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WHY PLANETS GOT PUMMELED LONG AGO p. 28

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HOW WE FOUND visitors from other solar systems p. 18



'Oumuamua, the first identified interstellar visitor to our solar system, is several times longer than it is wide.

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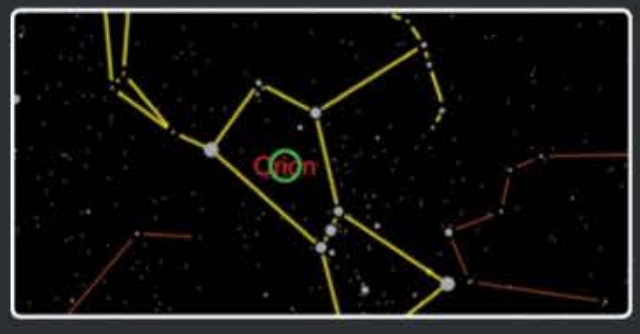


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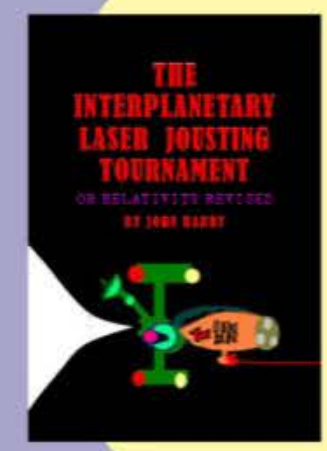


Picture of the Day
Gorgeous photos from our readers.



Dave's Universe
The inside scoop from the editor.





If two spaceships pass each other at super high speeds, does space invert and time change speed so that light can continue to travel at the correct speed for them to keep the other in sight? Or if light travels at a broad range of speeds and we can only detect that which is moving at the right speed for us, then where is the rest hiding?

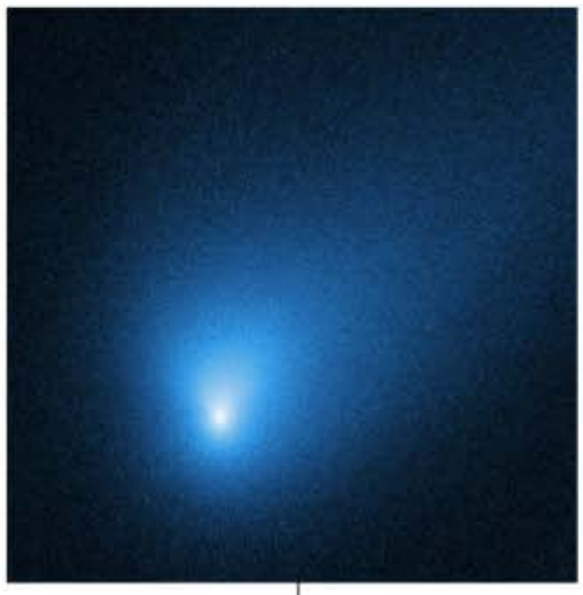
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Interstellar visitors



In 2019 Comet 2I/Borisov became the second known visitor from another solar system. NASA, ESA, AND D. JEWITT (UCLA)

Well, it wasn't an asteroid ship from a *Star Trek* episode or an Arthur C. Clarke novel, but that's exactly what everyone thought at first. When the asteroid 'Oumuamua was discovered in late 2017, it caused a furor. Orbital studies showed the space rock, which astronomer Robert Weryk found using the Pan-STARRS Telescope at Haleakala Observatory in Hawaii, to be the first interstellar object ever detected moving through our solar system.

Research revealed that 'Oumuamua, from the Hawaiian word for "scout," is an elongated, cigar-shaped rock measuring between 330 feet (100 meters) and 1,310 feet (400 m) long and only 40 to 170 m wide. Similar to asteroids in the outer solar system, it is dark red in color, and only its orbit and high velocity gave it away as an interstellar visitor. It will depart our solar system in about 20,000 years, and continue whizzing right along. Associate Editor Alison Klesman's story, "Our first interstellar visitor" (page 18), highlights all of the amazing facts we know about this rogue space rock.

As if this wasn't enough, in August 2019 Crimean amateur astronomer Gennady Borisov discovered a comet, 2I/Borisov, that turned out to be the second known interstellar visitor. This faint object encountered the Sun at a distance of about twice that between the Sun and Earth in December 2019, and will exit the solar system on a hyperbolic orbit.

Lots of objects might gravitationally escape their stars and be floating freely through the galaxy, encountering other star systems. It's just in the last two years, however, that we have developed the capability and timing to find the first two.

A few staff notes: Senior Editor Michael Bakich recently retired after serving on the magazine's staff for 16 years. Undoubtedly, many of you have read and enjoyed Michael's numerous contributions, chiefly focused on the hobby side of astronomy. He will be missed in our building, but will continue to contribute his talents to the magazine from his new home in Tucson, Arizona.

Furthermore, I wish to welcome the distinguished planetary scientist Jim Bell, Arizona State University professor and the president of The Planetary Society, to our Editorial Advisory Board.

Yours truly,



David J. Eicher
Editor



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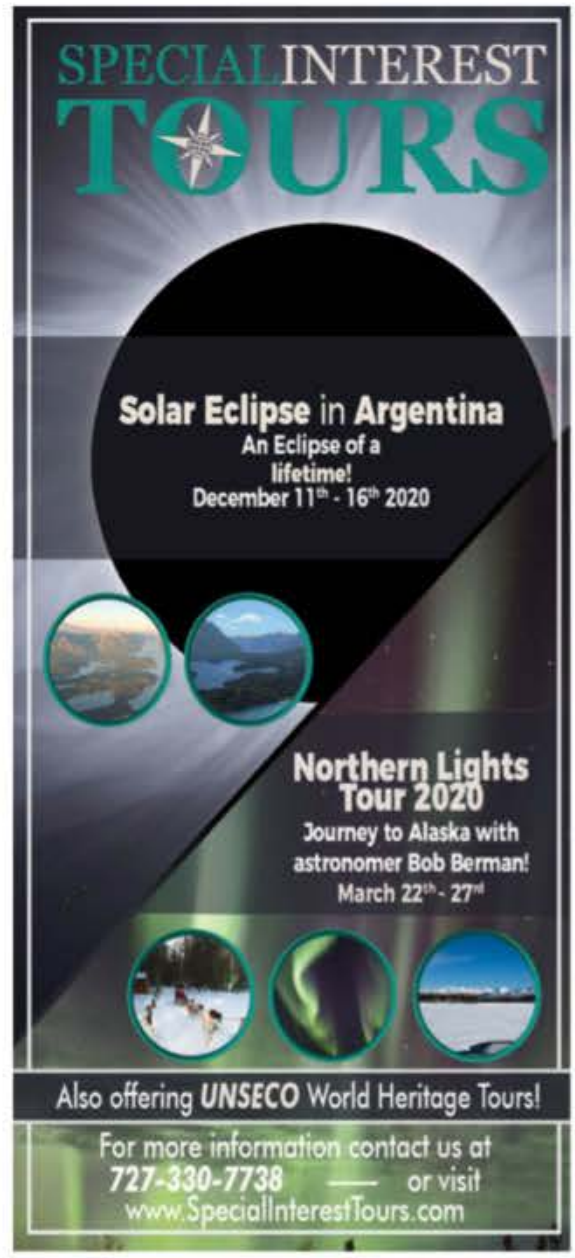
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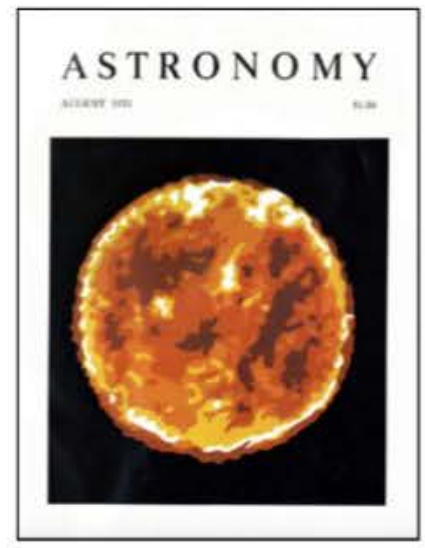
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Press coverage

Bob Berman's column in the October 2019 issue of *Astronomy* correctly elaborates on the "Gross Overstatement Syndrome" that infects our society. I hesitate to reveal my interest in astronomy in public. This usually leads to insane questions, which I must answer carefully to avoid insulting the questioner. The errors are usually directly traceable to an inaccuracy in the news coverage. On the plus side, the revival of the press coverage of "space" is gratifying, as it replaces headlines about people acting inhumane and stupid.
— Jack Peterman, Lady Lake, FL

Continuously classic

Every issue of *Astronomy* magazine is a classic issue for me. Visually — full of stunning photos that leave us spellbound — as well as content-wise, the magazine is opulent. I always start by reading David J. Eicher's inspiring words. The Sun's history from Moon rocks in the October issue was a great read, and Michael Carroll's extensive write-up on Ceres was a revelation. In June, Robert Naeye's "Tension at the heart of cosmology" was particularly informative. I can never get



enough of your magazine and I'm thankful for the knowledge I have gained in the past six months. This is just the beginning!
— Shobha Kaicker, Mississauga, Ontario

The end of Super Moons?

By all means, *Astronomy* should drop the term "Super Moon." I would have lost interest in the heavens decades ago if I had been fed these ridiculous exaggerations. The press promises things like, "Mars will appear as large as the Moon!" without adding that considerable magnification is needed to verify this claim. "View 200 meteors per hour!" — but only if you live in utter, remote wilderness. These hyperboles kill interest in astronomy through repeated disappointment for those who might otherwise have come to love it. *Astronomy* can do our science a great service by simply presenting the unvarnished facts about what one can see in the sky. **— Robert Miller,** Berlin, VT

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

By proving the new discovery claim (2007) over rotation to the Sun (by the materialistic particles curved rays) as wrong and false. The Sun releases a continuous flow of particle rays (light and other kinds of the rays) which are materialistic in nature. Outgoing materialistic particles curved rays along with other solar ejects put back thrust over every particle of the Sun which encircles the Sun's particle matter faster (or rotates the Sun faster) at its equator than near to its Poles. The same reason of back thrust by the rays over every particle of the Sun also keeps the Sun a perfect sphere and does not allow it to become oblate in spite of its fast rotation. The discovery claim disapproves centuries old understanding that the Sun rotates by the conservation of angular momentum.

Further, gravity is not the only factor which governs formation and working mechanism of the celestial bodies as the World understands; it is the backward thrust over the body by the outgoing materialistic particles curved rays and forward thrust by the rays over the celestial bodies along with the factor gravity which does the said job.

The entire Universe is materialistic; no pocket of the Universe is with absolute nothing. Whatsoever trillions and trillions of stars release in the form of invisible matter by losing their mass in their respective galaxies or into the space that all is matter to be called as white matter which has been falsely understood by the Scientists as dark matter.

Acceptance of unique materialistic particle properties of the rays as discovered and claimed would result to replace almost all theories, hypotheses, postulations and speculations over the subjects Astronomy and Physics (Rays and states of the matter) with the scientific facts.

Read in detail the discovery claim on website:
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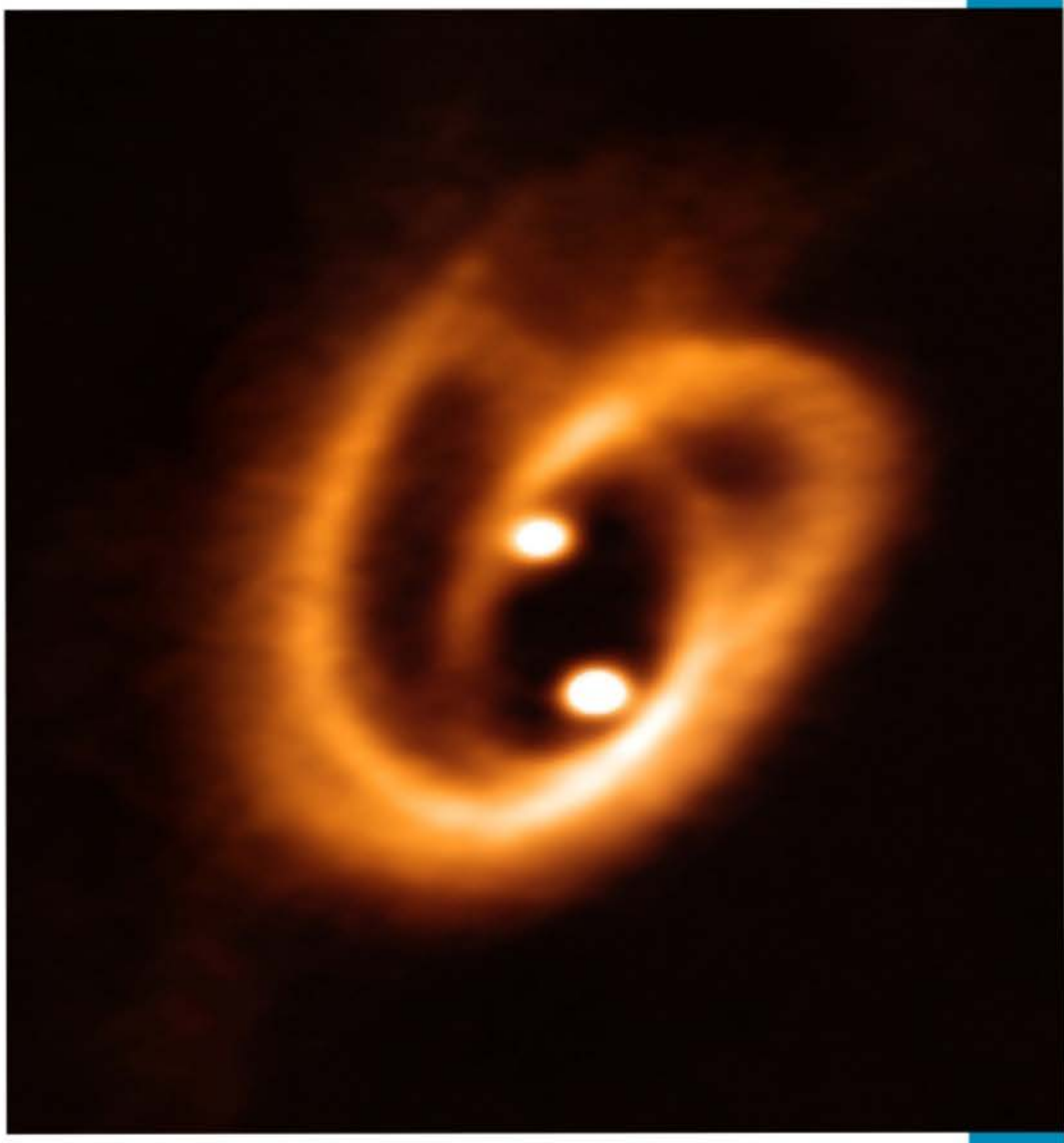
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A COSMIC PRETZEL

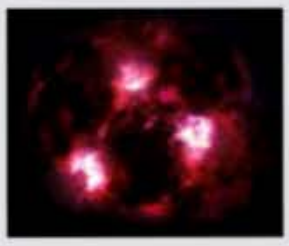
Astronomers get a clearer look than ever before at these forming stars, revealing complex rings.



Astronomers using the Atacama Large Millimeter/submillimeter Array recently captured this image of two baby stars locked in a gravitational waltz that's twisting the disks of material around them into a knot. Cumulatively, the intertwined disks contain about 260 Earth masses of dust, leading researchers to speculate the system may eventually form rocky, terrestrial planets. "This is a really important result," Paola Caselli, co-author of the study and managing director of the Max Planck Institute for Extraterrestrial Physics, said in a press release. "We have finally imaged the complex structure of young binary stars with their feeding filaments connecting them to the disk in which they were born. This provides important constraints for current models of star formation." The research was published October 4 in the journal *Science*. –JAKE PARKS

ALMA (ESO/NAOJ/NRAO), ALVES ET AL. BOTTOM FROM LEFT: JAMES JOSEPHIDES, SWINBURNE ASTRONOMY PRODUCTIONS, CHRISTINA WILLIAMS, UNIVERSITY OF ARIZONA AND IVO LABBÉ, SWINBURNE UNIVERSITY; FLORIAN PIRCHER (PIXABAY); NASA/JHUAPL/SwRI

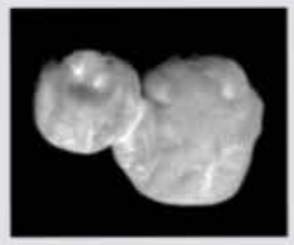
HOT BYTES



HIDDEN MONSTER
An international team of astronomers has discovered the faint glow of dust, which obscures starlight, shrouding a massive "monster" galaxy that is rapidly forming stars in the early universe.



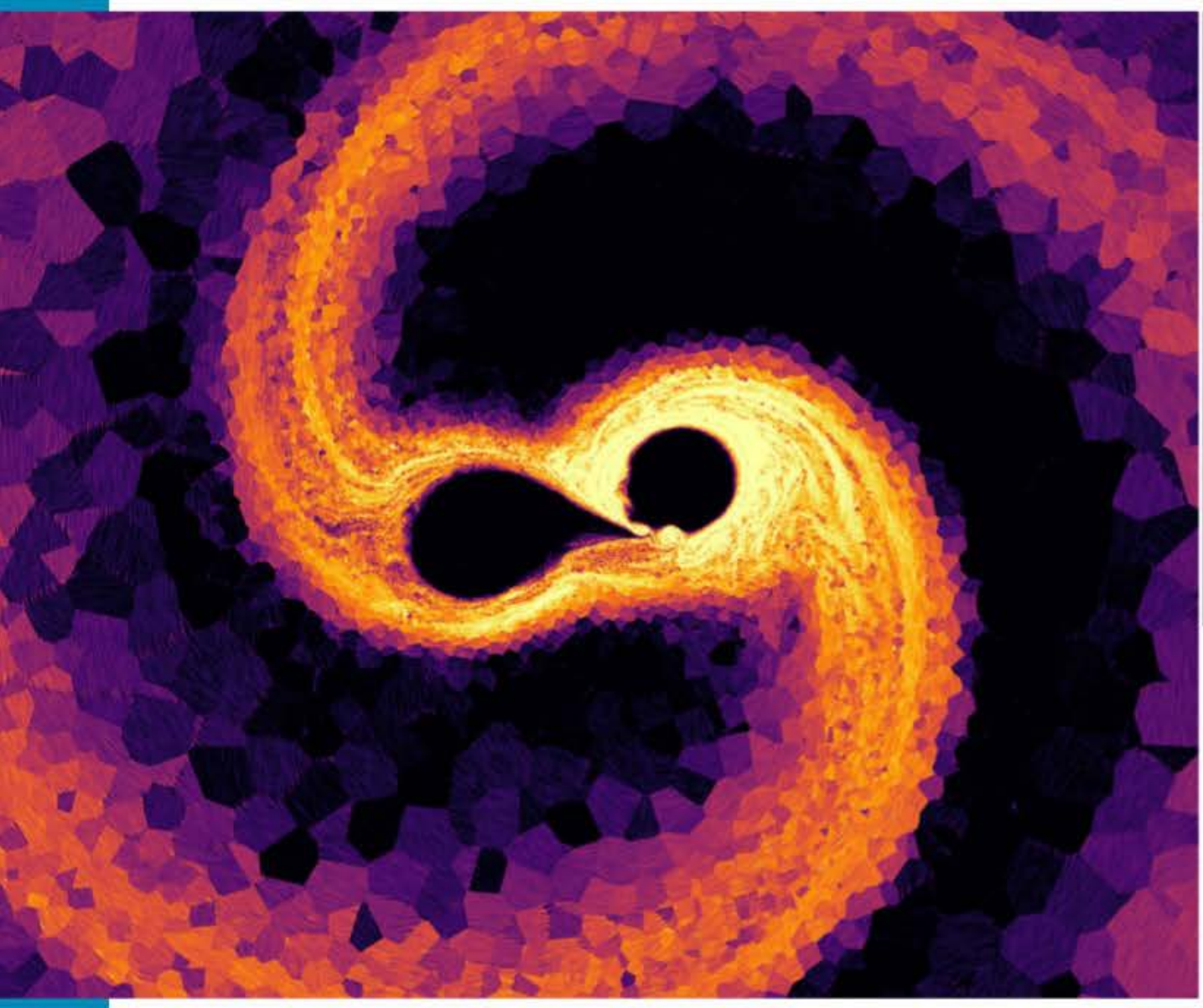
NOBEL WINNERS
James Peebles, Michel Mayor, and Didier Queloz received the Nobel Prize in physics in 2019 — Peebles for his work in cosmology, and Mayor and Queloz for their discovery of the planet 51 Pegasi b.

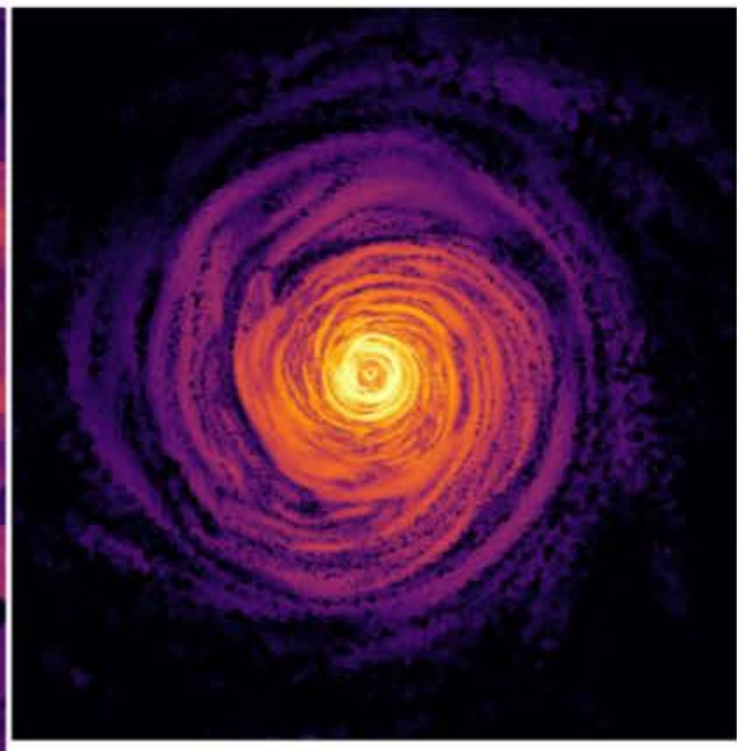


NEW NAME
Previously nicknamed Ultima Thule, the Kuiper Belt object 2014 MU_{69} has been officially named Arrokoth, which means "sky" in the Native American Powhatan/Algonquian language, by the IAU.

CREATING THE UNIVERSE'S MOST POWERFUL MAGNETS

When two stars collide, the resulting product may explain rare, extremely magnetic objects called magnetars.





MAGNETIC MERGERS. These snapshots from simulations of two merging stars show the overall strength of the magnetic field in color (yellow is more magnetic). The stars on the left, which don't have very strong magnetic fields, are just about to merge into a more massive and magnetic star (right). According to new research, such mergers can dramatically bolster the strength of the final star's magnetic field. OHLMANN/SCHNEIDER/RÖPKE, FROM F. SCHNEIDER ET AL. (*NATURE* VOLUME 574, P. 211–214 (2019))

More than 60 years ago, astronomers realized that about 10 percent of massive stars have powerful magnetic fields bursting from their surfaces. But the exact origin of these magnetic fields — which can reach hundreds to thousands of times the strength of the Sun's — has remained a mystery.

The answer, it turns out, may be due to collisions between two normal stars.

A German-British team of scientists recently used cutting-edge simulations to uncover an evolutionary path they think explains the formation of extremely magnetic stars. And as a cherry on top, their findings may also shed light on a slew of other astronomical oddities. These include magnetars (a rare type of hypermagnetic neutron star), blue stragglers (massive stars that appear too young for their age), and maybe even enigmatic cosmic events like fast radio bursts, which are intense blasts of radio energy lasting just milliseconds. Their research was published October 9 in *Nature*.

MAGNETIC MERGERS

As a star spins, its inner layers rotate faster than its outer layers. Running through and connecting each of these layers are magnetic field lines, Fabian Schneider of Heidelberg University, the first author of the new study, tells *Astronomy*. Because each layer rotates at a different speed, the magnetic field lines connecting the layers get twisted and tangled up, he says. This amplifies the overall strength of the star's magnetic field.

When two stars collide, it can kick up their spin even more, increasing their magnetic fields. At the same time, during a merger, stellar material gets violently sloshed around. This turbulence further stirs the already tangled magnetic field lines, exponentially increasing the final star's magnetism.

But the new research doesn't just describe how colliding stars can form insanely magnetized stars — it also may explain the origins of blue stragglers.

MAKING A BLUE STRAGGLER

Blue straggler stars masquerade as being younger than they truly are. These "rejuvenated" stars are much hotter — making them bluer — and brighter than average main sequence (or middle-aged) stars of a similar apparent age.

But what is the fountain of youth that keeps blue stragglers looking so fresh? One leading theory is that merging with another star will do the trick. The group's results support this notion.

Main sequence stars power themselves by fusing hydrogen into helium in their cores. When that supply runs out, they move on to fusing concentric shells of hydrogen around the now-inert core. This causes the star to balloon into a red giant.

But if two main sequence stars collide, their material gets mixed together. The resulting product now has a restocked reservoir of hydrogen in its core, which allows it to chug along as a more massive — yet still main sequence — blue straggler, instead of evolving into a red giant. "In other words," Schneider says, "their internal clock has been set back."

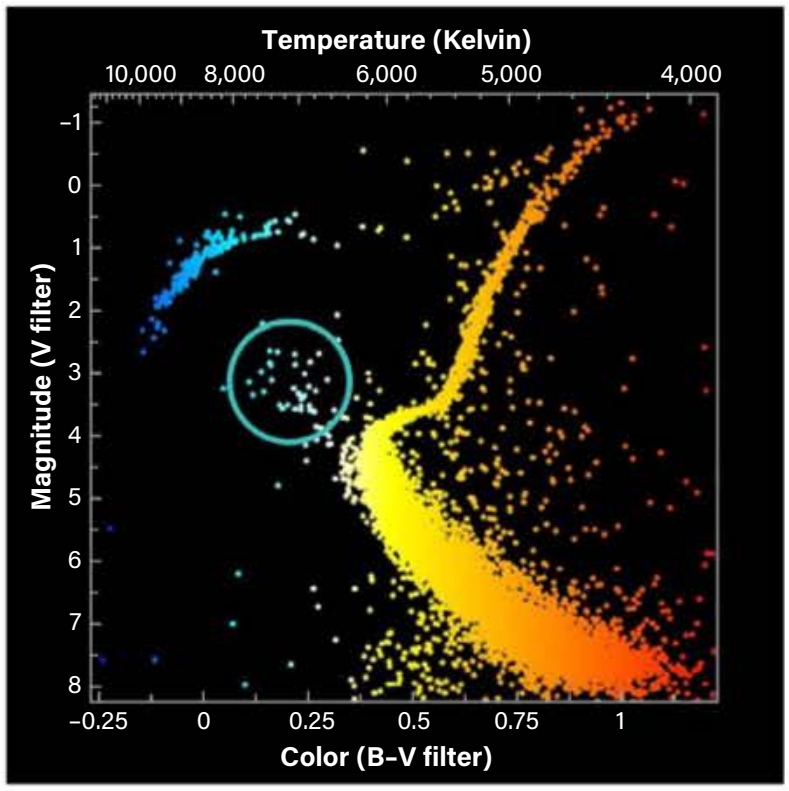
THE CONNECTION CONTINUES

And there's a further cosmic connection. According to the new study, blue stragglers may produce another exotic object when they die in explosive supernovae: magnetars.

"Magnetars are thought to have the strongest magnetic fields in the universe," said co-author Friedrich Röpke of the Heidelberg Institute for Theoretical Studies in a press release. These strange neutron stars have magnetic fields that are some 5 quadrillion (1 quadrillion is 1,000 trillion) times stronger than Earth's. And many researchers believe outbursts from magnetars might be the cause of fast radio bursts, a phenomenon that remains unexplained.

The team's results suggest that ultimately, magnetars could be "the natural end product" of mergers between main sequence — as well as younger, pre-main sequence — stars, Schneider says. "The biggest and yet-unsolved question," he says, "is whether the magnetic field produced in the merger can survive up to the supernova stage, and then whether the magnetic field is indeed maintained in the forming neutron star when the core of the star collapses."

That has yet to be determined, Schneider says, "but I think our suggestion is a very promising channel to finally understand the origin of magnetars and their strong magnetic fields." – J.P.



NEW LEASE ON LIFE. Blue stragglers within the globular cluster M55 are circled in this color-magnitude diagram, which plots the color and overall brightness of stars of the same age. Main sequence stars fall along the thick band spanning from the lower right to the center of this image. When they evolve into red giants, they start climbing up the thin band to the upper right. Blue stragglers are rejuvenated stars so massive (and therefore short-lived) that they seem like they should already be on the red giant branch, but instead form their own extended population along the main sequence. B.J. MOCHEJSKA, J. KALUZNY (CAMK), 1-M SWOPE TELESCOPE

QUICK TAKES

SHREDDED STAR

Scientists using NASA's planet-hunting TESS telescope witnessed a star getting torn apart as it passed too close to a supermassive black hole some 375 million light-years away.

LUNAR ICE

New research suggests water ice trapped in shadowy craters on the Moon's south pole may come from more than one source — and some deposits may be relatively recent.

RAVENOUS NEIGHBOR

The Andromeda Galaxy has likely cannibalized numerous dwarf galaxies in at least two separate smorgasbords, set apart by billions of years. Astronomers found evidence of the meals in the form of star streams left over from the doomed dwarfs.

GAS GUZZLER

Astronomers spied gas flowing like a waterfall into gaps in the disk of material around a young star, which may provide insight into how nascent planets collect their atmospheric gas.

TRANSFORMERS

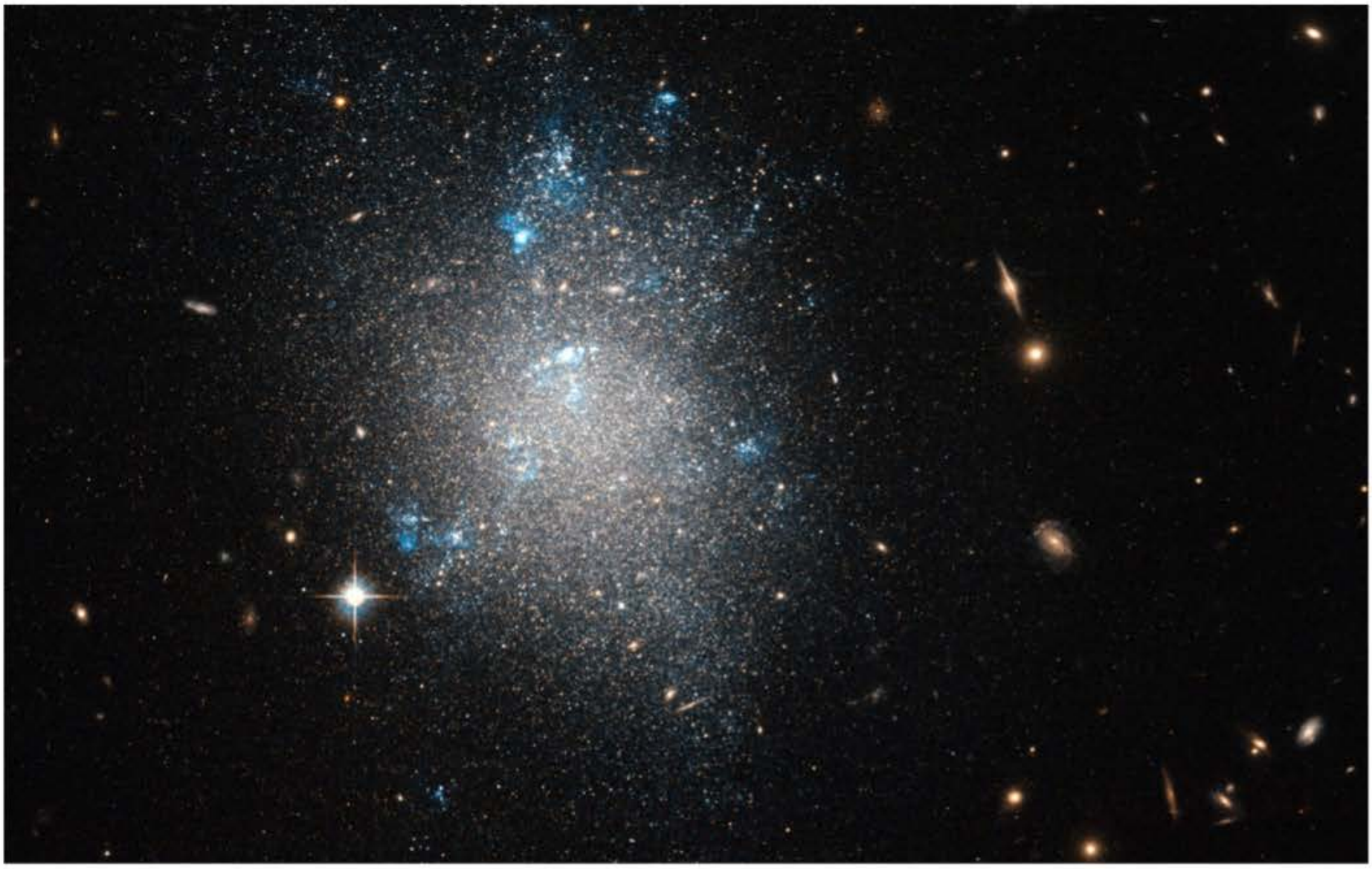
NASA is experimenting with small robots that could help explore Saturn's moons by joining together to form a rolling rover, a flying drone, or a swimming submersible.

RAPID ROTATORS

"Super spiral" galaxies with 10 to 20 times as much visible matter as the Milky Way whip their stars around much faster than expected, suggesting they have an even higher ratio of dark matter to normal matter than other galaxies.

FROZEN FUEL

NASA has awarded $17.4 million to four private aerospace companies (Blue Origin, SpaceX, OxEon Energy, and Skyre) to develop technologies that can produce rocket fuel from the icy deposits on the Moon and Mars. – J.P.



PUTTING THE BRAKES ON. NGC 5477 is a dwarf galaxy still forming stars at a high rate. A new study, however, shows that in some dwarf galaxies, winds from the central supermassive black hole could shut down star formation by blowing gas away before it can make new stars. ESA/HUBBLE & NASA

Supermassive black holes stunt dwarf galaxies

Most galaxies host a supermassive black hole in their center. In large galaxies, winds of energetic gas and particles blasted out by these black holes can slow or even stop the formation of stars. But this process has not been studied well in smaller dwarf galaxies. Now, a paper published October 11 in *The Astrophysical Journal* shows that supermassive black holes in dwarf galaxies are capable of shutting down star formation, just like their more massive counterparts.

Stars form when gas in a galaxy cools, contracts, and ultimately collapses. But winds — say, from a supermassive black hole or a massive star exploding as a supernova — stop star formation by either heating up the gas so it can't cool and collapse, or by pushing the gas out of the galaxy entirely, removing the raw material available for new stars.

"Typically, winds driven by stellar processes [such as supernovae] are common in dwarf galaxies," said first author Christina M. Manzano-King of the University of California, Riverside, in a press release. So, astronomers have long assumed these winds, and not winds from a supermassive black hole, affected star formation in dwarf galaxies, she said.

But in six dwarf galaxies, her team spotted winds that clearly came from the galaxies' black holes. Those winds were surprisingly swift and strong, negatively impacting the galaxies' ability to form stars, said study co-author Laura V. Sales, also of UC Riverside. The winds were so strong that they pushed the gas out beyond the galaxies' boundaries, making it unavailable to form stars.

Dwarf galaxies represent the building blocks of larger galaxies, which grow through collisions of smaller galaxies. This result, the team said, is an important step toward building a better picture of dwarf galaxies, and the larger galaxies they ultimately create. – ALISON KLESMAN

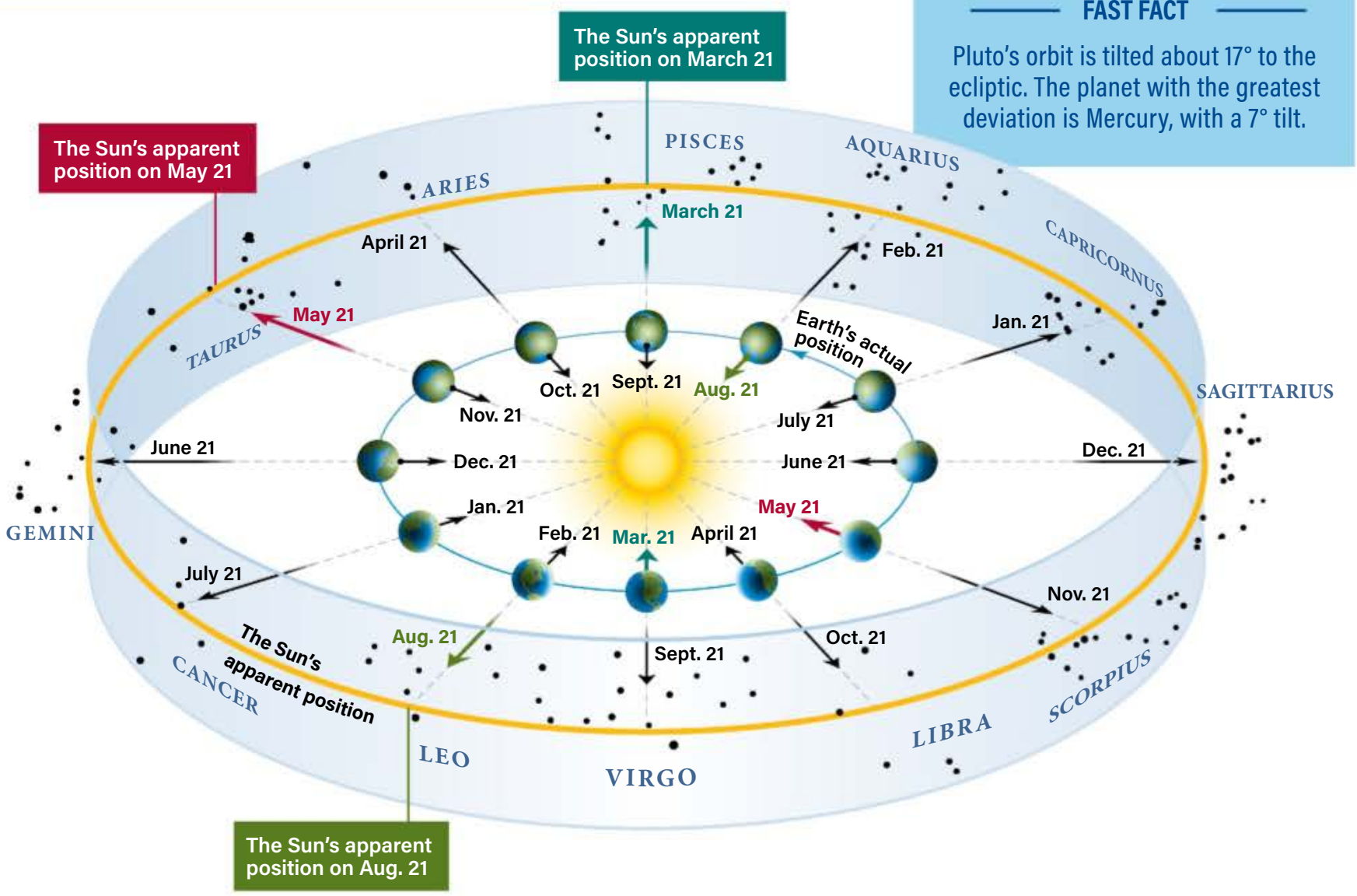
3.5 million

The number of years ago that the Milky Way's supermassive black hole flared up, sending out intense radiation above and below the plane of our galaxy.

THE SUN AND THE STARS

FAST FACT

Pluto's orbit is tilted about 17° to the ecliptic. The planet with the greatest deviation is Mercury, with a 7° tilt.



