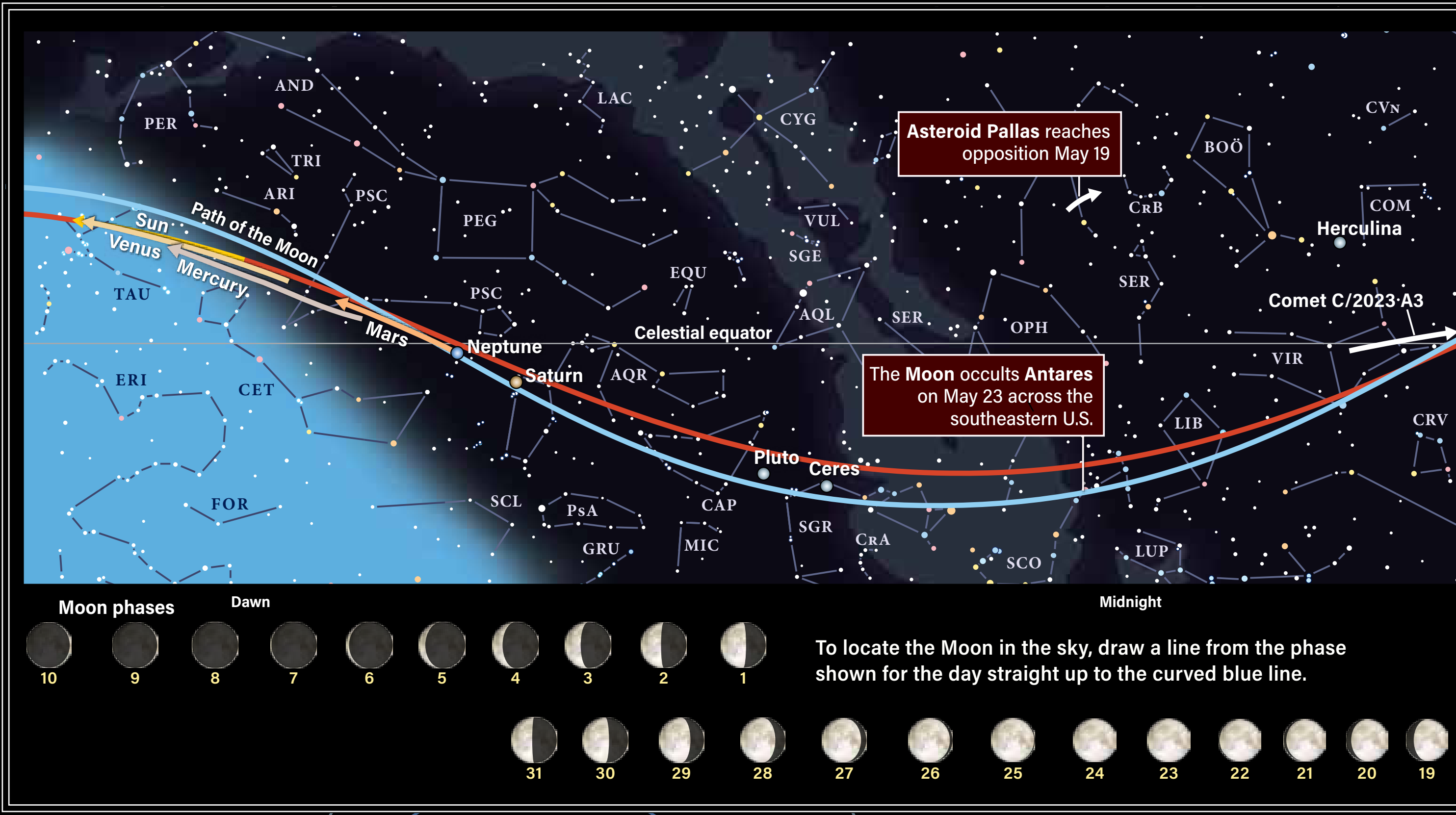
27 The Moon passes 0.9° south of dwarf planet Ceres, 1 A.M. EDT

30 Last Quarter Moon occurs at 1:13 P.M. EDT

31 The Moon passes 0.4° south of Saturn, 4 A.M. EDT

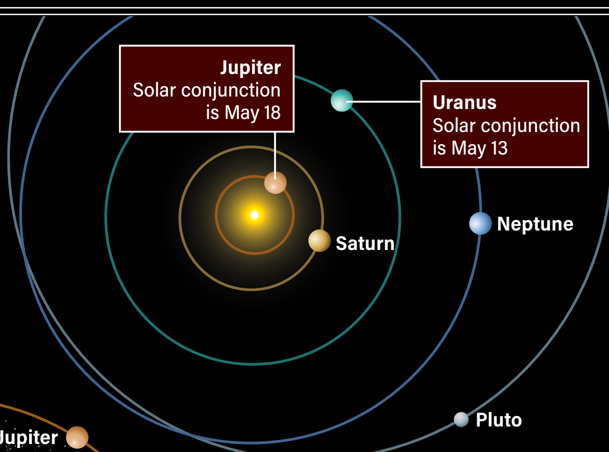
The Moon passes 0.02° south of Neptune, 11 P.M. EDT

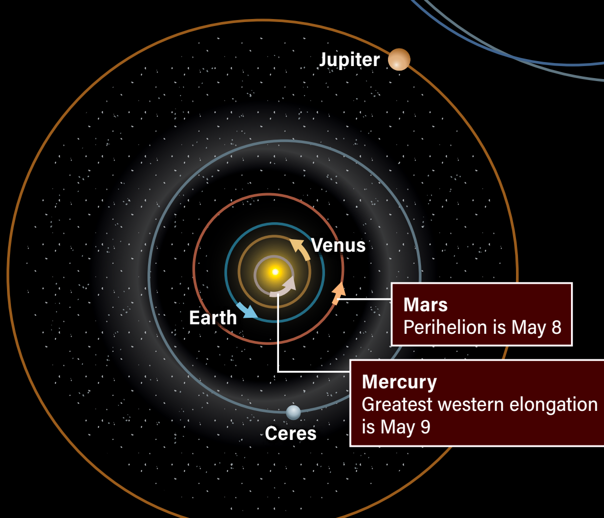
PATHS OF THE PLANETS



THE PLANETS IN THEIR ORBITS

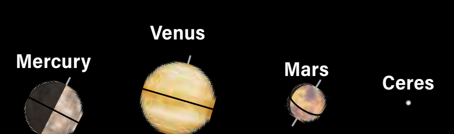
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

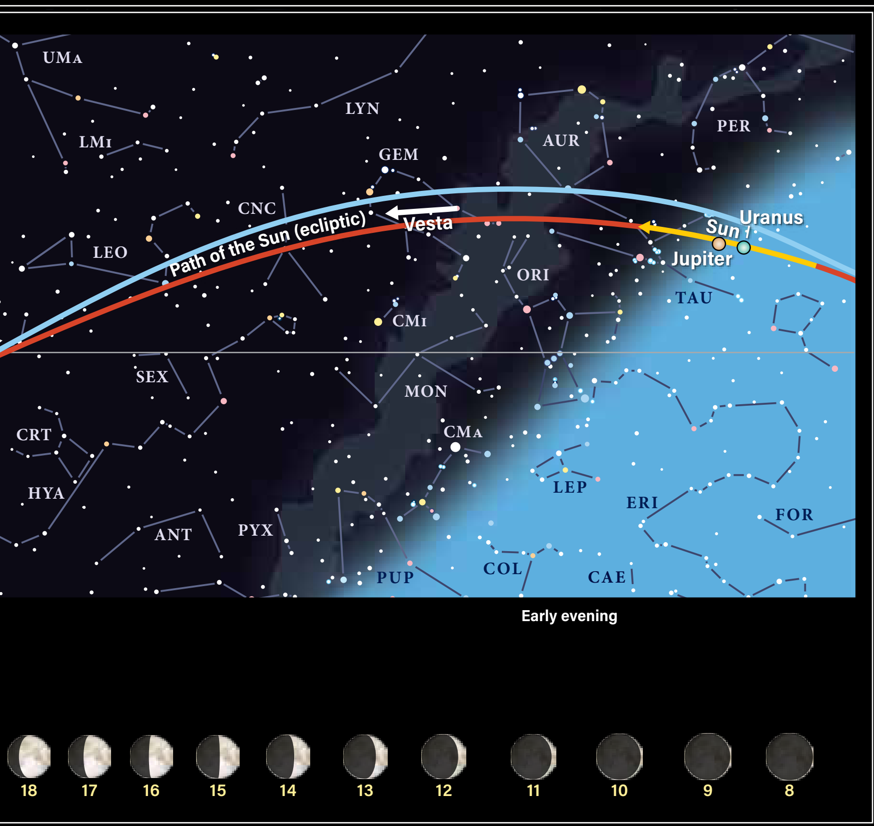
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	May 15	May 15
Magnitude	0.3	–3.9
Angular size	7.4"	9.7"
Illumination	50%	100%
Distance (AU) from Earth	0.911	1.723
Distance (AU) from Sun	0.439	0.723
Right ascension (2000.0)	1h51.6m	3h06.2m
Declination (2000.0)	8°05'	16°37'

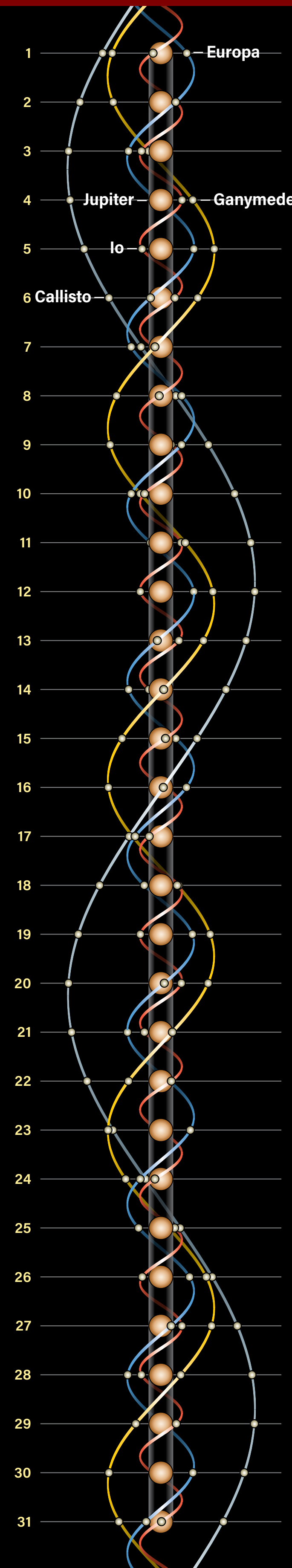
This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

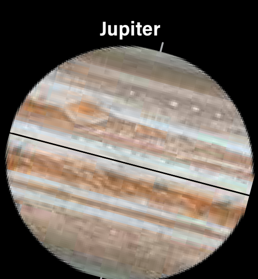
MAY 2024

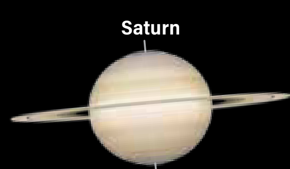


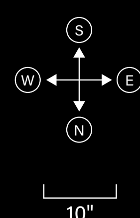
JUPITER'S MOONS

Dots display positions of Galilean satellites at 10 P.M. EDT on the date shown. South is at the top to match the view through a telescope.