ASTRONOMY: ROEN KELLY

LIKE CLOCKWORK. If you were to turn our solar system on its side and look at it edge-on, you would notice that the planets circle the Sun within a relatively flat plane. From Earth, the effect is that the Sun and planets appear to traverse a narrow strip of sky, called the ecliptic. This strip is where the 12 zodiacal constellations are located, and the Sun moves through each over the course of a year. The constellation in which the Sun appears located at any given time is actually directly behind the Sun's position in the sky, as seen from Earth. Because of its position, that same constellation rises and sets with the Sun during the daytime, and is not visible until several months later, when Earth has moved and the Sun appears in a different portion of the sky. –A.K.

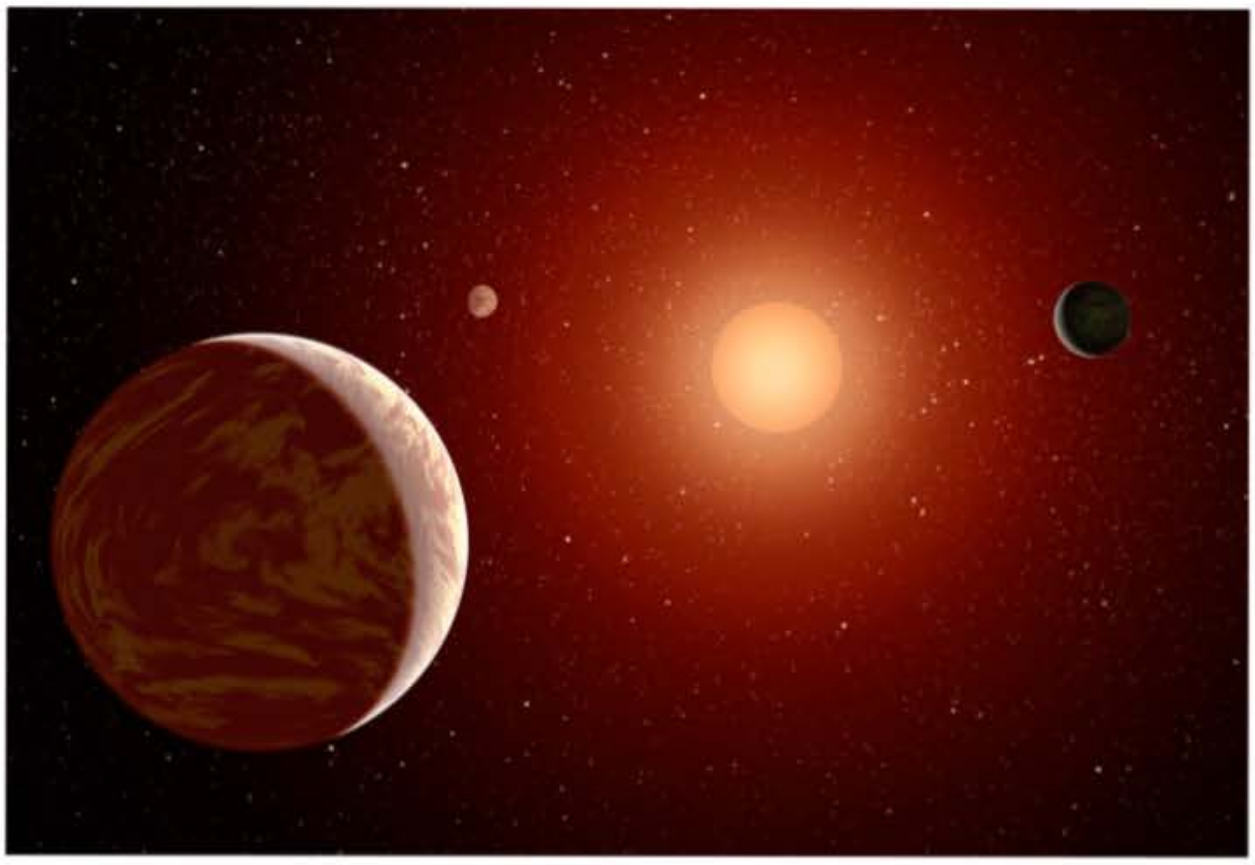
Young stars blow bubbles

Young, massive stars can have a big effect on their birthplace. The Spitzer Space Telescope, which views infrared light at wavelengths longer than human eyes can see, spotted a number of stars blowing bubbles roughly 10 to 30 light-years wide in the gas and dust surrounding them in a region in the constellation Aquila the Eagle. In this image, blue colors represent starlight, green colors are light emitted by dust and organic molecules, and red indicates regions of dust heated by starlight. Researchers counted more than 30 bubbles, which form as radiation and winds of particles from young stars heat and push dust and gas away. Also prominent at upper left is a red, curved bow shock, created when winds from a fast-moving star push aside material in front of the star as it flies by. –A.K.



NASA/JPL-CALTECH

Tiny star, giant planet



THEY GROW UP FAST. The newly discovered planet GJ 3512 b, imagined here in an artist's concept, is half the mass of Jupiter. Researchers think the planet might have formed through a process often considered unimportant around smaller stars. NASA/JPL-CALTECH

Astronomers have discovered a titanic planet orbiting a puny star some 30 light-years away — and, according to current theories, the planet shouldn't exist. Dubbed GJ 3512 b, the gas giant is at least half the mass of Jupiter. But it orbits a red dwarf star that's just one-tenth the mass of our Sun.

"Around such stars, there should only be planets the size of the Earth or somewhat more massive super-Earths," said Christoph Mordasini of the University of Bern in a press release. "GJ 3512 b, however, is … at least one order of magnitude more massive than the planets predicted by theoretical models for such small stars."

Scientists thought that gas giants like Jupiter always started their lives by developing heavy, solid cores before quickly accumulating thick, gaseous atmospheres (a process called core accretion). But because GJ 3512 b is such a big fish in a little pond, its existence is making researchers reconsider whether gas giants around small stars really *must* start their lives as massive embryos before gobbling up copious amounts of gas.

"One way out would be a very massive disk that has the necessary building blocks in sufficient quantity," said Hubert Klahr, a planet-formation expert from the Max Planck Institute for Astronomy in Heidelberg, Germany. If the star GJ 3512 initially started its life surrounded by a particularly massive disk of both gas and dust, the gravity of the disk itself would be strong enough to trigger instabilities within it. Some regions of the disk would then directly collapse, ultimately forming large planets without undergoing the typical two-stage growth process.

This is called the gravitational disk collapse model, and so far, it's been largely ignored when it comes to planets around red dwarfs. The major issue with this scenario is that researchers haven't yet found examples of such oversized disks around young red dwarf stars.

"With GJ 3512 b, we now have an extraordinary candidate for a planet that could have emerged from the instability of a disk around a star with very little mass," said Klahr. "This find prompts us to review our models."

The research was published September 27 in the journal *Science*. –J.P.



NASA/JPL-CALTECH/MSSS

CURIOSITY SNAPS A CELEBRATORY SELFIE

NASA has shared the Curiosity Mars rover's most recent selfie, taken October 11 from a location called Glen Etive on Mount Sharp. The photo, which is a composite of 57 individual snapshots, commemorates a special occasion: the rover's second-ever "wet chemistry" experiment. Curiosity can only perform nine experiments of this type, which exposes samples to chemical solvents in its onboard Sample Analysis at Mars lab. These solvents facilitate the detection of carbon-based molecules, called organic compounds, that play a role in the formation of life. Although this is the rover's second wet chemistry experiment, it is its first on a sample drilled from the ground; the previous wet chemistry experiment was on sand scooped up by the rover's arm. Curiosity gathered its latest samples from the two drill holes visible to the rover's lower left. –A.K.



NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STScI/AURA)-HUBBLE/EUROPE COLLABORATION; ACKNOWLEDGMENT: H. BOND (STScI AND PENN STATE UNIVERSITY)

Stellar database encourages amateur submissions

Since its founding in 1911, the American Association of Variable Star Observers (AAVSO) has been tracking and studying variable stars, such as RS Puppis (seen here). AAVSO is an organization of not only professional astronomers, but also amateur observers of all skill levels. One way to study variable stars is spectroscopy, which breaks apart starlight by wavelength to reveal information about the star's age, temperature, and type. On October 23, AAVSO announced its new AAVSO Spectroscopic Database (AVSpec), an open database that allows both AAVSO members and non-members to view and download spectra, free of charge. All observers, regardless of experience or equipment, are encouraged to submit spectra to the database, providing a deeper understanding of variable objects and even increasing the chances that one-off events, such as nova outbursts, will be seen. You can access AVSpec to contribute or download data at www.aavso.org/apps/avspec. – A.K.

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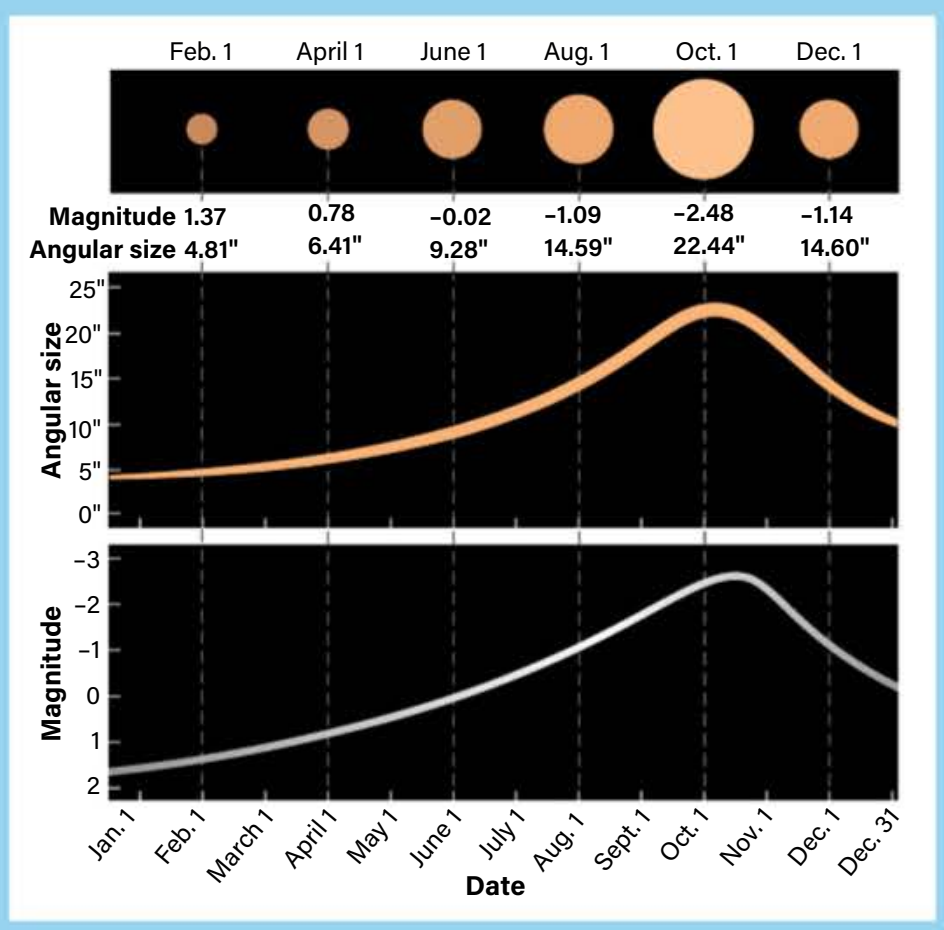
The number of new moons recently discovered around Saturn, bringing the planet's total to 82, which is three more than the known number of moons circling Jupiter.

MARS' SPLENDID SHOW

RED PLANET RENAISSANCE. Mars puts in a grand appearance during 2020. At its peak in October, it will shine at magnitude –2.6 — brighter than any other point of light in the sky besides Venus — and swell to an apparent diameter of 22.6". But Mars will exceed magnitude –1.0 from late July to early December and span more than 10" from mid-June through the end of the year. – RICHARD TALCOTT

FAST FACT

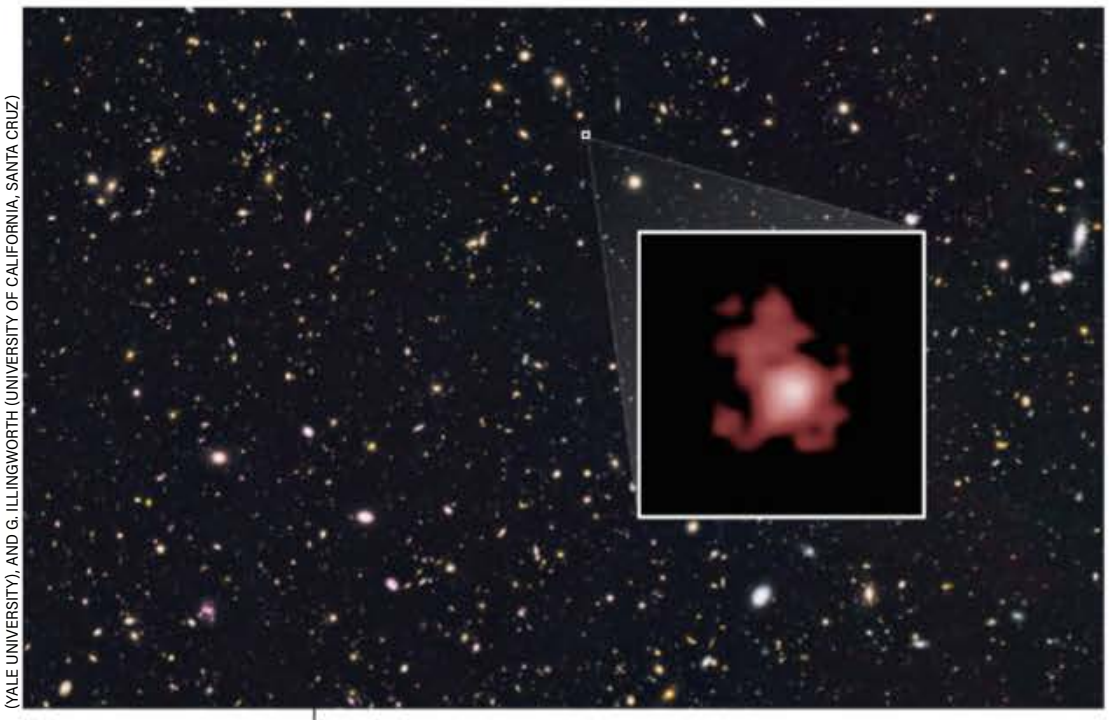
Mars appears especially nice from the Northern Hemisphere, where it climbs 30° higher than it did at its 2018 peak.



ASTRONOMY: ROEN KELLY

Farewell to a small universe

The edge of the cosmos sure is hard to find.



NASA, ESA, P. OESCH (YALE UNIVERSITY), G. BRAMMER (STScI), P. VAN DOKKUM (YALE UNIVERSITY), AND G. ILLINGWORTH (UNIVERSITY OF CALIFORNIA, SANTA CRUZ)

The GOODS-North field, observed by the Hubble Space Telescope, contains GN-z11 (inset), one of the most distant galaxies discovered to date. Its light has been traveling for 13.4 billion years, and the galaxy appears as it did just 400 million years after the Big Bang.



BY BOB BERMAN
Join me and Pulse of the Planet's *Jim Metzner in my podcast, Astounding Universe, at* **www.astoundinguniverse.com**

It may be the oldest question in astronomy: How big is the cosmos?

Our deepest astrophotos show ultra-distant quasars and galaxies whose redshifts indicate their light has traveled for nearly 13 billion years. Thus, they are 13 billion light-years away, right? And that must define the edge of the visible universe, right?

It's a widely repeated "fact." There's even a plaque in the Rose Center for Earth and Space in New York City that flat-out declares the radius of the visible universe to be 13 billion light-years.

But that figure only tells us how long an object's light has been traveling. It's not the end of the story, because ever since a given galaxy emitted the light we're now seeing, it's been zooming away from us. Today that galaxy is 46 billion light-years distant.

This should make our heads spin. How could anything reach a distance of 46 billion light-years in the mere 13 billion years since it emitted the light we now see? That would mean it's currently receding faster than light. Or that space is so warped we're not viewing it directly.

Actually, both are true. Faster-than-light recession doesn't violate relativity in this case because the galaxy's mass was never accelerated. It's merely the intervening empty space between galaxies that has been wildly inflating, which makes the real radius of the observable universe very nearly 46 billion light-years. Light from objects any farther away will never get here because space's expansion will stretch out, hopelessly weaken, and out-race their rays. So, it's a real boundary beyond which there is eternal blankness. We use the term *visible universe* for everything nearer, which is everything we can ever possibly know about.

Given the average density of space — five atoms per cubic yard (1 cubic meter) — the visible universe must contain 10^{56} tons of matter. And 10^{84} photons of light. It's a hefty universe.

But what about the universe beyond the part we can see? The real universe? How big is the whole thing?

There's no sign that galaxy clusters get any sparser as we approach the edge of the observable universe. A 2012 study led by Shirley Ho, then at the Lawrence Berkeley National Laboratory, charted 900,000 galaxies to show that the topology of the visible universe is perfectly flat, which means stuff keeps abundantly going on beyond the visible boundary.

One theory, using the most plausible figures for when the era of inflation began just after the Big Bang, concludes that the overall universe is 300 billion trillion times larger than the visible universe.

But it's also possible the real universe is infinite. If that's true, galaxies go on and on without end. Ho told me that their results do indeed permit an infinite universe. But because you can never *prove* infinity, it'll remain an open question.

If the 2012 results are wrong, then a much different scenario is also on the table. Before those data, in fact, it seemed that the real cosmos could even be *smaller* than the visible universe!

It may be the oldest question in astronomy: How big is the cosmos?

Huh? Could you imagine how that could even be possible?

Well, back in the '90s on my monthly page in *Discover* magazine, I mentioned that in an unbounded finite universe, the bending of space-time along its circumference would permit galaxy light to circle around. Thus, we earthly observers could see a second image of a nearby galaxy. That duplicate observation would be of the galaxy's far side after its light had circled the cosmos. It would probably be unrecognizable as the same object, since we'd be seeing it in the distant past, at an earlier stage of its evolution. But if there's a bunch of such duplicates out there, then the cosmos is smaller than it seems.

We started out asking a simple question and ended up nauseated. Now you know why I prefer observing beloved lunar craters like Copernicus and Eratosthenes. They're 50 miles (80 kilometers) wide, a known distance away, and none of that is ever going to change.

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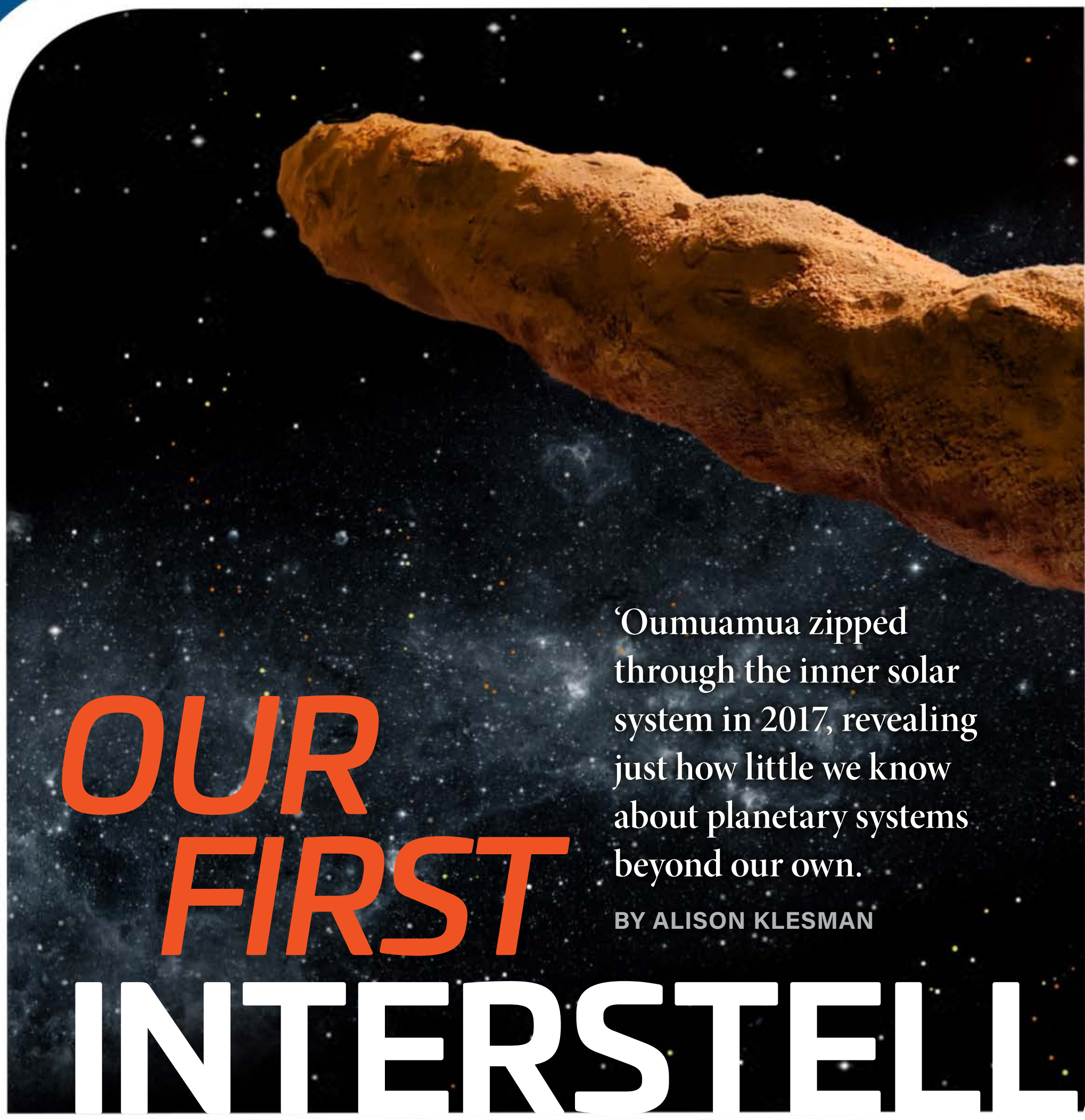
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OUR FIRST INTERSTELL

'Oumuamua zipped through the inner solar system in 2017, revealing just how little we know about planetary systems beyond our own.

BY ALISON KLESMAN

Sometime around the year 1837, a strange object passed an invisible cosmic mile marker: 1,000 astronomical units from the Sun. (One astronomical unit, or AU, is the average Earth-Sun distance.) For more than a century, it continued undetected toward our star. Finally, on October 19, 2017, humans noticed the visitor.

That night, a faint, thin streak appeared in a 45-second-long image snapped by the University of Hawai'i's Pan-STARRS1 Telescope on Maui. The next morning, postdoctoral researcher Robert Weryk spotted the streak and compared it to an image taken the day before. The object was there, too. It was moving steadily across the sky, covering about 6.2° each day.

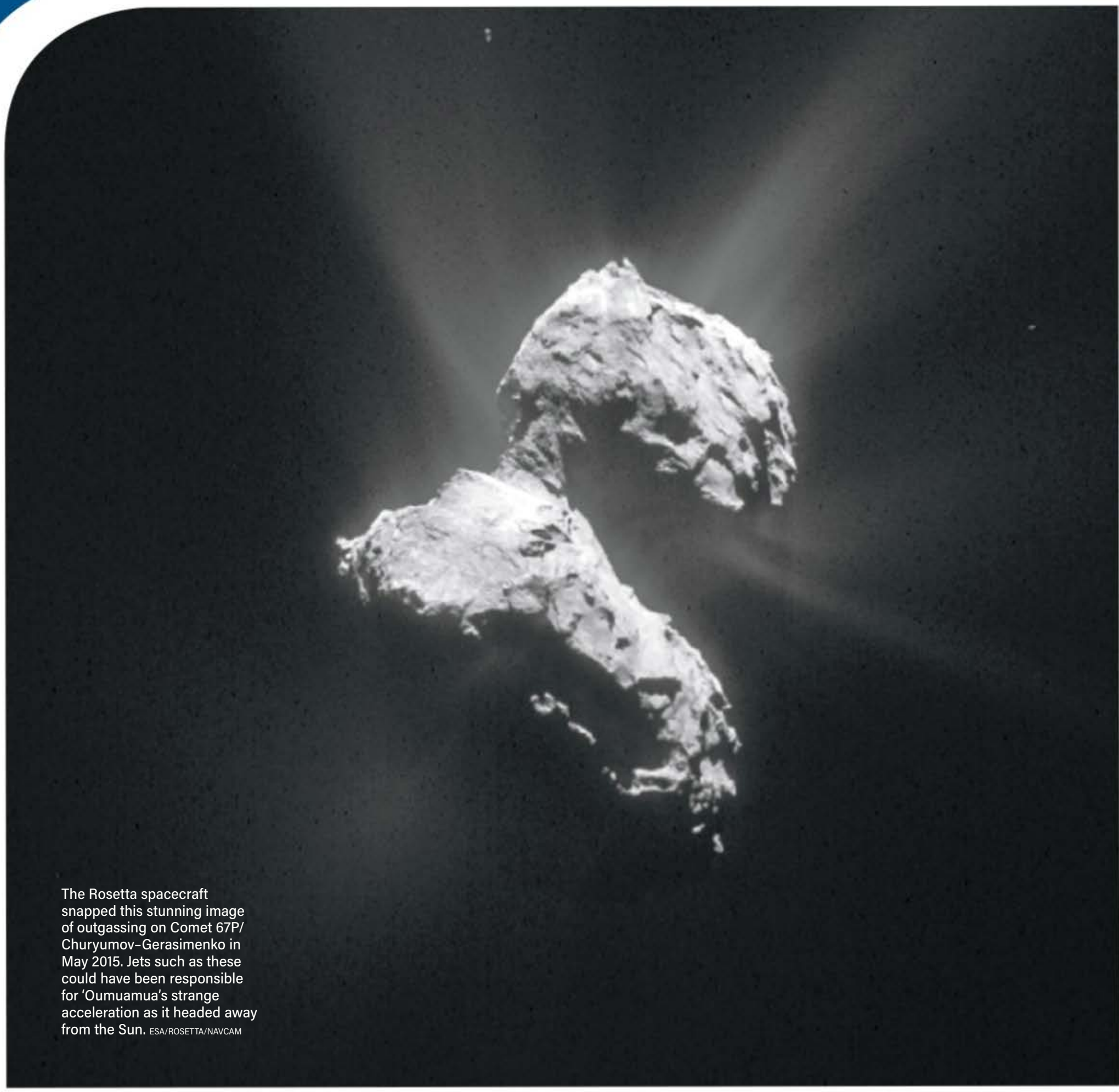


AR VISITOR

Based on the light it reflected over time, astronomers have determined that ‘Oumuamua, the first identified interstellar visitor to our solar system, is red in color and several times longer than it is wide. RON MILLER FOR *ASTRONOMY*

By October 22, two things were clear: The object was on a hyperbolic orbit, meaning it comes close to our Sun only once and then shoots away again, never to return. And, based on its orbit, it did not originate in our solar system at all, but instead came from another star system.

It was our first known interstellar visitor. Officially named 1I/2017 U1, the object is also known as ‘Oumuamua (oh-MOO-uh-MOO-uh), which means “a messenger from afar arriving first” in Hawaiian. Following its discovery, ‘Oumuamua was moving so fast that astronomers had a scant four months to observe it. After that, the object had retreated too far from the Sun, fading past our ability to track it. In just a short time, ‘Oumuamua gave us a peek at where it had



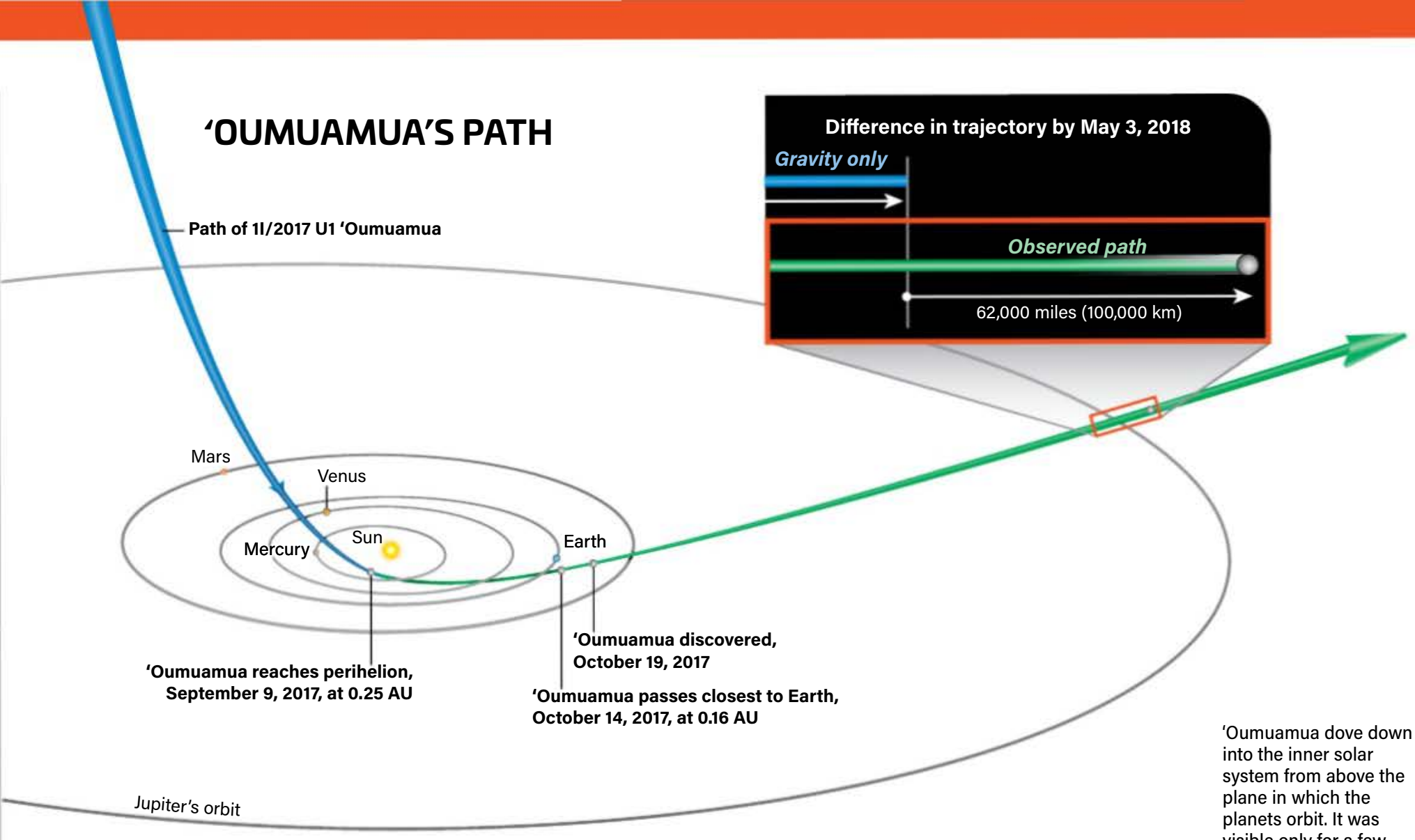
The Rosetta spacecraft snapped this stunning image of outgassing on Comet 67P/Churyumov–Gerasimenko in May 2015. Jets such as these could have been responsible for ‘Oumuamua’s strange acceleration as it headed away from the Sun. ESA/ROSETTA/NAVCAM

come from — but it still left us with many questions unanswered.

Strange space rock

Weryk spotted ‘Oumuamua less than a week after its closest approach to Earth, when it had come within 0.16 AU of our planet, more than 60 times the distance to the Moon. It had passed perihelion — its closest point to the Sun — more than a month before, flying within 0.25 AU of our star on September 9, 2017. ‘Oumuamua had entered the solar system moving about 16 miles (26 kilometers) per second and swung around the Sun at nearly 55 miles (88 km) per second. Even the Hubble Space Telescope would lose the ability to spot it after January 2018.

Between October and January, astronomers scrambled to observe ‘Oumuamua with as many telescopes as possible. In all, more than 800 observations were made. Researchers started by measuring the light it reflected, which over time allowed them to create a light curve that showed



'Oumuamua dove down into the inner solar system from above the plane in which the planets orbit. It was visible only for a few months, speeding up as it retreated from the Sun. Based on the observed acceleration, astronomers calculated that by the time it reached the distance of Jupiter's orbit in May 2018, 'Oumuamua was about 62,000 miles (100,000 km) ahead of where it would be if only gravity dictated its motion. The planets are shown here as they appeared October 19, 2017. *ASTRONOMY*: ROEN KELLY

'Oumuamua, pronounced "oh-MOO-uh-MOO-uh," means "a messenger from afar arriving first" in Hawaiian.

how it rotates in space, as well as offered clues to its size and shape.

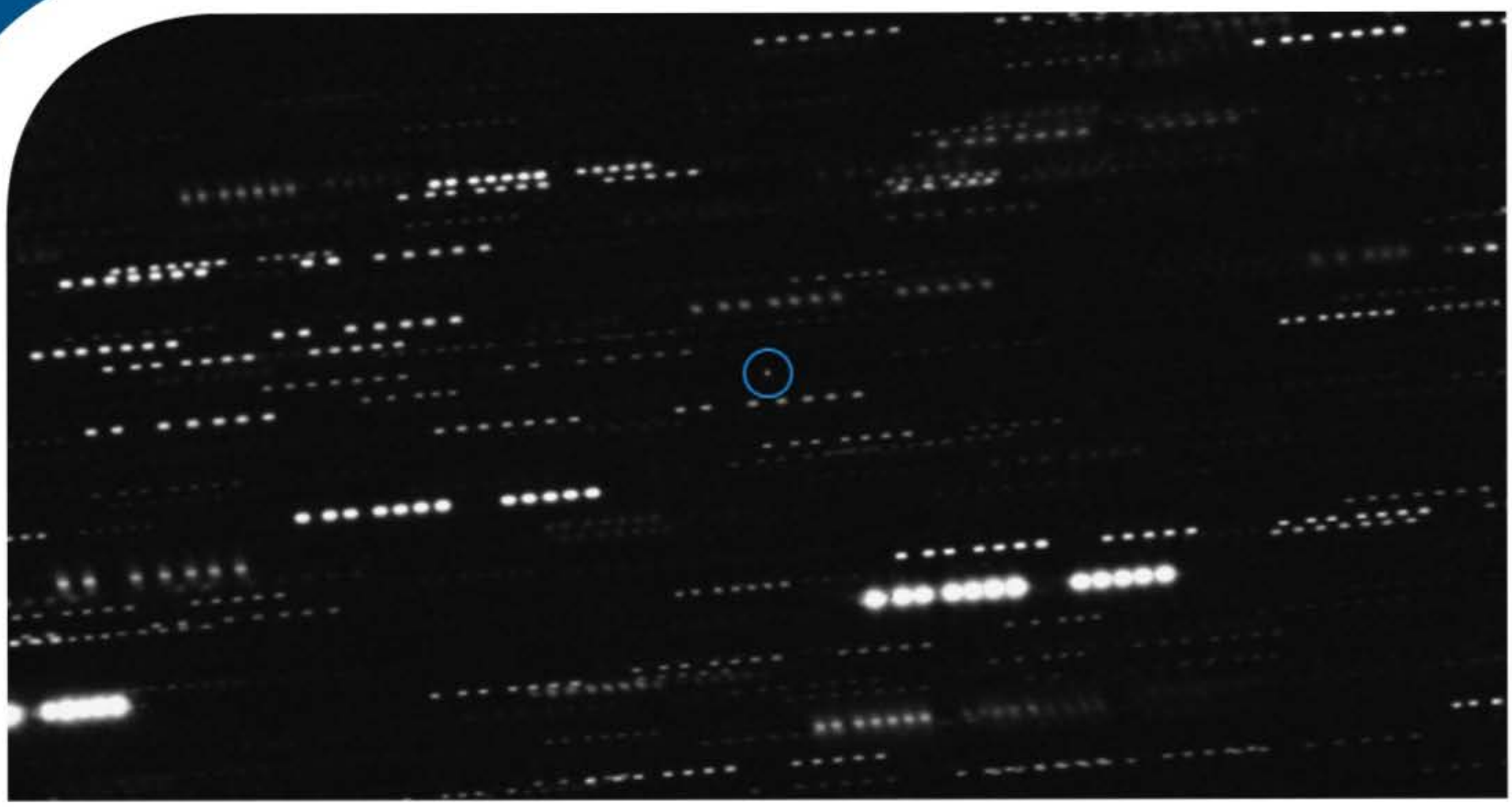
The brightness of 'Oumuamua's reflected light changed by more than a factor of 10 over regular intervals, indicating it was spinning as it flew. From the way its light dipped and rose, researchers determined that 'Oumuamua is roughly 330 to 1,310 feet (100 to 400 meters) long, with an elongated shape some 6 to 10 times longer than it is wide. It likely looks like a cigar or flattened oval. The most elongated objects that astronomers have found in our own solar system are, at most, three times longer than they are wide, making 'Oumuamua extreme by our standards — and difficult to explain, based on our current picture of how objects in our solar system evolve.

'Oumuamua's reflected light also showed it is tumbling through space, turning on its shortest axis every 8.7 hours and spinning on its longest axis every 54.5 hours. This type of motion is common among small solar system asteroids, particularly those of 'Oumuamua's size, but astronomers can't tell whether the object has been spinning like this since it left its home or if the complex rotation is more recent.

Its surface is red, which is typical of several classes of objects in our solar system, including comets; D-type asteroids, which are found in the outer main belt or sharing Jupiter's orbit; and bodies past Neptune, known as trans-Neptunian objects. But 'Oumuamua's color reveals frustratingly little about its composition because several factors can turn a body red: patches of organic material, including the tholins that color worlds such as Arrokoth; iron deposits on the surface; or space weathering, in which exposure to factors such as micrometeorites and sunlight alter a body's properties over time.

MIGRATING JETS

Some calculations showed that normal comet outgassing at the rate needed to match 'Oumuamua's motion would actually cause it to spin too quickly and ultimately fly apart. But this conundrum was solved in a May 2019 study published in *The Astrophysical Journal Letters* led by Darryl Seligman of Yale University, which proposed 'Oumuamua had "migrating jets." As 'Oumuamua twirled, the study says, the portion of its surface directly heated by the Sun would shift. If only that Sun-warmed area produced a jet, then it would cause 'Oumuamua to gently rock back and forth like a pendulum on one axis as the region undergoing outgassing shifted. Such motion, the team calculated, could produce the light curve astronomers saw. This is because often, many different types of motion can create the same type of light curve, making it difficult to distinguish between possible scenarios without more information. Seligman's work suggested that if 'Oumuamua is a comet, it likely lost about 10 percent of its total mass through outgassing on its journey through our solar system.



'Oumuamua appears as a faint dot in this composite image, created from several separate exposures taken with the European Southern Observatory's Very Large Telescope and the Gemini South Telescope. Background stars appear as streaks because the telescopes were set to track the asteroid, moving at a different rate. ESO/ K. MEECH ET AL.

Asteroid or comet?

Astronomers expected the first identified interstellar visitor would be a comet. That's because comets, for their size, are brighter than asteroids, which makes them easier to spot. In our solar system — and likely others — incoming comets originate far from the Sun, where they're easier to knock loose as the star's gravity wanes with distance.

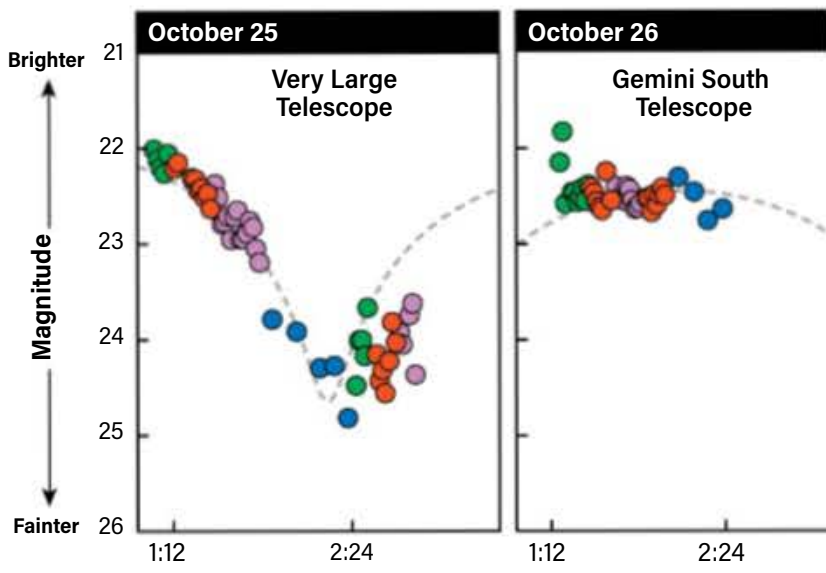
Many comets also have orbits that are highly eccentric. A perfectly circular orbit has an eccentricity of 0, elliptical orbits fall between 0 and 1, and orbits with eccentricities greater than 1 are hyperbolic, or non-returning. 'Oumuamua plunged into the solar system from above the ecliptic plane in which the planets orbit with an eccentricity of 1.2, meaning it would slingshot right through the solar system and never return. The most eccentric solar system comet, C/1980 E1, has an eccentricity of nearly 1.058 — it was freed from the Sun's gravity by an encounter with Jupiter. But 'Oumuamua's eccentricity was so much higher, it indicated the object came not from the Kuiper Belt or Oort Cloud, but another star entirely.

The Minor Planet Center initially classified 'Oumuamua as a short-period comet on October 20, says Karen Meech of the Institute for Astronomy at the University of Hawai'i, a member of the team that discovered and first studied 'Oumuamua. On October 24, with more orbital information, 'Oumuamua's classification was updated to C/2017 U1 — a long-period comet.

But 'Oumuamua had already swooped around the Sun by the time it was discovered with no tail in sight. Meech's team contacted the Minor Planet Center, which then reclassified 'Oumuamua by October 26 as A/2017 U1, using the A designation indicating a long-period comet orbit, but no coma or tail, Meech says. Ultimately, the astronomical community developed a new naming system for interstellar objects, christening the discovery 1I — the first interstellar object.

Then, a June 2018 *Nature* paper led by Marco Micheli of the European Space Agency's Space Situational Awareness Near-Earth Object Coordination Centre in Frascati, Italy, reported that 'Oumuamua was not moving as an asteroid should. Instead, 'Oumuamua's path indicated a

'OUMUAMUA'S LIGHT CURVE



"really strong nongravitational acceleration," says Meech, who is also a co-author on the paper. That meant gravity was not the only thing dictating ʻOumuamua's motion. Something was causing it to speed up as it departed the solar system.

ʻOumuamua's acceleration was in the direction opposite the Sun; it was also related to its distance from the Sun, growing weaker as their separation increased. "There were a number of things that can cause acceleration in that direction," Meech says. The team investigated eight of those causes, including friction or drag changing its trajectory, the possibility that ʻOumuamua was actually two or more objects tugging on each other, a strong magnetic field within ʻOumuamua interacting with the solar wind, and pressure from solar photons pushing on ʻOumuamua to speed it up.

One by one, they ruled out these scenarios. Friction or drag would pull it toward the Sun, not speed it up in the opposite direction. Images of ʻOumuamua showed no additional objects large enough to affect its motion in the way astronomers saw. And even a high magnetic field would not cause enough interaction with the Sun's charged particles to push ʻOumuamua as observed. For solar photons to push ʻOumuamua hard enough, the space rock would need an incredibly low density, like that of aerogel, a substance that can be up to 900 times less dense than water. Or, speculated Shmuel Bialy and Abraham Loeb of the Harvard-Smithsonian Center for Astrophysics, ʻOumuamua could be incredibly thin with a large surface area — like a solar sail.

Although the idea that ʻOumuamua is an alien spacecraft or abandoned extraterrestrial technology is certainly exciting, Meech and others argue it is extremely physically unlikely, especially given that one explanation the team investigated *did* work quite well: "The only thing that was left, which was the most logical, is that it's outgassing," Meech says.

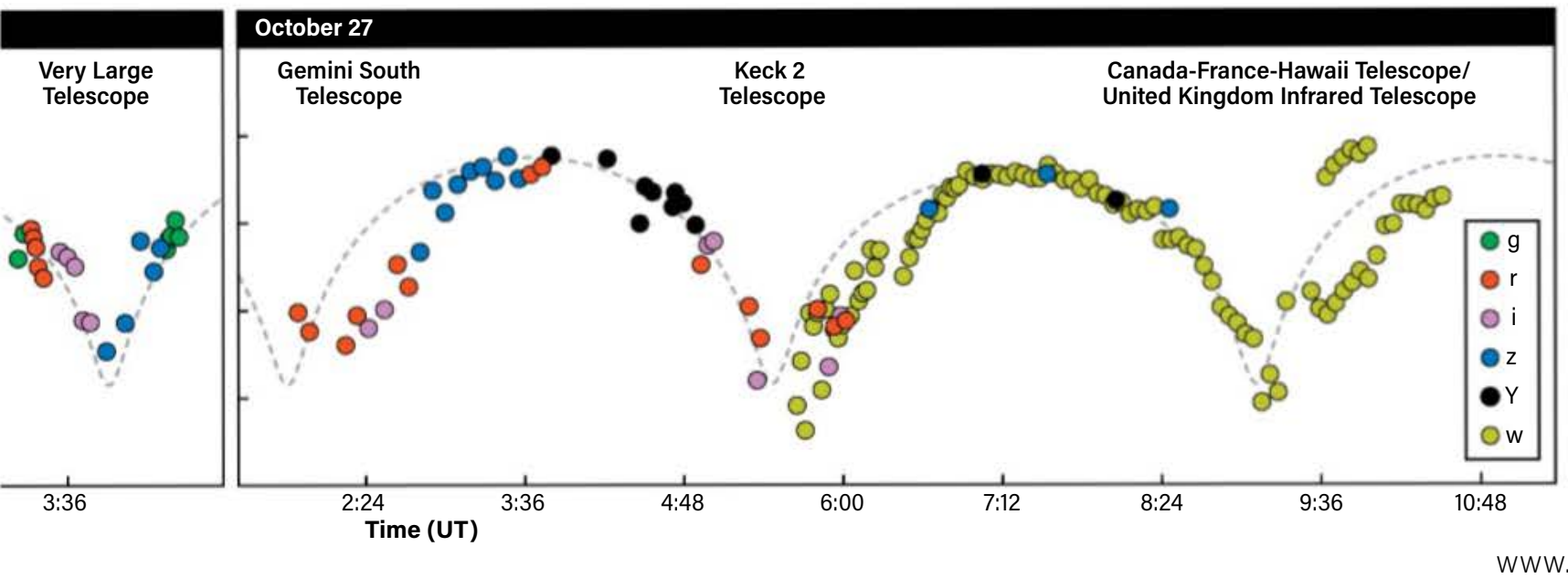
Outgassing is the escape of gas and dust as ices on the surface of a comet sublimate, turning directly from a solid to a gas as the object approaches the Sun and heats up. The escaping gas gives the comet an extra push in the opposite direction. "This was the same level of strength as you would typically see in comets," says Meech of ʻOumuamua's acceleration, if it were losing about 2.2 pounds (1 kilogram) of material each second. Based on what we know about solar system comets, that's not unusual. And, after all, astronomers had expected ʻOumuamua to be a comet in the first place.

But ʻOumuamua still had no tail, even in the deepest observations. Meech was part of a team looking for gas escaping ʻOumuamua, including CN, CO, CO_2, and H_2O. CN gas, which is bright and easy to spot, gets dragged off comets in our solar system when water leaves the surface, Meech says. It can be used as a proxy for water, which is harder to observe. The team also expected a fair bit of CO and CO_2 because, as ʻOumuamua zipped farther from the Sun, temperatures dropped and water became harder to sublimate from the surface.

ʻOumuamua's path indicated a "really strong nongravitational acceleration." That meant gravity was not the only thing dictating ʻOumuamua's motion.

The researchers tracked ʻOumuamua for 30 hours with the infrared-seeking Spitzer Space Telescope, but nothing showed up. That was strange, because they expected "a fair bit" of gas, particularly water — and, thus, CN — to be escaping if ʻOumuamua's acceleration was due to outgassing, Meech says.

But despite their sensitive measurements, "there was no CN at all seen. And that upper limit was strong enough that if there was that much water coming off, it says this comet's also unusual, chemically," she says. After all, comets in

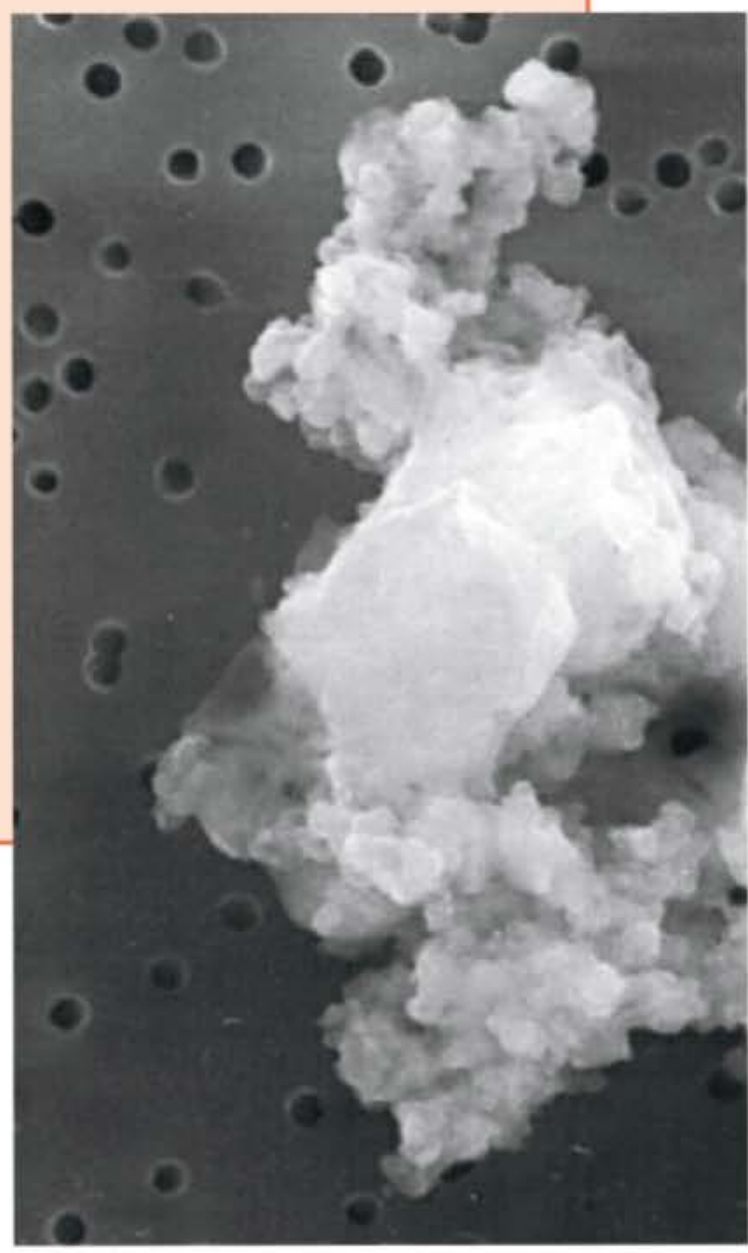


A light curve records brightness over time. It can tell astronomers about the size, shape, and rotation of an object. This light curve shows ʻOumuamua's brightness during three days in October 2017; each color depicts measurements taken in a different filter, which views only specific wavelengths of visible or infrared light. The large dips in brightness tell astronomers that ʻOumuamua is long but skinny, more like a cylinder than a ball. The dotted line represents the light curve of a model object that is 10 times longer than it is wide. *ASTRONOMY*: ROEN KELLY, AFTER OLIVIER HAINAUT (ESO)/ K. MEECH ET AL.

IS ‘OUMUAMUA FLUFFY?

One of the possible scenarios for ‘Oumuamua’s acceleration is radiation pressure. Sunlight is made of photons, which can exert force. But in ‘Oumuamua’s case, photons could only exert enough oomph if the object had an extremely low density compared to its size — about 1/100,000 the density of water. Amaya Moro-Martín of the Space Telescope Science Institute proposed, in a February 2019 paper published in *The Astrophysical Journal Letters*, that ‘Oumuamua could be a “fluffy aggregate” of icy dust particles. This type of structure, which could have such a low density, would indicate ‘Oumuamua formed beyond its host star’s snow line — the region past which water is found only in ice form — and, the study says, provide a unique window into how the building blocks of planets form.

Still, Moro-Martín’s paper concludes, “There are many open questions that need to be addressed in order to assess the viability of this scenario,” such as how such a porous object might survive not only ejection from its solar system, but also its journey through interstellar space. And Meech’s team deemed that unlikely: “We have no examples of anything like that in the solar system. While theoretically plausible on a mathematical scale, it’s not physically sensible,” Meech says.



Meech and her colleagues conclude that ‘Oumuamua is a comet, albeit an unusual one, with chemistry unlike that of the comets we see in our solar system.

our solar system can be pretty abundant in water.

“It’s always a little bit tricky to interpret too much out of not seeing something,” she cautions. But still, “it’s not quite hanging together as a typical comet.”

When gas escapes from a comet, it generally carries surface dust with it; the stronger the outgassing, the larger the grains of dust it can liberate. Meech’s team also looked for dust, but spotted none. But even that doesn’t kill the comet theory — Meech says that even if the comet was devoid of small dust, large dust could have been coming off the surface. Large dust is harder to see at visible wavelengths, where they were looking.

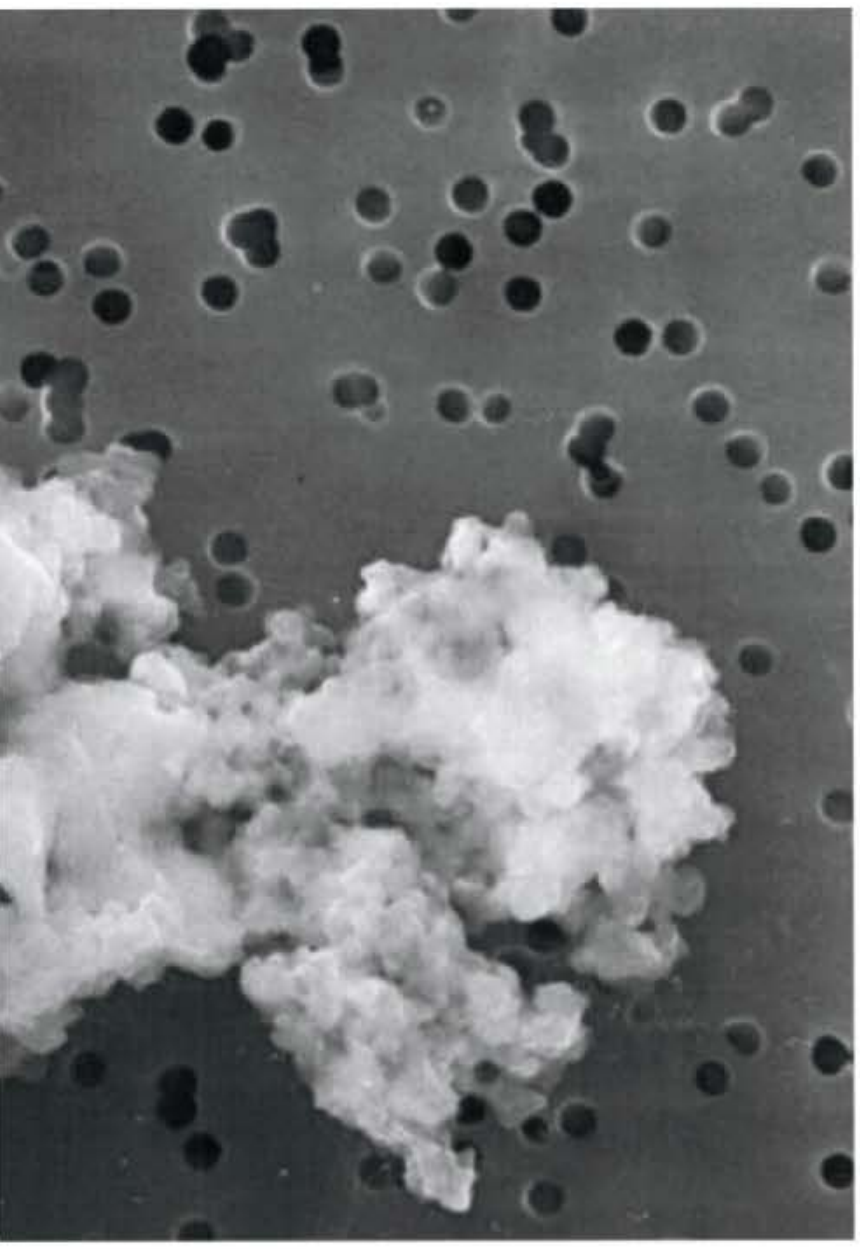
She and her colleagues conclude that ‘Oumuamua is a comet, albeit an unusual one, with chemistry unlike that of the comets we see in our solar system. “But that’s nothing surprising,” Meech says. “It’s coming from a different star system.”

What does ‘Oumuamua tell us?

With so much unknown, it may seem there is little ‘Oumuamua can teach us. Admittedly, ‘Oumuamua is a sample size of just one. But even one object can tell astronomers a lot, especially when compared to their expectations of what the first interstellar visitor would be like.

“‘Oumuamua is probably an ejected planetesimal or building block from the birth process of planets,” Meech says. As such, its discovery has implications for the number of such objects available for us to find. That’s because Pan-STARRS, which discovered ‘Oumuamua, began full science operations in May 2010 and was expected to see few, if any, interstellar objects larger than 0.6 mile (1 km) after 10 years of operation. Researchers mainly hoped to put a limit on the number of interstellar objects passing through our solar system, particularly smaller ones like ‘Oumuamua.

The 8.4-meter Large Synoptic Survey Telescope, which is scheduled to begin observing in 2022 and will produce about 20 terabytes of data each night, is expected to spot about one interstellar object per year. Meech says that if it had been up and running in 2017, it could have sighted ‘Oumuamua in late July, three months before Pan-STARRS saw it (and in time for astronomers to watch it fly through perihelion that September). But the fact that the 1.8-meter



Pan-STARRS1 Telescope spotted ‘Oumuamua could mean one of two things: Either there are many more interstellar objects than we thought, or ‘Oumuamua is not a normal member of the interstellar population astronomers expect.

As more surveys put eyes on the sky, astronomers are able to estimate, based on the amount of sky being covered and the rate at which they expect bodies to be ejected from around other stars, how many and what kind of interstellar interlopers we should see.

But the expected numbers depend on several factors, from an object’s size — ‘Oumuamua is smaller than our first expected find — to the rate at which planetary building blocks are tossed out of their home systems. The latter depends on even more factors, such as the size of the system, the number of giant planets available to scatter objects away, and whether other stars have passed close enough to nudge objects out of distant orbits around their suns.

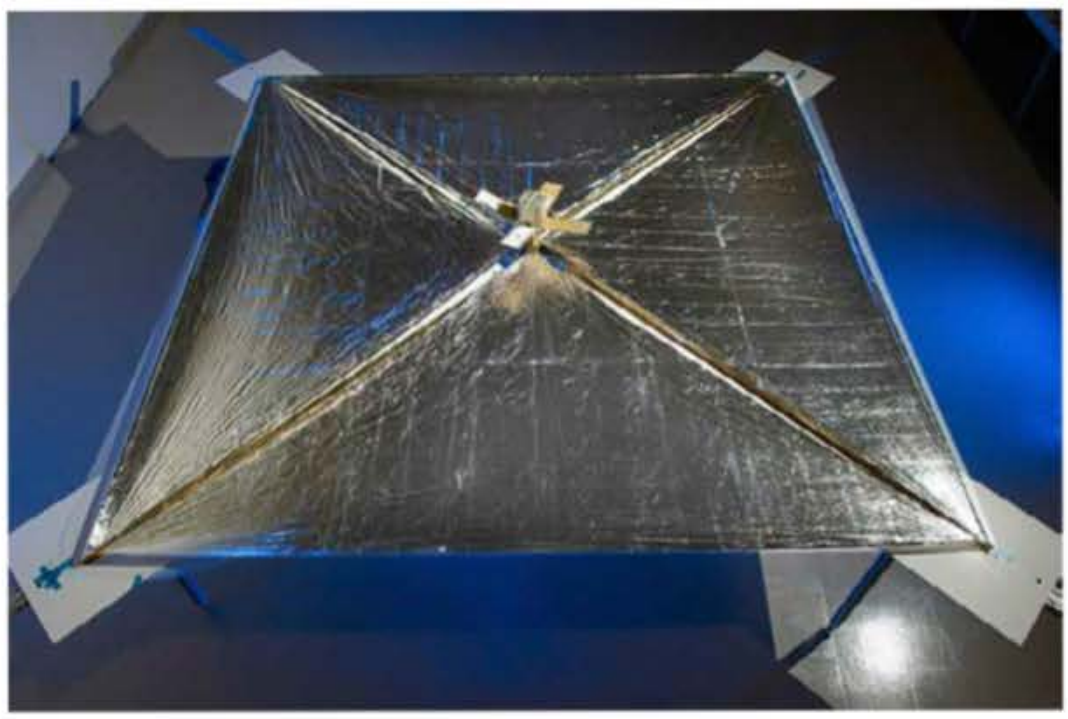
What ‘Oumuamua did reveal was that, based on its speed and trajectory, it is likely young and has been journeying between stars for only about 2 billion years, less than half the age of our solar system. Coryn Bailer-Jones of the Max Planck Institute for Astronomy in Heidelberg, Germany, calculated ‘Oumuamua’s track — which originated in the direction of Lyra the Harp — back to before it first entered the solar system. His calculations rewound the clock several million years to compare ‘Oumuamua’s path to the past positions of 7 million stars in the Milky Way measured by the Gaia satellite. Because stars are moving in the galaxy over time, he had to rewind their orbits, in addition to ‘Oumuamua’s, to look for places where the two might reasonably overlap.

He found four possible candidates that passed close enough to the rewound track of ‘Oumuamua’s motion that they might be its birthplace. “Close enough,” Meech says, means Bailer-Jones identified stars within 1 to 2 Oort Cloud radii — 100,000 to 200,000 AU — of ‘Oumuamua’s path. But a close encounter doesn’t necessarily mean that star is ‘Oumuamua’s point of origin. Furthermore, the encounters showed that ‘Oumuamua would have been ejected from its home system with a high velocity, between about 6 and 16 miles (10 and 25 km) per second. “It’s pretty hard to get ejection velocities this high just from a planetesimal getting too close to giant planets [in the same system],” Meech says. That process would have sent ‘Oumuamua zipping away at only a few miles per second. And none of the four stars have known planets.

The high speed would be more likely, she says, if ‘Oumuamua came from a binary star system. But none of the four candidates are binaries. “So, while these were our best candidates, none of them stood out as, ‘This is it! This is the home system!’ ” she says. The next Gaia data release — expected in late 2021 — may help, allowing astronomers to trace back the motions of even more stars and possibly find better candidates. “It would be great to revisit this in a couple of

LEFT: If ‘Oumuamua is not a comet, an alternate explanation could be that it is a lightweight “fluffy aggregate” of ices and dust. Such objects, like this interplanetary dust particle, have low densities because they have significant empty space within them. NASA

BELOW: Some researchers speculate ‘Oumuamua’s strange light curve and acceleration could mean it is large, thin, and of artificial origin — an alien solar sail. However, most astronomers don’t believe this is the case. NASA’S MARSHALL SPACE FLIGHT CENTER





The Pan-STARRS1 Telescope atop Haleakala, Maui, spotted ‘Oumuamua, our first recognized interstellar interloper, in October 2017.
ROB RATKOWSKI

years,” Meech says, when more data are available. But for now, astronomers are unable to pin down just where ‘Oumuamua came from.

Only the beginning

Since the last Hubble observations in January 2018, ‘Oumuamua has been beyond astronomers’ reach. According to Meech, ‘Oumuamua should reach the Kuiper Belt in about 2024 and pass its edge in late 2025. ‘Oumuamua will pass the most distant location the Voyagers have reached in about 2038. By 2196, it will again be 1,000 AU from the Sun, although our Oort Cloud is projected to extend beyond 100,000 AU. So, when ‘Oumuamua truly passes the “edge” of the solar system, she says, depends on where you define that edge.

Although it is gone from sight, it is not out of mind. Astronomers worldwide continue to speculate on the mysteries that remain. “We really wanted to know what [‘Oumuamua] was made of. We wanted to know its chemistry. And that experiment couldn’t be done well,” Meech says. “But finally, for ‘Oumuamua, it had that very strange elongated shape. And to me, that was one of the biggest puzzles that we couldn’t solve.”

Unlike ‘Oumuamua, Borisov has a clear tail, marking it immediately as a comet. Even after it fades from amateurs’ sight, professional observatories will be able to track Borisov through October 2020.

Now it appears ‘Oumuamua is not alone. On August 30, 2019, amateur astronomer Gennady Borisov at the MARGO observatory in Nauchnij, Crimea, spotted a new comet moving through the sky. Designated 2I/Borisov, it was moving at 93,000 mph (150,000 km/h), faster than expected for an object at its distance of roughly 2.8 AU from the Sun. Based on its blazing speed and its trajectory, which shows it delving into the inner solar system at an angle of 40° relative to the ecliptic plane on an orbit with a staggering eccentricity of 3.7, it too did not originate in our own solar system.

Unlike ‘Oumuamua, Borisov has a clear tail,



marking it immediately as a comet. And it is still on its way toward the Sun, estimated to swing around perihelion December 8, 2019, at a distance of about 2 AU from our star. That means it's going to get brighter before it gets fainter again, potentially reaching magnitude 15 by the time it passes closest to Earth on December 28. That's a magnitude amateur scopes larger than 10 inches can achieve under excellent viewing conditions. Even after it fades from amateurs' sight, professional observatories will be able to track Borisov through October 2020.

Meech's team has already observed the object and estimates its size between 1.2 and 10 miles (2 and 16 km). They've already spotted CN gas coming off its surface, although the comet was still too faint in October 2019 to detect other gases, she says. But "with 2I, we have a really long observing period of a year," Meech says. That will allow astronomers to explore its chemistry — unlike 'Oumuamua — even if, she says, the comet's gas and dust may hinder attempts to get a good handle on the shape and size of its nucleus. But ultimately, "[2I] looks like a comet, and it's red, and it's got CN."

WHY DIDN'T WE SEE 'OUMUAMUA SOONER?

If 'Oumuamua entered the solar system almost two centuries ago, why did it take astronomers this long to see it?

'Oumuamua's trajectory brought it down from above the plane of the solar system. That's an unusual and unexpected place to search for near-Earth objects, which is exactly what the Pan-STARRS1 Telescope was tasked with when it spotted the interloper. In the time shortly before its discovery, 'Oumuamua was just coming out of solar conjunction, when it was hidden behind our star. "You'd have to be pointing your telescopes really close to the Sun," to have seen it, says Meech, "which you don't do."

Additionally, 'Oumuamua is small — and therefore faint. Prior to solar conjunction, it was simply undetectable by any telescope, including Hubble. Although one pre-discovery image taken by the Catalina Sky Survey on October 14 shows 'Oumuamua, Meech says, even then it is too faint to pick out without knowing it's already there. "If you know there's something there, then you can actually see it. You can see it moving, and it's moving at the right rate in the right direction, but you would've never picked it up on its own," she says.



Comet 2I/Borisov is the second known interstellar visitor to enter our solar system. Imaged by the Hubble Space Telescope October 12, 2019, Borisov shows a clear tail, unlike its predecessor, 'Oumuamua. Astronomers are hoping the new comet will better reveal the chemistry of objects formed around other stars.
NASA, ESA, AND D. JEWITT (UCLA)

That means it looks very much like a typical solar system comet — and paints a very different picture of an interstellar traveler than 'Oumuamua. But those differences are valuable for astronomers trying to learn more about how other solar systems form, whether they are like or unlike our own.

Regardless of how many interlopers we eventually see skimming through our solar system, 'Oumuamua will always be the first. And although it's left astronomers with outstanding questions, it also represents the beginning of an era in which we may finally unlock many of the mysteries behind how stars form their planets, and what happens to the pieces they lose along the way.

Alison Klesman *is an associate editor of* Astronomy *with a keen interest in comets and asteroids from our solar system and beyond.*

Cataclysm in the EARLY SOLAR

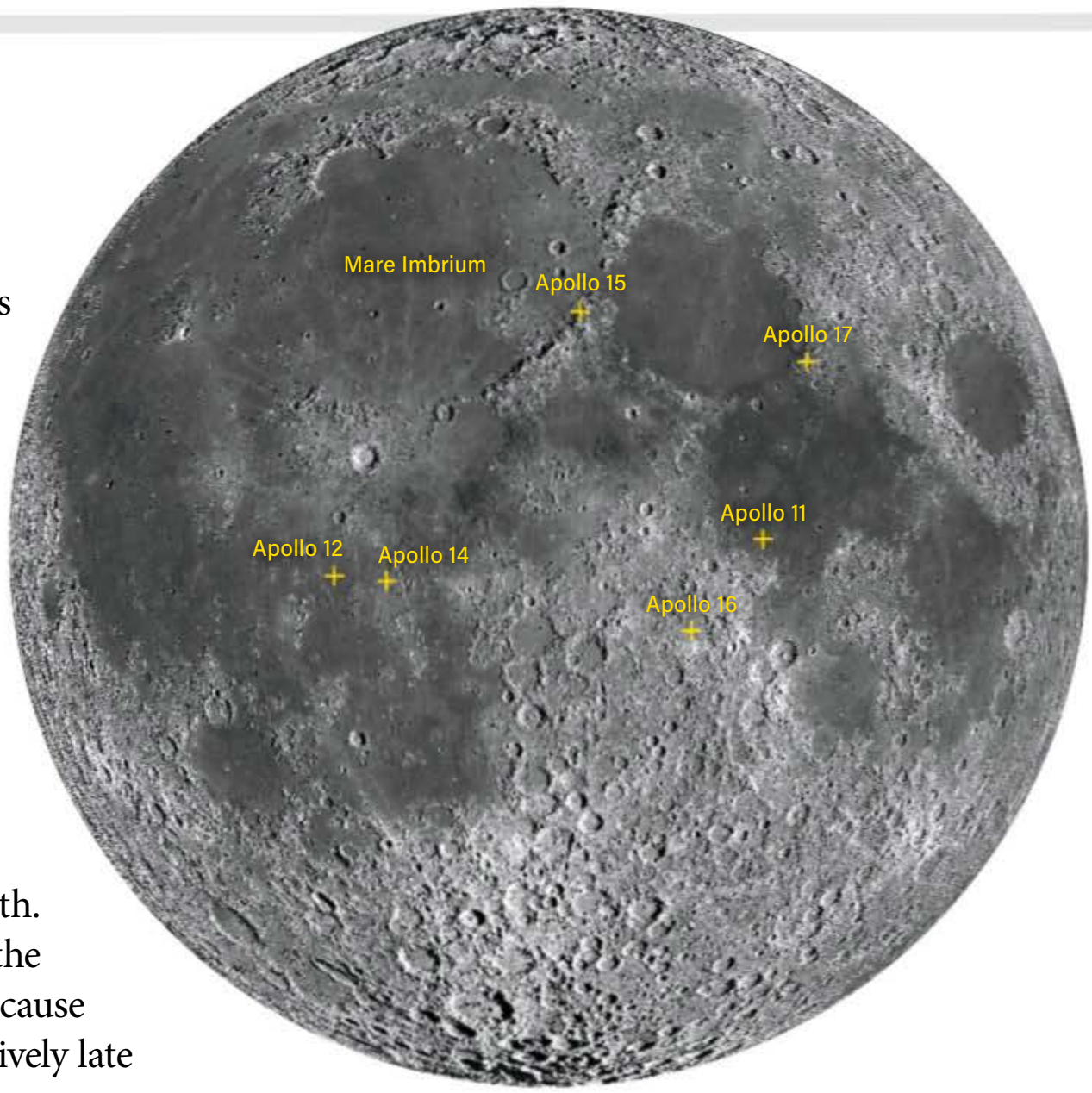
Apollo astronauts gathered rocks that hinted that large objects pummeled the inner planets some 4 billion years ago. Now, scientists aren't so sure. BY NOLA TAYLOR REDD



SYSTEM

For decades, astronomers thought the rate of impacts in the inner solar system spiked around 3.9 billion years ago, about the time a massive object crashed into the Moon (at right) and formed the giant Imbrium Basin.

RON MILLER FOR *ASTRONOMY*



Apollo astronauts brought back to Earth 842 pounds (382 kilograms) of Moon rocks — a treasure-trove that carried the secrets of lunar formation. Among the many insights that scientists teased from these samples was the previously unknown ages of lunar craters. The rocks hinted that Earth's satellite suffered a massive bombardment — a spike in the amount of material crashing into the Moon and, presumably, Earth. This catastrophe became known as the Late Heavy Bombardment (LHB) because researchers thought it occurred relatively late in the lunar lifetime, a few hundred million years after the Moon had formed, when the chaos of the early solar system had begun to calm down.

Now, new results across multiple fields of astronomy are causing many to question the existence of this spike. Some scientists argue that the LHB may not have come so late. Instead of a surge in impacts, the terrestrial bodies — including the Moon and Earth — probably suffered a more general decline of collisions as they swept up the last pieces of planetary debris.

"Since the Apollo era, the debate has been whether the Late Heavy Bombardment is just a decay of the population of impacts on the Moon and elsewhere in the solar system, or just some sort of spike," says David Nesvorny, who models planetary formation at the Southwest Research Institute (SwRI) in Boulder, Colorado.

A sudden burst of collisions

Before Apollo astronauts landed on the Moon, astronomers could gauge only the relative ages of craters to determine which came first and which were more recent. The solar system is about 4.5 billion years old, and if the Moon formed at that point — or soon after — then the oldest craters should be roughly the same age. But the Moon rocks revealed ages closer to 3.8 billion and 3.9 billion years. And it looked as though one of the Moon's biggest impact basins, Mare Imbrium, was about the same age as another large basin, Mare Orientale. "It was really surprising," says Nesvorny.

Other reports initially suggested there was no evidence for lunar impacts older than the returned lunar samples. To explain why the Moon would have suffered at least two massive collisions — estimates put the Imbrium impactor at 150 miles (240 kilometers) across, the size of a planetary embryo — so late in its lifetime, scientists in the 1970s raised the possibility of a cataclysm or spike. Something must have stirred up the solar system's loose rocks and sent them flying toward the Moon.

Exactly what did the stirring remained a decades-long debate. Then, in 2005, the Nice model (named for the French city where researchers developed it) began to garner attention. Under the new theory, the planets in the outer solar system were not born in their current orbits but instead moved around a great deal. In some versions, Neptune and Uranus eventually changed places. These

"When you take all of those pieces together, they point to something that was not a cataclysmic bombardment in a very short period of time." — astronomer Nicolle Zellner



LEFT: The idea of a Late Heavy Bombardment grew from the rocks Apollo astronauts brought back to Earth. The samples from six ostensibly diverse sites all seemed to date from about 3.9 billion years ago. Now, many scientists suspect the returned rocks all came from the impact that carved out Mare Imbrium. NASA/GSFC/ARIZONA STATE UNIVERSITY

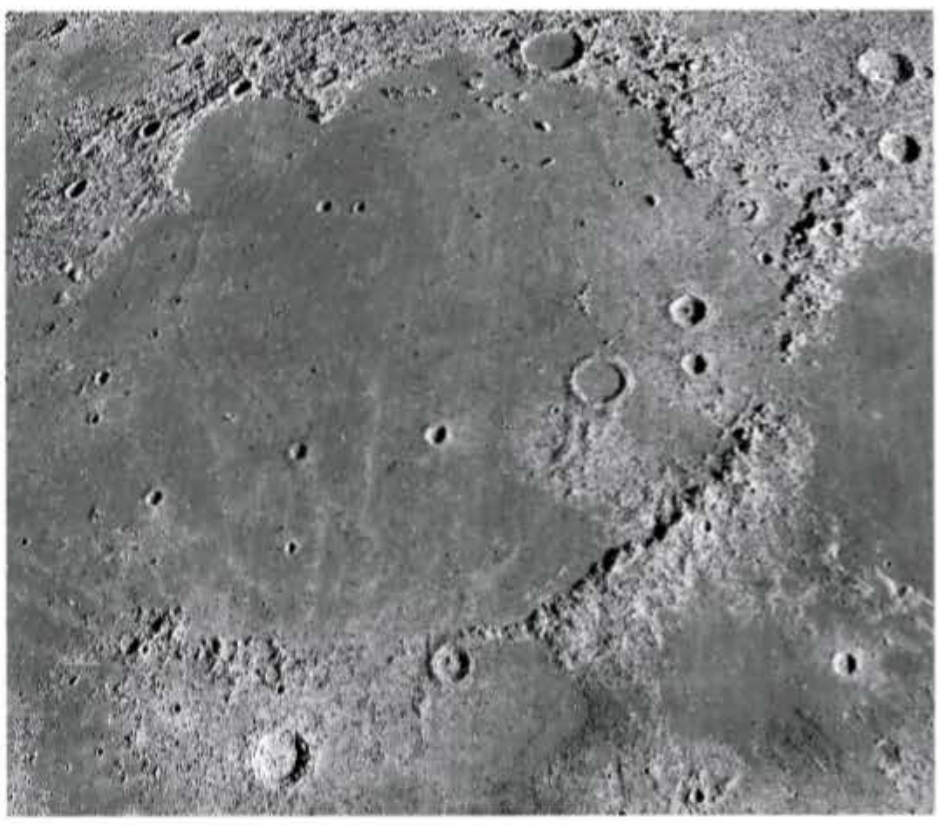
RIGHT: Mare Orientale lies on the Moon's western edge as seen from Earth and wasn't revealed in its full glory until the Space Age. Like Mare Imbrium, Orientale formed about 3.9 billion years ago. The Lunar Reconnaissance Orbiter captured this view of the 185-mile-wide (300 km) basin. NASA/GSFC/ARIZONA STATE UNIVERSITY

movements jostled the icy rocks of the Kuiper Belt, which lay at the solar system's outskirts, and flung some of them into the inner solar system. Suddenly, scientists had a viable way to produce a bombardment relatively late in the solar system's history.

Another key factor supporting the LHB was the relative amounts of highly siderophile, or iron-loving, elements (HSEs). Iron and the elements with which it bonds tend to sink into a world's core, causing the body to differentiate and leaving a surface relatively depleted in such substances. But subsequent collisions with smaller, undifferentiated objects can provide a fresh source of these elements to the surface. Scientists expected Earth to be 20 times more abundant in HSEs than the Moon, based simply on their relative sizes. Instead, our planet contains roughly 1,000 times more HSEs than its satellite, for reasons that long remained mysterious.

Lunar samples

Although the Apollo samples allowed scientists to determine the age of individual Moon rocks, the question of their source lingered. The astronauts picked up most of the material from the ground, but the rocks didn't necessarily form where they were found. On Earth, rocks can break off the sides of mountains or be carried away by rivers, glaciers, or the wind. Although the Moon never boasted liquid water and no winds weather the lunar landscape, it had another method of moving rocks around — impacts.



Mare Imbrium stretches 710 miles (1,145 km) from edge to edge. The nearly circular scar formed when a planetary embryo some 150 miles (240 km) across slammed into the Moon about 3.9 billion years ago. Several hundred million years later, lava oozed out through cracks in the basin's floor, imparting a grayish sheen to the mare. NASA/GSFC/ARIZONA STATE UNIVERSITY

When an object flying through space crashes into our satellite, it gouges out enough of the crust to form a crater. The excavated material must go somewhere. With the Moon's low surface gravity, most of it tends to end up in space. But that same low gravity allows debris to fly much farther across the lunar surface than it would on Earth. In recent years, some scientists have begun to question whether most of the samples came from the same source — the massive Imbrium impact. That would explain the similarities in the samples' ages.