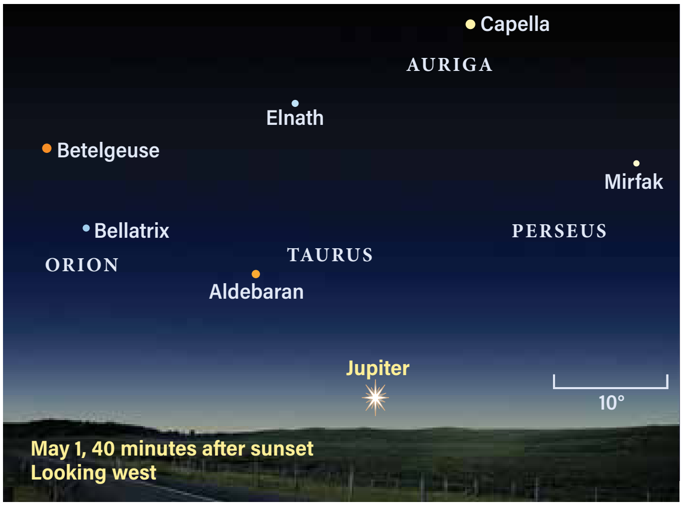




MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
May 15	May 15	May 1	May 15	May 15	May 15	May 15
1.1	8.3	–2.0	1.0	5.9	7.8	15.2
4.9"	0.6"	32.9"	16.5"	3.4"	2.2"	0.1"
93%	98%	100%	100%	100%	100%	100%
1.924	2.186	5.988	10.051	20.602	30.463	34.614
1.382	2.865	5.011	9.699	19.592	29.900	35.014
0h41.2m	19h34.0m	3h26.4m	23h16.5m	3h22.1m	23h58.2m	20h18.9m
3°05'	–25°04'	17°59'	–6°37'	18°14'	–1°33'	–22°46'

 — *Continued from page 29*

Gone soon



Jupiter shares the sky with the first few bright stars after sunset, but you'll need to catch it early in the month. Uranus (not shown) lies just to Jupiter's lower right; it is too dim and close to the Sun's glow to view.

4 A.M. local daylight time on the 1st for northern temperate latitudes. You'll find Saturn 7° northeast of a 24-day-old waning crescent Moon on the morning of May 3.

Saturn lies within a degree of Phi (ϕ) Aquarii, a 4th-magnitude star best seen in binoculars as the sky starts brightening soon after they rise. Regular observers will recognize this star: It was a guide to finding Neptune a few years ago.

The planet climbs higher before dawn as the month progresses. On May 1 it stands 11° high an hour before sunrise; this increases to a respectable 26° by the 31st. The waning crescent Moon has returned to the vicinity on May 31, now 23 days old and less than 2° from Saturn. On this day, the Moon occults Saturn for observers in southern South America and parts of Africa.

The ringed world is dramatic through a telescope. Its disk spans 16" and the rings just less than 40". This is the last year before the ring-plane crossing, so the rings appear beautifully slender, currently tilted 3° to our line of sight.

Neptune is difficult to spot at magnitude 7.8, low in the eastern sky as twilight begins. It lies in Pisces about 5° southeast of Lambda (λ) Piscium. On May 1, Neptune and Mars are only 1.7° apart. Mars is easy to spot at magnitude 1.2.

Keen observers might find the ice giant about 5° northeast of the waning crescent Moon on May 4. By the end of the month, the planet is 17° high about 90 minutes before sunrise, placing it in easier range for telescopes and binoculars.

Returning to **Mars**, its tiny 5"-wide disk reveals very little and the planet remains low in the eastern sky. It crosses southern Pisces, spends a few days in the second week of May cutting the corner of Cetus the Whale, then returns to Pisces for the remainder of the month. The Red Planet ends the month at magnitude 1.1.

Mercury returns to the

Uranus and Venus spend the month too close to the Sun for observation. Jupiter quickly joins them by the middle of May.

WHEN TO VIEW THE PLANETS

EVENING SKY
Jupiter (west)

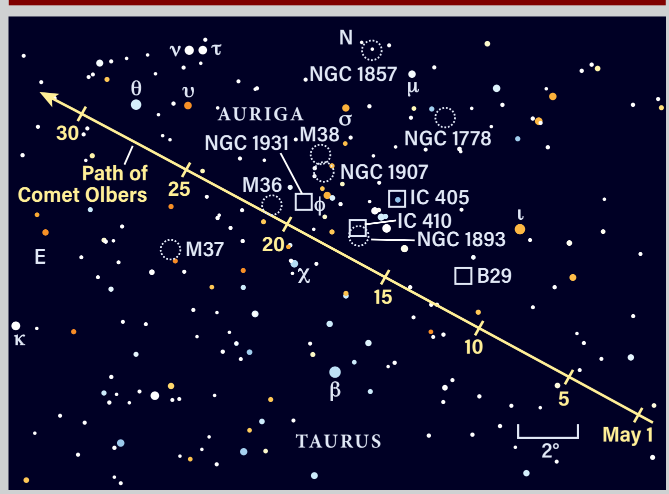
MORNING SKY
Mercury (east)
Mars (east)
Saturn (east)
Neptune (east)

COMET SEARCH | Plenty to see

BE READY at the end of astronomical twilight to catch Comet 13P/Olbers sinking in the northwest. It should be shining at 8th magnitude, comparable to the nearby Crab (M1), the nebula that started Messier on his catalog. Contrast their shapes and profiles. As you sweep between them, enjoy some starless voids: nearby corridors of interstellar dust, some sporting Barnard numbers.

Imagers will delight in the comet's diatomic carbon-green halo as Olbers courses past the hydrogen-red Tadpoles of IC 410 from the 16th to the 18th. The twilight is more of a challenge than the Moon. Catch the comet again on the evenings of the 20th to the 22nd, less than 1° from the splashy star cluster M36.

Comet 13P/Olbers



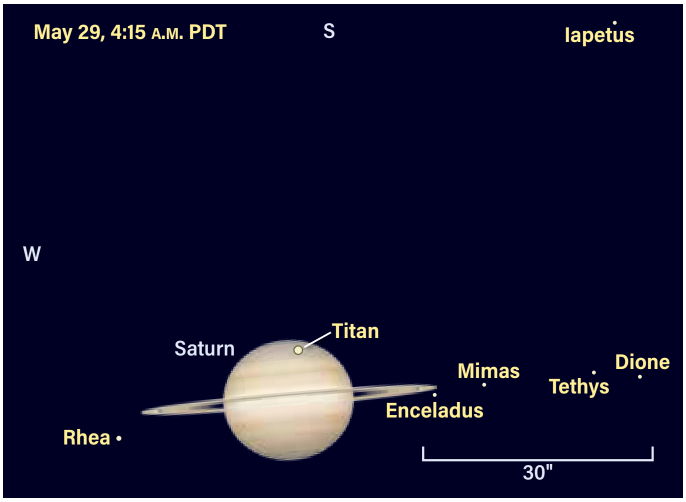
Comet Olbers is passing through a region rich with deep-sky objects for comparison, including M1 (located just south of the area shown here, near Zeta [ζ] Tauri).

Returning every 69.5 years, Olbers never gets closer to the Sun than Earth. It was first seen by Heinrich Olbers in 1815. (This is the same Olbers who famously framed the "Why is the sky dark?" paradox.)

A second comet, C/2021 S3 (PanSTARRS), keeps us company overnight in the first half of May, fading from 8th to 9th magnitude as it crosses the colorful star fields north of Deneb.

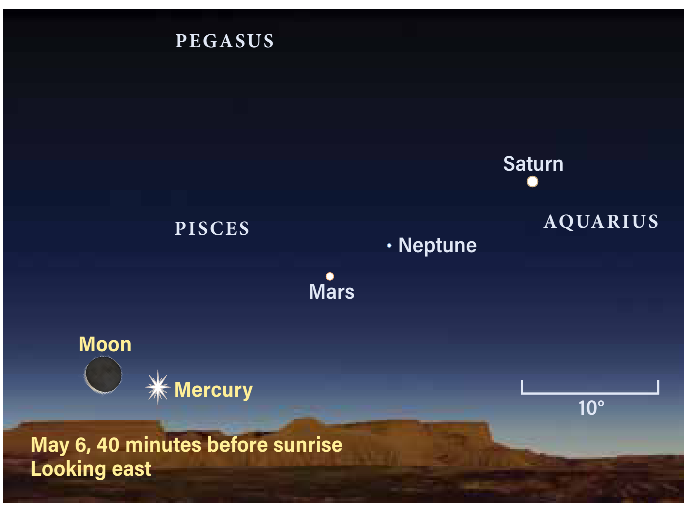
Evening observers south of the equator can savor the potentially naked-eye comet 12P/Pons-Brooks for a few more nights before it fades into binocular range.

Moon crossing



With Saturn's tilt shrinking, transits and occultations of its moons are common. Late in the month, observers in the western half of the U.S. can catch Titan crossing the planet's south polar regions. Iapetus is also part of the scene.

All in line



Mercury is back, now visible in the morning. Use the thin crescent Moon to find the smallest planet as it lines up with several others in the morning sky in early May. Note that Neptune is not visible without binoculars.

morning sky and stands less than 5° from a very thin waning crescent Moon early on May 6. With the sky brightening, look for the slender Moon just 3° high 40 minutes before sunrise, with Mercury to the lower right. Mercury shines at magnitude 0.7 and may be best viewed through binoculars, given the brightening sky.

On May 9 Mercury reaches its greatest western elongation, 26° from the Sun. The low angle of the ecliptic keeps the innermost planet quite low to the eastern horizon, making it much more favorable for observers in the Southern Hemisphere.

Mercury brightens and is magnitude 0 on May 19, when it is 4° high 30 minutes before sunrise. After this, it continues to brighten but maintains a similar altitude each morning when viewed at the same time before sunrise. Mercury reaches magnitude –0.5 by the 28th, when you might glimpse it standing 3° high 30 minutes before sunrise. It's a difficult object to spot, but observers with a clear eastern horizon — and in particular those that live at higher altitudes — have a chance of following the planet for another week.

Uranus passes through solar conjunction on the 13th. It is too faint and close to the Sun to view this month.

Venus is also too close to the Sun for observation this month, as it approaches conjunction with the Sun in mid-June.

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

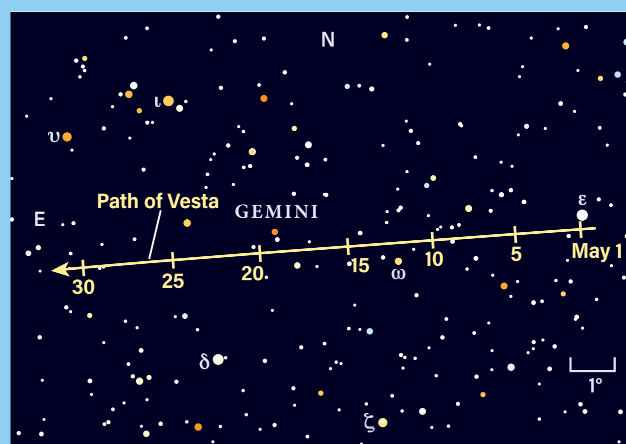
LOCATING ASTEROIDS | Crossing the Twins

FREQUENTLY, THE BRIGHTEST and easiest-to-track asteroid through suburban skies is 4 Vesta. Starting May at magnitude 8.3, the main-belt world is falling behind Earth in its orbit so slowly that it barely fades 0.1 magnitude all month. Vesta is typically the second- or third-brightest dot in the field of view, despite crossing in front of the rich winter Milky Way in Gemini.

By comparing star charts to the view in his telescope, Heinrich Olbers (the same guy who found Comet 13P) noted one light out of place, making it the fourth "missing planet" discovered between Mars and Jupiter. Like him, you should make a sketch of the field and return in a night or two to confirm that the interloper has moved. From May 22 to 26, Vesta is almost alone, but several other nights offer the chance to see it shift in a three-hour session as angles in a pattern change: May 1 to 3, 9, 19, 29, and 31.

The glorious crescent Moon, replete with earthshine, passes by on the 11th only 3° to the north, as Vesta lies an apparent Moonwidth north of 5th-magnitude Omega (ω) Geminorum. This time it's worth trying for the lunar conjunction instead of avoiding it.

Bright light



Vesta should be easy to follow this month as it tracks through Gemini the Twins.

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

The Cyclone Global Navigation Satellite System (CYGNSS) is loaded into a thermal and vacuum testing chamber, nicknamed "Deep Space 8," to check the spacecraft's ability to function in space. SWRI

INSIDE AMERICA'S UNSUNG SPACE CENTER

Deep in the heart of Texas, the Southwest Research Institute creates some of the most innovative space technologies.

BY ROBERT REEVES

WHEN WE THINK OF SPACE AND TEXAS, our thoughts jump to Houston and the Johnson Space Center, home of NASA's Mission Control Center, and where the amazing Apollo expeditions and the International Space Station were developed. But Texas has another connection to space.

Nested on a peaceful 1,500-acre campus on the west side of San Antonio, the Southwest Research Institute (SwRI) has been exploring the solar system for the past several decades. It has evolved into a major force in space science and robotics, responsible for some of NASA's biggest success stories. San Antonio's fame is often associated with the Alamo and sports teams, but SwRI is establishing the area as an active hub in the continued investigation of our solar system. During a visit to the campus, I got see some of these advancements firsthand.

UP-AND-COMING RESEARCH

SwRI was founded in 1947 by Tom Slick Jr., the son of a wealthy Oklahoma oil prospector. Slick leveraged his family's fortune to become an adventurer, world explorer, cryptozoology enthusiast, and philanthropist. In 1941, he created the Foundation of Applied Research, which later evolved into the prestigious Texas Biomedical Research Institute. Branching into chemistry and physics, Slick created SwRI, located on the Essar Ranch west of the once sleepy town of San Antonio. Since then, the town has grown into the seventh-largest city in the U.S. (by population), and SwRI has kept pace with that growth. It currently has more than 2.5 million square feet (232,000 square meters) of laboratory, testing, and office space to continue Slick's vision. Of the organization's 3,100 current staff, nearly 500 work in the space-exploration sector, with over 100 at the Solar System Science and Exploration Division in Boulder, Colorado.

SwRI branched into space exploration in the 1960s with projects such as zero-gravity fire extinguishers carried on all Apollo flights, and a body-mass scale used on the first U.S. space station, Skylab.

In the 1970s and 1980s, NASA's Mariner, Pioneer, and Voyager missions dazzled us with jaw-dropping close-up views of the solar system's major planets. These missions filled in the blank spots of our solar system, but a true understanding of these worlds required more specialized exploration. It was SwRI that began work on the development, operation, and science analysis of follow-up missions.

In 1985, experimental space physicist Jim Burch became a key figure in the story of SwRI's rise to scientific prominence by establishing the Space Sciences Division. A decade later, Burch became the principal investigator for NASA's Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) mission. Launched in 2000, this was the first space mission to explore the interaction of solar particles with Earth's magnetic field and atmosphere. Burch is now senior vice president of SwRI's space sector.

In the '90s, SwRI worked on projects like the Cassini Plasma Spectrometer (CAPS) and Ion and Neutral Mass Spectrometer (INMS), key space physics instruments for NASA's Cassini obiter, which surveyed the Saturn system from 2004 through 2017. In 2012, when NASA's Curiosity rover landed on Mars, it carried SwRI's Radiation Assessment Detector (RAD) to characterize the surface radiation levels on the Red Planet.

Today, the institute is home to five SwRI-led active space missions. These include the ongoing New Horizons mission exploring the Kuiper Belt and conducting heliophysics research, and the Juno mission orbiting Jupiter. Additional missions include Lucy, which is en route to the Jupiter Trojan asteroids, and PUNCH (Polarimeter to UNify the Corona and Heliosphere). Burch continues working on his space research as PI of the ongoing Magnetosphere Multiscale (MMS) mission, which launched in 2015 and features a constellation of four 3,000-pound (1,360 kilograms) spacecraft in high Earth orbit, jointly exploring Earth's magnetosphere. MMS has put SwRI at the forefront of developing and operating such constellations.

MISSION DIRECTIVE

The ongoing Juno and New Horizons missions have kept SwRI in the spotlight. Juno launched in 2011 and arrived at Jupiter five years later. It continues to characterize the strange environment of our solar system's largest planet and its moons. Juno also observed the entry of a 550- to 11,000-pound (250 to 5,000 kg) meteor into the jovian atmosphere in April 2020, adding evidence to the idea that incoming meteor and comet material contributes significantly to the chemistry of Jupiter's upper atmosphere.

New Horizons has no shortage of accomplishments as well. In 2015, it was the first mission to travel to Pluto, and in 2019 it was the first to conduct a close flyby of the Kuiper Belt object Arrokoth. As of this article's

In 1947, SwRI was founded on the grounds of the Essar Ranch west of San Antonio, in six buildings with a total of 23,500 square feet (2,183 square meters). SWRI

In 2022, nearly 3,000 staff members worked in 2.5 million square feet (232,000 square meters) of offices and laboratories on 1,500 acres. SwRI expansion has radiated out from the earliest buildings, which are located at what is now the center of campus. SWRI publication, the spacecraft continues to traverse the Kuiper Belt and will collect heliophysics data through at least 2028. SwRI's planetary exploration efforts also continue with the Lucy mission, which launched in 2021 and will examine nearly a dozen main-belt and Trojan asteroids, the latter of which share Jupiter's orbit.

And SwRI is hard at work on a slew of upcoming missions. Europa Clipper will carry SwRI's Mass Spectrometer for Planetary Exploration (MASPEX) as it investigates the habitability of the subsurface ocean of the Galilean moon of the same name. The instrument is the latest in a line of SwRI-built spectrometers carried previously by the European Space Agency's Rosetta asteroid exploration mission, NASA's Lunar Reconnaissance Orbiter (LRO), and New Horizons. MASPEX is hundreds of times more sensitive than its predecessors and will analyze the water ejected into space from Europa for signs of organic material.

SwRI's portfolio also extends to designing and testing Earth-observing satellites like the Cyclone Global Navigation Satellite System (CYGNSS). This group of eight low-Earth-orbit satellites uses both direct and reflected GPS satellite signals to monitor the roughness of the ocean surface. This, in turn, allows researchers to deduce surface wind speed and how that affects the formation of storms and impacts atmospheric moisture over land. Lofted to orbit in 2016 aboard an aircraft-launched Pegasus rocket, the mission has expanded to monitor diverse parameters including how much heat is exchanged between the ocean and the atmosphere, methane generation in wetlands, and pollution in the ocean.

Some of SwRI's most impressive research occurs at San Antonio's Center for Laboratory Astrophysics and Space Science Experiments (CLASSE). Here, space scientists perform laboratory experiments that help them interpret the data their robotic probes send back.

One such project involves determining the nature of the mysterious red cap at the pole of Pluto's moon Charon. CLASSE researchers were able to replicate the reddish material and found it was likely created by ultraviolet radiation breaking down methane molecules that escaped from Pluto's atmosphere. These methane molecules are thought to migrate to Charon and then become trapped as ice at the moon's pole during the region's centuries-long winter night.

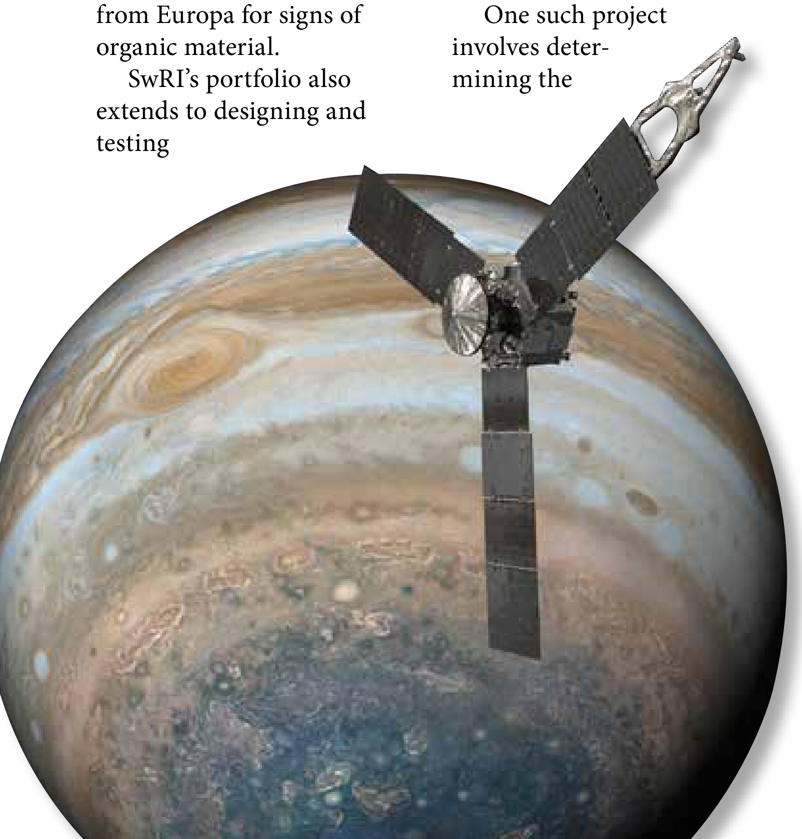
Another part of CLASSE is dedicated to supporting the data acquired by the SwRI-built Lyman-Alpha Mapping Project (LAMP), a spectrometer aboard LRO that searches for water ice on the Moon's surface. To do that, researchers used a vacuum chamber to take UV reflectance measurements of different surfaces, including lunar samples. The samples were examined by spectrometers that viewed the reflected wavelengths at various angles to help reproduce real-world measurements.

Interpreting data returned by LAMP in the context of these experiments indicates that over millions of years, water ice accumulated in the polar regions in the cold traps at the bottom of permanently shadowed craters.

The Cyclone Global Navigation Satellite System (CYGNSS) is assembled and tested at SwRI's satellite facility. The CYGNSS spacecraft underwent thermal vacuum, acoustical, and vibration testing at SwRI prior to launch. SWRI

A CLOSER LOOK

During my visit the campus, the vice president of SwRI's Space Systems Division, Michael McLelland, proudly showed me the newest building on the campus, the Space System Integration Facility. This will be the center for future SwRI spacecraft design, fabrication, and testing. There are numerous clean rooms where spacecraft can be assembled, and a brand-new environmental testing vacuum chamber where the crafts will be put through their paces to prove they are ready to handle the harsh environment of space. Roughly the size of a tanker



Missions like the Juno probe, which is currently orbiting Jupiter, keep SwRI at the forefront of NASA's planetary exploration. NASA/JPL-CALTECH truck, the chamber is used to verify if electronics are robust enough to function in temperatures that range from cryogenic cold to unbearably hot. The facility even has its own electrical substation to prevent summer heat-induced rolling blackouts from disrupting critical spacecraft-testing operations.

As I went into the testing bay of the building, four suitcase-sized satellites were laid before me, communicating with each other much like they will in space. These are part of the PUNCH mission that will be carried into a Sun-synchronous orbit in 2025 by a SpaceX Falcon 9 rocket. The mission will study how the Sun's corona transitions into the solar wind. Three of the spacecraft will take wide-field images of the corona around the Sun, while the fourth craft will obtain a closer-in view of the Sun's surroundings with a narrow-field imager. Imagery from all four spacecraft will then be assembled into a single 3D view showing about one-quarter of the sky. PUNCH will also monitor coronal mass ejections, which can be damaging to Earth's electronic infrastructure.

In the midst of the cutting-edge electronics and *Star Trek*-like hardware, I also witnessed a very low-tech test of the spacecraft Sun sensors: A technician waved a flashlight over the spacecraft, and the sensor obediently followed. This technology will help establish the spacecrafts' orientation and keep the solar panels aimed toward the Sun.

I was delighted to get a close look at SwRI's ongoing research on Apollo lunar samples as well. The initial examination of these samples in the 1970s and 1980s concluded that the Moon was just a desiccated mass. But scientists at the time acknowledged they needed more sensitive instruments to further understand its chemistry.

Today, SwRI is at the forefront of lunar sample analysis. SwRI Senior Program Manager and planetary scientist Kurt Retherford allowed me to examine the Apollo samples kept in a locked safe deep within the research laboratories, and to see the new lunar sample research instruments. Fifty-two years ago, I was glued to my television set watching astronauts Dave Scott and Jim Irwin gathering surface samples during the Apollo 15 mission on northeast Mare Imbrium. It was a thrill to hold them half a century later.