A key development came when NASA flew a geologist to the Moon on Apollo 17. Astronaut Harrison "Jack" Schmitt wasn't satisfied with collecting rocks off the surface. Instead, he removed a sample from a large boulder in the Taurus-Littrow region at the southeastern corner of Mare Serenitatis. "Jack knew what he was



Astronaut and geologist Harrison Schmitt chips a piece off a giant boulder during the third lunar excursion he and Gene Cernan made during Apollo 17. The rock sample they brought back was dated to between 3.8 billion and 3.9 billion years ago. NASA

looking for," says Bill Bottke, a lunar scientist at SwRI. The sample revealed an age between 3.8 billion and 3.9 billion years.

But Schmitt's massive rock may not have been source material. According to Bottke, in the last decade or so, scientists have begun to question whether that boulder originally came from Serenitatis or whether it flew over from the Imbrium impact. "It's a tricky business," Bottke says.

More recent spacecraft have helped improve our understanding of lunar cratering history. Missions such as the Lunar Reconnaissance Orbiter and the Gravity Recovery and Interior Laboratory have allowed investigators to reevaluate how impacts affected the Moon over time. "Craters not visible to the naked eye are visible [to the spacecraft]," says Nicolle Zellner, an astronomer at Michigan's Albion College. Some of these covert impact scars are enormous, up to 185 miles (300 km) across, though they've eroded away. The presence of these early giant craters means that massive objects bombarded the solar system longer than previously calculated, which affects our picture of how the collisions trailed off over time.

Proponents of a slowly declining bombardment rate point not only to younger craters but also to the gradual emergence of evidence for older impacts. As instruments have become more precise, they can measure smaller and smaller amounts of the elements that help researchers date the rocky samples. "Both in Apollo samples and lunar meteorites, we see evidence for impacts older than 3.9 billion years," Zellner says. "That kind of improved sensitivity in instruments is allowing us to refine our interpretation of the data as well. When you take all of those pieces together, they point to something that was not a cataclysmic bombardment in a very short period of time."

The Moon likely formed when a Mars-sized planetary embryo slammed into Earth roughly 4.5 billion years ago. The collision carved out part of our planet, which mixed with material from the obliterated impactor to form a large satellite. As the two bodies solidified, the iron-loving elements inside them settled down to their respective cores. Astronomers suspect that later impacts delivered all the HSEs, such as gold and iridium, found in the objects' crusts and mantles today.

Based on the Moon rocks and lunar meteorites, our satellite appears to have far less of these precious elements than it should. A spike in impacts was one of several reasons put forth to explain this deficit. New research suggests that such a cataclysm might not be required. Researchers simulated impacts at different velocities and found that the Moon retains material from large impactors less effectively than it does from smaller colliding bodies. This means our satellite would lose more of these iron-loving elements before they could ever accumulate on its surface. The scientists concluded that the Moon probably held on to one-third as much HSE-rich material than previously estimated.

In addition, they suspect that roughly half of this material sank into the core before our satellite's mantle crystallized. Because Earth's mantle crystallized more quickly, our planet's crust retained a higher percentage of iron-loving elements. "The late crystallization overturn sequesters HSEs," says Alessandro Morbidelli, an astronomer at the Observatoire de la

The Moon likely formed when a Mars-sized planetary embryo slammed into Earth roughly 4.5 billion years ago.

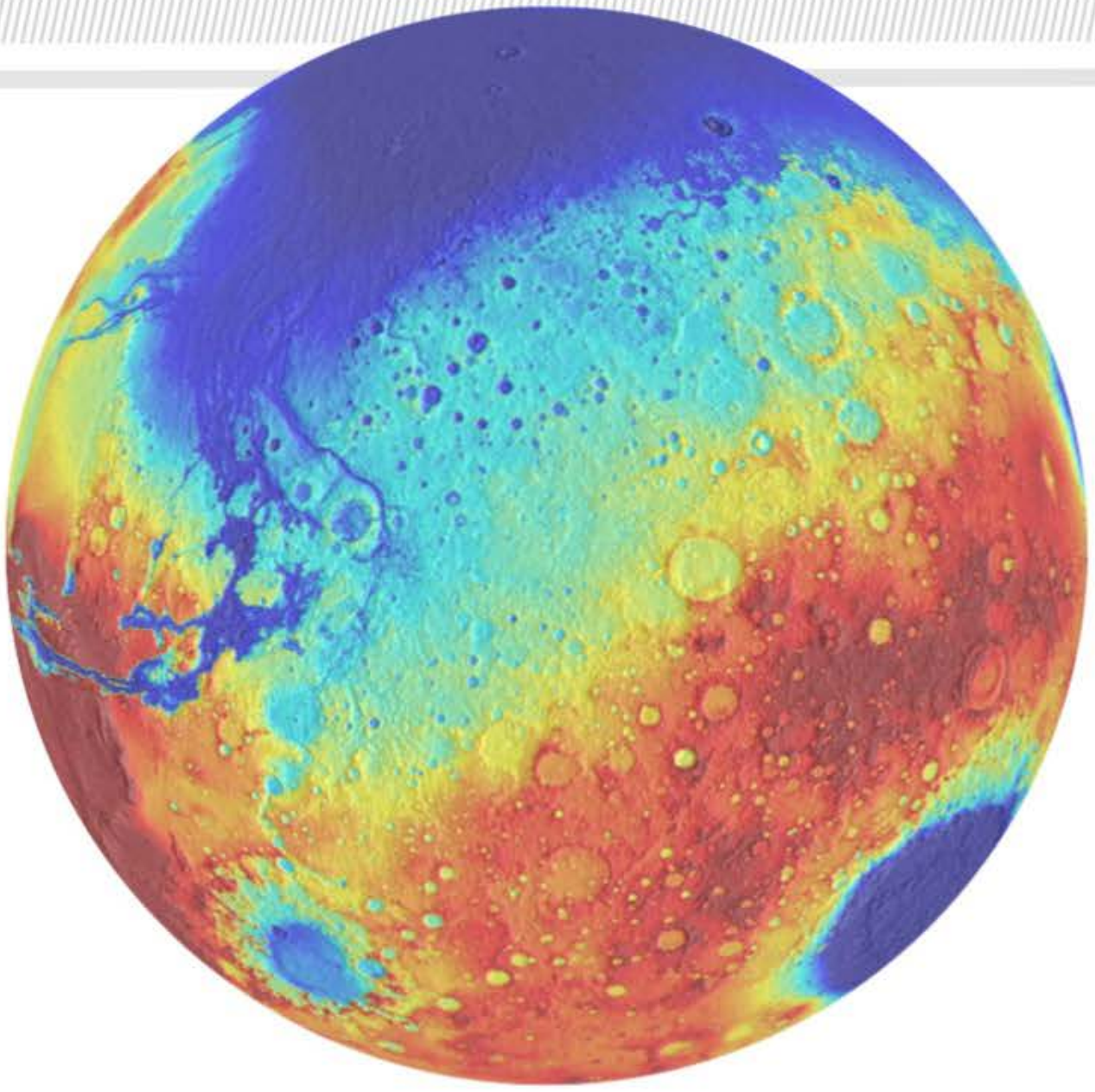
Côte d'Azur, in France. "Because of late sequestration, it's clear we don't need an impact spike 4 billion years ago."

Red scars

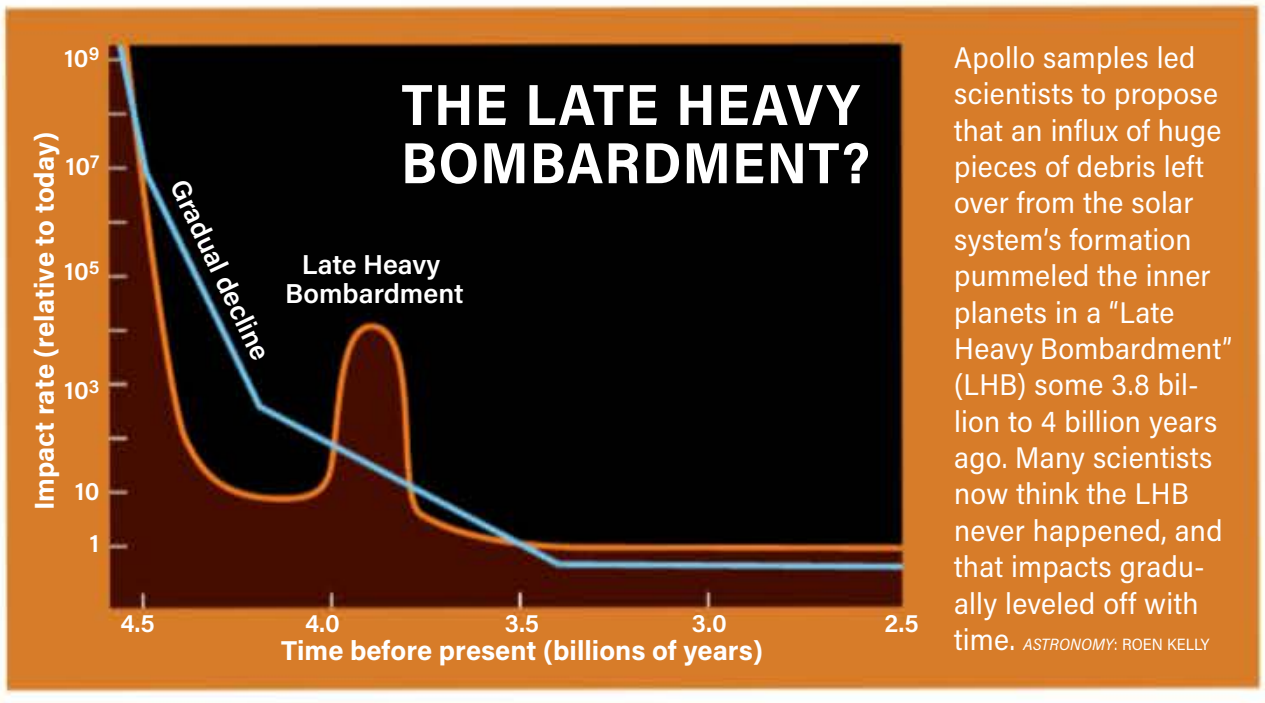
The Moon's surface isn't the only place capable of preserving the imprint of the solar system's past. Mars is also a relatively unchanging target. Although it likely once harbored oceans of water, the Red Planet lost most of this liquid early in its life, leaving behind a dry surface with little water to erode its bombardment history. Mars also lacks plate tectonics, which erase impact signatures on Earth. "If we want to understand impacts on the Moon, we have to solve Mars simultaneously," says Bottke.

While neither spacecraft nor astronauts have returned samples of Mars to Earth, the Red Planet has obligingly shipped some of its rocks to our world in the form of meteorites. The Northwest Africa 7034 meteorite, nicknamed "Black Beauty," came from the southern highlands and is unique among martian meteorites. Black Beauty is the only known breccia, a rock composed of bonded mineral fragments. "This is a collage of welded fragments of rocks from different places on Mars all cemented together," says Desmond Moser of Canada's Western University in London, Ontario.

Moser and his colleagues recently studied tiny zircons — minerals that form when lava cools — as well as the mineral baddeleyite hidden inside Black Beauty. From studies of meteorite craters on Earth, scientists know that the heat and pressure of an impact rapidly reshape most rocks. Zircons, on the other hand, react incredibly slowly to change. "Once something affects them, they really have incredible memories of those events," Moser says. Baddeleyite, on the other hand, changes predictably when exposed to high pressures.



Like the Moon, Mars preserves a record of giant impacts from the solar system's earliest days. In this topographic view, blues and purples represent low-lying areas. Scientists have dated the Borealis Basin (top) at 4.5 billion years old, while the smaller Hellas Basin (bottom right) and Argyre Basin (bottom left) are between 3.8 billion and 4.1 billion years old. UNIVERSITY OF ARIZONA/LPL/SwRI



Apollo samples led scientists to propose that an influx of huge pieces of debris left over from the solar system's formation pummeled the inner planets in a "Late Heavy Bombardment" (LHB) some 3.8 billion to 4 billion years ago. Many scientists now think the LHB never happened, and that impacts gradually leveled off with time. *ASTRONOMY*: ROEN KELLY

When a large body crashes into a planet, waves of pressure and heat sweep across the landscape, traveling farther the larger the impact. But Black Beauty shows no signs of the changes that would accompany such impacts, suggesting that cataclysmic bombardments on Mars have been virtually nonexistent since the rock formed 4.48 billion years ago. At the same time, the rock managed to escape the effects of the impact that blew it off the martian surface, presumably because the shock waves fortuitously canceled each other out. "We're just so lucky to get this sample that has been so unaltered by the ejection process from Mars," says Moser.

Although Bottke agrees with most of Moser's conclusions, he isn't completely convinced that Black Beauty's unchanged zircons spell the end of bombardment on the Red Planet. "Mars is a big world, much bigger than the Moon," he says. It's possible that significant impacts occurred but that their pressure and temperature waves avoided hitting Black Beauty.



The Caloris Basin on Mercury spans some 960 miles (1,550 km). Scientists seeking to understand the impact history of the inner planets and the Moon need to examine all these terrestrial worlds and not just Earth's next-door satellite. NASA/JHUAPL/CIW

A dance of giants

In the past few years, the Nice model has continued to evolve. The original model, which focused on the birth of ice giants in the outer solar system, was linked to the LHB through timing. As Uranus and Neptune performed an intricate dance in the outer solar system, Neptune bulldozed through the young Kuiper Belt, which was originally much larger than it is today. The marauding planet flung some of these cometary bodies out of the Sun's domain while hurling others into the inner solar system. In addition to colliding with the Moon and rocky planets, the cometary material may have stirred up the asteroid belt, sending some of these rocky objects inward as well. "You have both asteroids and comets," says the University of Arizona's Kathryn Volk, a planetary scientist who studies small bodies in the outer solar system. "That always mixed up the story."

According to Morbidelli, who was one of the original authors of the Nice model, the researchers didn't want to attach the model to the LHB. The reason was simple: While Nice could explain the LHB, it didn't have to. In fact, making Nice fit with the LHB required delaying the dance of the ice giants for roughly 700 million years, an idea that made some scientists uncomfortable.

"Dynamically speaking, I'd never been very satisfied with this late instability," says Sean Raymond, a planetary modeler at France's Laboratoire d'Astrophysique de Bordeaux. "If things are going to go bonkers, they do it right away." Sometimes unusual things happen, but scientists prefer not to rely on rare exceptions as explanations.

Nesvorny described his concerns a bit more tangibly. If you set a coin on the edge of a table, it's relatively easy to place it so that it immediately falls off. "It's hard to put it on the edge so that it falls an hour from now," he says. But that's what an LHB-triggering Nice model seemed to suggest.

Nesvorny began to investigate ways to time-stamp the planetary dance. Astronomers think the Kuiper Belt is responsible not only for the icy debris it holds on to today and the short-period comets that periodically swoop in from the solar system's outskirts, but also for the irregular moons around some of the giant planets and Jupiter's Trojan asteroids. This latter group comprises thousands of objects that orbit the Sun in stable locations positioned 60° in front of and behind the gas giant. Of the more than 7,000 Trojans scientists have identified, roughly 25 are larger than 60 miles (100 km) across. Two of these form the binary pair of Patroclus and Menoetius.

Patroclus and Menoetius — targets for NASA's Lucy mission to Jupiter's Trojans in 2033 — orbit each other at a distance of 415 miles (670 km). Scientists suspect the pair came together in the Kuiper Belt in roughly the solar system's first 10 million years, then traveled inward when things became unstable. But how long did they spend in the Kuiper Belt before embarking on their journey? To find out, Nesvorny modeled how long it would take the pair to become separated during the interactions of the pre-Nice Kuiper Belt. The longer the binary sat in the belt, the more collisions it would have endured, breaking their connection. Nesvorny and his colleagues wanted to know what the odds were that 1 in 25 such binaries would remain stable. They found that the Trojan binary had to have

One of the best ways to settle the debate over whether Earth and the Moon suffered from increased collisions early in their lifetimes would be to return to the Moon for more samples.

been ejected from the Kuiper Belt within 100 million years of its formation.

"This is really a smoking gun," Nesvorny says. "It rules out the Nice model as a source of the Late Heavy Bombardment."

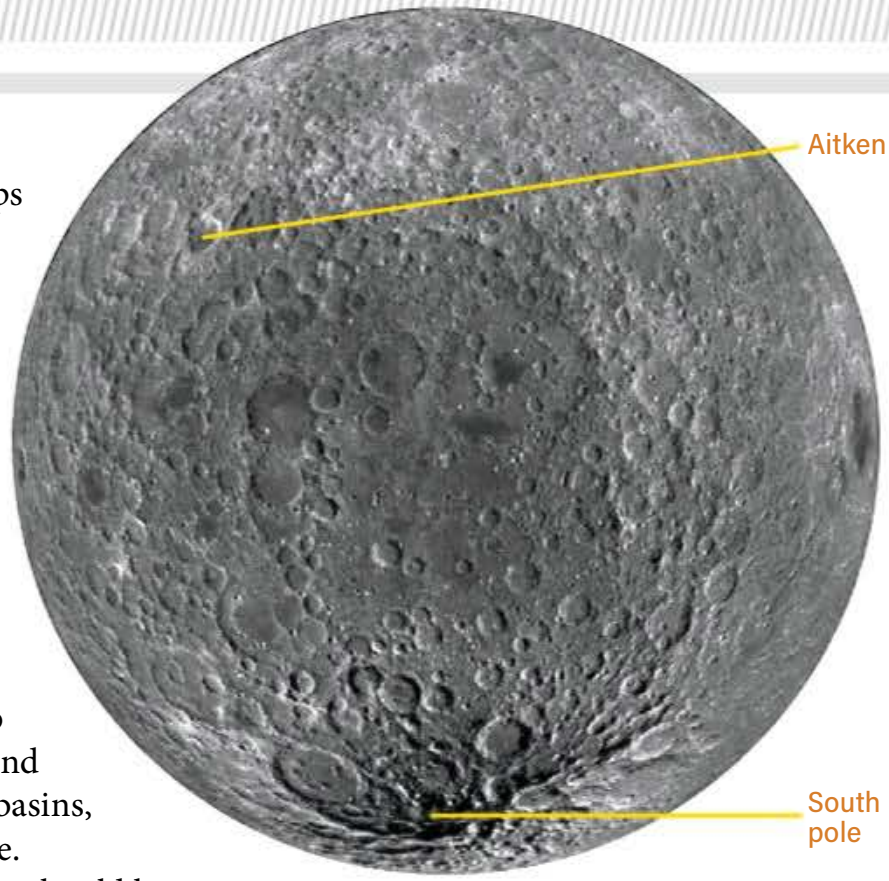
An early instability makes sense. According to Raymond, the most natural trigger for the planetary movement was the loss of the gas disk in which they were born. Within roughly 10 million years, most of the gas had either been swept up by the planets or dispersed by the Sun. The gas would have had a dampening effect. Once it was gone, the planets could more easily tug at one another gravitationally, changing their orbits. Nesvorny's 100 million years was an upper limit, with the circumstances that he modeled among the most optimistic.

That doesn't necessarily mean there wasn't an LHB — only that if there was one, the rearrangement of the ice giants didn't set it off. However, the Nice model was the best argument for causing an LHB, so the demise of this connection makes yet another argument against the hypothesis.

Not ready to give up

The chatter among the scientific community makes it seem as though time has run out for the LHB. Perhaps there wasn't a sudden increase of material slamming into the terrestrial planets after all, only the last of the debris that had built the planets being slowly swept up by collisions. Case closed, right?

Bottke isn't completely sold. "There's things that still need to be worried about," he says. He wants to know why Mare Imbrium and Mare Orientale, both huge basins, formed at the end of the line. Statistically, the largest rocks should have collided the earliest, leaving the more numerous smaller objects to make the final scars. More large impacts at the end can come from a spike in collisions, a change in the characteristics of the colliding population, or just bad luck. "What are the odds of two of the biggest [collisions] at the end of the line?" he asks. "I think that's going to be a really low probability number."



The Moon's largest and oldest impact feature is the South Pole-Aitken Basin, which spans roughly 1,550 miles (2,500 km) from the lunar south pole to the 80-mile-wide (130 km) crater Aitken. Scientists desperately want to secure samples from the basin to nail down its age. NASA/GSFC/ARIZONA STATE UNIVERSITY



The martian meteorite designated Northwest Africa 7034, and nicknamed "Black Beauty," weighs just 11 ounces (320 g), but scientists think it is worth its weight in gold. Researchers studying its embedded zircons have concluded that Mars has not experienced any cataclysmic bombardments in the past 4.5 billion years. NASA

The South Pole-Aitken Basin, the largest and oldest impact feature on the Moon, is another location with a mysterious age. According to Bottke, estimates range from 4.1 billion to 4.5 billion years. Nailing down its age would be "a big deal," he says. If it's only 4.1 billion years old, why don't we see signs of the craters that should have formed earlier in lunar history? Although several researchers have suggested that some process erased the most ancient craters, he remains unconvinced. "It's not enough to just get rid of basin rims," he says. "You have to get rid of gravitational signals and any compositional differences you have." He's not certain those changes are showing up on the Moon.

Finally, he points to concerns with meteorites. Meteorites from the Moon and the asteroid belt show signs that their parent bodies lost gas as a result of impact shock waves in two episodes — one around 4.5 billion years ago and the other between 3.5 billion and 4 billion years ago — but remain strangely quiet between 4 billion and 4.5 billion years ago. Bottke says this points to two components of inner solar system bombardment.

"I'm not quite ready to give up," he says.

One of the best ways to settle the debate over whether Earth and the Moon suffered from increased collisions early in their lifetimes would be to return to the Moon for more samples. NASA didn't select the Apollo landing sites for the purpose of nailing down crater ages, but perhaps that could be a key consideration on the next trip. Right now, NASA considers the South Pole-Aitken Basin a top choice for future landing sites. Confirming the basin's age could help to unravel some of the mystery surrounding the history of lunar bombardment.

"If we can be more selective and careful about landing sites that give us samples from the impact basin, they can help us to fill in some of the questions we still have," Zellner says.

With those ages in hand, perhaps scientists will be able to nail down what happened in the early solar system, revealing the end game of planet formation and perhaps unveiling when life could have first arisen on Earth and, perhaps, Mars.

"It's an exciting time of confusion," Morbidelli says. "Stay tuned."

Nola Taylor Redd *is a freelance science writer and frequent contributor to* Astronomy.

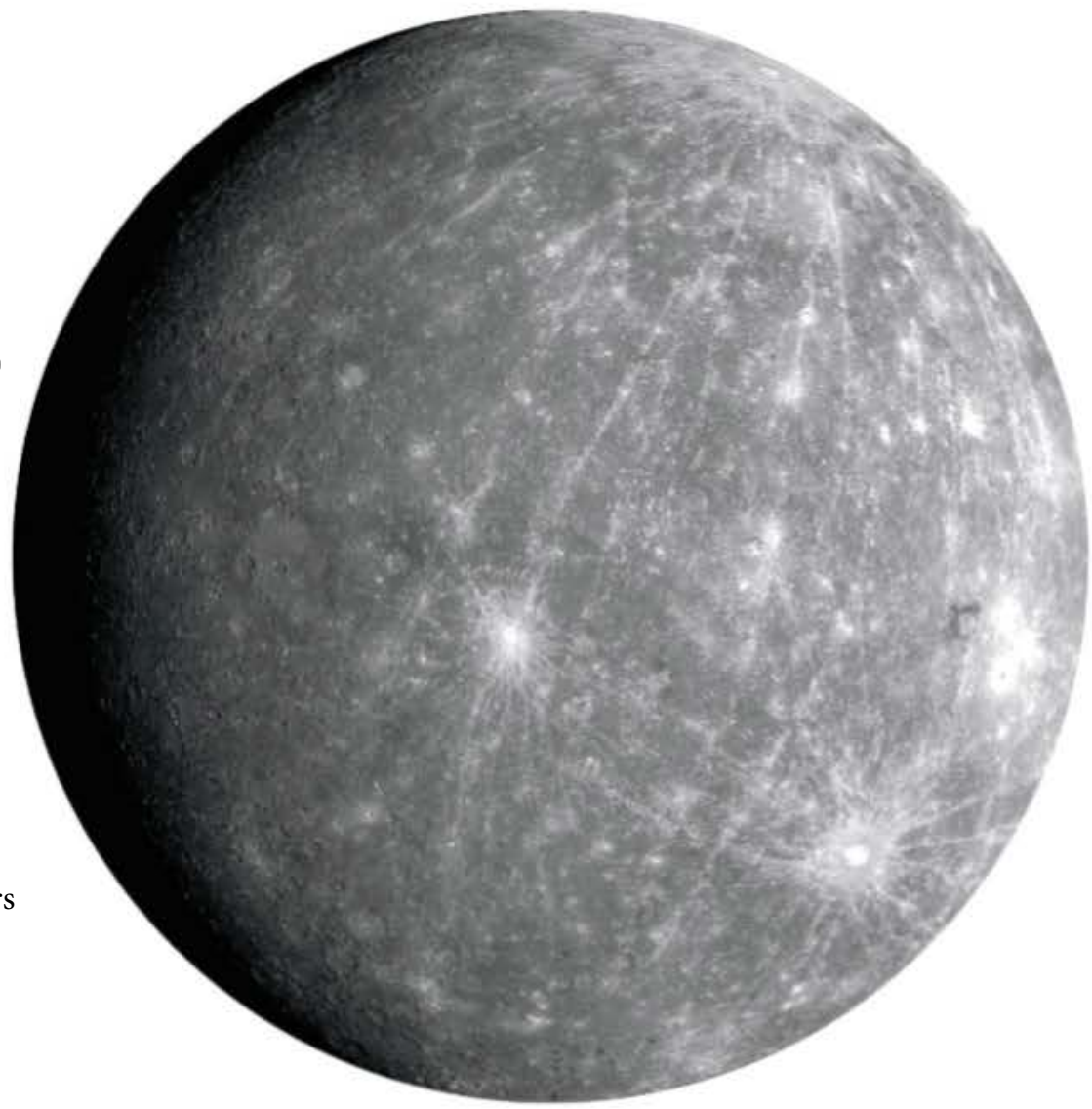
Visible to the naked eye
Visible with binoculars
Visible with a telescope

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

BY MARTIN RATCLIFFE AND ALISTER LING

FEBRUARY 2020

Mercury at its evening peak



Mercury's surface looked stunning to the MESSENGER spacecraft, though it appears unremarkable through amateur telescopes. NASA/JHUAPL/CIW

The solar system's two inner planets, Mercury and Venus, light up the early evening sky during February. These naked-eye jewels make a sharp contrast with the Sun's outermost planets, Uranus and Neptune, which occupy the same neighborhood but show up only with optical aid. Meanwhile, the three midrange worlds — Mars, Jupiter, and Saturn — add luster to the predawn sky.

Let's begin our tour soon after the Sun goes down in early February. On the 1st, you can find **Mercury** 7° high in the west-southwest a half-hour after sunset. Shining at magnitude –1.0, the planet is easy to see if you have a clear sky and unobstructed horizon. It lies against the backdrop of much fainter stars belonging to Aquarius the Water-bearer. Look for these stars as Mercury sinks lower and the sky darkens.

The inner world climbs higher each evening until it reaches greatest elongation February 10. Mercury then lies 18° east of the Sun and stands 11° high 30 minutes after sunset. Although it has faded slightly, to magnitude –0.6, the greater altitude makes it easier to spot. The combination of brightness and altitude makes this the planet's finest evening appearance of 2020.

Mercury looks equally appealing through a telescope. On the 1st, it shows a disk 6" in diameter that appears 83 percent lit. At greatest elongation, the planet spans 7" while the Sun illuminates half of its Earth-facing hemisphere.

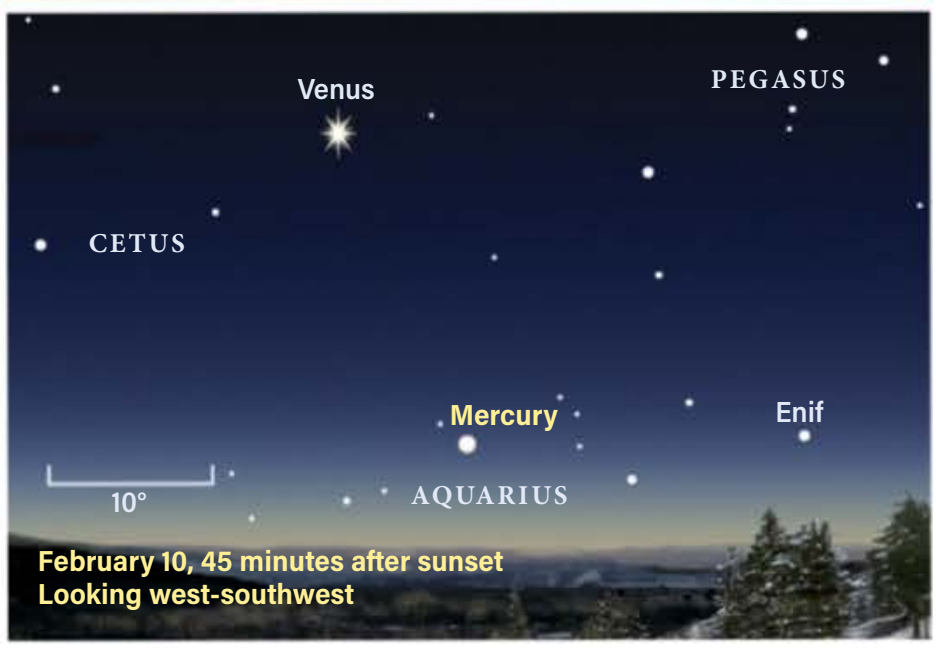
After its peak, Mercury dips lower and dims noticeably with each passing night. You can follow it for another week or so; on the 17th, the magnitude 1.2 world hangs 8° high a half-hour after sundown. A telescope then reveals a disk 9" across and less than 20 percent lit.

Like Mercury, **Venus** begins the month in Aquarius. The Water-bearer can't hold its prize for long, however, and Earth's twin crosses the border into Pisces the Fish on February 2. Venus, which brightens from magnitude –4.1 to –4.3 during February, appears more than 500 times brighter than any star in either constellation.

The planet dazzles even more than usual this month because it shines against a dark sky. Although you can spy it easily within a half-hour after sunset, it appears 20° high as the last vestiges of twilight fade away on the 1st and 5° higher by the 29th, when it doesn't set until after 9:30 P.M. local time. The increasing altitude is a sign that Venus is approaching its own greatest eastern elongation and peak visibility, which it will reach in late March.

February's final week features a close encounter between the night sky's two brightest

The innermost planet glows brightly



Mercury puts on a great show in early February, when it shines brightly at magnitude –1 in evening twilight. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

A waning crescent **MOON** occults **MARS** the morning of February 18.

objects. The waxing Moon first comes into view on the 24th, when it appears in twilight and sets about an hour after the Sun. The next evening, it's a lovely thin crescent standing 10° high an hour after sunset with Venus 20° above it. The gap between the two closes to 10° on the 26th and 7° on the 27th. The two make a stunning pair visible for two to three hours both nights.

Venus' appearance through a telescope doesn't change as rapidly as Mercury's, though Earth's next-door neighbor is still worth tracking. During February, Venus' apparent diameter grows from 15" to 19" while its illumination shrinks from 73 to 63 percent. Your best views will come during twilight, when the contrast between sky and planet is less intense.

You can use Venus and Mercury as guides for finding **Neptune** in early February. A line between the two inner planets traces the ecliptic — the Sun's path across our sky that the planets follow closely — and intersects the position of the solar system's most distant major planet.

On February 1, Neptune lies 6° west of (below) Venus, or about one binocular field. Because Neptune glows at magnitude 7.9, however, you'll need to wait until dark and then use binoculars or a telescope to find it. First locate 4th-magnitude

— *Continued on page 42*

RISING MOON | The mark of the Ram

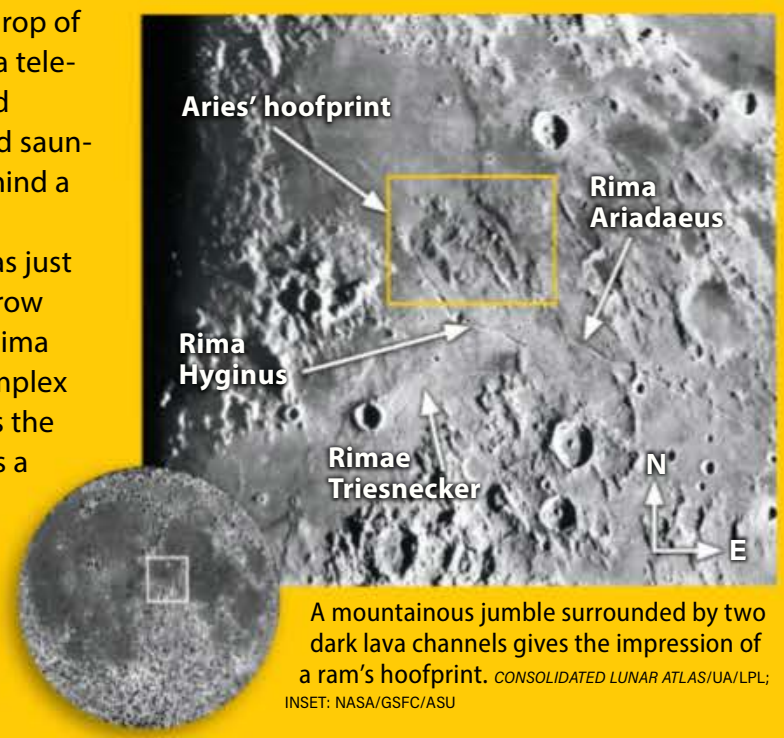
THE FIRST QUARTER MOON STANDS HIGH in the southwest once darkness falls February 1. Earth's satellite appears against the backdrop of southern Aries. Coincidentally, if you aim a telescope at the Moon this evening, you could almost convince yourself that the Ram had sauntered across the lunar surface and left behind a large hoofprint.

On February's first evening, the Sun has just risen over a fascinating series of long, narrow channels known as rilles, highlighted by Rima Ariadaeus, Rima Hyginus, and the rille complex Rimae Triesnecker. But what really catches the eye in this area just north of the equator is a delightful feature dubbed "Aries' hoofprint." The combination of brightly lit mountains and two deep channels of especially dark lava creates this striking play of light and shadow. At low power with the entire half-lit Moon in view, the hoofprint stands out.

It's easy to understand why lunar cartographers didn't label this feature on their maps. After all, it's only a jumble of mountains left over from the giant impact that created Mare Imbrium with a lava channel on either side. Furthermore, lunar scientists focused on Rima Hyginus with good reason — this series of small pits is almost certainly volcanic in origin. It stands out nicely on the 1st because one of the rille's walls is brightly sunlit while the other remains in shadow.

Sadly, Aries' hoofprint doesn't stand out for long. By the evening of February 2, the Moon has moved on to Taurus, and the increasing glare of the Sun has reduced both the Ram's artifact and Rima Hyginus to mere echoes of their previous magnificence.

Aries' hoofprint and some nearby rilles



A mountainous jumble surrounded by two dark lava channels gives the impression of a ram's hoofprint. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

METEOR WATCH | Discover the zodiac's elusive glow

Catch the eerie zodiacal light



This cone-shaped glow rises from the western horizon after evening twilight fades away in mid-February. ROB RATKOWSKI

THE LONGEST LULL in the yearly meteor calendar runs from early January (the brief but prolific Quadrantids) to late April (the more modest Lyrids). But meteor enthusiasts shouldn't abandon all hope this month. Many ancient meteor streams that dispersed long ago create a sporadic background rate of about a half-dozen meteors per hour, with the best views coming before dawn.

Meteoritic dust also shows up on February evenings, but in a completely different form. The dust ejected by comets fills the inner solar system and concentrates along the orbital plane of the planets. On dark February evenings, you can catch sunlight glinting off this debris.

The zodiacal light is a cone-shaped glow that appears above the western horizon once evening twilight fades away. Roughly as bright as the Milky Way, the zodiacal light passes through Aquarius, Pisces, and Aries. (This year, Venus sits in the middle of the glow.) Look for the zodiacal light from a dark site when the Moon is gone from the evening sky, from February 10 to 24.

STAR DOME

HOW TO USE THIS MAP

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

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

10 P.M. February 1
9 P.M. February 15
8 P.M. February 29

Planets are shown at midmonth

MAP SYMBOLS

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

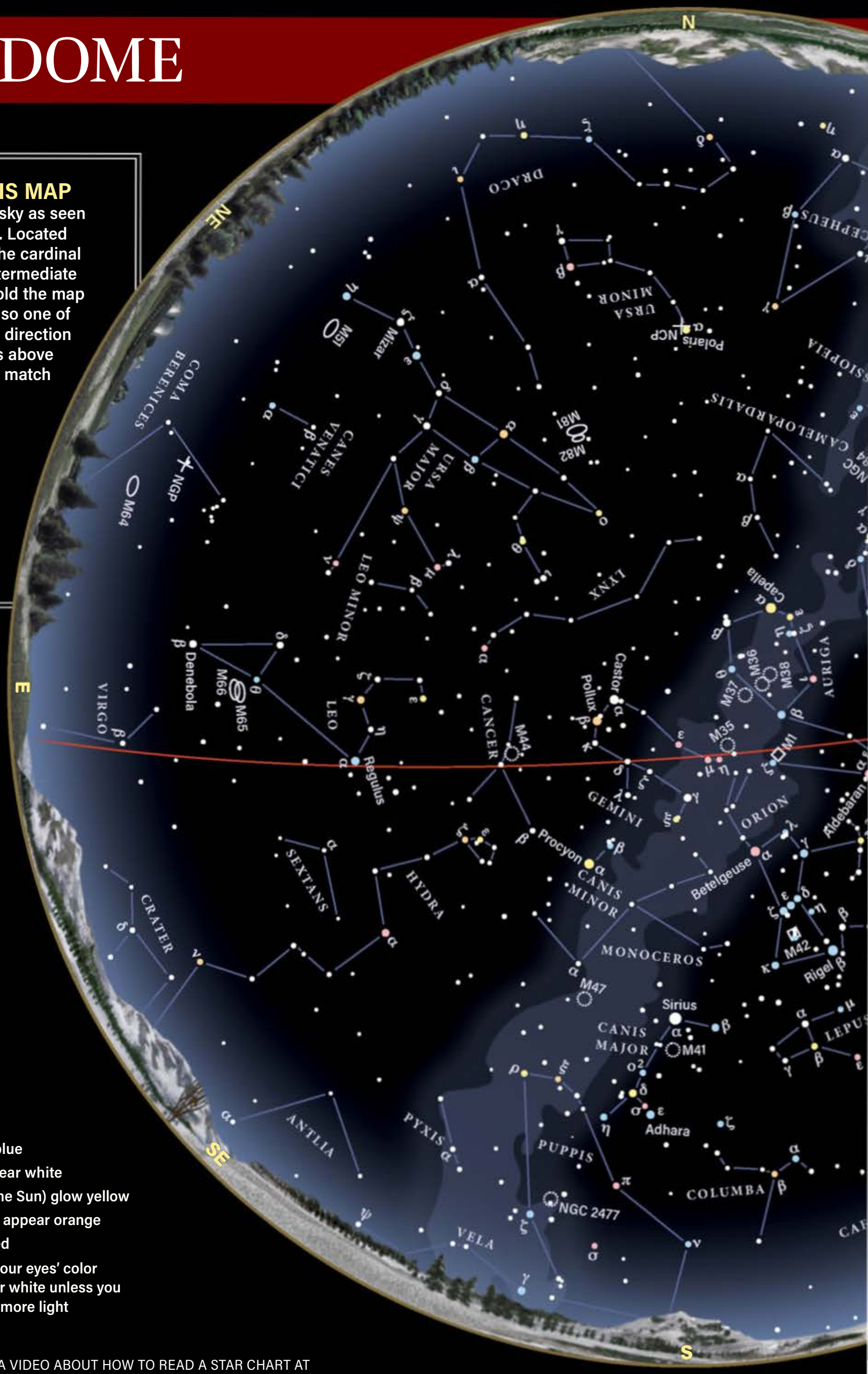
STAR MAGNITUDES

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

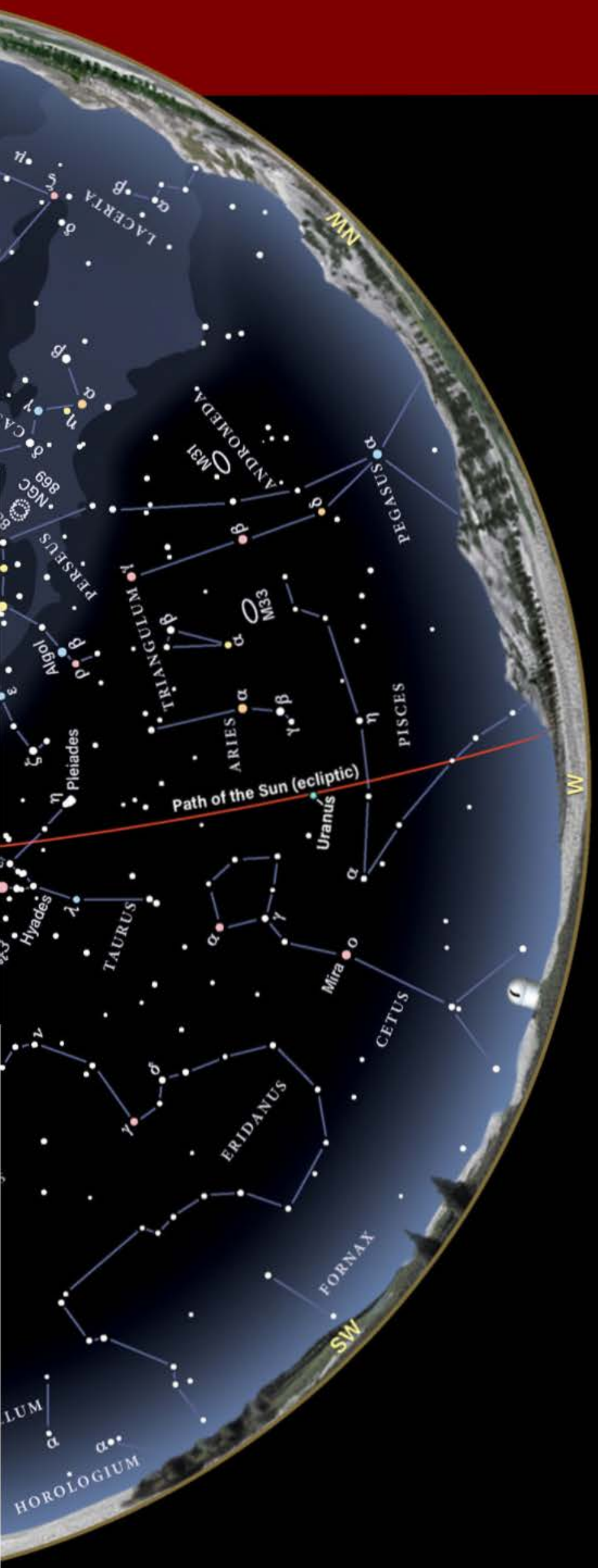
STAR COLORS

A star's color depends on its surface temperature.