SwRI recently completed assembly and testing of the Mass Spectrometer for Planetary Exploration (MASPEX) to be carried by the Europa Clipper mission. It will search for organic material in Europa's oceans. SWRI

PUSHING AHEAD

SwRI continues to incorporate the newest technology into its large upcoming projects. For instance, the institute supports NASA's Artemis program through ongoing projects that will utilize NASA's Commercial Lunar Payloads Services (CLPS) program. The payload will include tools for measuring heat outflow from the Moon's crust as well as indicating its electric conductivity. The Integrating CAvity enhanced Raman Ultraviolet Spectrograph (ICARUS) is another project with a highly sensitive instrument designed to detect trace minerals and volatiles on the Moon and Mars.

An SwRI-developed instrument will land in the large lunar Mare Imbrium basin, riding aboard Firefly's Blue Ghost lander: the Lunar Magnetotelluric Sounder (LMS). It will probe the lunar interior to a depth of 700 miles (1,127 km) by measuring naturally occurring electromagnetic fields. Another Moon-bound SwRI instrument, the Lunar Interior Temperature and Materials Suite, is destined to land near Schrödinger Basin on the Moon's farside via CLPS. And to help solve the mystery of mysterious bright swirls caused by magnetic anomalies on the Moon's surface like Reiner Gamma on Oceanus Procellarum, SwRI has developed and delivered the Magnetic Anomaly Particle Spectrometer (MAPS) to NASA for the Lunar Vertex mission. Landing near Reiner Gamma, MAPS will use a spectrometer to map the region's magnetic field with a resolution four times higher than previous efforts via orbiting spacecraft. And, when observing in conjunction with orbiting spacecraft, it will also provide a 3D view of the regional magnetic fields.

SwRI is proving that the sky is not the limit. As the institute expands its reach, the universe itself is within its sights. The next time you hear about San Antonio, don't just remember the Alamo: Think also about SwRI, where the spacecraft that will explore the solar system are being built and tested, deep in the heart of Texas.

Robert Reeves *is an accomplished astrophotographer and author, with a current passion for lunar photography and science.*

ASTROPHO

The Rosette Nebula (NGC 2237-9/46)
The Rosette is in full bloom in this collaborative image comprising more than 110 hours of exposure. The high exposure time also allowed for sharpening the image and increasing contrast to reveal fine features, like the wispy structure of Bok globules and dust across the top of the image. The center of the image displays the faint particle streams created by sulfur and oxygen gas blown away from the bright cluster of stars. Through the center of the image, faint wisps of glowing sulfur gas are visible above the dominant oxygen gas. WILLIAM OSTLING/JUSTIN P./JENS UNGER/ROB OLSON/DOMINIC ANNIS/AMRIT PRASAD/TOMMY LEASE/JAY AIGNER

TOGRAPHY AND THE ART OF COLLABORATION

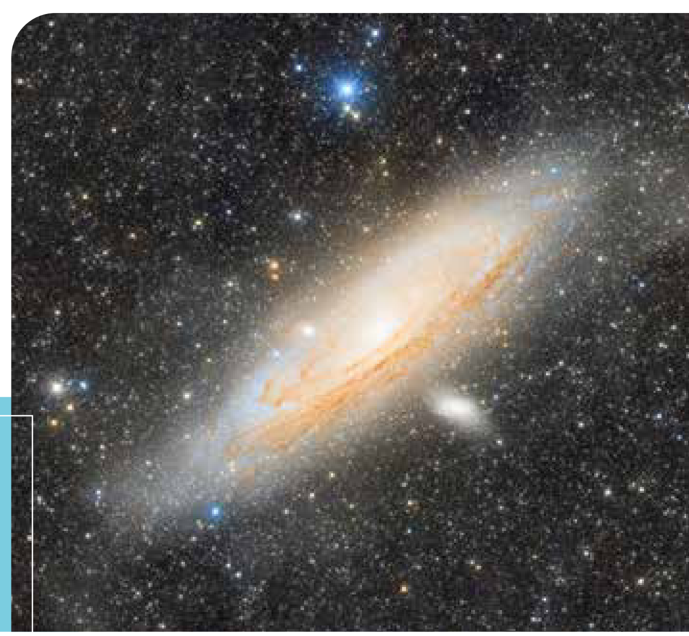
One young photographer's journey shows how teamwork is expanding the bounds of astroimaging.

STORY AND IMAGES BY WILLIAM OSTLING

I CAN STILL REMEMBER the night that marked the start of my journey into astrophotography. It was a clear and moonless August evening five years ago, and the year's Perseid shower was at its peak. As I looked toward the north, I could see meteors streaking across the sky in bright lines. I raced back inside to grab my Nikon D90 and tripod, then pointed the camera in the general direction of the meteor shower's radiant and simply took a couple of five-second exposures.

My setup was rudimentary at best. The only lens I had at the time was a 200mm telescopic lens — not exactly suited for wide-field shots! — and my tripod was about as steady as a wobbly restaurant stool. The results were even worse: The star trails looked more like zigzags due to my tripod, and I had only gotten one meteor in the frame. Still, that experience proved that I could start doing astrophotography from my yard.

Since then, I have never stopped trying to improve my images. Every new year brings huge advancements in hardware, software, and processing techniques that enable everyone to create better and better astrographs. My goal is to prove that even though it's far easier to produce high-quality images with a monochrome, cooled camera, publication-worthy images can still be created with a DSLR and lens — it just takes a bit more time and care.



The Andromeda Galaxy (M31)
Our galactic neighbor is so vast it would take light 200,000 years to cross it. This deep astrograph comprises 26 hours of data from a Bortle 1 site with a Nikon D90 DSLR and Sigma 300mm prime lens at f/4 and ISO 800. The faint shell around the bright galaxy was most likely created by past gravitational interactions with other galaxies.

GETTING STARTED

As a college student who took several years of astronomy classes in high school, I'm quite familiar by now with the technical side of observing and data reduction. I know how to check what target to image using software like Stellarium, choose the imaging settings I need, and set up an observing run. Even when I started in astrophotography, thanks to my astronomy research, I was used to setting up sequences in the software suite Nighttime Imaging 'N' Astronomy (NINA) and I knew how to connect the camera, computer, and mounts. It was a bit of a pain to learn how to take flat calibration frames, but I was comfortable with the idea of a calibration pipeline.

The hardware side of astrophotography was a completely different beast to handle. At first, progress came quite slowly, but my need for perfection pushed me to constantly improve. After a few months with my new Sky-Watcher Star Adventurer 2i tracking mount, I quickly realized the unit had some limitations. Luckily, I had the tools and support I needed to take the entire mount apart, repair scratched gears and a loose clutch, and re-oil and optimize it.

Achieving and maintaining focus was also a big challenge for me. At the observatories I used for my research, I would just have to click a few buttons and the entire image would be in focus. But with my camera lenses, I found myself 3D-printing a Bahtinov mask and locking ring to achieve better focus and hold it in place.

THE CHALLENGES OF DSLR ASTROPHOTOGRAPHY

Once I had familiarized myself with the basics of astrophotography and gotten comfortable with simple processing techniques, more difficult challenges of DSLR astroimaging began to appear, beginning with thermal noise. In longer exposures, hot pixels became more apparent, and the backgrounds grew increasingly blotchy. Dark frames only worked up to a point — once I started taking three- to four-minute exposures, they could not correct all of the thermal background glow.

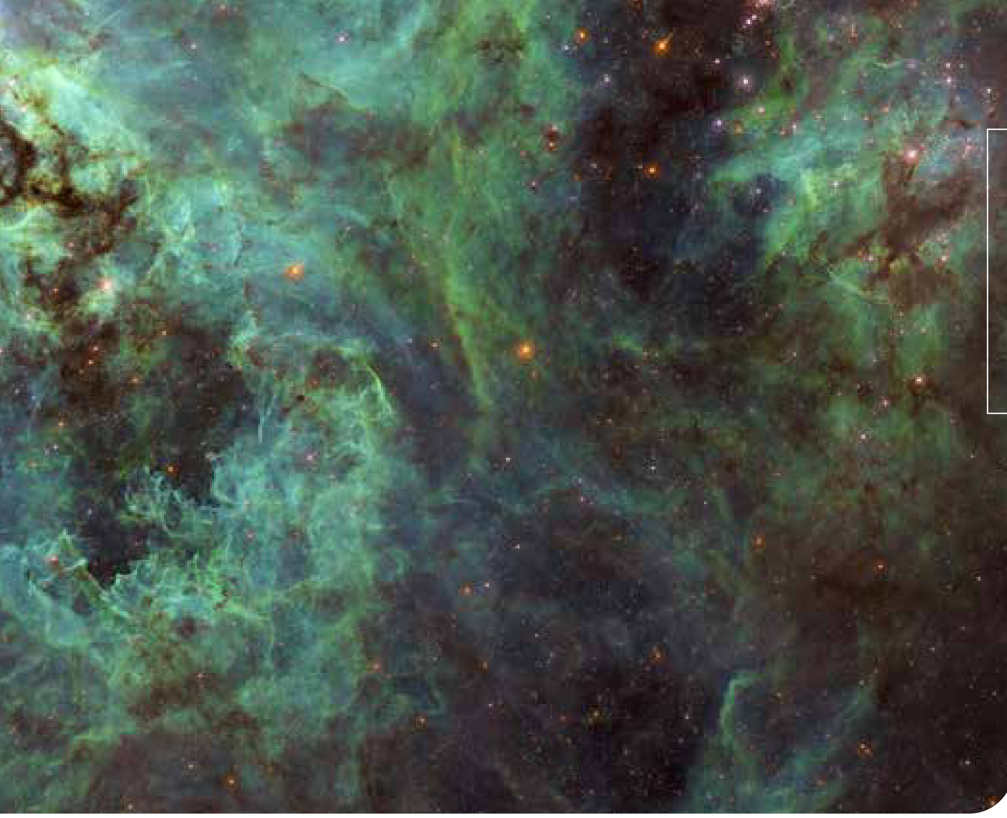
I couldn't figure out a processing workflow to fully remove that chrominance (color) noise, so I started to look for hardware solutions. I knew that the best way to reduce thermal noise in my images was to cool my camera's sensor, so I began experimenting with ways to remove the excess heat. After a lot of trial and error, I came up with a method to blow cold air across the back of the sensor with a fan and tubes, ensuring that no vibration from the apparatus could interfere with the tracking of my mount.

But just as I solved one problem, another popped up in its place: the Bayer filter, which covers a camera sensor. The very filter that allows DSLRs to image in RGB (red, green, and blue — one color for each pixel) results in less detailed images with high-frequency chrominance and luminance noise over complex regions, and color artifacts in stars. I looked into many scripts and processing modules to try and remove these artifacts and noise in PixInsight. However, after a lot of careful research, I concluded that the artifacts caused by the Bayer filter were nearly impossible to remove using software alone.

Again, I investigated hardware solutions, this time researching ways to remove the Bayer filter from a sensor. I bought several used DSLRs to test different methods of removing the Bayer filter, including chemical solutions and washing or carefully scraping the filter off. However, the artifacts created by the residue left behind were impossible to remove using flat frames or software — which meant that even though the images were less noisy and much sharper, they were unusable.

In the end, to create the highest-quality images, I decided to get at least 50 hours of data per image, and only shoot wide-field scenes. That way, I could focus on revealing large, faint structures without having to worry about fine detail, which was perfect for the equipment I had.

The Orion Nebula (M42)
This famous object consists of glowing red hydrogen and darker, cooler dust. The image comprises 4.1 hours of exposure with a Nikon D800 and 600mm f/4 lens at ISO 800.



The Tarantula Nebula
When I process Hubble data, there are images that I revisit again and again. The Tarantula Nebula — a giant star-forming region in the Large Magellanic Cloud — is perhaps my favorite region in all of the archives. Hubble spent nearly six days (143.1 hours) gathering the visible and near-infrared data in this image over the course of several years. WILLIAM OSTLING/NASA, ESA, E. SABBI (STSCI)

HUBBLE PROCESSING

Because I was spending so much time per object, I was only able to turn out one final image per month — at most. Though the images I produced were very low noise and high quality, the rate at which I was creating them didn't quite scratch the itch of wanting to image different targets. As I got more restless, I decided to start processing Hubble data to improve my skills.

In many ways, Hubble data were the exact opposite of my data. Where I had low noise and low detail, Hubble had extremely high detail but very high-amplitude noise. This complete 180° shift in processing was exactly what I needed to improve. With fellow astrophotographers, I pioneered new algorithmic techniques that enabled me to preserve most of the detail while removing nearly all of the noise. And because Hubble data have so many sensor-based artifacts, I learned how to deal with and remove banding and column glow artifacts.

Hubble data also offered me an opportunity to learn how to work with large images and volumes of data. With my DSLR, I had gotten used to working with one image at a time and maybe the occasional mosaic. But because Hubble has such a small field of view, it was natural to work with mosaics with 50 panels, often resulting in 3- to 4-gigabyte images. Because running any processing on these images took hours at a time, I was forced to learn how to streamline my pipeline. My processing skills improved to the point where I was featured by NASA's Astronomy Picture of the Day several times and asked to process versions of new observations. But by far the best thing about processing Hubble data was that I noticed a marked improvement in my DSLR images, allowing me to take on more ambitious imaging projects.

COLLABORATIVE ASTROIMAGING

As with most complicated hobbies, I couldn't improve just on my own. The COVID-19 pandemic overturned many of the in-person communities that I had been a part of. But because I had to remain at home, I could explore the freedom to meet and collaborate with

M81/2 and NGC 3077
The interacting triplet M81, M82, and NGC 3077 are featured in this collaborative image created from more than 216 hours of exposure. On the top of the image lies NGC 3077, a small starburst dwarf galaxy with a starforming core. Below lies M81, a grand design spiral about 12 million light-years away. To the right is M82, a starburst galaxy with a huge superwind triggered by interaction with M81 and NGC 3077. All around the image is galactic cirrus, dust in the Milky Way that lies in our line of sight, lit by the glow of our galaxy. Overlaid in blue are HI emission data from the Very Large Array, which reveal what of the background is neutral gas from the interactions and what is dust from the Milky Way. WILLIAM OSTLING/JUSTIN P./ANDRE VILHENA/DOMINIC/JENS UNGER/STEVE GILL/OVIDIU DASCALU/W.J.G. DE BLOK ET AL. (2018)

The Jellyfish Nebula (IC 433)
The stupendously complicated nebula was created by the remains of a massive star that went supernova. This collaborative image represents a total of 112.4 hours of exposure in the Hubble palette. WILLIAM OSTLING/JUSTIN P./ANDY BROWN/DOMINIC/JAY AIGNER/OLIVER CARTER/TOMMY LEASE/JENS UNGER/SENDHIL

astrophotographers not just in my neighborhood but across the world.

At the beginning of the pandemic, my astrophotography group was small, with about 20 of us chatting online. The group grew quickly as astrophotographers seeking a community found our Discord server, Friendly Cosmos. The leaders of this group — me, Steve Gill, and Jay Aigner — quickly realized the potential that each member could bring. Because astrophotography was (and still is!) a rapidly progressing field, our group aimed to provide a space where people of all skill levels could learn from each other and contribute.

We decided to hold two monthly competitions: a target of the month competition and a processing competition. The idea of the monthly target was to provide a single object to image, have the members of the astrophotography group show off their best effort, then vote on the winner. On the other hand, the processing challenge was to improve our skills and even the playing field in terms of equipment by providing a common dataset to work with. We all used each other's experience and advice to improve our astrophotography.

OUR FIRST COLLABORATION

Our skills progressed, but a new problem appeared: As the targets we tried to capture grew fainter and trickier, the time required for each image increased exponentially. The obvious solution was to collaborate by sharing data so we could produce better images. To prove that an astrophotography collaboration with more than five people was even possible, we decided to image a large, bright target: the Rosette Nebula (NGC 2237–9/46) in Monoceros. However, even that proved to be a huge challenge. Coordinating framing, planning sequences of images, and combining data across states and continents was uncharted territory and proved to be a big hurdle to overcome. Even figuring out how to weight subframes with completely different pixel scales creates huge mathematical problems.

Processing took a huge amount of time to finish as well. Not only were the images extremely large, but we all also wanted to create the perfect final image. With perseverance and hard work, though, we were able to create our first image from 150 hours of data collected from four continents. It took 23 iterations of processing to reach a final product that we all agreed was the best, but it was well worth it. And that was only the beginning.

The Lagoon (M8) and Trifid (M20) nebulae
The pair of nebulae in Sagittarius are perennial favorites of amateur astronomers. This image was taken with just under six hours of exposure with a Nikon D90 DLSR and a 300mm prime lens.

IMPROVING COLLABORATIONS

We tried again, focusing on a dimmer and more detailed target: the Jellyfish Nebula (IC 443), a supernova remnant in Gemini. This project far outclassed our first, as we collected more than 200 hours of data from 10 astrophotographers. We were able to reveal details never shown before, including the extent of the shock waves from the stellar explosion and the escaping filaments caused by changing magnetic fields. Our work was even recognized by NASA's Astronomy Photo of the Day site.

Having completed two narrowband collaborations, we decided to start a broadband collaboration. Our target was the interacting spiral galaxies of M81 and M82, with the goal of revealing as much faint dust as possible without sacrificing any detail. This collaboration was far more challenging than any of the previous images we had created. Not only did we decide to include one-shot color DSLR and Hydrogen-alpha data in our final image, but every image also had different gradients and artifacts that needed to be corrected and normalized. Additionally, the different pixel scales proved to be a much larger problem, as they created far more obvious artifacts.

We decided to adopt an avant-garde method to remove most of the artifacts with local normalization and selective drizzle. And to remove the complicated gradients throughout the image, we adapted what was then a pioneering method, multi-scale gradient removal.

The resulting image was a resounding success. It displayed incredible detail in the core of M81 and shock waves of M82, as well as huge amounts of galactic cirrus. We were also able to corroborate our observations with ground-based neutral-hydrogen observations of the surrounding region. Now, our group is working on a new collaboration to fully display the detail in the region surrounding the Lion's Mane Nebula (NGC 2392).

The Question Mark Nebula
The cosmic punctuation comprises two objects: NGC 7762 is the question mark's curvy part, and Sharpless 2–170 is the dot at the bottom. The red glow is caused by hydrogen gas ionized by nearby stars. This two-panel mosaic represents 6.3 hours of exposure with a Nikon D90 and a 300mm f/4.0 lens at ISO 800.

CONTINUING ASTROPHOTOGRAPHY

As I immerse myself in the world of astrophotography, I continue to meet incredible people. This enriching hobby has been one of the most powerfully connective shared interests in my life. I've met extremely intelligent and diligent imagers who have not only taught me how to be a better astrophotographer, but also a better person. Though astrophotography seems like a niche subject, the skills I've learned under the stars and with my group also apply to everyday life.

Over the years, I've had my work shared by NASA, the SETI Institute, Earthsky.org, and many other astrophotography groups around the world. And I've also used my images to explain the research I've done and create more curiosity and interest in astronomy.

Through astrophotography, I've found a way to explore the expanse of the universe by myself and with others. I've found so much inspiration in capturing the beauty and detail of the cosmos and reflecting on the part I play in it. I hope that through this hobby, you can find that love of space as well.

William Ostling *is a student and science research fellow at Columbia University, and astrophotographer with a huge passion for astronomy and astrophysics research.*

The easy-to-use eQuinox 2 telescope lets you take impressive astrophotos even under light-polluted skies. BY RAY SHUBINSKI

UNISTELLAR'S NEW SMART SCOPE REVIEWED

The automated Unistellar eQuinox 2 telescope can be easily operated through the Unistellar app to target and photograph countless cosmic objects with the tap of a finger. UNISTELLAR

THE JAMES WEBB SPACE TELESCOPE (JWST) and the long-lived Hubble Space Telescope have been providing amazing images to earth-bound viewers for some time now. Along with other instruments, these telescopes have fueled a new enthusiasm for state-of-the-art astronomical images.

Capturing your own portraits of the cosmos has also become easier over the last decade due to increased optical resolution and the merging of telescopes with advanced technology. Now another fantastic tool has arrived: The eQuinox 2 is the newest iteration of the eQuinox telescope, first introduced in 2020. Like its predecessor, the new version is a dedicated imaging device (note that it's not designed for visual observations — it lacks an eyepiece, either optical or electronic). For those seeking an image-oriented approach to exploring our night sky, the eQuinox 2 offers a capable all-in-one package that will turn you into an astroimaging pro in no time.

Unistellar was founded in 2015 and is based in Marseille, France. The company is dedicated to providing instruments that can be used by anyone to capture the wonders of the heavens, even in light-polluted urban areas. Unistellar also promotes citizen science projects in diverse fields of astronomical research, such as exoplanets, comets, and more.

A breezy setup

I was excited to see the Unistellar eQuinox 2. The telescope arrived in a well-designed box with plenty of protection. It is supplied with a sturdy tripod that allows the scope to be raised from 18 inches (45 centimeters) to 51 inches (130 cm), depending on your needs. A charging adapter with multiple plug configurations for international use is included. There is also a small toolkit of wrenches for tripod assembly.

Setup felt like a breeze. The telescope easily mounts to the tripod and is locked into place and secured with manual screws. Then it is just a matter of charging the battery. When fully charged, the battery will last at least eight hours, enough for a full night of observing. The telescope charges via a standard USB-C port on the bottom of the scope that is right next to a USB-A port. Since neither is easy to see, you'll want to ensure that the charger is properly seated in the correct port. I laid the scope across a hassock to see both ports and then set it back into the upright position once it was plugged in. One thing to note is that the tube cannot be manually moved on the single fork arm — it can only slew when the scope is powered on and operational. And once the cord is connected to the telescope, you can easily charge it at home or with the convenience of a power bank.

As with most automated telescopes, Unistellar has developed a comprehensive app to operate the eQuinox 2. The app can be downloaded on any smartphone or tablet from the Apple App Store or Google Play Store. I prefer using a large-format iPad, which makes the app easy to see and use under any conditions. Linking the telescope with your smart device is extremely simple. There is only one button needed to power up the telescope. Press and hold the button for two seconds until it flashes with a purple glow. Once the power button stops flashing, the scope is ready. Next, go into the settings on your device and choose the eQuinox2-aie4mc Wi-Fi network to link with the scope's built-in Wi-Fi, and away you go.

On the app's home screen, a catalog page will appear. In the lower right corner is a small telescope icon — tap this to access the operation mode. At the bottom of this new screen, tap "Move," which will allow the scope to be set manually. You can also open the settings and go to the "My Telescope" section to see information such as battery level and remaining image-storage space.

There is a small bubble level embedded in the base of the telescope. The scope must be carefully leveled before observing or the orientation and tracking will not function properly. The eQuinox 2 is a modified optical-digital hybrid Newtonian reflector with a 4.5-inch mirror that may need to be focused. Once the dust cap is removed, the tool needed to focus will be waiting for you: Underneath the cap is a plastic Bahtinov mask, a tool developed by a Russian amateur astronomer in 2005. To focus the scope, choose a bright star from the catalog and move to it. Once the star is centered on your screen, place the Bahtinov mask on the telescope. This will produce an X-shaped pattern on the screen, which can be calibrated using a focusing knob on the bottom of the telescope tube. I was quite impressed by this feature, which allowed me to achieve very sharp images of diffuse objects such as nebulae and galaxies.

Getting to work

Once I finished setting up the eQuinox 2 telescope in my backyard, I sat in a chair with my tablet and contemplated what I would photograph first. The Unistellar catalog contains thousands of objects to choose from. The catalog is divided into categories: asteroids, comets, star clusters, galaxies, nebulae, planets, stars, etc. You can further filter them however you like. After you choose a category, the listing will display which objects are best positioned for observing at your local time and location.