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



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



FEBRUARY 2020

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

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 First Quarter Moon occurs at 8:42 P.M. EST

2 The Moon passes 0.5° north of asteroid Vesta, 4 A.M. EST

9 Full Moon occurs at 2:33 A.M. EST

10 Mercury is at greatest eastern elongation (18°), 9 A.M. EST

The Moon is at perigee (223,980 miles from Earth), 3:28 P.M. EST

13 Asteroid Juno is stationary, 2 A.M. EST

The Moon passes 0.6° north of asteroid Juno, 5 A.M. EST

15 Last Quarter Moon occurs at 5:17 P.M. EST

16 Mercury is stationary, 5 A.M. EST

18 The Moon passes 0.8° north of Mars, 8 A.M. EST

19 The Moon passes 0.9° south of Jupiter, 3 P.M. EST

20 The Moon passes 0.7° south of Pluto, 3 A.M. EST

The Moon passes 1.7° south of Saturn, 9 A.M. EST

23 New Moon occurs at 10:32 A.M. EST

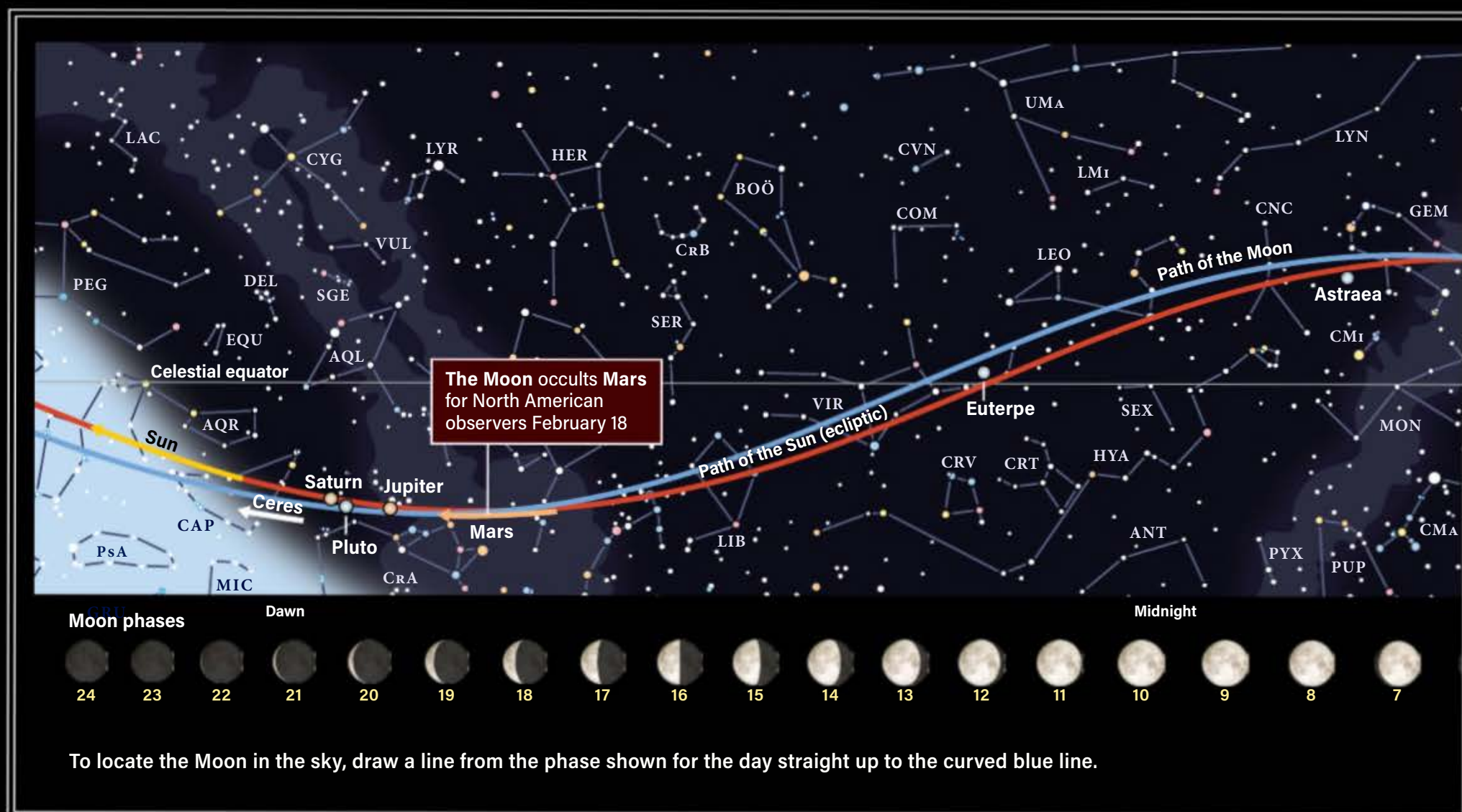
25 Mercury is in inferior conjunction, 9 P.M. EST

26 The Moon is at apogee (252,450 miles from Earth), 6:34 A.M. EST

27 The Moon passes 6° south of Venus, 7 A.M. EST

28 The Moon passes 4° south of Uranus, 7 A.M. EST

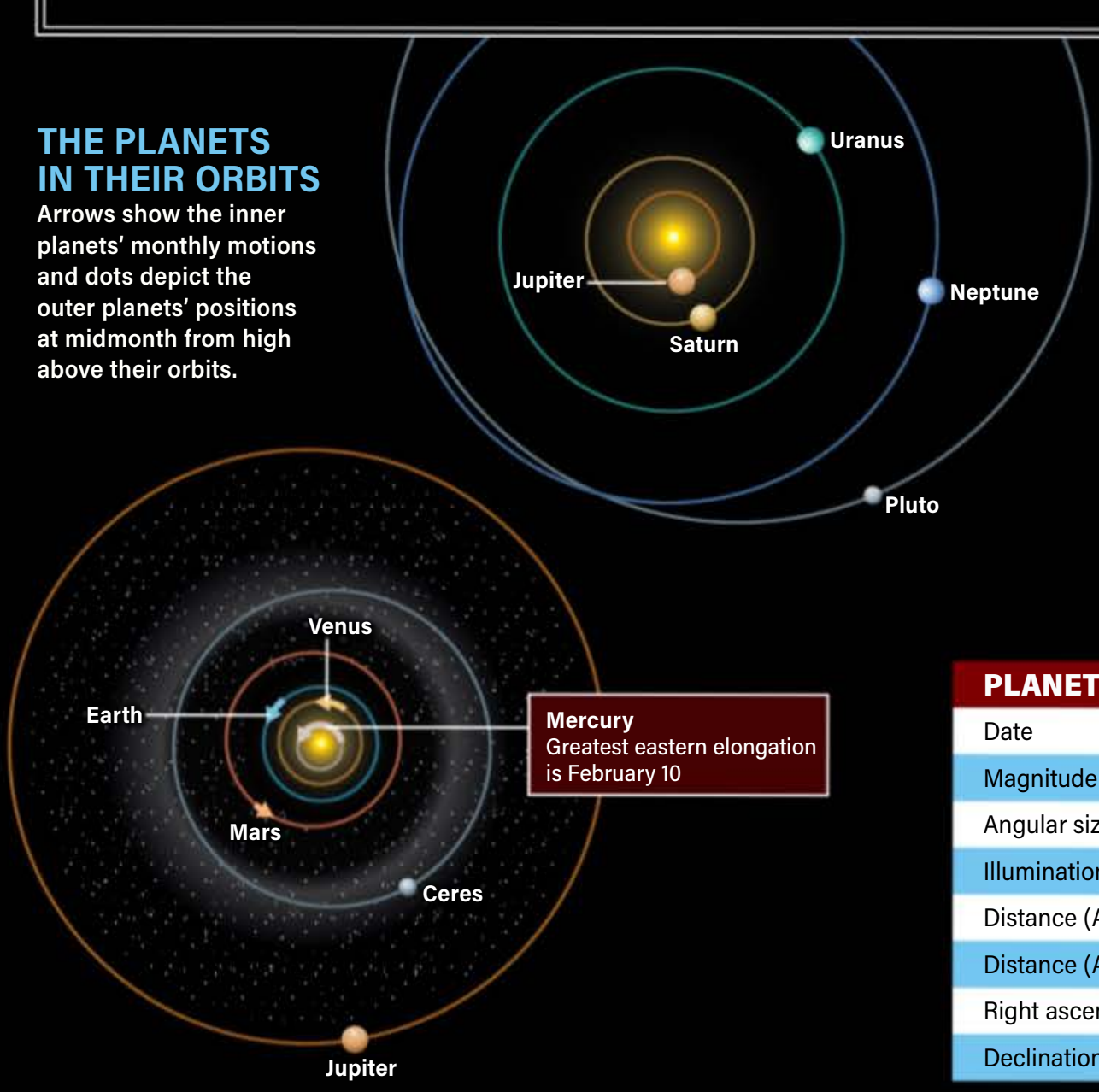
PATHS OF THE PLANETS



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

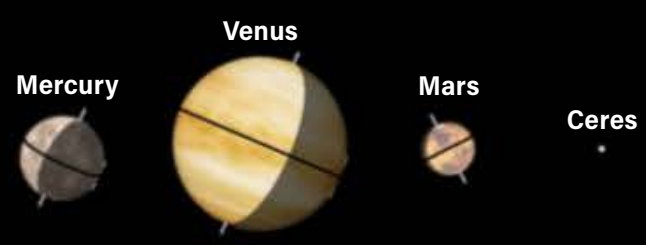
THE PLANETS IN THEIR ORBITS

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



THE PLANETS IN THE SKY

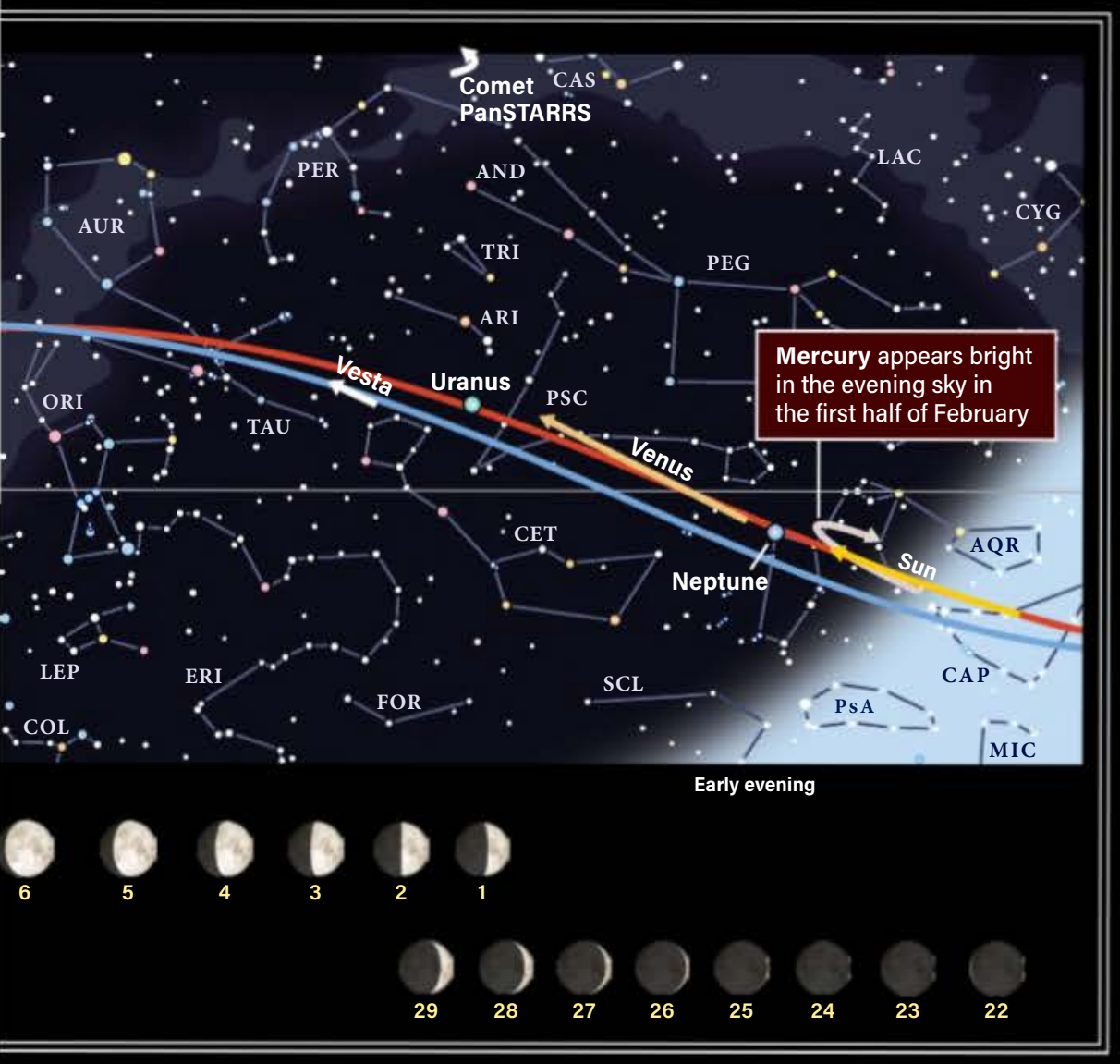
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	Feb. 15	Feb. 15
Magnitude	0.2	–4.2
Angular size	8.1"	16.8"
Illumination	31%	69%
Distance (AU) from Earth	0.827	0.995
Distance (AU) from Sun	0.310	0.721
Right ascension (2000.0)	22h51.6m	0h29.8m
Declination (2000.0)	–5°12'	3°12'

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

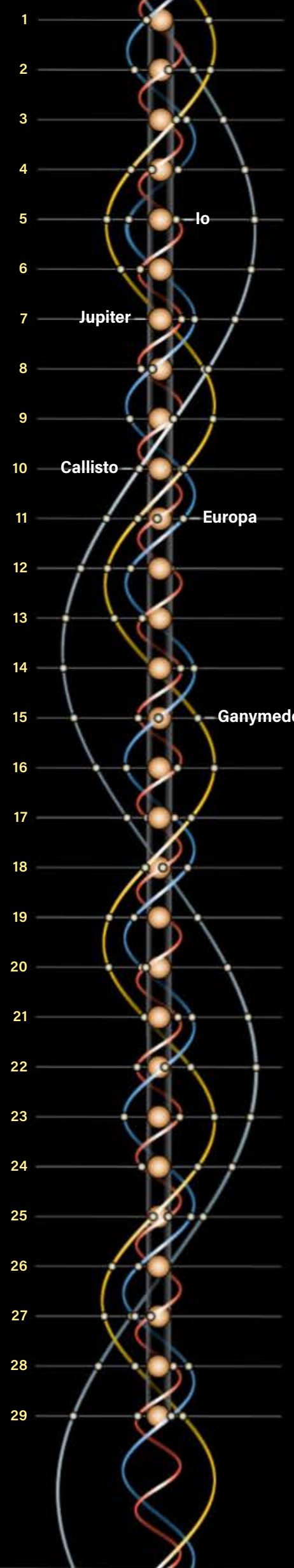
February 2020





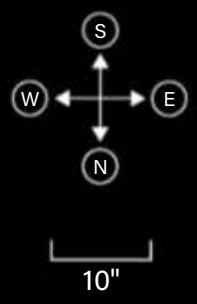
JUPITER'S MOONS

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











MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15	Feb. 15
1.3	9.1	–1.9	0.6	5.8	8.0	14.8
5.1"	0.3"	33.2"	15.3"	3.5"	2.2"	0.1"
92%	100%	100%	100%	100%	100%	100%
1.835	3.842	5.940	10.881	20.171	30.847	34.814
1.535	2.938	5.211	10.030	19.813	29.932	33.980
17h54.4m	20h36.8m	19h10.9m	19h53.4m	2h03.4m	23h14.8m	19h42.3m
–23°37'	–23°49'	–22°25'	–20°53'	12°02'	–5°57'	–22°05'

 — *Continued from page 37*

The Moon occults Mars



A waning crescent Moon slides in front of the Red Planet before dawn February 18. In this 2006 scene, Mars poses on the waxing Moon's limb. TUNÇ TEZEL

right area, first find magnitude 2.0 Hamal (Alpha [α] Arietis). The brightest star in Aries the Ram appears two-thirds of the way from the southwestern horizon to the zenith once darkness falls in early February. Uranus lies 12°, or nearly two binocular fields, south of Hamal.

As with Neptune, Uranus reveals its true nature through modest telescopes. The seventh planet sports a distinctive blue-green color on a disk that spans 3.5".

If you follow the evening planets all month, you'll notice Venus climbing higher while Uranus dips lower. Forty degrees separate the two February 1, but the gap shrinks to 8° by the 29th. The two are destined for a close meeting during the second week of March.

Uranus sets around midnight local time in early February and some two hours earlier by month's end. Planet lovers can then get some shut-eye before the next planet rises several hours later.

Mars appears first, poking above the southeastern horizon shortly before 4 A.M. local time. Because the Red Planet travels eastward along the ecliptic at nearly the same rate as the Sun, its rising time changes little during the entire month. On February's first morning, magnitude 1.4 Mars lies in Ophiuchus the Serpent-bearer. Don't confuse it with its ancient rival, Antares, which rises about a half-hour earlier and appears 11° west (upper right) of Mars. Although the two objects have a similar hue, the star shines slightly brighter than the planet.

WHEN TO VIEW THE PLANETS

EVENING SKY
Mercury (west)
Venus (west)
Uranus (southwest)
Neptune (west)

MORNING SKY
Mars (southeast)
Jupiter (southeast)
Saturn (southeast)

Mars crosses into Sagittarius the Archer on February 11, setting the stage for a series of terrific conjunctions. On the 17th, the Red Planet passes between the Lagoon Nebula (M8) and the Trifid Nebula (M20), two of the Milky Way's finest emission regions. The two Messier objects lie just 1.4° apart and make a marvelous backdrop for astroimagers.

Phi (ϕ) Aquarii. Neptune stands 18' due west of this star on the 1st. To confirm a planet sighting, aim a telescope at your suspected target. Only Neptune shows a 2.2"-diameter disk and subtle blue-gray color.

The separation narrows in the days ahead. On the evening of the 10th, Neptune skims just 2' north of Phi. That's slightly less than the distance between Io and Jupiter when the innermost jovian moon reaches greatest elongation. Alas, you won't be able to follow the pair for much longer — the two succumb to low altitude and twilight after mid-February.

Uranus fares far better than Neptune because it's seven times brighter (magnitude 5.8) and much higher in the sky. Binoculars easily gather enough light to reveal this ice giant — the challenge comes from the fact that it lies in a sparse region of the sky with few signposts. To get to the

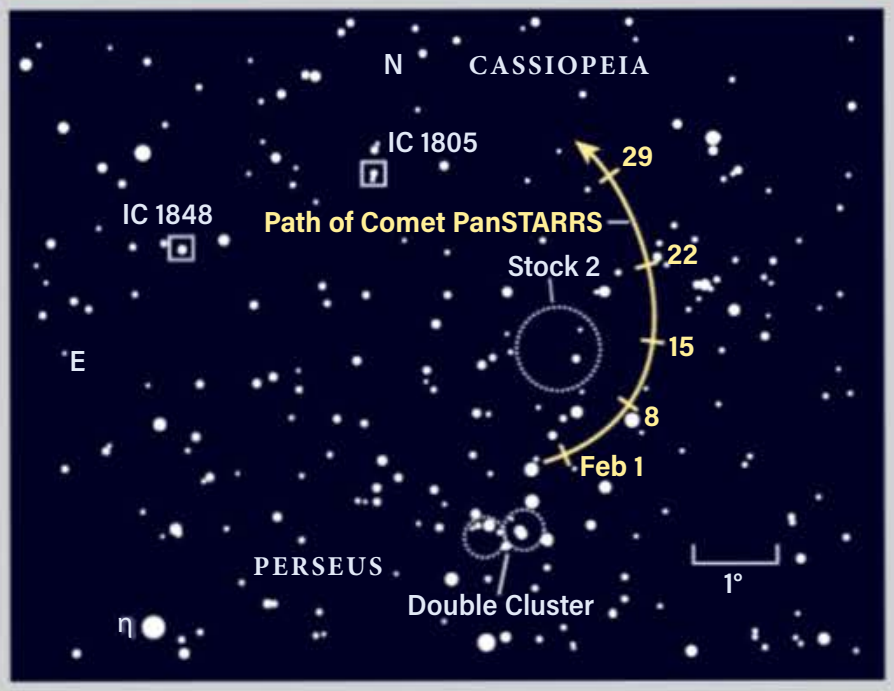
COMET SEARCH | Taking Stock with the Heart and Soul

COMET PANSTARRS (C/2017 T2) enjoys a series of close encounters with impressive deep-sky objects this month. The comet moves slowly northward along the Milky Way near the Perseus-Cassiopeia border. It begins February 1° northwest of the Double Cluster, curves around the pretty binocular cluster Stock 2 around midmonth, and closes the month a few degrees west of the Heart and Soul nebulae (IC 1805 and IC 1848, respectively). This all makes for a stunning backdrop for wide-field images.

PanSTARRS' northern location makes it a circumpolar object for observers across most of the U.S. Still, it lies highest in the sky early in the evening and dips low in the north after midnight, so plan to observe it shortly after darkness falls. The best Moon-free window occurs between February 11 and 26.

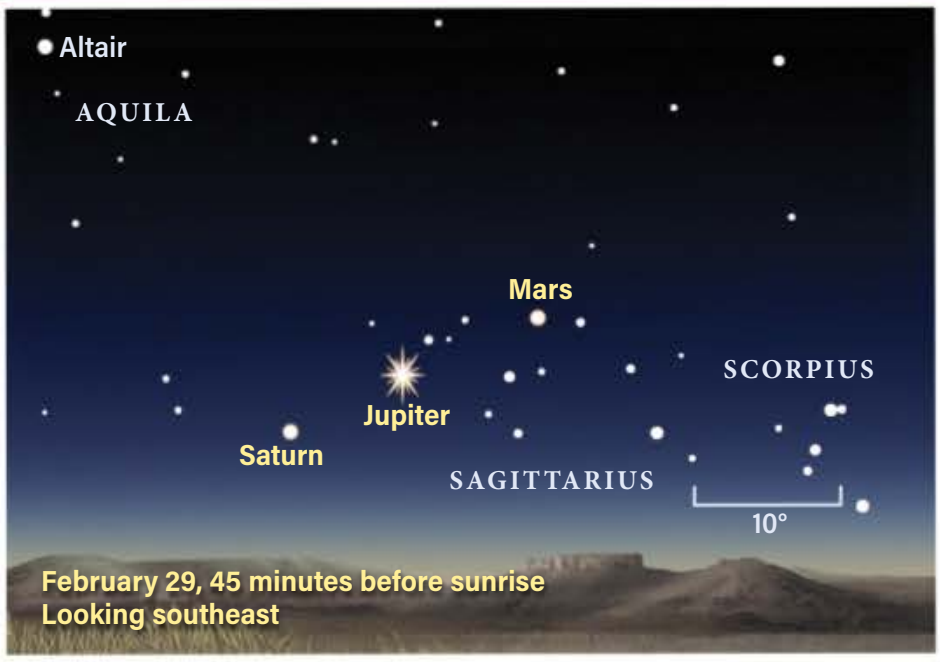
Astronomers expect the comet to glow around 8th or 9th magnitude this month, on its way perhaps to 7th magnitude at its peak in May. Through 12-inch and larger telescopes, you might pick up the comet's subtle greenish hue.

Comet PanSTARRS (C/2017 T2)



Cassiopeia and Perseus host a rich collection of Milky Way wonders and, this month at least, a passing visitor from the distant Oort Cloud.

A trio of planetary delights



The southeastern sky brims with bright planets late this month as Saturn joins Mars and Jupiter against the background stars of Sagittarius.

As spectacular as this will be for imagers, the following morning holds more drama for observers in the western two-thirds of North America. Shortly before dawn on the 18th, the waning crescent Moon arrives at Mars' position and slides in front of the Red Planet. The Greek philosopher Aristotle first recorded an instance of the Moon hiding Mars on May 4, 357 B.C.

You can view this stunning occultation with your naked eyes, but binoculars or a telescope reveal far more detail. Use a scope if you want to watch Mars fade away as the Moon's bright limb gradually overtakes it. Depending on your location, the Moon can take up to 15 seconds to completely cover the Red Planet's featureless, 5.2"-diameter disk.

The event occurs earlier the farther west you live. Although Mars disappears before the two objects rise along the West Coast, observers there can witness the planet's equally stunning reemergence from behind the Moon's dark limb. Those in the mountain states get to view the disappearance against a dark sky, while Midwesterners see the same event during twilight. Unfortunately, East Coast skygazers miss out because the occultation occurs after the Sun rises. Even so, they'll enjoy a beautiful close conjunction between the two objects before dawn. You can find precise times for the occultation on the International Occultation Timing Association's website at http://occultations.org.

Two more planets emerge closer to dawn. **Jupiter** rises about 90 minutes before the Sun on February 1, and **Saturn** follows 40 minutes later. The two stand 11° apart in Sagittarius, with Jupiter shining at magnitude –1.9 and Saturn at magnitude 0.6.

After the Moon occults Mars on February 18, it slides 4° to Jupiter's right on the 19th and 2.5° to Saturn's lower right on the 20th. This splendid three-day stretch should prove unforgettable for early risers.

By the end of February, all three planets rise before twilight begins. They spread out 19° along the ecliptic, with Mars highest, Jupiter 10° to its lower left, and Saturn 9° farther on.

With the giant planets at such a low altitude, you'll be hard-pressed to get sharp views of them through a telescope. Even at the end of February, Jupiter's 34"-diameter disk likely will show only its two dark equatorial cloud belts. And although you'll be able to see Saturn's ring system, which spans 35" and tilts 22° to our line of sight, it won't look nearly as spectacular as it will in the coming months.

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LOCATING ASTEROIDS |
Grabbing the Bull by its toes

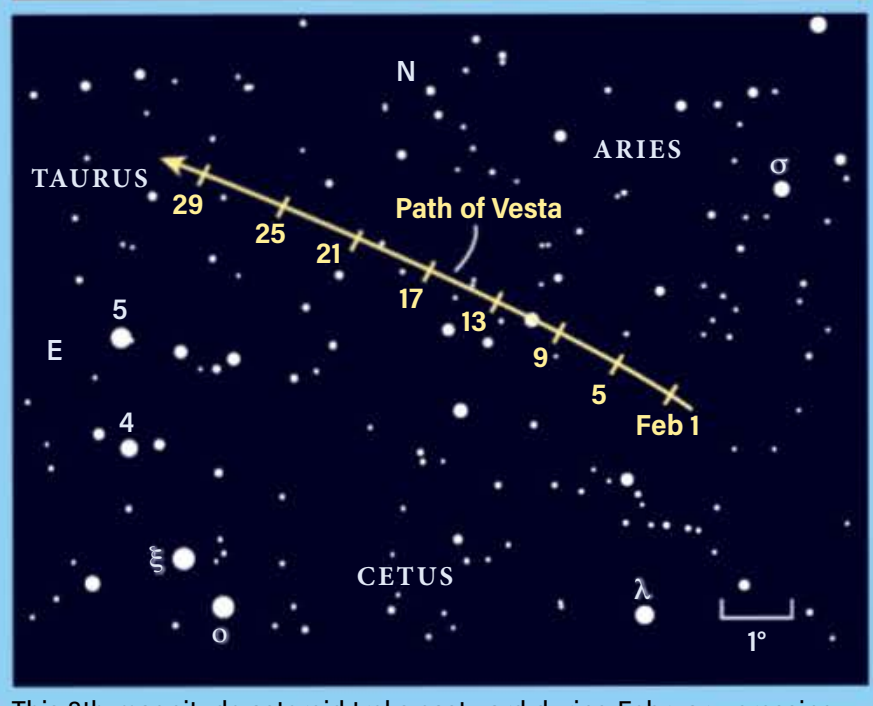
ASTEROID 4 VESTA IS NOTHING IF NOT RELIABLE. Although it is not the largest object in the main asteroid belt, it is consistently the brightest. For that, we can thank its high reflectivity and its relatively close orbit to the Sun.

Vesta lies some 20° — about three binocular fields — west of 1st-magnitude Aldebaran in Taurus. If you think of the V-shaped Hyades Cluster as an arrowhead, it points to the west. Our guide stars are Omicron (ο) and Xi (ξ) Tauri — two 4th-magnitude suns that lie in far western Taurus and form one of the Bull's front feet.

You'll want to hunt for the 8th-magnitude asteroid in the early evening when this region lies high in the southwest. Vesta should be fairly easy to pick out because it glows brighter than most of the surrounding stars. Confirming an asteroid sighting requires seeing it move relative to the starry background, however. Typically, this means sketching the field of view one evening and then returning the following night to see which object changed position. But you'll be able to see Vesta move in a single night February 11 when it passes within 2" of a magnitude 5.6 field star.

On February 1, the First Quarter Moon occults Vesta for observers in Alaska and Western Canada. While a star disappears instantaneously behind the Moon's limb, Vesta's 0.3" angular diameter makes it fade away over nearly a second.

Vesta vies for evening views



This 8th-magnitude asteroid treks eastward during February, crossing the invisible border between Aries the Ram and Taurus the Bull.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, has watched the skies since 1975.*


Lowell

1894–2019



A worker takes a break atop Mars Hill in Flagstaff, Arizona, during construction of the Clark Telescope Dome on May 5, 1894. LOWELL OBSERVATORY ARCHIVES



Within the dome protecting the 24-inch Clark refractor at Lowell, many historic observations were made, including Percival Lowell's viewings of Mars. DAVID J. EICHER

Observatory TURNS 125

More than a century after opening its doors, "America's Observatory" remains a hotbed for scientific discovery and public outreach. BY JEFFREY HALL AND KEVIN SCHINDLER

Percival Lowell, founder of historic Lowell Observatory, targets Venus during the daytime from the observer's chair of the famous 24-inch Clark Telescope on October 17, 1914.
LOWELL OBSERVATORY ARCHIVES

On May 28, 1894, wealthy Boston businessman, mathematician, and astronomer Percival Lowell stepped off the train in Flagstaff, a hamlet of 800 people in the Arizona Territory, and headed up a hill just west of town. He would spend the rest of his life on what came to be known as Mars Hill, where he fastidiously studied martian features he thought were intelligently designed structures, and exhaustively calculated the predicted location of an undiscovered hypothetical world called Planet X.

In the 125 years since Percival's arrival in Flagstaff, his observatory has evolved considerably. Known to many as America's Observatory, the site now boasts a research faculty of 14 Ph.D.-level astronomers and an informal outreach program that draws more than 100,000 visitors to the campus each year.

Telescopes then and now

Lowell Observatory has long benefited from ownership of some of the finest tools of the astronomer's trade. And while a comprehensive description of all of them could fill a book, two are especially distinguished: The famed Clark Telescope and the Discovery Channel Telescope.



Percival Lowell observes Venus through the Clark refractor, built by Alvan Clark & Sons of Cambridgeport, Massachusetts, in 1897. LOWELL OBSERVATORY ARCHIVES



The Discovery Channel Telescope (above) is located in Happy Jack, Arizona, and provides Lowell astronomers with the freedom to explore almost any research project that intrigues them. LOWELL OBSERVATORY

Shortly after founding the observatory, Lowell commissioned a 24-inch refractor from Alvan Clark & Sons in Boston for the princely sum of $20,000, which equates to about $600,000 today. The telescope still graces its historic dome overlooking Flagstaff. It is now used solely to give the public spectacular views of the universe, but it has played a role in some of the most important observations of the 20th century.

For instance: In 1912, Percival Lowell directed astronomer Vesto M. Slipher to observe so-called spiral nebulae with the Clark. The first object he observed was the Andromeda Galaxy (M31). To his surprise, he found Andromeda was hurtling toward our solar system at some 670,000 mph (1.1 million km/h). In a one-page notice in the *Lowell Observatory Bulletin* the following year, Slipher penned one of the greatest understatements in astronomical literature: "It might not be fruitless to observe some of the more promising spirals … Extension of the work to other objects promises results of fundamental importance." His later observations with the Clark revealed the first cosmological redshifts — the stretching of light waves that's a result of the expanding universe. Perhaps the recently renamed Hubble-Lemaître Law should be further amended to the Hubble-Lemaître-Slipher Law?

The modern bookend to the historic Clark telescope is Lowell's 4.3-meter Discovery Channel Telescope (DCT), taking its name from the well-known media company. Discovery founder and former CEO John Hendricks has long been a member of the observatory's Advisory Board. And Discovery, Hendricks, and his wife, Maureen, made gifts totaling $16 million toward the $53 million cost of the project. These were gifts, not purchases: Discovery has no ownership of the telescope, nor any direction regarding the research it conducts. In return for their contributions,

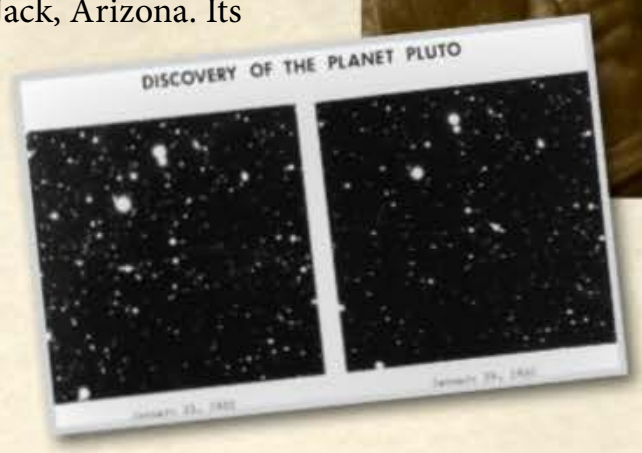


Vesto M. Slipher uses a spectrograph built by John Brashear. Slipher relied on this spectrograph to discover the first evidence of an expanding universe. LOWELL OBSERVATORY ARCHIVES

they received naming rights and first right of refusal for use of images in educational broadcasts. The research carried out with DCT proceeds as it would at any other professional telescope.

Groundbreaking for the DCT occurred on an especially hot day in July 2005. The first-light gala celebration was almost exactly seven years later, featuring a marvelous keynote address by Neil Armstrong — his final public appearance before his death several weeks later. Today, the fully commissioned telescope operates night in and night out at an elevation of about 7,800 feet (2,400 meters), some 40 miles (64 km) southeast of Flagstaff in Happy Jack, Arizona. Its finely figured thin meniscus primary mirror, held in shape by a 156-element active optics system, regularly delivers impeccable seeing — a measure of the sharpness of a telescope's image — to any of its five instruments at the Ritchey-Chrétien focus. The DCT can switch between any of these instruments in about a minute, making it uniquely suited for observing programs that target quickly evolving cosmic objects, such as gamma-ray bursts and supernovae. Boston University, the University of Maryland, the University of Toledo, Northern Arizona University, and Yale University have joined Lowell as partners with access to the DCT, and the consensus of its users is that the DCT is one of the best-performing and most efficient 4-meter telescopes they have experienced. It is a testament to the outstanding engineers who built and maintain it, and it will be Lowell's research flagship for decades to come.





ABOVE: Clyde Tombaugh uses a Zeiss Blink Comparator to compare differences between two images. This tool allowed him to quickly identify any objects that moved between two images of the same part of the sky taken at different times, which is how he discovered Pluto. LOWELL OBSERVATORY ARCHIVES

LEFT: The discovery images of Pluto, taken six days apart in January 1930, are seen here with arrows identifying the position of Pluto. LOWELL OBSERVATORY ARCHIVES

A scientific haven

The core of Lowell's research philosophy is to provide outstanding telescopes and instrumentation and then let its faculty use them to do whatever science they find interesting. Astronomers coming to Mars Hill are handed, in effect, an academic blank check. Lowell welcomes projects that take longer to complete than the three-year cadence of a typical research grant. Also welcomed are ideas that might be given the slightly derisive term "fishing expeditions." Sometimes such pursuits are indeed dead ends — though dead ends can also be decidedly revealing — but sometimes you catch some very interesting fish. Perhaps the most dramatic example is Slipher's spectroscopic observations of "spiral nebulae," which Lowell pushed for to see if their compositions matched those of the solar system's gas giants. Unlike Slipher's measurements of Andromeda, many of these objects showed recessional velocities, which proved to be the first evidence of the expanding universe.

Today, Lowell's programs include extensive studies of the outer solar system's icy moons, as well as comets and asteroids. Researchers at Lowell explore the characteristics and variations of stars ranging from Sun-like dwarfs to massive supergiants, as well as investigate the formation and characteristics of exoplanets around those stars. Farther afield, the formation and evolution of dwarf galaxies and the characteristics of galaxy clusters are topics of interest. And tomorrow? We'll let the curious minds on Mars Hill chart that course.

The great demotion

Slipher's redshift observations are arguably the most fundamental astronomical observations ever made at Lowell, but surely one of the best known is the discovery of Pluto. Spurred on by perturbations found in Uranus' orbit in the late 19th century, Lowell spent the latter years of his life searching for a possible ninth planet whose gravitational pull could explain Uranus' orbital oddities. He dubbed the predicted world Planet X.

Ninety years ago, on February 18, 1930, Clyde Tombaugh walked into Slipher's office and said, with what must have been trembling excitement, "I have found your Planet X." Eventually, the

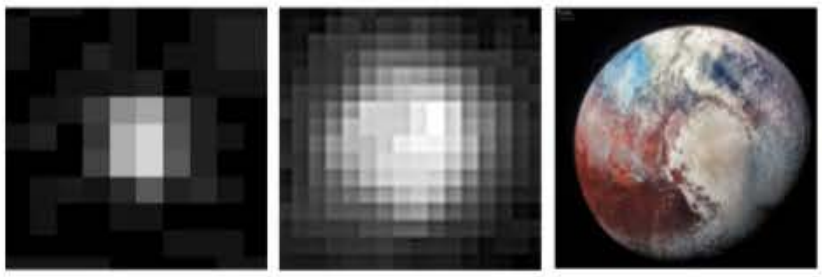


Percival Lowell sent this telegram establishing his famed observatory's name on March 15, 1894. It reads: "In answer to name simply call it the lowell observatory." LOWELL OBSERVATORY ARCHIVES



Giovale Open Deck Observatory is a 4,300-square-foot plaza with six permanently mounted telescopes available for public use. The $4 million site, which opened its doors last fall, aims to increase the roughly 100,000 visitors Lowell Observatory draws in each year. LOWELL OBSERVATORY

distant and diminutive world showed it was not gravitationally assertive enough to be the Planet X Percival Lowell had in mind. Instead, it was an enigmatic little object revealed in detail only in July 2015 during the historic New Horizons flyby — a mission in which current and former Lowell astronomers have played a pivotal role.



Our evolving view of Pluto is seen in this series of images, showing how the dwarf planet appeared to Tombaugh in 1930 (left), Hubble's Faint Object Camera in 1994 (middle), and the New Horizons spacecraft in 2015 (right). LEFT: LOWELL OBSERVATORY/C. TOMBAUGH. MIDDLE: NASA/ESA/A. STERN/M. BUIE. RIGHT: NASA/JHUAPL/SWRI/Z. DOYLE

As we all know, the Pluto of 2006 was classified as a "dwarf planet," which is not — through logic one could find a bit head-scratching — a planet. The famous (or, depending on your point of view, notorious) "demotion" of Pluto to a dwarf planet by the International Astronomical Union in 2006 has encouraged ongoing curiosity about the outskirts of the solar system. This curiosity reached a fever pitch during New Horizons' 2015 flyby of Pluto, and again on January 1, 2019, when the spacecraft briefly encountered the Kuiper Belt object Arrokoth (2014 MU_{69}).

Consider the Pluto of today, as further revealed by New Horizons, for which Lowell scientist Will Grundy leads the surface composition team. Pluto, we now know, is a place with five moons, a complex atmosphere, variegated terrain and surface regions, and patently active geology. Holding all this up to the idiosyncrasies of the other planets and non-planets in the solar system, as well as to the strange and new planetary characteristics and system architectures being revealed around most planet-harboring stars, one could argue it might be a reasonable time to reexamine this matter. Perhaps we would arrive at a more thoughtful taxonomy than we currently have.

Bringing science to everyone

Percival Lowell was much more than just an impressive businessman and academic. He was also an avowed popularizer of astronomy. His controversial ideas about Mars were often aired to the irritation of the professional community. But he also inspired many with his belief that the excitement of scientific discovery should be shared with everyone, making them "co-discoverers" of the objects, laws, and phenomena that make up our weird and wonderful universe.

Lowell Observatory continues that commitment today as an integral part of its mission. The observatory's modest, one-room operation of the early 1990s expanded dramatically in 1994 with the opening of the Steele Visitor Center. Visitation at Lowell then held steady at 60,000 to 70,000 people per year until the New Horizons flyby, when it rose sharply and has since remained at 100,000 or more.

In response to this example of a good problem to have, Lowell is now in the advanced stages of design and fundraising for a new $29 million,

What we know about the universe pales in comparison to what we don't.

18+

WHAT IS AVAXHOME?

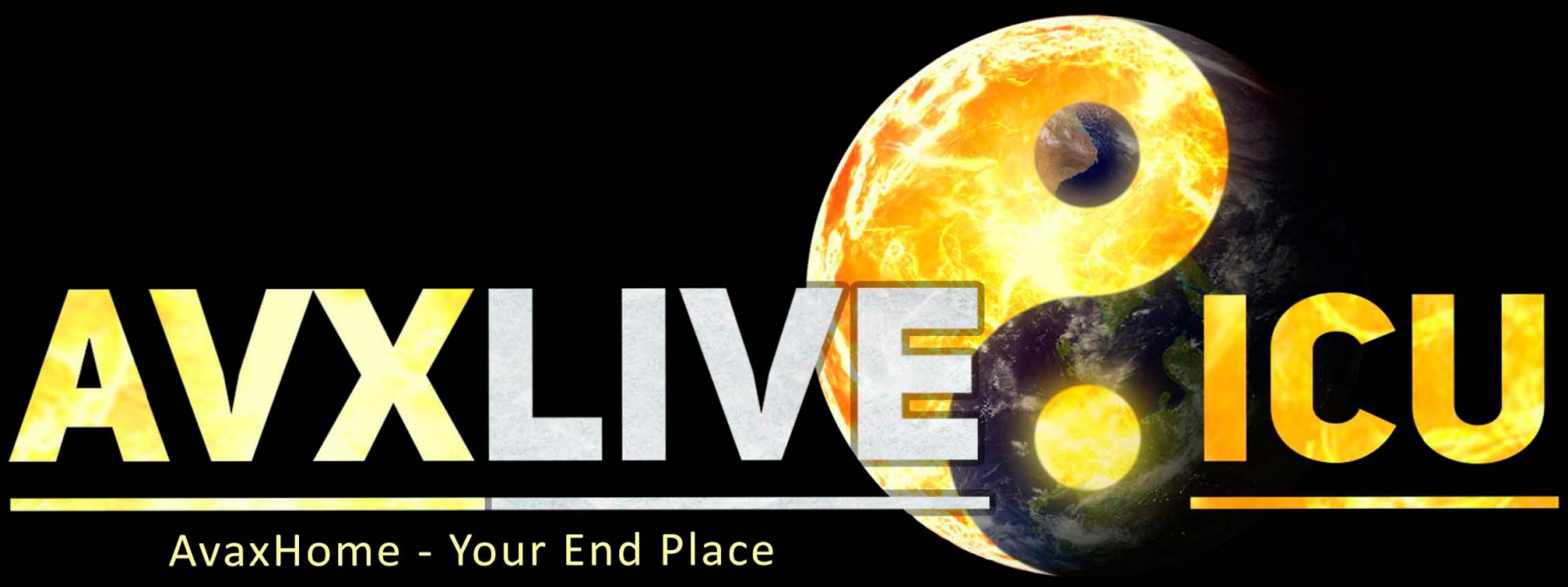
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Unlimited satisfaction one low price
Cheap constant access to piping hot media
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32,000-square-foot (3,000 square meters) visitor facility.

As a nonprofit institution, Lowell relies increasingly on philanthropy to support research as well as outreach. And in June 2019, the observatory staff was thrilled to announce the naming of the Kemper and Ethel Marley Foundation Astronomy Discovery Center, the result of a $14.5 million pledge from the eponymous foundation to fund 50 percent of the center's cost. Lowell is now proceeding full steam ahead with the remaining fundraising, and our goal is to open the new center in 2023. Our vision is for it to be the premier facility in the world for communicating the marvels of the universe to all.

In the meantime, to alleviate crowding and long lines, in the fall of 2019, Lowell opened the $4 million Giovale Open Deck Observatory, a suite of six permanently mounted telescopes under a roll-off building. Among the instruments are a 0.8-meter Starstructure Dobsonian, 0.6-meter and 0.5-meter PlaneWave reflectors, and a strikingly beautiful 0.2-meter Moonraker refractor. Exhibits, a classroom, a huge planisphere, and our own version of Stonehenge will further enhance the experience. The technical description of this new public observing plaza — at least, according to many of our visitors — is "way cool."

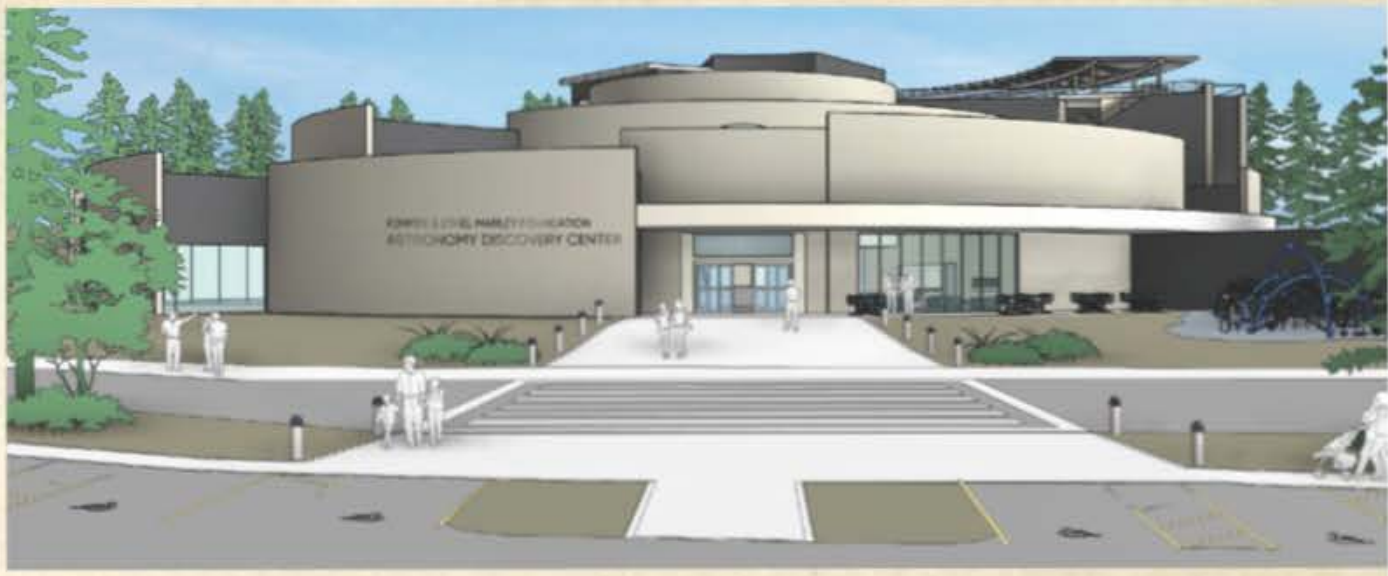
Why?

For all of us who love our calling, it's fun to talk about *what* we do. But it's perhaps trickier, albeit equally or more important, to understand and discuss *why* we do it.

Lowell's employees often speak of their mission as encompassing dual pillars of research and outreach, but they are, in fact, both related components of the unified goal of communicating science. Whether our audience is a professional astronomer reading an *Astrophysical Journal* article by a Lowell researcher or a 12-year-old asking one of Lowell's educators about the workings of a black hole, the observatory communicates the wonders of the universe and promotes scientific, evidence-based curiosity and thinking.

Any way you choose to interact with Lowell Observatory, the goal is to have you come away with the simple pleasure of knowing something you didn't before, such as a perspective or idea about our universe that provides you with a new insight into how this vast physical system works.

Those at Lowell want you to feel *curious*. You don't need to visit the observatory or read a research paper to find out the mass of Jupiter or to get a list of the names of all the planets; you can get this information off the internet. More important is wondering about the greater whole that might come into focus after learning about the smaller parts. What can humans deduce from the store of knowledge with which we've armed ourselves?



The Kemper and Ethel Marley Foundation Astronomy Discovery Center, seen here in this artist's concept, is expected to open in 2023 and help boost annual attendance to more than 250,000 guests. LOWELL OBSERVATORY

Lowell Observatory wants everyone to feel *comfortable* with the unfamiliar. What we know about the universe pales in comparison to what we don't. We live in a cosmic sea of uncertainty, a universe governed by the strikingly counterintuitive rules of relativity and quantum mechanics. It's a place where our perceptions are often well out of sync with reality. However, all too often, our public discourse and policy decisions are ruled by absolute certainty in the correctness of our point of view and the feeling that those who hold different points of view are idiots — or, worse, enemies.

Science, in contrast, is about deeply exploring data, taking pleasure in the power of codifying and understanding physical principles in the beautiful language of mathematics, and maintaining open-mindedness to challenges to long-held beliefs. Imagine the beauty of a world in which all of us do not reject the unfamiliar, but instead embrace it.

And Lowell Observatory wants everyone to feel *humble*. A good scientist should always hold the sentence, "I might be wrong," front and center in their mind. Experiencing the universe in all its vast weirdness encourages us to wonder, to feel humble, and to be willing to change our minds when the data demand that we do.

Some years back, an email arrived from a mom in a state far from Arizona. She and her family had visited Lowell, and afterward, their son was so excited by what he had experienced that he promptly went home and wrote a school report about Clyde Tombaugh and his discovery of Pluto. She wrote in her email that Lowell educators had "amazed, challenged, and opened a young mind."

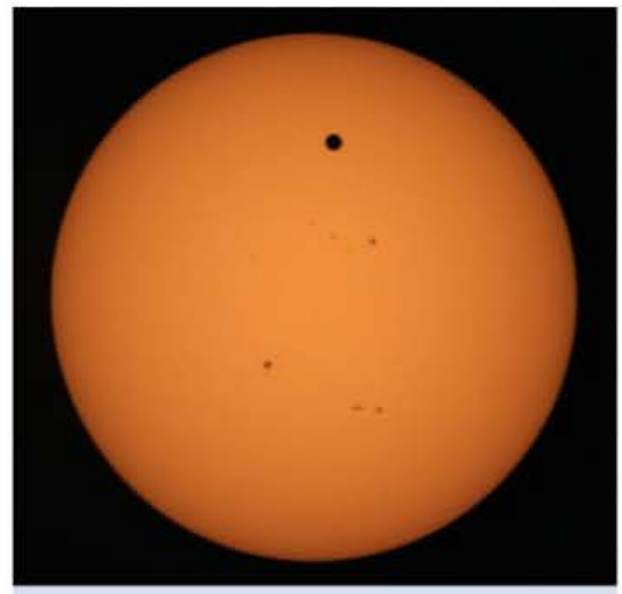
That is why we do what we do. For young and old, amateur astronomers and professionals, everyone who wonders about the incredible sights that wheel overhead every night, we want to amaze and challenge, and to show how much fun it is to be part of the uncertainty and excitement of discovery.

And this is not merely doing well by doing good. In today's rapidly evolving, technical, and often fraught world, it is a societal and national imperative. We welcome all to join us on the journey.

Jeffrey Hall *studies solar-stellar activity cycles and, since 2010, has served as Director of Lowell Observatory, where* **Kevin Schindler** *is the historian.*

The planet named for the goddess of beauty is a stunning sight through any telescope, especially this spring. BY MICHAEL E. BAKICH

See Venus at its best



RODNEY POMMIER

Venus transited (crossed in front of) the Sun from the perspective of earthbound observers June 5, 2012. The next transit of Venus visible from our world won't occur until December 10–11, 2117.

VENUS RANKS AS THE THIRD-brightest object in the sky, outshone only by the Sun and the Moon. At times, the planet's light can cast shadows.

From the earliest times, humans have been captivated by its brilliance. The oldest surviving document regarding the planet is the Venus tablet of Ammisaduqa, which was created before 1600 B.C. This cuneiform tablet records Venus' appearances over two decades, giving the correct time intervals between them.

Observing Venus

Because it's so bright and its appearances in the morning and evening skies last for months, Venus is easy to observe. During its orbit, the planet goes through a pattern of inferior conjunction (when it's between Earth and the Sun), greatest western elongation (when it's at its maximum distance from the Sun in the morning sky), superior conjunction (when it's on the other side of the Sun from Earth), and greatest eastern elongation (when it's at its maximum distance from the Sun in the evening sky).

One more event — greatest brilliancy — occurs approximately 36 days before and after inferior conjunction when the planet lies 39° from the Sun. The geometry of the Sun-Venus-Earth angle at these times makes Venus appear brightest from Earth.

The phases of Venus are of interest to observers, as is another easy-to-see aspect: size change. Mercury looks twice as big near inferior conjunction as it does at superior conjunction. Venus, on the other hand, is more than six times larger.

Daytime observations of Venus are not as difficult as most amateur astronomers imagine. In fact, it's far better to observe Venus during the daytime, or at least in twilight, because the background sky brightness reduces the deleterious effects of the planet's brilliance. And observing Venus in the daytime sky is easy: Simply point your telescope at Venus before daybreak and allow the drive to track it until after sunrise.

The problem with daytime observations is that solar heating of the air (and your telescope) can produce some really bad seeing (atmospheric steadiness). Most locations report the worst daytime seeing in the afternoon. (Yours may not.)

If you observe Venus in the daytime, use a yellow, orange, or red filter. Any of them will enhance the contrast by filtering out the sky's blue light. But remember: The darker the filter you use, the bigger your scope will have to be. It's a simple matter of light throughput.

If you're going to observe Venus at night, limit your viewing to when the planet is at least 20° above the horizon. The air below that level is so thick that image quality will suffer.

Amateur astronomers have reported seeing an irregular terminator, dusty shadings, bright spots, and caps on the cusps, to name the most obvious sightings. Viewed in visible light, there are no permanent features discernible in the clouds of Venus. The atmosphere is in a continuous state of mixing, and any patterns observed quickly dissipate.

The best — really, the only — way to see features in the atmosphere of Venus is through a dark blue (No. 38A) or violet (No. 47) eyepiece filter. Such filters, unfortunately, don't allow much light through. They have transmissions of 17 percent and 3 percent, respectively. So this advice really is for those who have access to a telescope with an aperture of 10 inches or more.

The most-reported sighting using these filters is of an immense C- or Y-shaped feature centered on and symmetrical with the planet's equator. This is a short-lived phenomenon, but it tends to re-form often enough to be considered a "permanent" feature in the clouds of Venus.



PETE LAWRENCE

This sequence shows how the illuminated portion and the apparent size of Venus changed from July 25 to August 15, 2015. The leftmost image shows the planet 12.9 percent illuminated with a diameter of 47.6". In the rightmost image, the illumination has fallen to 0.9 percent, but the size has increased to 57.9".



Venus often pairs with the Moon in the early evening and early morning sky. Both objects are bright, allowing for pictures that incorporate a moderately lit landscape. JOHN CHUMACK



Venus made a retrograde loop through the background stars of eastern Sagittarius from November 7, 2013 (bottom right), to March 14, 2014 (upper left). The photographer captured 28 exposures of the planet and then digitally stacked and aligned them to show Venus' movement during this interval. TUNÇ TEZEL

A tough catch

The orbit of Venus tilts nearly 3.4° to the plane of Earth's orbit. This means that, at inferior conjunction, Venus may stand nearly 9° north or south of the Sun. I've made it a challenge several times to observe Venus at the moment of inferior conjunction. Such a feat is obviously a daytime observation. If your telescope has setting circles, you can attempt this.

First, find the date and time of inferior conjunction and the right ascension and declination of the Sun and Venus at that time. With a solar filter in place, and using your lowest-power eyepiece, center the Sun in the field of view. Finally, offset your telescope by the appropriate amount north or south in declination, and remove the solar filter. And now, the safety note: If you don't see Venus immediately, use extreme care in searching for it. Remember, the Sun is near!

When Venus reaches inferior conjunction June 3, 2020, it will lie only 29' north of the Sun — much too close for a safe observation. The situation improves for the planet's next inferior conjunction. On January 9, 2022, it will lie 4°51' north of the Sun. And on August 13, 2023, conditions will be ideal when Venus stands 7°41' south of our daytime star.

It's worth the wait, though, to spot Venus when it's closest to Earth. It appears huge, but the really cool sighting happens when you see the cusps (points) of the ultra-thin crescent appear to extend beyond 180°.

Go see Venus

Sixty-two percent of people have sisters. But 100 percent of us can look into the sky and observe Earth's sister planet. So, take some time during morning or evening twilight — or even in the daytime — to reacquaint yourself with the third-brightest object in the sky. You won't even need a finder chart!

OBSERVATIONAL TIMELINE

Here are some of the highlights of the last two and a half millennia of observations of Venus.

- **Fourth century B.C.** — Turkish-born Greek astronomer Heraclides Ponticus becomes the first to suggest that Venus (along with Mercury) travels around the Sun, and not around Earth.
- **15th century A.D.** — Persian astronomer Ulugh Beg uses a sextant 60 feet (18.3 meters) in radius to make detailed observations of Venus.
- **1582–1588** — Danish astronomer Tycho Brahe makes daytime measurements of Venus and compares its position to the Sun; at night he compares Venus' position to stars.
- **1610** — Italian astronomer Galileo Galilei becomes the first to observe the phases of Venus, and states that it imitates the Moon. He also sees that when Venus is nearly full it is small, and when he observes Venus as a thin crescent, it is large. These two observations are strong observational evidence for the validity of the Copernican theory, which places the Sun at the center of our solar system.
- **1645** — Italian astronomer Francesco Fontana records dusty shadings on Venus, but it will take more than 100 years before Venus is scientifically shown to possess an atmosphere.
- **1666** — French astronomer Giovanni Domenico Cassini makes the first measurements of Venus' rotation rate: 23 hours 21 minutes.
- **1761** — Russian scientist Mikhail V. Lomonosov observes a transit of Venus. He notices that the planet is surrounded by a luminous halo as it enters and exits the solar disk and correctly concludes that Venus has an atmosphere.
- **1911** — American astronomer Vesto M. Slipher determines by spectral analysis that the rotation rate of Venus is much greater than one day.

Michael E. Bakich *is a contributing editor of* Astronomy *who enjoys observing the inner planets.*



Astronomy's electronic revolution

As ground-based telescopes approached their size limit in the early 20th century, new technologies focused on improving light detectors.

BY SAMANTHA THOMPSON

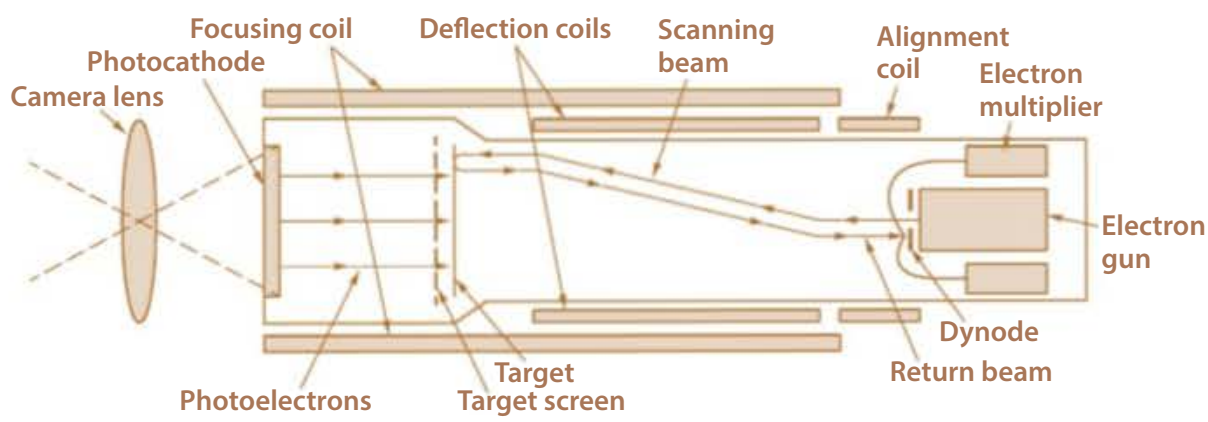
At the 1933 annual meeting of the American Association for the Advancement of Science, Canadian astronomer Francois C.P. Henroteau proposed that rapidly advancing electronic television technology could greatly extend the range of telescopes by more efficiently collecting light. Henroteau argued that mounting a television-type camera on the 200-inch Hale Telescope being developed in Southern California — the largest telescope of its time — could create the equivalent of a 2,000-inch mirror.

American newspapers printed articles detailing the new reaches of space that television would make observable. A *New York Times* article anticipated "Mars and its 'canals' projected as a disk a foot in diameter, the frontiers of the universe pushed out several hundred million light-years, stellar distances measured with an unheard-of accuracy, new revelations of the structure of the great nebula in which we live and we call the Milky Way — the vistas opened are endless."

Though electronic imaging garnered considerable enthusiasm and had great potential to aid telescopic observations, astronomers dawdled in adopting the technology. In 1964, the National Academy of Sciences published a report noting that "only a few results not attainable by photography had been achieved." By 1973, they reported that,

ABOVE: A large image orthicon camera tube is attached to the Dublin Observatory's refracting telescope, as part of a demonstration to the International Astronomical Union in 1955.
SOMES-CHARLTON, "PHOTO-ELECTRIC IMAGE" P. 429

IMAGE ORTHICON CAMERA TUBE



The image orthicon camera tube was designed by RCA and used in American broadcast television from 1946 to 1968. Due to its sensitivity, efficiency, and ease of use, several astronomers tested and adapted the image tube to aid telescopic observations. *ASTRONOMY*: RICK JOHNSON, AFTER TECCHESE/WIKIMEDIA COMMONS

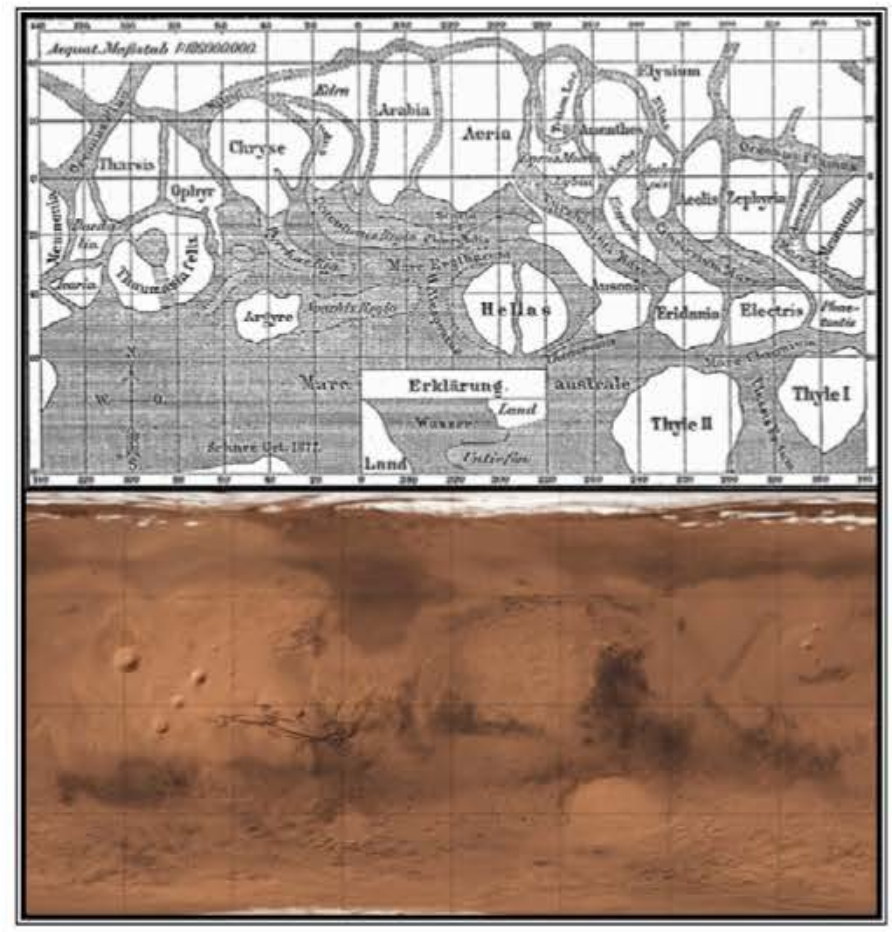
despite recent advances, astronomers were still a long way from producing a suitable electronic imaging device, and the goal for the next stage of astronomical detectors was still to realize the potential of electronics.

The old ways

Early astronomers had no other option than to sketch what they saw, drawing only what their eyes could detect. But in the late 19th century, photographic emulsions revolutionized astronomy. Photography not only provided a permanent record that was independent of an astronomer's artistic talent, but also allowed astronomers to take extended exposures and record much fainter objects. But because photographic emulsions were not linear (i.e., the number of photons that struck a grain of emulsion was not directly proportional to how dark that emulsion became), astronomers had to calibrate each photograph.

In 1910, scientists first exploited photoelectric principles, which showed how photons of light could be converted into electrons to measure stellar brightness. Because photoelectric devices did not require calibration, the accuracy of this method far exceeded that of photographic methods. The disadvantage, however, was that only one star's brightness could be measured at a time, whereas a single photograph could record hundreds of stellar magnitudes simultaneously. To overcome this shortcoming, astronomers began to experiment with electronic imaging devices, generally called image tubes.

Image tubes offered astronomers an opportunity to take a different path than just developing bigger and bigger telescopes. By the early 20th century, large telescopes appeared to approach a limit in size, largely due to funding and material constraints. Few institutions could afford to construct a telescope as large as the proposed 200-inch Hale Telescope, so many in the astronomical community saw a need to focus efforts on improving light detectors that could be used in conjunction with modest-sized telescopes. Numerous astronomers saw the potential of electronic imaging to increase the light-gathering power of telescopes as more realistic than building increasingly huge telescopes.



Before photography, astronomers sketched observations by hand. Here, Giovanni Schiaparelli's 1877 hand-drawn map of Mars (top) is compared to a map created using data collected by the Mars Global Surveyor and Viking in the latter part of the 20th century. TOP: MEYERS KONVERSATIONS-LEXIKON; BOTTOM: NASA/JPL/USGS

To explore the possibilities, some astronomers experimented with image tubes already successfully employed in commercially available television cameras, which were not designed for the extremely low light levels required in astronomy. Others, however, chose to develop instrumentation specifically for astronomical use.

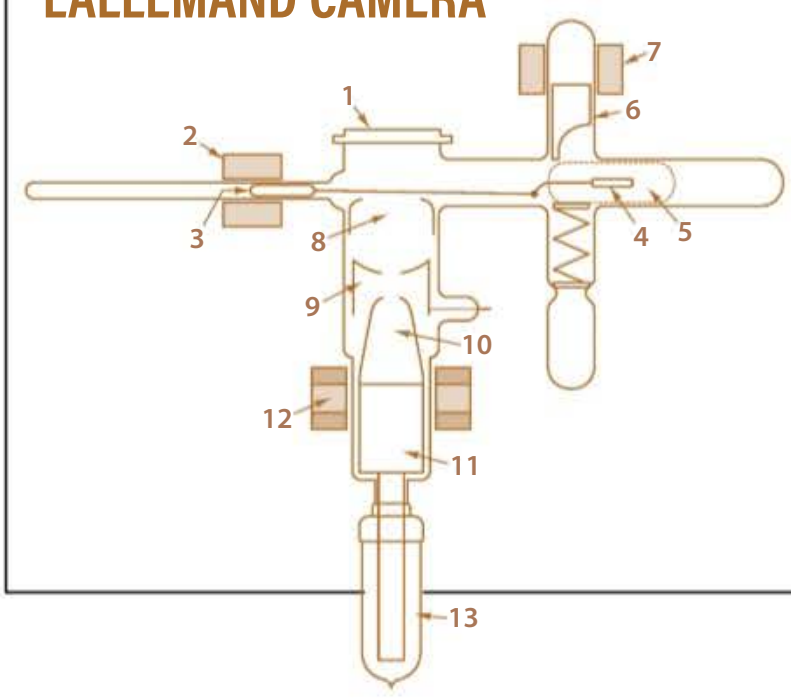
Electronic cameras

In 1934, French astronomer André Lallemand began developing his *caméra électronique*. With this electronic camera, Lallemand converted the light coming through a telescope into electrons, which could be recorded on an electron-sensitive photographic emulsion.

The main weakness of Lallemand's camera was its complicated operation. After each exposure, the astronomer had to break a sealed glass vial, called an ampoule, to recover the photographic plate. This process destroyed the vacuum inside, requiring the astronomer to commit a day's labor to prepare the next exposure. Formerly routine observing nights were transformed into complex science experiments, which dissuaded many astronomers from using the device. Still, Lick Observatory astronomers used the Lallemand camera into the 1960s, which helped them collect some of the earliest evidence of active galactic nuclei at the center of Seyfert galaxies.

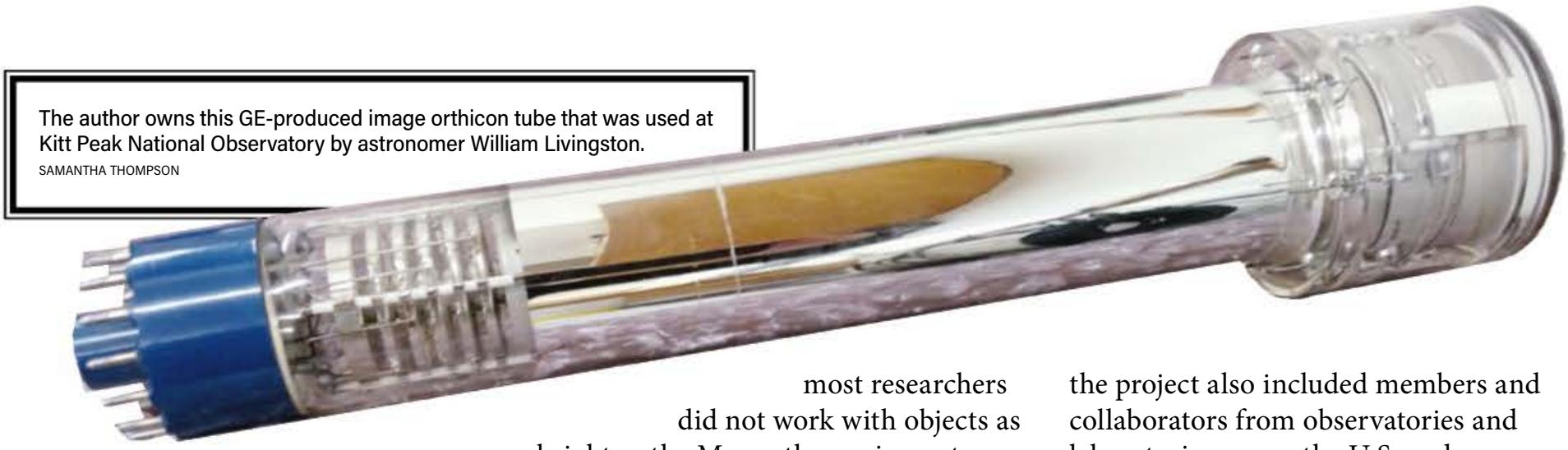
Companies like the Radio Corporation of America (RCA) in the U.S. and Electric and Musical Industries (EMI) in England poured extensive funds into developing television camera tubes and receivers in the first half of the 20th century. During World War II, these labs developed cameras that could detect heat exhaust from airplanes, allowing them to be spotted at night. Though wartime work postponed much of astronomers'

LALLEMAND CAMERA



In this schematic, we begin with the entrance window (1) of Lallemand's *caméra électronique*. An electromagnet (2) and iron plunger (3) are used to position the camera's photocathode (4) in a glass ampoule (5) that's later broken with an iron hammer (6) and electromagnet (7). The electron lenses (8, 9, and 10) electrostatically focus the photoelectrons before they reach the cartridge (11) carrying electron-sensitive plates. The cartridge can be rotated by another electromagnet (12) to change plates. Both the cartridge and the plates are kept cool with liquid nitrogen in a dewar (13).

ASTRONOMY: RICK JOHNSON, AFTER A. LALLEMAND



The author owns this GE-produced image orthicon tube that was used at Kitt Peak National Observatory by astronomer William Livingston. SAMANTHA THOMPSON

and physicists' efforts to apply television technology to astronomical observations, they benefited from developments spurred in the service of military projects. This led to the mass production of enhanced imaging technology, which became readily available to other groups that might be interested in their use. But, although the commercially available devices were tested by several groups, they did not meet the specifications astronomers had hoped for.

In 1951, astronomer B.V. Somes-Charlton, in collaboration with Cambridge Observatory in England, observed the Moon's surface with a commercially available RCA image orthicon camera. Somes-Charlton produced images by attaching the camera tube to the back end of a telescope and sending the video signal output from the image orthicon tube to a television receiver, which produced an image on the television screen. He then photographed the screen using a film camera. When Somes-Charlton compared direct photographs to television-aided observations, he noted the television images had higher contrast. Plus, because the image orthicon tube amplified the light coming from the Moon, the observations took less time. This shortened exposure time decreased some of the blurring effects of Earth's atmosphere, which astronomers call seeing, resulting in a clearer image. Additionally, Somes-Charlton performed quantitative tests and determined television was superior in sensitivity, resolution, and efficiency.

Somes-Charlton's early experimental work gave researchers further confidence that electronic imaging could benefit astronomical observations in limited applications. The promising results of these initial tests encouraged astronomers of the potential of the underlying technology, but because most researchers did not work with objects as bright as the Moon, the equipment was not considered employable as an off-the-shelf product. Most astronomers needed a modified system to account for the dim objects they hoped to study.

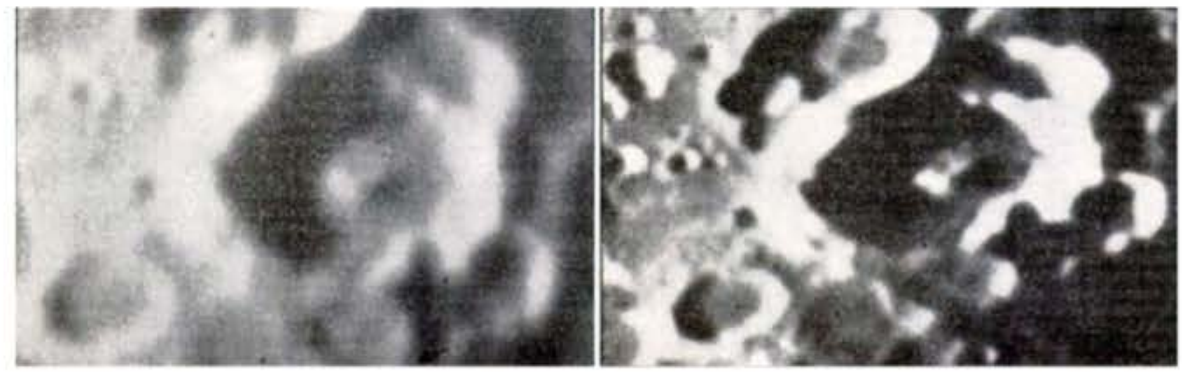
Bolstering brightness

By the 1950s, astronomers began to seriously investigate possible methods of electronically amplifying the light from a faint object. Numerous efforts — each with different resources, design philosophies, and audiences — focused on developing a system that could amplify and record two-dimensional signals. The devices they proposed ranged widely in feasibility and usability.

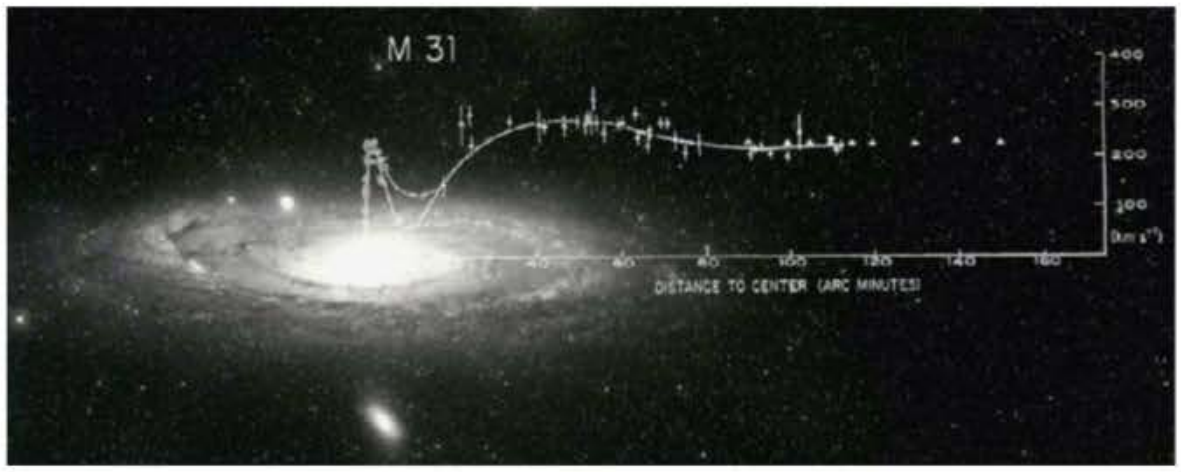
The Carnegie Image Tube Committee (CITC), a multi-institution project, was the highest-funded endeavor to develop an image tube that could aid and advance ground-based astronomical observations. Carnegie Institution President Vannevar Bush — who during World War II led nearly all of the American civilian-military research and development efforts from the U.S. Office of Scientific Research and Development — established the CITC to bring together astronomers, physicists, and engineers who could develop such an image tube.