To start, I decided on the Ring Nebula (M57). I simply tapped the image of the Ring on the screen, oriented the scope, hit "GoTo," and watched the eQuinox2 swing into action. You can see the progress on the screen of your device as the scope moves to find the target. Once the Ring was located, the scope centered it perfectly in the field of view. However, I could see the focus was a little off on the tablet screen. Fortunately, the Bahtinov mask I attached brought the image into sharp focus. I then started the exposure.

PRODUCT INFORMATION

eQuinox 2
Type: Hybrid Newtonian reflector
Focal ratio: f/4
Focal length: 450mm
Field of view: 34.2' by 45.6'
Battery life: 11 hours, extendable
Tube length: 549mm
Tube weight: 15.4 pounds (7 kg)
Weight: 19.8 pounds (9 kg)
Price: $2,499
Contact: contact@unistellaroptics.com

The optical system scans and stacks the image as well as processes it in real time — what Unistellar refers to as Enhanced Vision Technology. The folks at Unistellar have also developed what they call Deep Dark Technology, which consists of algorithms trained to process out unwanted light pollution. This is a purely software-based approach — the eQuinox 2 features no narrowband filters. But it works, providing amazing detail in the final image. Within a few hours, I had captured a wonderful collection of celestial objects that were directly downloaded to the app and my tablet's photo album.

The app's catalog contains a huge selection of stars. I swung the scope over to the colorful double star Albireo. This was the only slight disappointment I had with the eQuinox 2. This little scope has a fast f/4 optical system and a short focal length of 450mm, effectively making it a rich-field system. I was unable to split Albireo, even by adjusting the length of the exposure. I sought advice from one of the company's representatives, who suggested turning off the Auto function and adjusting the gain; that did help.

Being a visual observer all my life, I've always loved putting my eye to the telescope and the challenge of experiencing an outstanding real-time connection with the universe that comes along with it. Nonetheless, I truly loved using the eQuinox 2 to capture and preserve the objects I was observing. Unistellar is dedicated to developing an instrument that can give both urban-dwellers and rural observers like me an amazing experience under any sky conditions. The eQuinox 2 is a great addition to any arsenal of equipment for capturing the beauty of the universe. I highly recommend Unistellar's eQuinox 2 telescope.

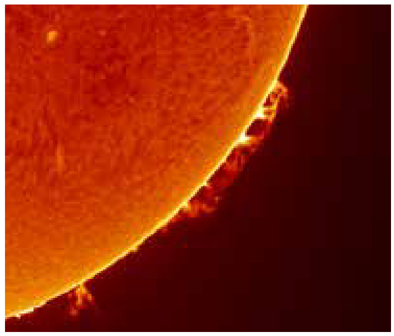
Ray Shubinski *is a longtime contributor to* Astronomy *magazine who loves recovering the lost ephemera of astronomy.*

ABOVE: The Whirlpool Galaxy (M51) lies 31 million light-years away in Canes Venatici. RAY SHUBINSKI

LEFT: NGC 1977 is also known as The Running Man due to its resemblance to a man moving through a cloud of interstellar gas and dust. UNISTELLAR

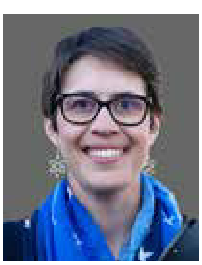
Staring at the Sun

Your explorations of the Sun don't need to stop after the Great North American Eclipse.



ABOVE LEFT: Sunspots, filaments, and plages are seen through a Coronado PST with a ZWO ASI290MM camera on March 4, 2023, in this artificially colored monochrome image. MOLLY WAKELING

ABOVE RIGHT: A massive treelike series of prominences sprouts from the Sun's limb as seen through a Coronado Solarmax III 90mm Double-Stack with a ZWO ASI1600MM Pro. A sunspot and some filaments are also visible. This is a monochrome image that has been artificially colored and inverted for better contrast. MOLLY WAKELING



BY MOLLY WAKELING

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

You heard it from your parents. You've seen it printed in bold on telescopes. "Do not look at the Sun!" But how can you resist observing the fiery ball of furious fusion that dominates the sky?

Fortunately for the curious among us, there are some safe ways to do just that. And while the total solar eclipse of April 8, 2024, may be in the rearview mirror, the Sun's 11-year cycle of activity is nearing its peak, so there is plenty to see.

How to observe the Sun

First, don't throw away your eclipse glasses! You can use them on any sunny day to get a safe view of the Sun.

But to get a close-up view of our nearest star with a telescope, there are two types of filters you can use. One is a white-light filter, which is a very dark neutral-density filter that blocks 99.999 percent of the Sun's light. White-light filters can be broken into two categories: glass and film. Glass filters are safer for group events because they are harder to accidentally break or puncture than film. However, the quality of the images they produce is generally not as good as film, and they can be more expensive. Film filters, such as Baader film or mylar, might not look like much, but can provide sharp views of the Sun. Different materials can make the Sun appear different colors, from white, blue, or pink to a "Sun-like" golden yellow. Always be sure to visually inspect for punctures or tears before using a film filter!

The other type of filter is Hydrogen-alpha, or Hα (pronounced "H-alpha"). Unlike white-light filters that let through a wide swath of the optical spectrum, Hα filters pass an extremely narrow slice centered around the 656.281-nanometer wavelength, less than 1 angstrom (0.1 nm) wide. These are much more expensive than white-light filters but provide much greater detail. Because the filter passes only this wavelength, the image appears a vivid red.

There are Hα telescopes designed specifically for observing the Sun, like the Coronado Personal Solar Telescope or the more expensive Lunt telescopes. Alternatively, devices like the DayStar Quark add Hα solar-observing capability to almost any scope. However, note that in such cases a separate energy rejection filter is still required for the front of any nonrefracting telescope and for refractors with apertures larger than 3.2 inches (80mm) to prevent the dangerous buildup of heat.

Whether you view the Sun in white light or Hα, there is always something to see.

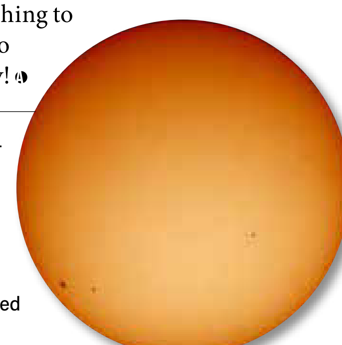
Solar features to observe

There's a lot to see on the ever-changing Sun, especially as we approach solar maximum this year. Easiest to spot are sunspots, which are active regions with chaotic magnetic fields in the Sun's convection layer. They appear darker because they are cooler than the rest of the Sun's surface by as much as 4,000 degrees Fahrenheit (2,200 degrees Celsius).

With white-light filters, you can primarily see sunspots, as well as plages and faculae — bright areas that sometimes appear around sunspots. White-light filters are great for the partial phases of solar eclipses as they are easy to remove when totality arrives. However, they won't offer as detailed a view as in Hα.

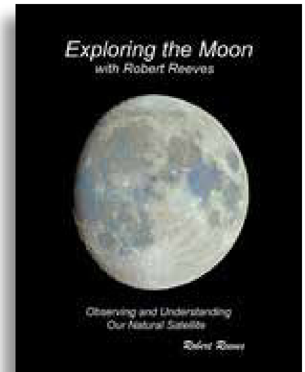
Hα devices or telescopes allow you to see much more surface granularity. They also reveal prominences: beautiful, towering structures of hot gases that follow magnetic field loops and change constantly. You can spot differences in as little as a few minutes! If you're lucky, you may catch a massive eruption from the surface, which is sometimes associated with a coronal mass ejection, throwing plasma off into space. Prominences on the surface facing Earth appear as slightly darker structures, called filaments, that span thousands of miles.

Whether you view the Sun in white light or Hα, there is always something to see — and now you can do astronomy 24 hours a day!



The Sun as seen using a white-light filter on a Celestron 8-inch Schmidt-Cassegrain with a 0.63x focal reducer and a ZWO ASI1600MM Pro camera. This is an artificially colored monochrome image, but the Seymour Solar filter used here makes the Sun appear a golden yellow. MOLLY WAKELING

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



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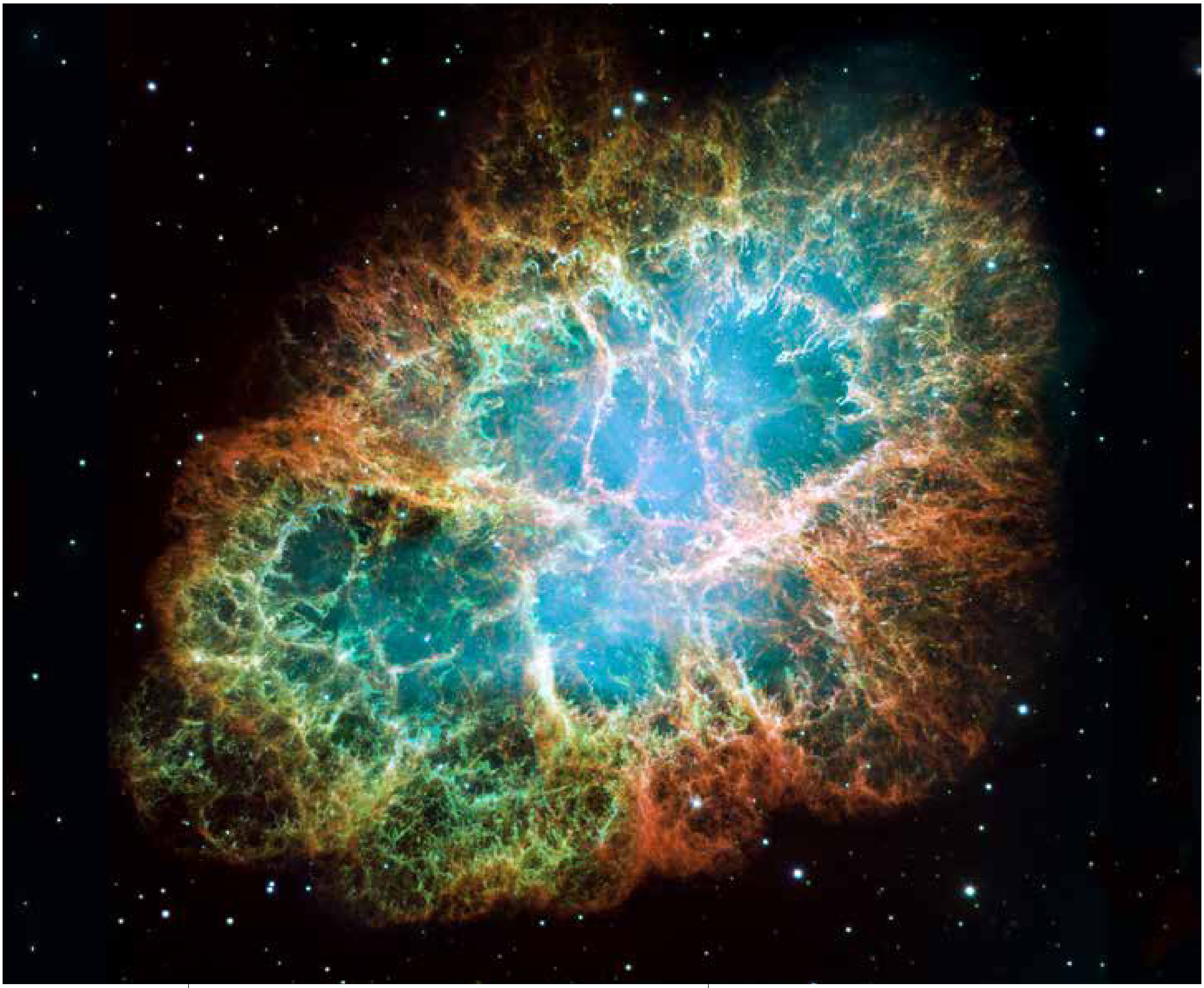
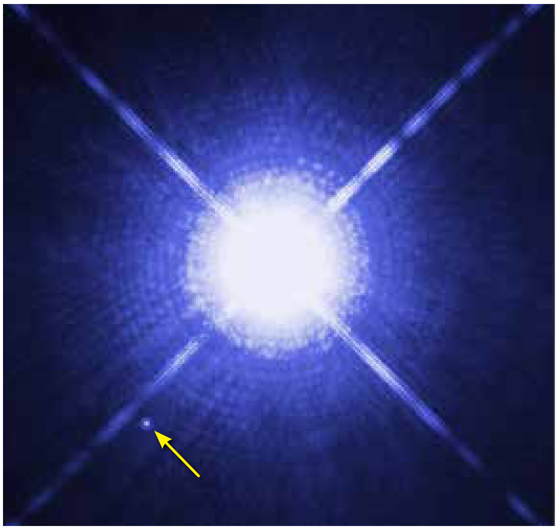




When stars "die," they leave one of two objects behind. Massive stars explode as supernovae, creating remnants of gas and dust like the Crab Nebula (M1, above). Sun-like stars do not explode, instead leaving behind their hot, dense cores, called white dwarfs. Sirius B (right, indicated with an arrow) is the white dwarf companion of the bright star Sirius A. NASA, ESA, J. HESTER AND A. LOLL (ARIZONA STATE UNIVERSITY); NASA, ESA, H. BOND (STSCI), AND M. BARSTOW (UNIVERSITY OF LEICESTER)

Star deaths

Q | HOW MANY STARS DIE IN THE MILKY WAY EACH YEAR?

Martin J. Heuer
St. Petersburg, Florida

A | Before diving into the astronomy here, we first need to acknowledge that we are borrowing the word *die*, which really belongs to biology. While we can try to apply the concepts of life and death to astronomy, so that stars burning fuel to produce energy are considered alive and those that are not are considered dead, the analogy is not perfect and there are edge cases where it all falls in a heap.

That said, there are predominantly two ways stars die. Normal low- to intermediate-mass stars (like our Sun), after swelling through their red giant phases, throw off their outer layers and dwindle away as white dwarf stars. This pathway to stellar death is trod about once every two years in our galaxy. For stars more than eight times heavier than our Sun, death becomes something of a spectacle, heralded by the explosion of a core-collapse, or type II, supernova. Core-collapse supernovae happen about once every 60 years. They occur much less frequently than white dwarf deaths because these massive stars are much rarer than their low- and intermediate-mass counterparts. This brings our grand total of stellar deaths to about 52 per century or one every 1.9 years.

However, we have not accounted for brown dwarfs, whose masses fall between those of stars and planets. Brown dwarfs can't sustain long-term nuclear fusion of hydrogen, but they can, for a fleeting stage, shine by burning deuterium (an isotope of hydrogen) or in some cases lithium. This continues until this limited fuel runs out and brown dwarfs eventually become dark objects made of cold gas. Although, what they lack in mass they make up for in sheer numbers — our galaxy is teeming with these objects and accounting for their life cycle would swamp the numbers above, bumping us up to something around one to three deaths per year.

But were these brown dwarfs ever sufficiently "alive" enough to die? That's for the philosophers to decide.

David Sweeney and Peter Tuthill
Ph.D. Student and Professor of Astronomy, respectively, Sydney Institute for Astronomy at the University of Sydney, Australia

WHILE WE CAN TRY TO APPLY THE CONCEPTS OF LIFE AND DEATH TO ASTRONOMY, THE ANALOGY IS NOT PERFECT.

Q | HOW CLOSELY PACKED ARE JUPITER'S TROJAN ASTEROIDS COMPARED TO THE DENSITY OF THE MAIN BELT?

Doug Kaupa
Council Bluffs, Iowa

A | Jupiter's Trojans are asteroids that share the gas giant's orbit around the Sun, clustering at one of two Lagrange points in the Jupiter-Sun system (L4 or L5, 60° ahead of or behind Jupiter in its orbit, respectively).

It turns out that main-belt asteroids (MBAs) and Trojan asteroids occupy a relatively similar volume in space. The bulk of MBAs lie between 2.1 and 3.3 AU from the Sun, while Jupiter's Trojans are 5 to 5.3 AU from our star. Most of these bodies (in both groups) have orbital inclinations less than 30°.

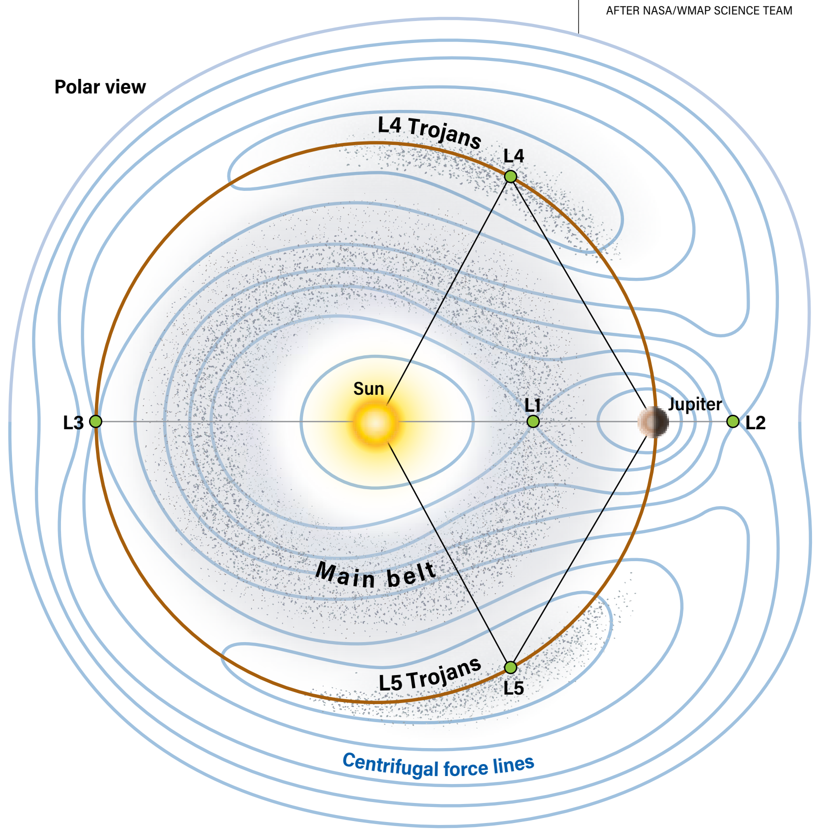
You can approximate the volume these asteroids occupy using rings. So, picture a torus with a circular cross-section, with the inner and outer diameter being the inner and outer extents of the orbits just given, so that the volume each occupies is 61 AU^3 and 58 AU^3, respectively, for MBAs and Trojans. (One AU, or astronomical unit, is the average Earth-Sun distance of 93 million miles [150 million kilometers]. So, 1 $AU^3 = 8 \times 10^{23}$ $miles^3$ [2.7×10^{24} km^3].)

There are about 10^8 MBAs larger than about 330 feet (100 meters) in diameter, and about 10^7 Trojans of this same size. That makes the volume density of asteroids in the main belt about 10 times higher than that of Jupiter's Trojan asteroids.

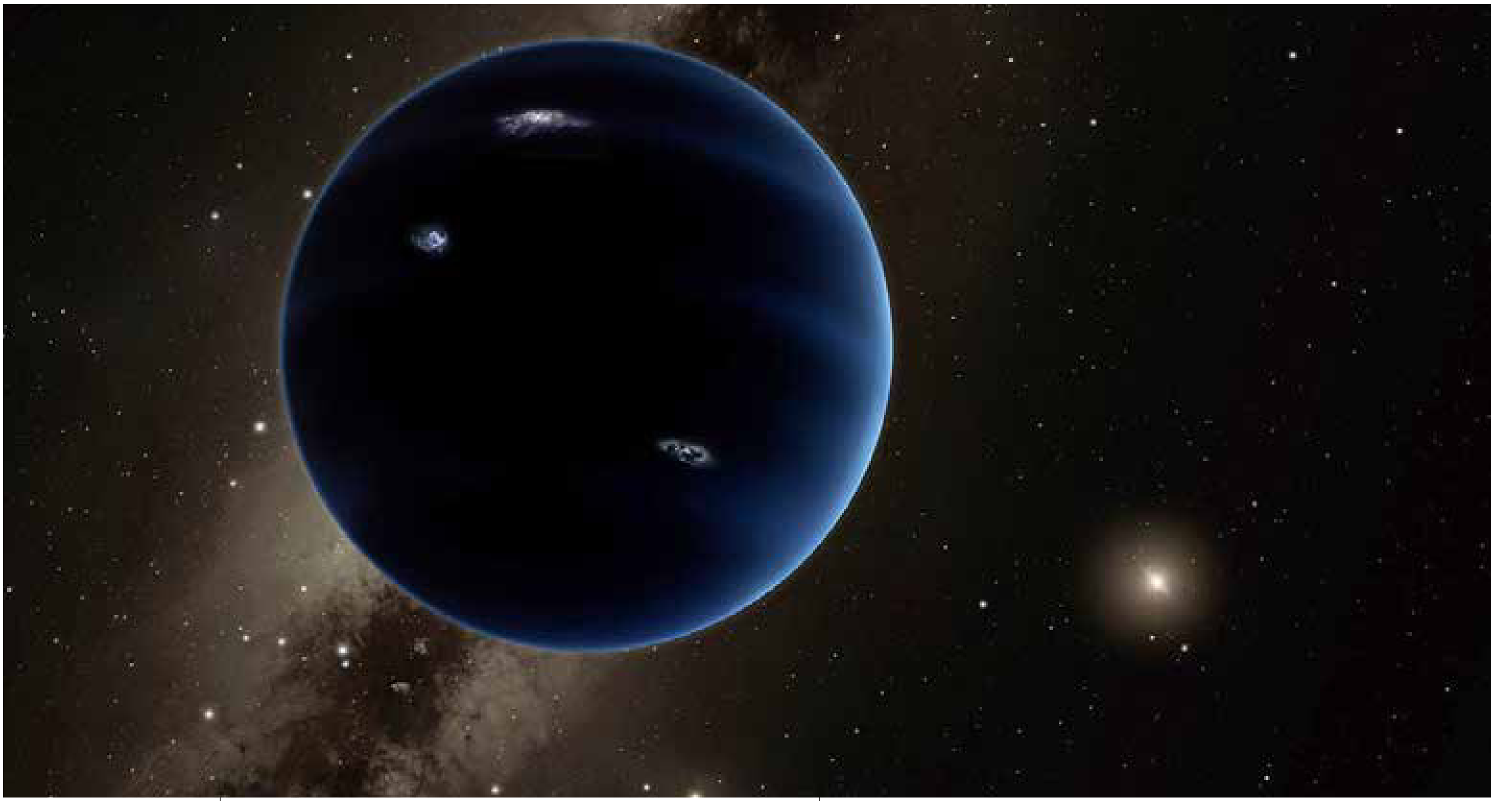
Still, MBAs are hard to come by in the vastness of space. A sphere with a radius of about 249,000 miles (400,000 km) contains only one MBA larger than 330 feet (100 m) in diameter.

Simone Marchi
Staff Scientist, Southwest Research Institute, Boulder, Colorado

JUPITER'S TROJAN ASTEROIDS



Jupiter's Trojan asteroids congregate at the L4 and L5 Lagrange points of the Jupiter-Sun system, meaning they orbit in groups that lead and trail the gas giant planet. The density of Trojans is about 10 times less than the density of asteroids in the main belt. *ASTRONOMY*: ROEN KELLY, AFTER NASA/WMAP SCIENCE TEAM



This artist's concept depicts the distant, hypothetical, Neptune-sized Planet X in our solar system. Although astronomers are searching, catching a glimpse of this planet — if it exists — is challenging, even with powerful telescopes such as JWST.
CALTECH/R. HURT (IPAC)

Q IF THE JAMES WEBB SPACE TELESCOPE CAN SEE GALAXIES BILLIONS OF LIGHT-YEARS AWAY, WHY CAN'T IT FIND THE PROPOSED PLANET X SOMEWHERE IN OUR SOLAR SYSTEM BEYOND PLUTO?