Carnegie's Department of Terrestrial Magnetism coordinated the CITC, but the project also included members and collaborators from observatories and laboratories across the U.S. and England. The initial goal of the CITC was to explore the possibility that an image tube could supplant or supplement photographic methods, thereby increasing the range of telescopes. The committee hoped their efforts would lead to the development of a manufacturable device with enough sensitivity to light to be beneficial for astronomers engaged in most research programs and whose operation was simple enough that any astronomer at any observatory could use it. During its first decade of operation, the CITC worked with industrial and military laboratories, private and public observatories, and individual astronomers to develop an image tube they could market to observers.

Though U.S. astronomers wished to make further improvements to the device, they quickly grew impatient with what they saw as a lack of productive development from the Carnegie group. By 1964, after a 10-year period of research and development, the Carnegie committee felt they needed to release an image tube for astronomical research. Once released, their tube did receive some modest use, helping astronomers acquire groundbreaking scientific results. But many astronomers never fully adopted the image tube or the technology.



Using the Cambridge Solar Tunnel Telescope, B.V. Somes-Charlton took these two images of the Moon for comparison. At left is a standard telescopic photograph taken with an exposure time of 4 seconds, while at right is a 0.2-second exposure of a television screen receiving its signal from an image orthicon tube. B.V. SOMES-CHARLTON, "PHOTO-ELECTRIC IMAGE TECHNIQUES IN ASTRONOMY" (1959)



With the help of a Carnegie image tube, Vera Rubin famously discovered that the faint outskirts of the Andromeda Galaxy rotate faster than expected, indicating the existence of dark matter. V. RUBIN/ W.K. FORD, "ROTATION OF THE ANDROMEDA NEBULA FROM A SPECTROSCOPIC SURVEY OF EMISSION REGIONS" (1970)



Vera Rubin and Kent Ford (in white) check equipment at Lowell Observatory during one of their first observing runs together in 1965. CARNEGIE INSTITUTION, DEPARTMENT OF TERRESTRIAL MAGNETISM

Unlike prior introductions of new imaging technologies, astronomers did not question the trustworthiness or effectiveness of this device, but not every astronomer could immediately use the new tool, either. Though 19th-century astronomers had many avenues to learn photographic techniques, 20th-century astronomers were limited in their access to electronic training. Many of those with the required training acquired the necessary skills during wartime work, limiting the number of astronomers who felt confident using electronic imaging devices. However, although not adopted across the entire astronomical community, the CITC-developed device was still one of the most widely used electronic image tubes available to astronomers.

By the 1970s, several decades after Henroteau proposed using electronic imaging devices in astronomy, astronomers from the world's largest observatories had successfully applied image tubes in a limited capacity. Astronomer William Livingston calculated that during the final quarter of 1972, 26 percent of the observing time on the Steward Observatory 2.25-meter telescope and 45 percent of the observing time on the Kitt Peak National Observatory 2.1-meter telescope were assigned for image tube-aided observations. Though designed to aid modest-sized telescopes, astronomers preferred to use the Carnegie-produced tubes on the largest available telescopes. This was particularly important for those interested in investigating new areas of research that such equipment opened up, such as the study of the physical properties of distant, dim galaxies.

Vera Rubin most famously used a Carnegie image tube with her colleague Kent Ford, one of the device's main developers, to measure and study the internal motions of several dozen spiral galaxies similar to the Milky Way. Rubin discovered that the outer arms of each spiral galaxy were rotating at speeds that should not be possible given the amount of visible mass, primarily in the form of stars and dust. From this data, Rubin inferred a non-luminous material — detectable only by the gravitational pull it exerted on the material around it — must be present in the galaxy. This provided the strongest evidence yet found for the existence of dark matter, which by 1980 was believed to comprise 90 percent of the total mass in the universe.

Vera Rubin most famously used a Carnegie image tube to measure and study the motions of several dozen spiral galaxies.

Though Rubin's research exemplified the potential of image tubes, change was looming; solid-state devices would sweep in and replace image tubes and direct photography in the 1980s. In 1984, Rubin and Ford traveled to Palomar Mountain to obtain spectra of a large spiral galaxy with a spectrograph attached to the Hale Telescope. What made this observing run significant was that the spectrograph was not attached to an image tube, but rather, for the first time, to a solid-state detector. This new charge-coupled device, or CCD, eventually became ubiquitous in most imaging devices, including the cameras on the Hubble Space Telescope. For astronomers, adopting the new technology meant that they no longer needed to carry photographic plates home with them after observing runs, but instead hauled reels of computer tape that could be rapidly analyzed with coded programs.

Rubin's 1984 observing run at Palomar signaled the beginning of the end of astronomers' use of image tubes. And although the astronomical community failed to fully adopt image tubes, the ability to see brighter objects and measure them more precisely greatly benefited those hoping to look further into the cosmos to observe fainter objects. Despite the usefulness of electronic image tubes, this oft-forgotten relic of astronomical history highlighted astronomers' — and humans' — occasional reluctance to adopting new ways of practicing their art.

Samantha Thompson *is a curator at the Smithsonian Institution. She recently completed her Ph.D. dissertation on the development of astronomical electronic imaging.*

Observe winter's TWIN TREATS

The Medusa Nebula (Abell 21) in Gemini pairs with open cluster NGC 2395, which lies to the upper left, out of this image's field of view. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

On frigid February evenings in the Northern Hemisphere, we get crystalline views of Gemini the Twins riding high in the sky. The celestial Twins represent this month's deep-sky survey theme: namely, objects in the night sky found in pairs or in such close proximity that we see them as twin delights. We'll begin in a region likely avoided by star-hopping amateur astronomers armed with equatorial mounts: the area around the North Celestial Pole.

Way up north

Alpha (α) Ursae Minoris, popularly known as Polaris, Stella Polaris, Lodestar, or the North Star, also has a deep-sky moniker: **Struve 93** (Σ93), because it is a magnificent double star. Visible in a 2.4-inch refractor at 60x under excellent seeing conditions, Polaris AB is a celestial wonder that can be shared by all. The 2nd-magnitude golden primary has a 9th-magnitude secondary 19" to the southwest. The secondary is white, but a contrast illusion may make it appear green or blue. In his and Wil Tirion's beautiful *The Cambridge Double Star Atlas*, James Mullaney notes, with wit, that the pair displays a "24-hour orbital period" caused by Earth's rotation.

Polaris is also part of a magnificent binocular asterism popularly known as the **Engagement Ring**. Look for a semicircle of eight conspicuous stars (6th magnitude and fainter) just southeast of Polaris, which not only completes the ring but represents its dazzling gem.

Look about 4¼° southeast of Polaris for the starburst spiral galaxy **NGC 2276**, which is a prodigious supernova factory in Cepheus. It may be interacting with the lenticular galaxy **NGC 2300**. It's unknown whether the asymmetrical appearance of NGC 2276 is due to tidal interactions with NGC 2300 (or other members of the sparse NGC 2300 galaxy group), or due to the galaxy's motion through a massive cloud of gas.

German astronomer Friedrich Winnecke discovered the pair in 1876 with a 6.5-inch refractor, although French astronomer Alphonse Borrelly had already found NGC 2300 some five years earlier with a 7-inch comet-seeker. Glowing at 11th magnitude, NGC 2300 is not only a full magnitude brighter than NGC 2276, but also 1' smaller, making it more readily visible in backyard telescopes. The galaxy pair lies about 120 million light-years away and is separated in the sky by only 6'.

> You'll get twice the bang for your buck when you point your scope at these celestial pairings.
>
> BY STEPHEN JAMES O'MEARA

Moving 12° farther southeast, we meet another interacting pair of small (2') and moderately dim (12th magnitude) galaxies: ellipticals **NGC 2633** and **NGC 2634** in Camelopardalis. Discovered by German-born Wilhelm Tempel in 1882 with an 11-inch refractor, the pair is oriented roughly north-south and separated by 8'. NGC 2633 is the northern component.

For those with larger telescopes, the non-interacting, magnitude 13.5 edge-on galaxy **NGC 2634A** lies 2' south of NGC 2634. Anyone with a large-aperture, wide-field telescope might also challenge themselves to detect the wisps of Integrated Flux Nebula (IFN) — dust clouds illuminated by the background glow of the Milky Way. These clouds are most apparent southeast of NGC 2634 and run east to west. See the image of Polaris below for a good look at the IFN.



1 The face-on spiral galaxy NGC 2276 (left of center) makes a striking pair with NGC 2300, the lenticular galaxy to its right. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

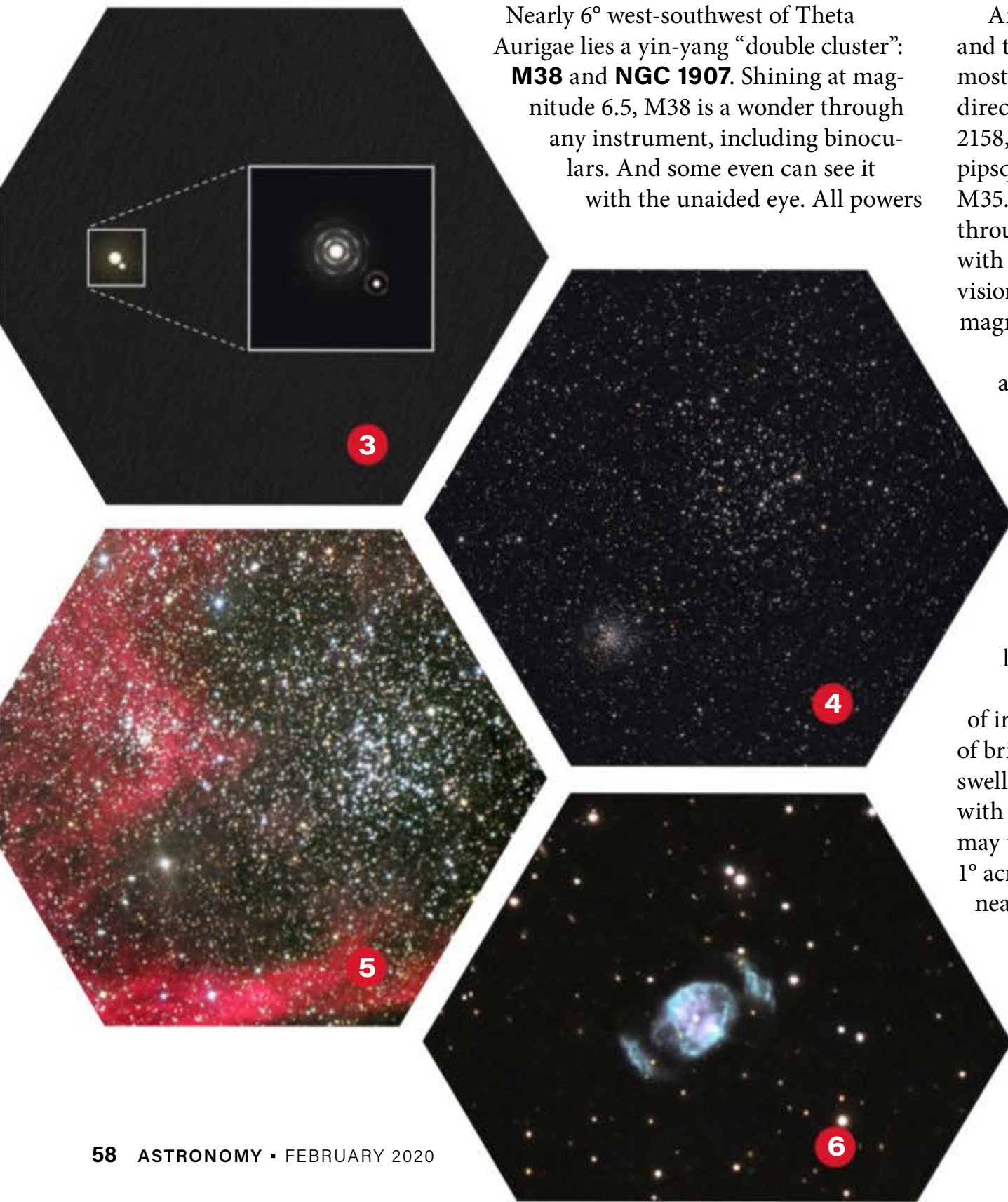
2 Struve 93, or Polaris (Alpha [α] Ursae Minoris), the bright star to the left in this image, is an easy double star to split. The Integrated Flux Nebula also shows up nicely in this photo. SCOTT ROSEN

3 Wasat (Delta [δ] Geminorum) is an easy split through just about any telescope. What colors do the stars look to you? JEREMY PEREZ

4 M35 is the larger, looser cluster at center, while much more compact NGC 2158 lies to its lower left. CHUCK KIMBALL

5 Open cluster M38 is the rich cluster to the right of center. Smaller NGC 1907 sits to its left within a pocket of red emission nebulosity. Both clusters lie in the constellation Auriga. DEAN SALMAN

6 The Double Bubble Nebula (NGC 2371–2) is a bipolar planetary nebula whose discoverer thought it was two objects, thus the double NGC designation. DIETMAR HAGER



Auriga, Gemini, and Taurus

Third-magnitude Theta (θ) Aurigae, otherwise known as **OΣ545** (the O stands for Otto), is a beautiful double star with a 7th-magnitude companion 4" to the west-northwest. Don't be fooled by the separation; the primary can visually subjugate the secondary under poor atmospheric seeing. It's a great challenge for 4- to 5-inch telescopes at 250x.

Through an 8-inch, catching a glimpse of the aqua secondary — a contrast illusion because the star is white — hugging its yellow luminary lends a warming impression of a distant view of our Earth and Sun. For added enjoyment, check out Theta's magnitude 11 C (line-of-sight) companion roughly 50" farther to the west-northwest.

M35 IS ONE OF THE RICHEST AND MOST COMPACT OPEN CLUSTERS LOCATED IN THE DIRECTION AWAY FROM THE GALACTIC CENTER.

Nearly 6° west-southwest of Theta Aurigae lies a yin-yang "double cluster": **M38** and **NGC 1907**. Shining at magnitude 6.5, M38 is a wonder through any instrument, including binoculars. And some even can see it with the unaided eye. All powers reveal the 15'-wide cluster's cross-shaped core (whose center is wreathed by scintillating starlight) and starfish arms. NGC 1907 lies in the same field of view 30' to the south-southwest and appears merely as a compressed phantom glow at low power. At high magnification, it resolves into a rectangle of 30-odd suns crisscrossed with dark veins. Once considered to be physically related, the two clusters are only "flying by" one another, some 1,200 light-years apart.

M38 and NGC 1907 are a dimmer doppelgänger of **M35** and **NGC 2158** in northwestern Gemini. Only, in this case, M35 is the one with the rectangular shape. At 5th magnitude, M35 is visible to unaided eyes even from some suburban locations as a pale glow rivaling the apparent size of the Full Moon.

An exquisite cluster through binoculars and telescopes, M35 is one of the richest and most compact open clusters located in the direction away from the galactic center. NGC 2158, on the other hand, is a magnitude 8.5 pipsqueak (5') cluster about 0.5° southwest of M35. Like NGC 1907, it appears at low power through a 4-inch scope as a milky splotch with some stars hovering near the limit of vision. It resolves well, however, with higher magnifications and larger apertures.

Just north of Orion's Shield, we find another twin cluster treat: **NGC 1807** and **NGC 1817** in Taurus. At 33x in a 5-inch, these objects appear as two magnitude 7.5 knots of starlight separated by 20'. While NGC 1807 is 0.7 magnitude brighter than NGC 1817, it is less visually appealing, containing some two dozen stars in an area 12' across and looking much like a stick figure.

NGC 1817 is a more dynamic grouping of irregularly bright suns — a lightning bolt of brighter members with direct vision that swells into a 20'-wide ball of noisy starlight with averted vision. These dueling objects may truly be twins — a single cluster nearly 1° across in the sky, with dual cores lying nearly 6,000 light-years distant.

Next, slip over to **Castor** (Alpha Geminorum or Σ1110), which is Gemini's most famous twin wonder and one of the night sky's most celebrated double stars. The 2nd-magnitude white primary has a hint

of green, while its 3rd-magnitude secondary (5" to the northeast) shines with a pale pumpkin light. Resolving the close pair requires medium to high magnifications on a night of steady seeing.

The **Double Bubble Nebula** (NGC 2371-2) is an 11th-magnitude bipolar planetary nebula 1½° north of 4th-magnitude Iota (ι) Geminorum. When William Herschel discovered these objects, he saw them as independent, thus the two NGC numbers. The planetary's southwestern lobe is NGC 2371; NGC 2372 is the northeastern one. Through a 5-inch refractor at 33x, the nebula is a mere 1'-fleck of fuzz. Seeing the binary nature requires magnifications of 100x and greater. Though I have yet to see it, the magnitude 14.8 central star has been sighted at 225x through a 12-inch telescope.

Wasat (Delta [δ] Geminorum) holds a special place in the hearts of those who knew the late American astronomer Clyde Tombaugh. In 1930, Tombaugh discovered Pluto a mere ½° east of this star. To observers, it is another prize double star: Σ1066. The magnitude 3.5 bleached-yellow primary has an 8th-magnitude red dwarf companion about 7" to the northwest. The 19th-century observer William Henry Smyth saw this companion shining with a purple light, though rose-lavender comes to my mind.

Near Gemini's southern border, about 1¾° northwest of the magnitude 4.5 star 6 Canis Minoris, is the 8th-magnitude, low-surface brightness open star cluster **NGC 2395**. This loose and scattered aggregation of about 30 dim suns that form an ellipse lies in the same field of view as a planetary nebula just 30' to the southeast: **Abell 21** — more popularly known as the Medusa Nebula.

I've spied this large (10'-wide) waif of nebulous tendrils through an 8-inch reflector at its lowest magnification on the darkest of nights. Sweeping was required to pick out the brightest arc of its ancient light (without a filter), which appeared as a phantasm. However, repeated hits secured its impression. Most people have success with an Oxygen-III filter.

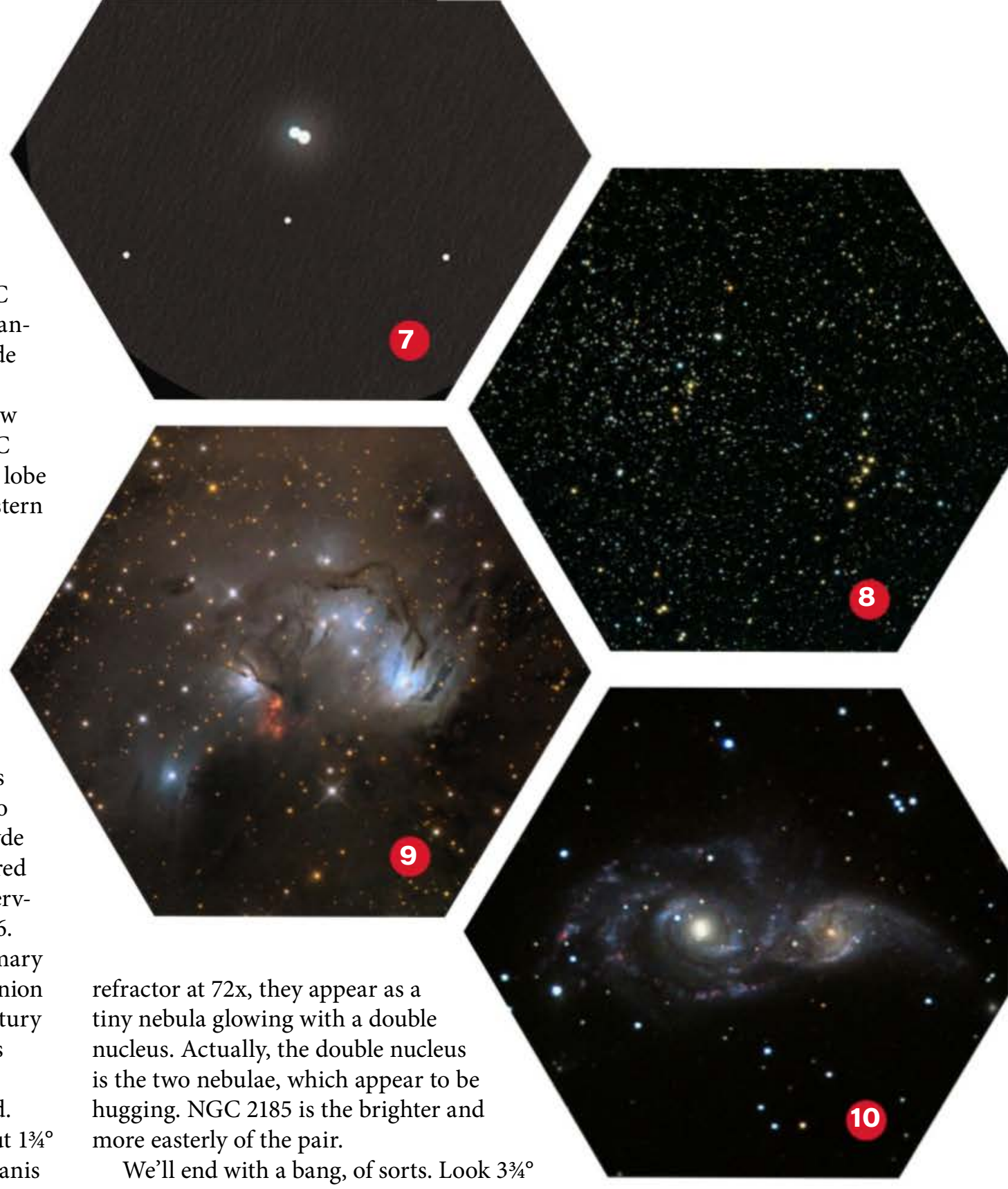
Southward

Next, move southwest into Monoceros. Just 1° west of Gamma (γ) Monocerotis, you'll find a double "dwarf nebula": **NGC 2183** and **NGC 2185**. Through a 4-inch refractor at 72x, they appear as a tiny nebula glowing with a double nucleus. Actually, the double nucleus is the two nebulae, which appear to be hugging. NGC 2185 is the brighter and more easterly of the pair.

We'll end with a bang, of sorts. Look 3¾° southwest of 2nd-magnitude Mirzam (Beta [β] Canis Majoris) for a pair of colliding spiral galaxies, **NGC 2207** and **IC 2163**, some 80 million light-years distant. Strong tidal forces from NGC 2207 have distorted the shape of IC 2163, flinging stars and gas into long streamers stretching out 100,000 light-years. This near collision is one of the most dynamic visible through backyard telescopes. Through an 8-inch at 300x, magnitude 10.8 NGC 2207 appears as a 5'-wide mass of light with a bright core, while IC 2163 is a conspicuous 12th-magnitude bullet of light 2' across with a soft central concentration.

I hope you enjoyed this celestial soirée with these select twins of the night. The deep sky is filled with wonders like these, which help us better appreciate the depth, grandeur, and beauty of our infinite universe.

Stephen James O'Meara *is a contributing editor and a columnist of* Astronomy.



7 The artist sketched Castor (Alpha [α] Geminorum) while using an 8-inch f/6 reflector and an eyepiece that gave a magnification of 200x. JEREMY PEREZ

8 NGC 1807 and NGC 1817 make a striking pair when seen through a wide-field telescope. NGC 1817 is the loose group of stars left of center; NGC 1807 has fewer but brighter members to the lower right. BERNHARD HUBL

9 NGC 2183 and NGC 2185 are a pair of blue reflection nebulae in the constellation Monoceros. NGC 2185 is the larger, brighter one just to the right of center. Smaller NGC 2183 lies to its left. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

10 NGC 2207 and IC 2163 are interacting galaxies in the constellation Canis Major the Big Dog. NGC 2207 is the larger galaxy to the left in this image. THALIA AND NORMAN TERRELL/ADAM BLOCK/NOAO/AURA/NSF

WE TEST

Celestron's Nature

High-quality glass, light weight, and lots of features make the DX ED 10x50 worthy of your consideration.

BY PHIL HARRINGTON

WHETHER YOU'RE A NOVICE stargazer or a veteran observer, every amateur astronomer should own binoculars. They're the perfect grab-and-go instrument for an impromptu viewing session, especially when you're tight on time. The aesthetic element of viewing with both eyes rather than only one through a conventional telescope is another selling point: It's more relaxing and feels more natural to use binoculars. As I often say, "two eyes are better than one."



Binoculars come in many sizes and designs. The best compromise for most stargazers is a 10x50 unit. Binoculars with a magnification of 10x can be hand-held without too much involuntary hand shaking being transmitted to the view. And 50-millimeter lenses gather enough light to reveal good detail on the Moon, the rings of Saturn, and many deep-sky objects invisible to the unaided eye.

Binoculars use one of two internal prism designs — roof prisms or Porro prisms — to make sure that images exiting the eyepieces are right-side up, not flipped like in astronomical telescopes. Porro-prism binoculars have zigzagged barrels, while those with roof prisms have sleek, straight barrels.

Features

Recently, I toured the universe using Celestron's Nature DX ED 10x50 Binoculars. Celestron's line of Nature binoculars includes 10 roof-prism models ranging from 8x32 to 12x56. All have fully multicoated optics and phase-coated Schmidt-Pechan roof prisms made of BaK-4 glass, both highly desirable in roof-prism binoculars. Such features are usually limited to models costing twice as much (or more) than the Nature DX ED.

Phase coatings correct for light loss inherent in the roof-prism design. As an image passes through a roof-prism assembly, polarization splits its light cone into two perpendicular paths; by the time they exit the prisms, the horizontal plane is slightly out of phase with the vertical plane. The net result is some dimming of the image and a loss of contrast. Celestron resolved this "phase error" by applying a special dielectric coating to the prism surface to produce bright views with sharp contrast.

The Nature DX ED 10x50, one of four entries in the group introduced in 2019, adds extra-low-dispersion (ED) objective lenses to further improve contrast and virtually eliminate false-color fringing due to chromatic aberration.

Two of the biggest ergonomic benefits of roof-prism binoculars are their compact size, and their lighter weight compared to similar Porro-prism models. For instance, my own 10x50 Porro-prism binoculars weigh 32 ounces (907 grams), while the DX ED 10x50s are only 28.4 ounces (806 g). Part of the credit goes to the choice of materials. Celestron made the ED's housings out of polycarbonate, which is known for its strength, light weight, and low cost.

The barrels have a rubber finish that makes holding them sure and comfortable. The flat black color prevents reflections from nearby light sources when raising the binoculars to your eyes. Two textured, slightly depressed areas guide your hands to the proper position.

The Nature DX ED comes with lens caps tethered to the barrel so they can't be lost. You also can tether the dual eyepiece cap to the neck strap.

To work properly, the span between the eyepieces — called the interpupillary distance — must match the distance between the observer's eyes. For the average adult, that's between 2.3 and 2.8 inches (58 and 71 mm). I measured the adjustment range of the Nature DX ED 10x50s to be between 2.2 and 2.9 inches (56 and 74 mm).

Rubberized twist-up eye cups with click stops help make centering each eye easier. The eye cups extend 0.35 inch (8.9 mm) when twisted all the way out. I found them great for observing, and the generous 17.8 mm of eye relief also added to viewing comfort. This is important if



Everything shown here is included with Celestron's Nature DX ED 10x50 Binoculars.

Binoculars

PRODUCT INFORMATION

Celestron Nature DX ED 10x50 Binoculars
Front lenses: 1.97 inches (50 mm)
Magnification: 10x
Eye relief: 17.8 mm
Interpupillary distance: 2.2 to 2.91 inches (56 to 74 mm)
Field of view: 5.9°
Dimensions: 6.4 by 5.3 by 2.4 inches (163 by 135 by 61 mm)
Included: Case, lens caps, neck strap
Weight: 28.4 ounces (806 g)
Price: $209.95
Contact: Celestron
2835 Columbia St.
Torrance, CA 90503
310.328.9560
www.celestron.com



Celestron's Nature DX ED 10x50 Binoculars offer great low-light performance.
ALL IMAGES COURTESY OF CELESTRON

you must wear eyeglasses to correct for astigmatism. I normally remove my glasses, but I found seeing the full 5.9° field of view was easy even with them on.

The focusing knob works smoothly with just the right amount of resistance to prevent it from being turned by mistake. The fine-thread mechanism takes almost two full turns of the knob to bring the focus from one extreme to the other. As with most binoculars, the right eyepiece can be focused +/- 3 diopters for people whose eyes aren't identical.

Although binoculars are great for grab-and-go viewing, I prefer securing mine to a tripod when using a star chart to find unfamiliar targets. The Nature DX EDs include a built-in tripod mount in the front of the central hinge between the barrels. The barrels are quite close to one another, however, so some L-shaped tripod brackets may not fit. Celestron's model No. 93524 binocular tripod adapter L-bracket does work.

Testing

I always test binoculars on daytime and nighttime benchmarks. I check for misalignment, field curvature, and distortion by day. Field curvature occurs when the light passing through the edge of the objectives doesn't focus in the same plane as that passing through the lens' center, making one zone out of focus. Distortion bends objects geometrically, changing straight lines into arcs at the edge of the field of view. Both are best checked by aiming at a distant pole, a brick wall, or other horizontal or vertical references.

I quickly became impressed with the Nature DX ED's performance. Both barrels were aligned. Field curvature was marginally detectable at the extreme edge of the field, while distortion proved negligible. These results are noteworthy at this price point. I have seen greater evidence of both aberrations through binoculars costing twice as much.

I waited for a clear night to check for other potential imperfections, such as astigmatism, coma, and chromatic aberration. Astigmatism elongates images on either side of focus. On one side, images will stretch horizontally, while on the other, the elongation will flip 90°, extending them vertically. Coma causes stars near the edge of the field to warp into tiny blobs resembling comets, while stars at the center appear sharp. Chromatic aberration is unwanted color fringes, typically purple and yellow, around brighter objects such as the Moon, Venus, Jupiter, and bright stars.

I checked the binoculars against some favorite test targets. Sure enough, the high marks scored during daytime testing continued into the night. None of those optical anomalies spoiled my viewing experience. Stars focused uniformly and remained sharp to nearly the edge of the field. Even as I swung the binoculars toward the unforgiving waning crescent Moon and brilliant Sirius early one morning, I saw no evidence of color fringing caused by chromatic aberration. Those ED lens elements sure paid off.

With my testing done, I sat back and simply enjoyed the sky. Many old favorites, such as the Double Cluster, the Pleiades, the Orion Nebula, and the Andromeda Galaxy put on fine displays. The sharp focus even let me detect the color difference in Albireo (Beta [β] Cygni), which I consider a challenge for this magnification and aperture.

Bringing the binoculars back inside my air-conditioned home from the damp nighttime air, I saw no evidence of internal moisture or fogging. That's thanks to the nitrogen-filled barrels, which prevent the growth of fungus on optics that you'll often see with old binoculars.

The bottom line

In summary, I give the Nature DX ED 10x50 binoculars high marks indeed. This unit combines an attractive price with many desirable features normally reserved for more expensive binoculars.

Phil Harrington *is a contributing editor of* Astronomy *who enjoys both checking out new equipment and binocular observing.*

Satellite tracking for amateurs

Where astronomy meets global politics.



SatTrackCam Leiden Station is an amateur satellite tracking camera network based in the Netherlands.
MARCO LANGBROEK

Ah, the deep-sky-obliterating plague of city lights. Wouldn't it be nice if there were something city-bound amateur astronomers could see with their telescopes, right from their own backyards?

You're in luck! Even before SpaceX Starlink satellites turn the night sky into a disco ball, there are roughly 1,950 operational satellites orbiting Earth. Add a video camera to your telescope, link in a GPS feed, and you are all set to join the exciting world of amateur satellite tracking.

One such amateur is archeologist Marco Langbroek. When not thinking about artifacts from the Lower and Middle Paleolithic, Langbroek operates an amateur observing station in the middle of the Dutch city of Leiden. From that unlikely vantage point, he tracks things that the powers that be would prefer we not know about; Langbroek can tell you exactly where to find every spy satellite in the sky.

Langbroek's hobby got especially interesting on August 30, 2019, when a startling image appeared on President Donald Trump's Twitter feed. The tweet showed an until-that-moment top-secret image of Iran's Imam Khomeini Space Center, taken shortly after the explosion of an Iranian Safir rocket. The Safir can put a payload into Earth orbit, which is sort of a big deal.

Soon after the release of the photograph, an interesting post appeared on Langbroek's website, sattrackcam.blogspot.com. Langbroek saw the obvious. The shadows of the structures at the space center form a pretty good sundial. With that information, along with the perspective of the image, he (and others working independently) quickly determined where the image was taken from.

Lo and behold, when he checked to see if there was anything in the vicinity, Langbroek found a spy satellite dubbed USA 224 in the right place at the right time. USA 224 is a KH-11 Enhanced CRYSTAL satellite (commonly called a Key Hole) with a 2.4-meter mirror.

It's not too surprising that, by this point, the intelligence community's collective hair was on fire. There's nothing quite like dropping your pants in public. Melissa Hanham, deputy director of the Open Nuclear Network in Vienna, Austria, told NPR, "When I saw the image, it was so crystal clear and high-resolution that I did not believe it could come from a satellite." That's one heck of a capability to give away on Twitter just so you can thumb your nose at the Ayatollah.

I have to say, though, that Hanham's shock seems a bit disingenuous. You don't need more than a pen and a beer-stained napkin to figure out that from 186 miles (300 kilometers) up, the diffraction-limited resolution of a down-looking 2.4-meter telescope is about 2 inches (5 centimeters). If you've got lots of photons to play with, multiple images, small pixels, fast shutter times, and don't care about precision photometry, call that 1.5 inches (3.8 cm). That's a factor of 4 or 5 better than typically discussed ... at least until last August. The people in Langley doubtless do better.

Earth's atmosphere shouldn't be too much of a problem. The turbulent layers responsible for distorting our view of the sky are mostly close to the ground. Even at an altitude of a mile, turbulence that would blur an astronomical image by an arcsecond would only blur an image of the ground by one-fifth of an inch (½ cm).

There are lots of things that you just can't keep classified. Orbital mechanics is one of them. The physics of light is another. Having spent much of my career using a 2.4-meter orbiting telescope named Hubble, I don't see much about the image that is technically surprising.

There are roughly 1,950 operational satellites orbiting Earth.

But it's no longer a back-of-a-napkin question. Now everyone knows that the U.S. has that capability. They also know that we were able to get satellite images immediately after the explosion. And since the Iranians know exactly what was on the ground when the photo was taken, they've doubtless learned a thing or two about hiding stuff from our eyes in the sky.

Over a second beer, I scratched my head about the telescope that took that image. With its basic capabilities known, what could it do with dichroic splitters, tunable filters, adaptive optics, real-time AI processing and control, LIDAR, interferometry, spectroscopy, object recognition ... ?

Then I stopped speculating and threw my napkins away.

I never imagined I would see a KH-11 image of anything, much less a secret Iranian launchpad appearing on social media, direct from the horse's mouth. But for you long-suffering, city-dwelling amateurs out there, hey! Satellite tracking is brilliantly geeky fun.



BY JEFF HESTER
Jeff is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com**

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February's finest sights

Don't scramble to see it all. Focus on the highlights.



Every month, the Las Vegas Astronomical Society selects an object for their Observer's Challenge. This month, the target is the nebula NGC 1931 in the constellation Auriga, which many compare to a small Orion Nebula.

AL FERAYORNI/ANDY FERAYORNI/ADAM BLOCK/NOAO/AURA/NSF

The weather forecast promises clear skies tonight, and the Moon won't rise until the wee hours of morning — perfect conditions for an evening of skygazing. What celestial sights will you explore? You turn to the Star Dome map in the middle of this issue and are immediately overwhelmed by the wealth of sky objects it shows. Where do you even begin?

Whoa! It's time to slow down and take a deep breath. Clear, moonless nights are all too rare, and when one comes along, it's tempting to try to chase down dozens of celestial sights. But an evening skygazing session is much more enjoyable if you settle on a handful of select objects. Save the rest for future clear, moonless evenings. Believe it or not, there will be others.

Now that your breathing rate is back to normal, grab a pencil and paper and prepare an organized, *short* observing list. If you plotted major celestial happenings on a desk calendar like I suggested last month, begin by seeing if any must-see events are on tap for tonight. If you didn't, use *Astronomy*'s Sky This Month section (page 36) as a guide.

But what about the rest of your list? Here are a few suggestions for the astronomical "newbie" who would like a taste of the finest sights a February evening has to offer. All are plotted on the Star Dome map.

You'd give yourself more than 10 minutes to look at the Grand Canyon. So why rush your visit to this cosmic wonder?

The all-sky deep-space sampler: The Andromeda Galaxy (M31), the Double Cluster (NGC 869 and NGC 884), M41 (an open cluster located 4° south of Sirius), the Beehive Cluster in Cancer (M44), and a galaxy pair in Ursa Major (M81 and M82).

The all-sky double-star sampler: Gamma (γ) Andromedae, Eta (η) Cassiopeiae, Castor (Alpha [α] Geminorum), Gamma Leonis, and Mizar (Zeta [ζ] Ursae Majoris).

The Orion Nebula (M42): This celestial masterpiece deserves an evening all to itself. Start by checking out its visibility with both the unaided eye and binoculars. Then, with a telescope, carefully study the nebula at various magnifications. Can you see M43 — a detached part of the Orion Nebula? Are you able to discern any color? Now, key in on the Trapezium — that amazing multiple star embedded in the nebula. Four stars are easily seen, but a 6-inch or larger scope can reveal a few fainter members. How many can you see? Your goal is not just to look at the Orion Nebula, but to literally experience it. You'd give yourself more than 10 minutes to look at the Grand Canyon. So why rush your visit to this cosmic wonder?

Back to your roots session: Do you still have that 60mm refractor you bought as your first telescope? If so, use it to view the offerings listed in the deep-space and double-star samplers. You may have forgotten how capable such a small telescope can be.

Phil Harrington's "Binocular Universe": Here's a thought. Check out the binocular targets in Phil's column (he's on hiatus this month, but will be back in March). Then view them with your telescope. It's a great way to compare the capabilities of these instruments.

NGC 1931 (bright nebula and cluster in Auriga): In "New month, new target" (January 2016), I described the monthly Observer's Challenge put out by the Las Vegas Astronomical Society. The Observer's Challenge encourages you to spend an evening on a single deep-space object. You then send your image/sketch/notes to Challenge co-founder Fred Rayworth, who assembles a monthly summary that's posted online. This month's Observer's Challenge is NGC 1931, an emission and reflection nebula located about a degree west of M36. An archive of past Observer's Challenge posts can be found at rogerivester.com/category/observers-challenge-reports-complete.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: My favorite observing guides. Clear skies!



BY GLENN CHAPLE

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

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Venus' crescent

Can you make this difficult observation with your naked eyes?



A passing cloud may help cut down on contrast when you try to sight Venus' phase in daylight. The author captured this shot May 2, 2017.
STEPHEN JAMES O'MEARA

This month, Venus appears in the western sky, where it will shine at magnitude –4.3 by month's end. Although on the 29th the planet's disk is small (19") and its illuminated phase is 63 percent, that's the time to start a naked-eye observing project that will last until late May, when you can attempt seeing the crescent of Venus with your unaided eyes.

Why start so soon? Through long-term monitoring, you may become aware of subtle differences in the planet's appearance as its gibbous phase wanes into a crescent. You also may sense how atmospheric conditions affect the view. Keeping good records of both will help when drawing any conclusions.

Is that it?