Terry Murray
Cincinnati, Ohio

A Your excellent question demonstrates that at times celestial reality can defy terrestrial intuition.

One would think that astronomical objects within our solar system would be more readily observable than galaxies billions of light-years away. However, in astronomy, apparent brightness is more important than proximity. For instance, the Andromeda Galaxy (magnitude 3.4) appears approximately 12,000 times brighter in our sky than Pluto at its maximum brightness (magnitude 13.6) despite the former's 2.5-million-light-year distance. All the same, one can observe Pluto with a sufficiently powerful telescope because its location is precisely known at any given time.

Finding Planet X, assuming it exists, is far more complicated. In January 2016, Caltech astronomers Konstantin Batygin and Mike Brown published a paper in *The Astronomical Journal* in which they cited evidence for a giant planet that might be five to 10 times more massive than Earth, with an average distance between 400 and 800 AU from the Sun. Pluto's average heliocentric distance is 39 AU. Even if Planet X is truly a giant and reflects a lot of light, it will appear quite faint because the intensity of light diminishes with the square of the distance. At the minimum 400-AU distance, the Sun will appear at least 100 times fainter than it does at 39 AU. Any reflected light from Planet X will appear even fainter after traversing the solar system a second time to reach Earth.

Considering its distance, the uncertainty in its location, and the breadth of its orbital path, this planet would be exceedingly difficult to detect in conventional sky searches. And astronomers will not only have to detect Planet X, but also distinguish it from background stars by virtue of the motion it exhibits relative to them. Recall that Clyde Tombaugh (1906–1997) detected Pluto after a year of meticulous searching with a blink comparator, a machine that compares two different images of the sky to look for differences. The search field for Planet X is broader and, owing to its greater distance and commensurately slower orbital motion, its changes in position relative to the background will be smaller and more difficult to detect, even with current technology.

Edward Herrick-Gleason
Planetarium Director, Southworth Planetarium, University of Southern Maine, Portland, Maine

Q | DO WE KNOW THE ORDER IN WHICH THE PLANETS IN OUR SOLAR SYSTEM FORMED? HOW OLD IS EACH PLANET?

Robert Hawk
Canal Winchester, Ohio

ESTIMATING SPECIFIC AGES IS ONE OF THE MOST DIFFICULT PROBLEMS IN ASTROPHYSICS.

A | Estimating ages of specific events is one of the most difficult problems in astrophysics. While we have a precise (and probably accurate) age for the solar system, we do not have precise ages for each planet.

The solar system's age comes from radiometric dating of rock samples from Earth, the Moon, and meteorites. If an isotope of one element decays into an isotope of another element, then measuring the ratio of both to a stable isotope of either element lets you work backwards to determine how many half-lives have passed since the initial concentration. (One half-life is the time it takes for half of a radioactive parent isotope [or radionuclide] to decay into its product, or daughter, isotope, with half of the parent remaining.) This only works for situations where elemental concentrations do not get mixed up between different material samples (e.g., the system is "closed" — adding in fresh material with different initial values of the radiogenic material, or indeed bulk elemental composition differences, will invalidate the analysis), one has radioactive elements of the right half-life, and these elements are in large enough concentrations to measure. Using this technique, we find that the absolute age of Earth is 4.54 billion years old, with an uncertainty of only 1 percent.

We can also determine relative ages of various rocks using extinct radionuclides, such as aluminum-26 (which decays into magnesium-26), whose half-life is so short (0.72 million years) that its original concentrations are now unmeasurable. The clock is usually set by the initial concentrations found in calcium-aluminum-rich inclusions, or CAIs — the first solids in the solar system — in meteorites, and we can measure ages relative to those. This technique gives relative ages good to half a million years for rocks from the first 10 million years of the early solar system (such as meteorite fragments or interplanetary dust grains). Other isotopic systems with different half-lives can be used to date specific events, like the formation of Earth's core, which is related to the giant impact that formed the Moon.

Our best guess is that the gas giant planets — Jupiter and Saturn — formed first from the gas-rich disk that accompanied the formation of the proto-Sun. Of the planets, Jupiter and Saturn's compositions are most like the Sun. However, even they have higher concentrations of heavy elements (beyond hydrogen and helium on the periodic table) compared to our Sun. This is evidence that even early on, solid materials that formed from these heavy elements — like silicon-oxygen-rich and carbon-rich dust, as well as ices that form at various distances from the Sun — play an important role in planet formation.

We suspect that the ice giants Uranus and Neptune formed next because they have gas-to-dust ratios intermediate between the big gas giants and the rocky terrestrial planets (Mercury, Venus, Earth, and Mars). Uranus and Neptune likely formed just as the gas disk that accompanied the forming Sun was dissipating, on a timescale of less than 10 million years. Next to form were the rocky inner planets. While their initial building blocks probably came together quickly to form planetary embryos, it took between 10 million to 100 million years after the gas disk was gone for these building blocks to further crash into each other and form the terrestrial planets we know today. We can estimate the time since a terrestrial planet's surface was last "reset" (e.g., globally altered, such as by lava flows) based on crater counting, but those times are not formation ages. And finally, the dwarf planets in the outer solar system are still growing slowly.

Nailing down this sequence of events is of consequence for exoplanetary systems as well, which we can study with both theoretical models and observations. A Jupiter-like gas giant that forms early beyond the ice line (where it is cold enough for volatiles like water, ammonia, and carbon dioxide to exist as ices) probably has a strong impact on the delivery of water and other materials to potentially habitable planets. The evolution and final architecture of planetary systems have a lot to tell us about how planets form, as well as the prospects for life in the universe.

And, of course, we still have a great deal to learn when it comes to our own solar system as well.

Michael Meyer
Professor of Astronomy, University of Michigan Ann Arbor, Michigan

Planets form from the disks of debris around young stars, called protoplanetary disks, such as that around the star HD 163296. Astronomers think gas giants form first within these disks, followed by ice giants and terrestrial planets. ALMA (ESO/NAOJ/NRAO); A. ISELLA; B. SAXTON (NRAO/AUI/NSF)

SEND US YOUR QUESTIONS

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

READER GALLERY

Cosmic portraits

1. A HEAVENLY OBJECT
The Angel Nebula (NGC 2170) in Monoceros paints a vivid skyscape with dark veins of dust overlapping regions of glowing hydrogen emission and reflected light from young stars. This HαLRGB image comprises 5.5 hours of exposure with a 24-inch scope. **▪ *Kfir Simon***

2. WAY UP NORTH
Five Geminid meteor trails streak across an aurora-lit sky in northern Sweden Dec. 14/15, amid temperatures of minus 22 F (minus 30 C). The main image is a 10-second exposure taken at f/2.8 and ISO 3200, with four additional frames blended for the rest of the meteors. **▪ *Felipe Menzella***

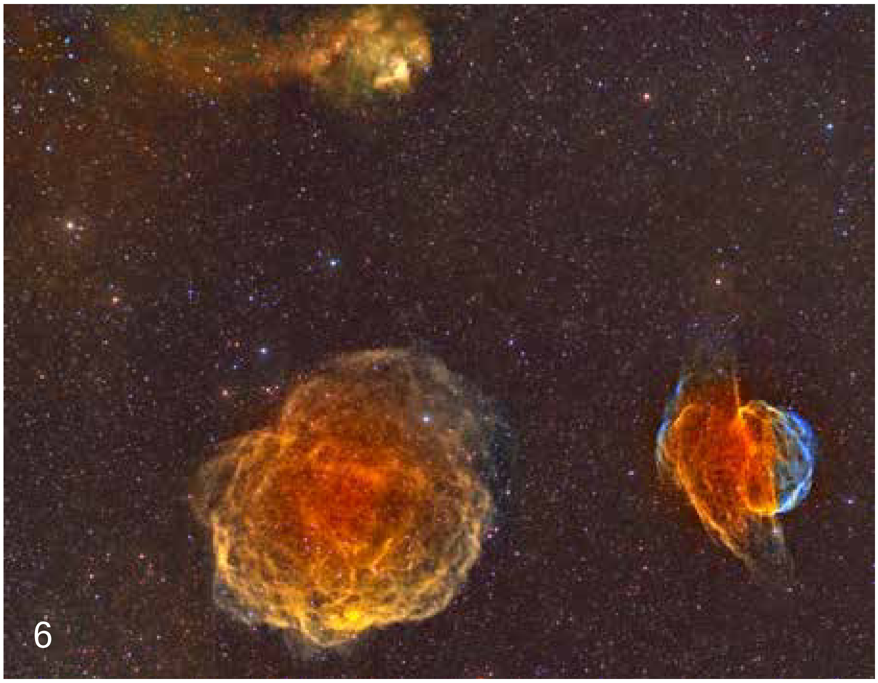
3. SHADOW PLAY
Hubble's Variable Nebula (NGC 2261) can change its appearance noticeably over the course of just a few weeks as dense clumps of gas pass in front of the variable star R Monocerotis, causing the projected light to play off its surroundings. This image was taken with a one-shot color camera and 10 hours of integration on a 10-inch scope.
• Tommy Lease

4. KNOTTY NEBULA
Hartl-Dengel-Weinberger 3 (HDW 3) is a very faint planetary nebula in Perseus around 3,000 light-years away. As the expanding shell of gas from the central dying star runs into the surrounding gas and dust, it forms a bright, swirling arc of ultraviolet emission. The imager took 75 hours of exposure in Hα/OIII/RGB filters with a 4-inch scope.
• Douglas J. Struble

5. ORION RISING
The Orion Molecular Cloud Complex rises over a tent pitched in the Himalayas with the city lights of Darjeeling in the background. The imager captured each of the two sky panels of this vertical mosaic with a modified Canon 700D, a 28mm f/1.4 lens, and 14 one-minute frames at ISO 1600.
• Soumya Banerjee

6. A FAINT TRIO
This scene in Auriga contains the unusual supernova remnant Sharpless 2–224 (right) and the glowing hydrogen clouds of Sh 2–223 (left) and Sh 2–225 (top). This Hα/OIII/SII/RGB image was taken over 80 hours with a 4-inch scope; background frames were taken with a DSLR and 200mm f/2.8 lens. ▪ ***Bill Batchelor***

7. POWER-UP
NGC 281 is known as the Pac-Man Nebula. But beyond its bright circular region, diffuse waves of nebulosity ripple outward. This RGB image comprises 10.25 hours of data with a 10-inch f/2.8 scope. ▪ ***Chris Schur***



8. THE BLUE HORSEHEAD
Orion may lay claim to the most famous equine figure in the galaxy, but Scorpius has the Blue Horsehead Nebula (IC 4592), a reflection nebula lit by the star Nu (ν) Scorpii, some 470 light-years away. This image represents 4.5 hours of exposure with a 2.4-inch Petzval refractor and a one-shot color camera.
• *Don Spencer*

9. WAGGING ITS TAIL
The dust and ion tails of 12P/Pons-Brooks — the so-called "Devil Comet" — are visible in this image taken Feb. 14. The longer ion tail has curves and distortions, perhaps due to interactions with coronal mass ejections from the Sun that passed by a few days prior. The imager used an 11-inch f/2.2 RASA telescope to take four 2-minute exposures with a one-shot color camera.
• *Allen Hwang*

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

STAR BIRTH HEADS OFF TO THE RACES

The glowing clouds of hydrogen that pepper the Milky Way serve as incubators for our galaxy's next generation of stars. Only a few of these nurseries surpass the beauty of the Running Chicken Nebula, however. Located in southern Centaurus just west of the Southern Cross, this nebula lies 6,500 light-years away. Its brightest part, IC 2948, forms either the chicken's head or its rear, depending on which observer you ask. IC 2944 and its bright, vertical ribbons of gas dominate the image's center. The bright star embedded in it is 3rd-magnitude Lambda (λ) Centauri, a blue giant only 400 light-years from Earth. The three splashes of nebulosity along the right side are (top to bottom) Gum 39, Gum 40, and Gum 41. ESO/VPHAS+ TEAM

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