Naked-eye sightings of the crescent have long been disputed, with opinions strong on both sides. Chaldean sightings date to 3000 B.C. Some naysayers, however, tout the golden rule that the eyes' angular resolution is 1' (60") — roughly the apparent size of Venus when largest, making sightings of a crescent impossible.

But rules are made to be broken, especially given that Dawes' limit (a formula that gives the resolution of optics) does not apply to planetary observing or daytime/twilight observing, when the resolving power of our eyes' cone cells are still employed. It applies only to stars of similar magnitude and color seen against a dark sky. Besides, not everyone's visual acuity is the same, so it's hard to judge what your results will be.

Naked-eye sightings of the crescent have long been disputed.

The simplest proof that Dawes' limit breaks down is the discovery of the Cassini Division in Saturn's rings. At the ansae (the apparent ends of the rings), the division measures between 0.5" and 0.6" across, depending on the apparition. Dawes' formula would make seeing that feature a challenge through an 8-inch telescope. But Giovanni Domenico Cassini discovered it in A.D. 1675 using a 2.5-inch scope.

Perhaps we should consider the advice from French ophthalmologist Damien Gatinel, who says about naked-eye resolution: "In practice, visual acuity may cross that line [Dawes' limit], and separate patterns still fine (up to 30 seconds of arc)." So try freeing your mind, go outside without any preconceived notions, and just see what you can see.

Details and hints

On April 27, Venus attains its greatest brilliancy for this apparition, magnitude –4.7. By May 31, it fades to magnitude –4.0, while the illuminated part of Venus shrinks as the planet grows in size. During the last week of May, Venus will appear between 55" and 58" across, bringing the slender crescent into the realm of visibility for those with acute eyesight. Those who wear glasses should also try, even if they get a slight boost in magnification. After all, we're experimenting.

Please remember that the phase of Venus is difficult to detect when the planet appears against a dark sky because the eye's iris opens wide to receive more light, exposing the outer part of the lens. That region is not as good optically, so it softens the focus.

My own experiences have shown that the planet's brightness overpowers the view even when seen in twilight, so observations in the daytime will provide the best results.

Perhaps you'll have luck like H.W. Cornell of the Milwaukee Astronomical Society, who, in its bulletin for December 1934, said that as he followed the planet from morning twilight into the day, Venus' brilliance still interfered — until his employer's "whistle blew to summon its early shift of workers." The cloud of steam rising from the whistle passed right in front of Venus. Then, as the cloud slowly dissipated, he saw, "for two or three seconds only," the crescent with his unaided eyes. "Quickly I looked with opera glasses — the crescent was at the exact angle at which I had seen it with the naked eye … I consider it my most remarkable naked eye observation."

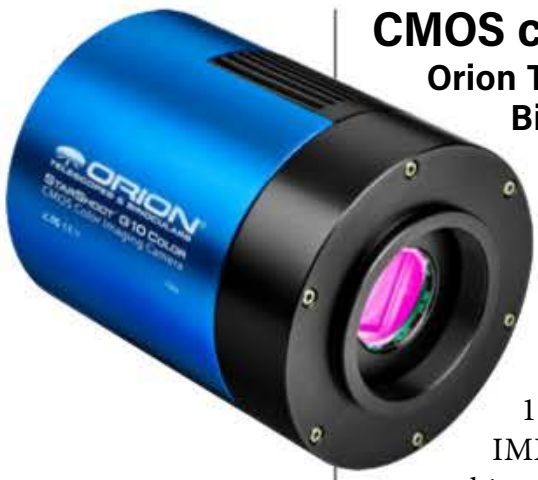
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BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

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Orion's 8-24mm Pro Lanthanum Zoom eyepiece fits 1¼" focusers and provides 20 millimeters of eye relief. The parfocal design keeps the eyepiece in focus as you change focal lengths. All optics are fully multicoated. The eyepiece measures 3.9 by 2 inches (99 by 51 millimeters) and weighs 11 ounces (312 grams).

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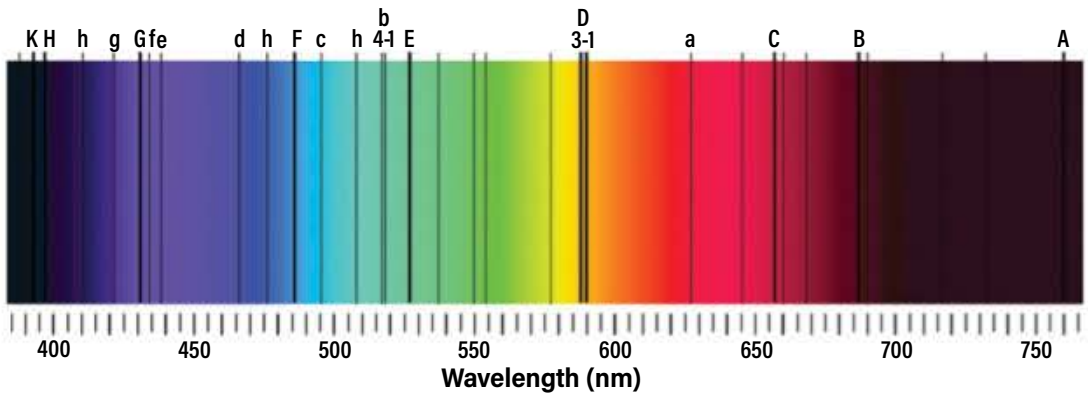
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Breaking down the Sun's light by wavelength allows astronomers to identify the elements it contains. This portion of the solar spectrum shows fingerprints of several elements in our star, including hydrogen, sodium, iron, and calcium. SAPERAUD (WIKIPEDIA)/CEPHEIDEN (WIKIPEDIA)

Elements in the Sun

Q DOES THE SUN CONTAIN ELEMENTS OTHER THAN HELIUM, SUCH AS URANIUM AND IRON, IN ITS CORE?

Mike Burkhardt
El Cajon, California

A Hydrogen and helium are by far the most abundant elements found in the Sun, making up about 98 percent of its mass, but other, heavier elements play an important role in the physical processes that occur in the Sun. The process of nuclear fusion combines hydrogen atoms to produce helium and the energy that keeps the Sun shining.

The next three elements heavier than helium — lithium, beryllium, and boron — are sometimes formed as intermediate products during the fusion process. Elements even heavier than these are present throughout the Sun. They come not from nuclear fusion in our own Sun, but from previous generations of massive stars in the solar neighborhood, the remains of which have been scattered by supernova explosions. The same cloud of enriched material that formed the Sun also formed Earth and the other planets. Thus, the same naturally occurring elements that can be found on Earth, up to and including elements as heavy as uranium, are also present in the Sun.

Although elements heavier than helium are much less common than hydrogen and helium in the Sun, elements like iron, nickel, calcium, sodium, and magnesium are prominent in the solar spectrum and are important tools for astronomers studying the Sun.

Sarah A. Jaeggli
Daniel K. Inouye Solar Telescope Scientist and Assistant Astronomer, National Solar Observatory, Maui, Hawaii

SEND US YOUR QUESTIONS

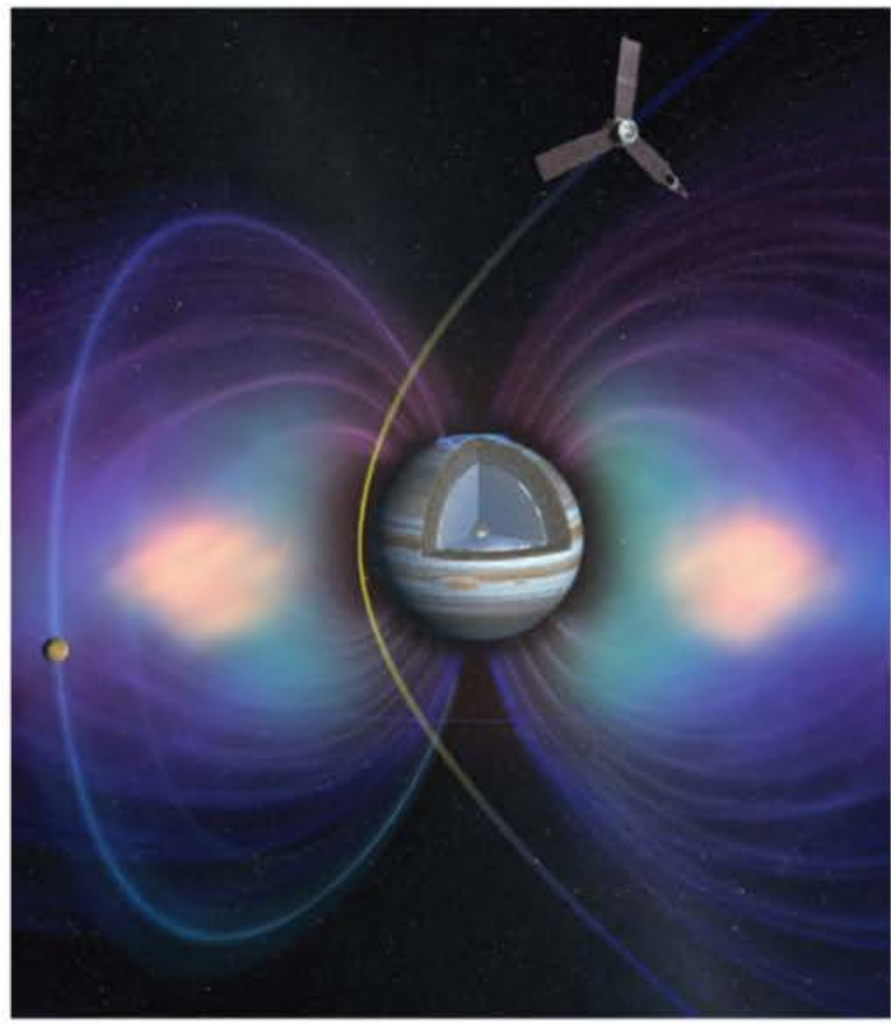
Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Q WHAT IS THE SOURCE OF JUPITER'S RADIATION, AND WHAT TYPE OF RADIATION IS IT? WHY IS IT SO INTENSE, AND ARE THERE OTHER PLANETS IN OUR SOLAR SYSTEM WITH SIMILAR RADIATION FIELDS?

Dean A. Treadway
Knoxville, Tennessee

A Not surprisingly, the king of the planets has the strongest magnetic field among the planets of our solar system, with a reach extending far beyond its orbiting moons. The huge region around the planet where Jupiter's magnetic field controls the environment is called its magnetosphere.

Any charged particles in the space around Jupiter will experience the planet's strong magnetic field and get accelerated to high energies. These negatively charged electrons and positively charged ions of hydrogen (i.e., protons), oxygen, and sulfur form Jupiter's radiation belts. The source of the protons is some combination of particles escaping from Jupiter's ionized atmosphere (the ionosphere) and particles leaking in from the solar wind. The dominant particle source, however, is the volcanic moon Io, which dumps a ton per second of sulfur dioxide



NASA's Juno spacecraft flies close to Jupiter — and the radiation that surrounds it — in this artist's rendition. Also depicted are the loops of the planet's strong magnetic field, as well as its moon Io. Juno's unique orbit minimizes the time it spends in the deadly radiation, while still allowing the spacecraft to study it. NASA/JPL-CALTECH

gas into space where the molecules are broken up and ionized. These processes around the moon drive million-amp currents between Io and Jupiter's ionosphere, where they excite intense aurorae on the planet.

The highest fluxes of energetic particles are found closest to the planet, where they form a doughnut-shaped belt around the equator (which causes radio emission that astronomers have measured from Earth since the 1960s).

Most spacecraft avoid the radiation belts and the damage they cause to sensitive electronics. But the polar orbit of NASA's Juno spacecraft will evolve, and the craft will eventually cross the radiation belts, receiving a dosage equivalent to about 10 million dental X-rays!

It is Jupiter's combination of a strong magnetic field, Io's prodigious source, and the magnetic coupling of charged particles to the planet's rapid (10-hour) spin that drives the intense radiation. Earth's radiation belts (named after James Van Allen, who discovered them with the U.S.'s first satellite in 1958) are much weaker. Saturn, Uranus, and Neptune also have radiation belts — but, again, these are much weaker than Jupiter's.

Jupiter's magnetosphere is the largest structure in the solar system. Its size varies with fluctuations in the solar wind, but on average this magnetic bubble is around 12 million miles (20 million kilometers) wide. That's about 150 times wider than the planet itself, and almost 15 times wider than the Sun. The Sun's own wind of charged particles streams past Jupiter, stretching the planet's magnetosphere into a tadpole shape. Its long tail reaches all the way to Saturn's orbit — roughly twice as far from the Sun as Jupiter.

Fran Bagenal
Professor of Astrophysical and Planetary Sciences and Juno Co-Investigator, University of Colorado, Boulder

Q | WHY IS A PARSEC 3.26 LIGHT-YEARS AND NOT SOME OTHER NUMBER?

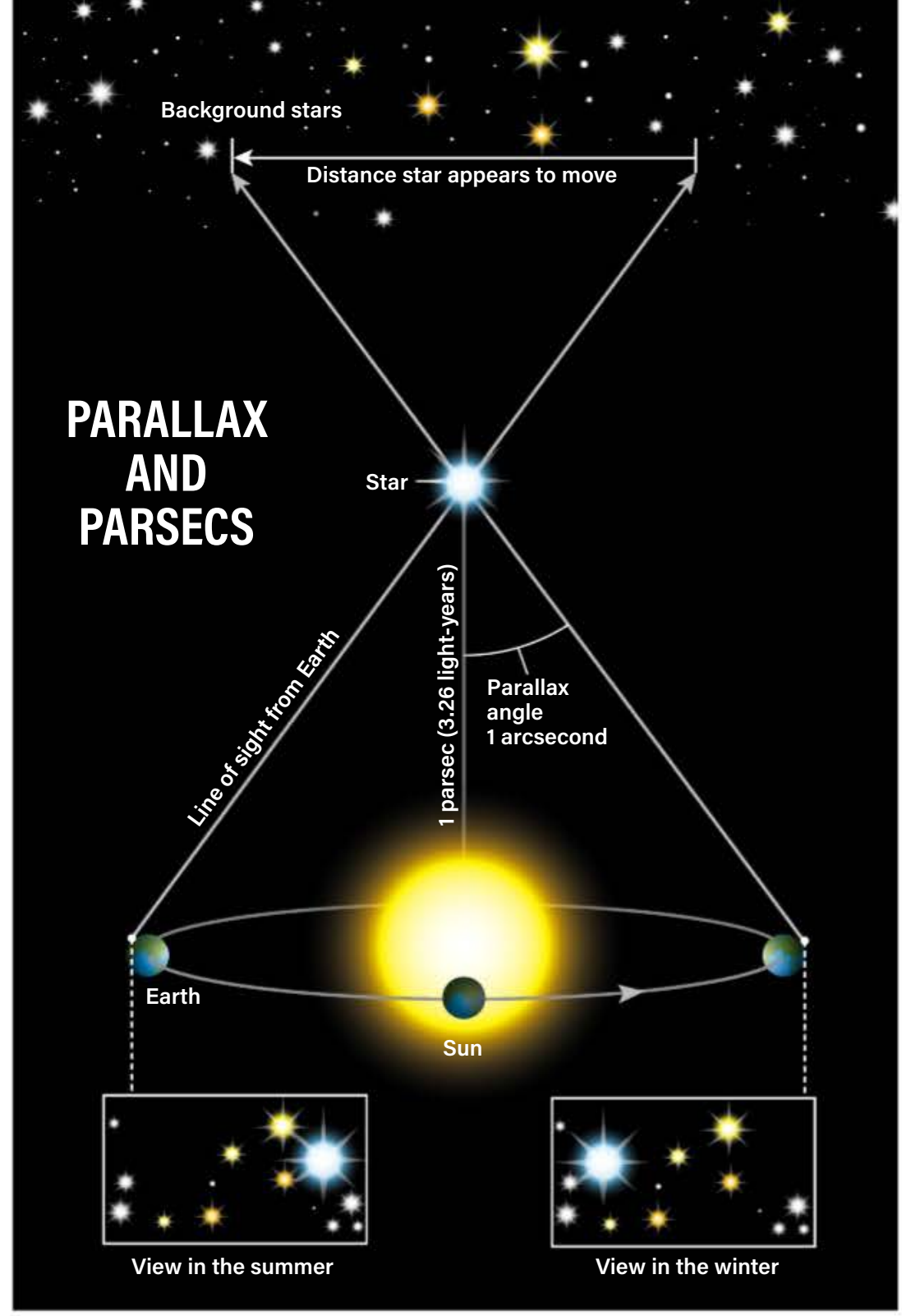
Launie Wellman
Festus, Missouri

A | A parsec, or "parallax second," is defined as 3.26 light-years because of how it is measured. Earth circles the Sun, making one complete orbit per year. Over the course of several months, nearby stars appear to move with respect to more distant objects — an effect called parallax — because as our planet moves, our viewpoint changes. One of the simplest ways to see for yourself how this works is to hold your hand at arm's length in front of your face and raise one finger. Close just your left eye and observe where your finger appears against the background; next, open your left eye and close your right. Your finger will appear to shift because each eye views it from a slightly different angle.

Translated to the stars in the sky, two photographs of the same nearby star taken six months apart will show it appearing to move against the background of more distant stars because Earth has moved to the other side of the Sun in its orbit. If you draw a simple diagram, you'll see that the distance the star appears to move is related to the angle at which it is viewed. The two different sightlines, one at each end of Earth's orbit, create a triangle; the parallax angle is defined as half the angle at the triangle's apex. And a parsec is the distance — 3.26 light-years — that a star must lie from the Sun for its parallax angle to be exactly 1". That's why a parsec has that value, and not any other.

Although astronomers often measure distant objects in parsecs or megaparsecs (1 megaparsec is 1 million parsecs), only nearby objects have parallaxes, or shifts on the sky, that we can actually measure. The European Space Agency's Gaia mission, currently underway, can measure parallax angles of just a few millionths of an arcsecond. It can measure, to within 20 percent accuracy, the distances of stars that lie tens of thousands of light-years away.

Alison Klesman
Associate Editor



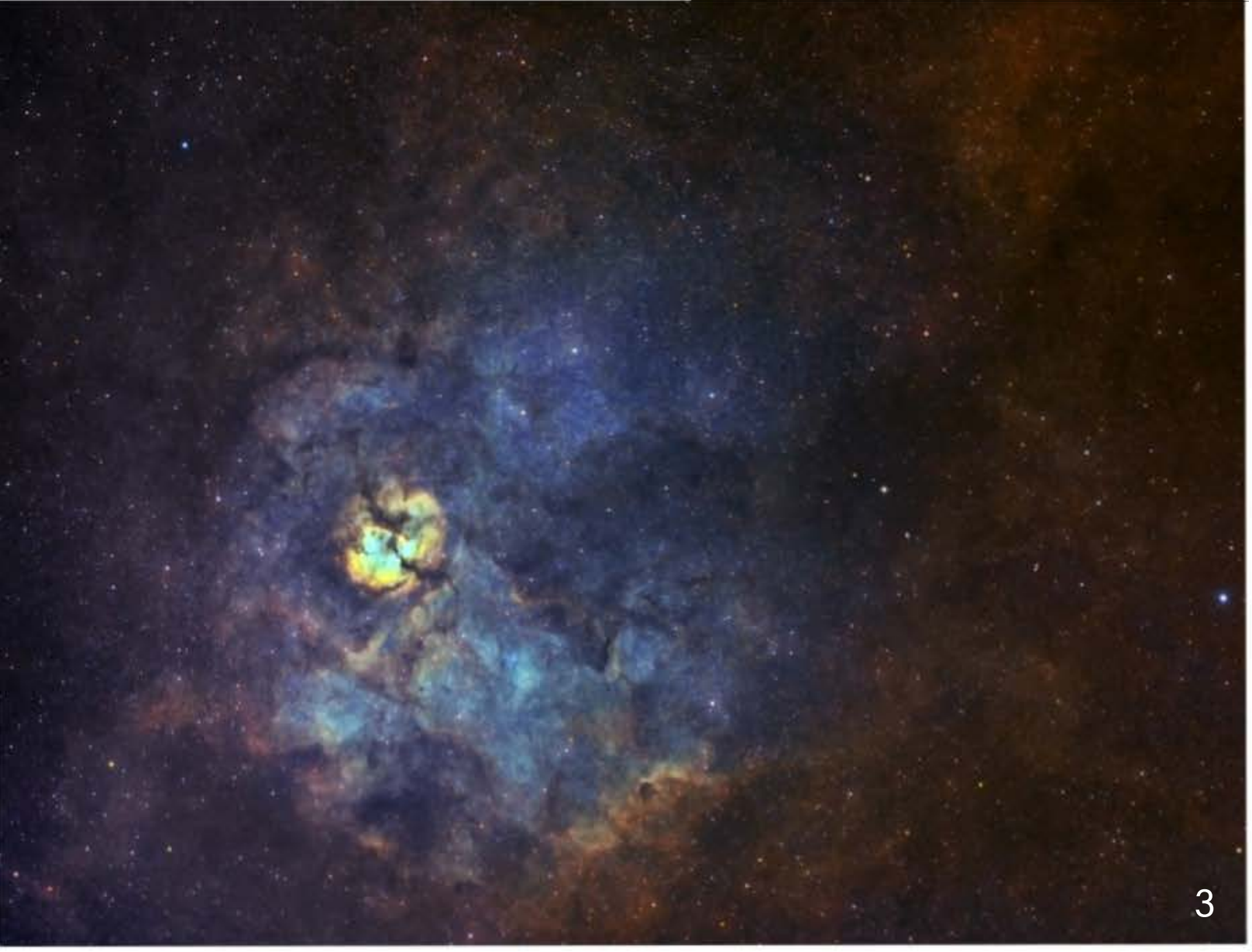
As Earth circles the Sun, nearby stars appear to move relative to more distant background stars — a phenomenon called parallax. The distance a star lies is related to the amount it appears to move when viewed from opposite sides of Earth's orbit. One parsec — 3.26 light-years — is defined as the distance at which a star must lie for its parallax angle to be 1".
ASTRONOMY: ROEN KELLY

Cosmic portraits


1


2

SEND YOUR IMAGES TO: *Astronomy* Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**



3



4

1. SHADOWS AND DUST
Barnard 22 is a patch of dark nebulosity that's part of the Taurus Molecular Cloud. A few stars poke through this uneven mass of dust and cold gas and the small flamelike glow of reflection nebula IC 2087. ▪ ***Terry Hancock/Tom Masterson/Grand Mesa Observatory***

2. SHOW-OFF
Centaurus A's (NGC 5128) appearance is the result of a collision of two galaxies. The event created a great deal of stray material that a supermassive black hole — a billion times the Sun's mass — is consuming in the galaxy's center. Centaurus A lies some 12 million light-years away. ▪ ***Bernard Miller***

3. BLUE SKY AT NIGHT
Sharpless 2–124 is an emission nebula in the northern part of the constellation Cygnus the Swan. It's also faint. This image required a total of 28.6 hours of exposures through Hydrogen-alpha, Sulfur-II, and Oxygen-III filters. ▪ ***Douglas J. Struble***

4. 'ROUND AND 'ROUND
The volcanic caldera on the Greek island of Nisyros was the setting for 176 stacked 2-minute exposures showing how Earth's rotation affects the starry sky. The short, bright trail near the center of the circles is Polaris. ▪ ***Anthony Ayiomamitis***

5. DON'T GET STUNG
To create this image of the Moon passing in front of the Beehive Cluster (M44) in the constellation Cancer the Crab on May 10, 2019, the photographer combined one exposure of the bright part of the Moon with a second exposure of the Moon's dark section and the stars. ***• Scott Dommin***

6. STARS OVER BADLANDS
This 30-exposure panorama captures a wide swath of the Milky Way above the Bisti/De-Na-Zin Wilderness Area in New Mexico. ***• John Vermette***



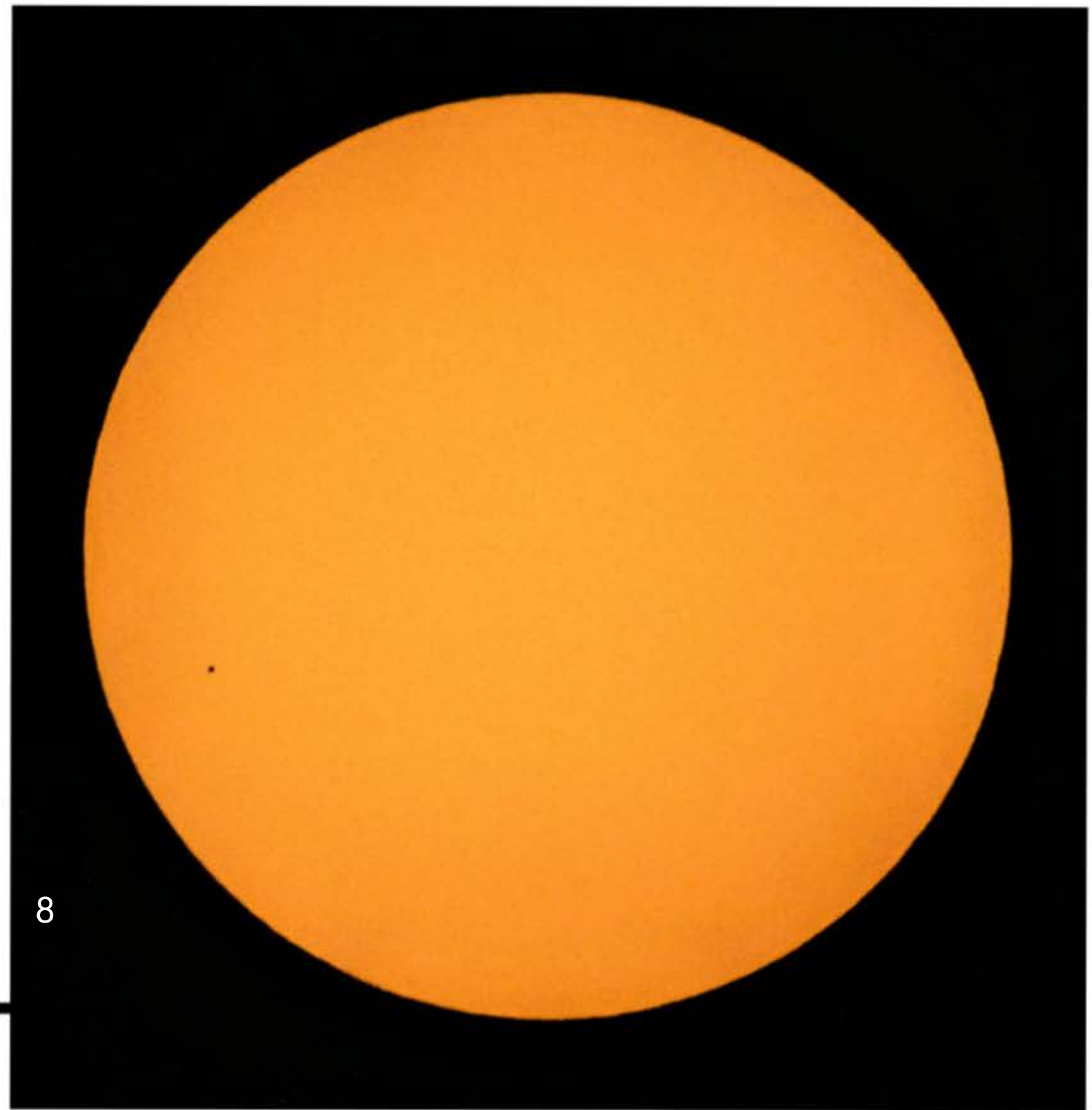




7. OUT ON A LIMB
The spectacular Carina Nebula (NGC 3372) rises behind a stand of baobab trees in Madagascar. This was a single 13-second exposure for which the imager mounted his camera on a motorized tracker. ▪ ***Amirreza Kamkar***

8. PLANET CROSSING
Mercury transited (crossed in front of) the Sun on November 11, 2019. This image was taken at 7:14 A.M. EST from the Bronx, New York. ▪ ***Chirag Upreti***

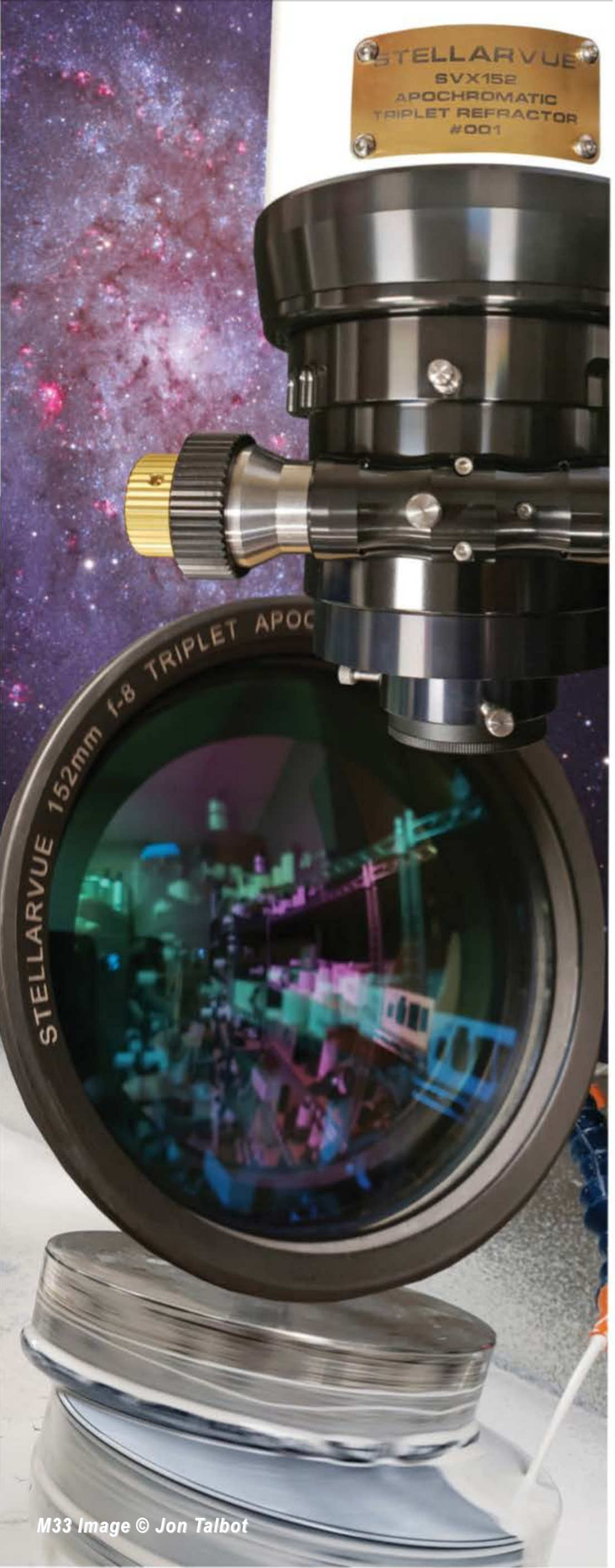






TRACE EVIDENCE FOR A GALAXY COLLISION

Elliptical galaxies have a bad reputation. These repositories of ancient stars all seem to look alike, and none offers the visual appeal their spiral cousins display. But an ongoing survey of elliptical galaxies in the southern sky is starting to reverse this perception. Look carefully at NGC 5018, the milky-white elliptical near the center of this image, and you'll see a faint tail of stars and gas streaming from it. Gravitational interactions with other galaxies typically produce such tidal tails. In NGC 5018's case, the culprit appears to be the edge-on spiral NGC 5022 just to its left. Astronomers captured this image with the European Southern Observatory's 2.6-meter VLT Survey Telescope on Cerro Paranal in Chile. ESO/SPAVONE ET AL.

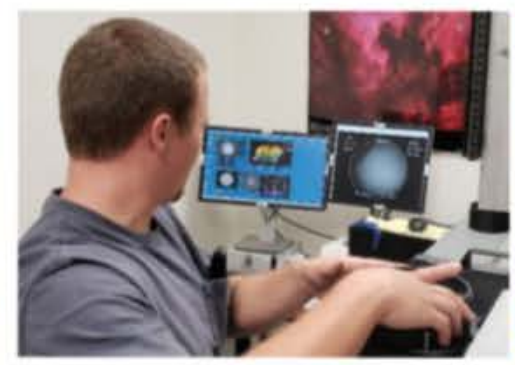


M33 Image © Jon Talbot

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April 2020
Venus meets the Pleiades

As April opens, Orion stands about halfway up the northwestern sky as darkness falls. The familiar V-shaped Hyades star cluster in Taurus hangs below the Hunter while brilliant Sirius in Canis Major towers above it. Despite these wonders, dazzling **Venus** steals the show from its perch closer to the horizon. The inner planet treks eastward across Taurus this month, passing through the southern section of the Pleiades Cluster (M45) on April 3 and 4. Be sure to view this spectacular event through binoculars. Gleaming at magnitude –4.6, Venus shines 250 times brighter than all of M45's stars combined.

Although the planet lies low in the sky, it's well worth observing through a telescope. Venus shows a large disk and a lovely crescent phase all month. In early April, the world appears 26" across and just under half-lit. By month's end, Venus' disk spans 38" and the Sun illuminates just one-quarter of its Earth-facing hemisphere. Despite its slimmer crescent then, the planet shines slightly brighter, at magnitude –4.7, than it did in early April.

Once Venus sets, several hours elapse before another naked-eye planet appears. But by around 2 A.M. local daylight time in early April, a beautiful trio of solar system worlds graces the eastern sky. Magnitude –2.1 **Jupiter** dominates the scene from its position in eastern Sagittarius near the border with Capricornus.

The giant planet's disk grows steadily during April, from 37" to 41" across, as the distance between our two worlds shrinks. This makes Jupiter a great sight through any telescope. Look for delicate details in its cloud tops, which show up particularly well during moments of good seeing. You also should see the four bright Galilean satellites unless one or more of them is hiding behind or passing in front of the jovian disk.

Just below Jupiter, Mars and Saturn form a close pair with a striking color contrast — the Red Planet glows a warm orange while the ringed planet appears slightly yellowish.

Saturn lies near the western edge of Capricornus, roughly one binocular field to the right of the distinctive pair formed by Alpha (α) and Beta (β) Capricorni. The planet, which shines at magnitude 0.6, appears 10 times brighter than either star. Like Jupiter, Saturn ascends rapidly in the eastern sky as morning progresses.

Many observers consider Saturn to be the most beautiful planet to view through a telescope, and it's hard to disagree. Its disk measures 16" across in mid-April while the rings span 37" and tilt 21° to our line of sight. Also keep an eye out for 8th-magnitude Titan, the planet's largest moon. Through a 10-centimeter or larger scope, a trio of 10th-magnitude satellites — Tethys, Dione, and Rhea — also shows up.

On April 1, **Mars** lies just 0.9° south of Saturn. But the magnitude 0.8 Red Planet moves quickly eastward and crosses most of Capricornus by month's end. If you are up in the small hours of the morning to watch the gas giant planets, Mars is also worth a look through your telescope. By April's close, the ruddy world glows at magnitude 0.4 and shows a disk 8" across. That's big enough that you might be able to spot some subtle surface details. The most conspicuous will be the bright white south polar cap, which currently tilts 21° toward us.

Mercury completes the string of morning planets. As April begins, the innermost planet lies 27° west of the Sun and appears nearly 15° high in the east an hour before sunrise. Mercury hangs on until the month's final week, when it disappears into the twilight and brings to a close its finest morning apparition of 2020. The best views through a telescope come in early April, when the inner world's 7"-diameter disk appears slightly gibbous.

The starry sky

Unlike our friends in the Northern Hemisphere, we don't have a bright star like 2nd-magnitude Polaris to mark our celestial pole. The nearest naked-eye star to the South Celestial Pole is 5th-magnitude Sigma (σ) Octantis, so finding the pole presents a challenge.

The easiest way is to use Crux the Southern Cross. The method nicely parallels the way those north of the equator locate Polaris. In the northern sky, the bright stars Alpha and Beta Ursae Majoris in the Big Dipper have nearly the same right ascension and point toward Polaris. For us, the stars at the top and bottom of the Southern Cross, Alpha and Gamma (γ) Crucis, also lie along nearly the same line of right ascension and, similarly, point toward the pole.

The rule is to extend the line joining Gamma and Alpha by 4.5 times its length. This gets you within 2.7° of the pole, reaching a declination of –87.3° at a right ascension of about 6h48m.

Observers can also use Alpha and Beta Centauri to find the pole. Although these luminaries don't point toward the right spot themselves, both lie at a similar declination. This means a line drawn perpendicular to the line joining the stars and starting at the midpoint will angle southward.

If you have trouble judging what 4.5 times the height of the Cross works out to, the point where the line from the Cross intersects the southward trending line from Alpha and Beta Cen comes close to the pole. That spot lies 2.9° from the South Celestial Pole at a right ascension of about 8h26m.

STAR DOME

HOW TO USE THIS MAP

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

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

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

Planets are shown at midmonth

MAP SYMBOLS

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

STAR MAGNITUDES

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

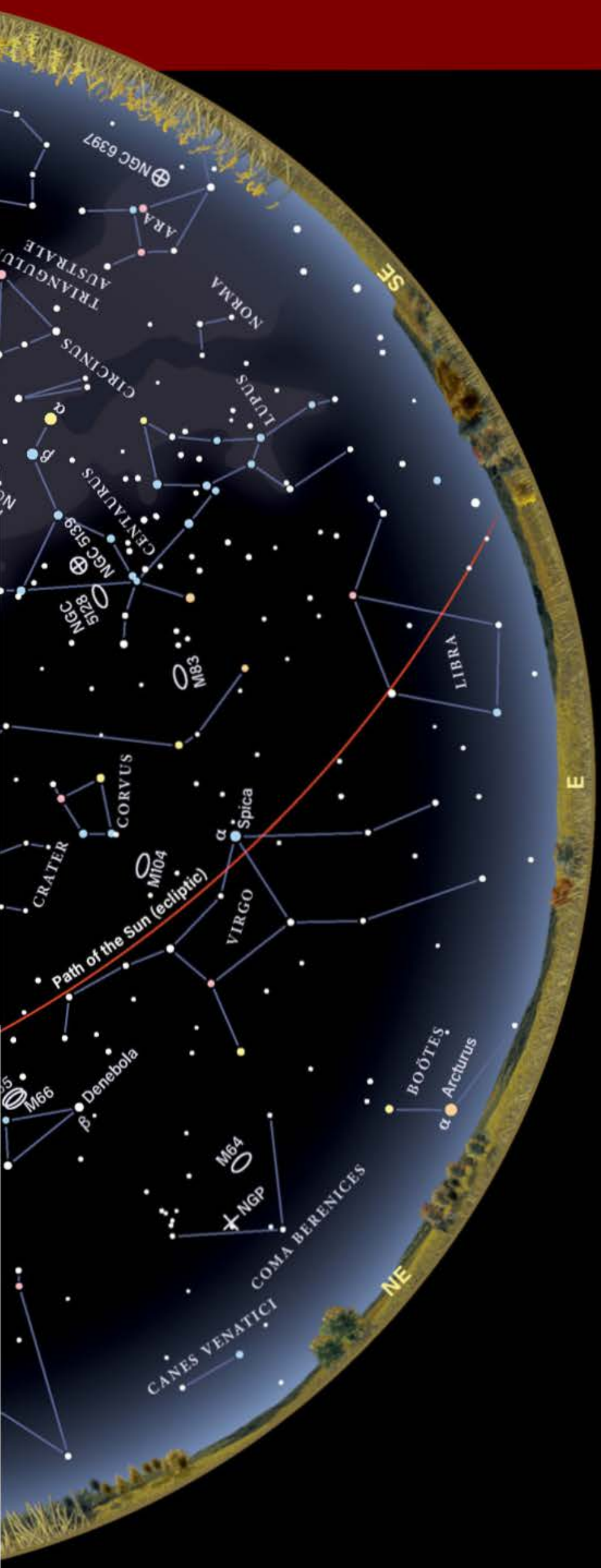
STAR COLORS

A star's color depends on its surface temperature.

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



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



APRIL 2020

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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

CALENDAR OF EVENTS

1 First Quarter Moon occurs at 10h21m UT

2 Asteroid Juno is at opposition, 20h UT

3 Mercury passes 1.4° south of Neptune, 15h UT

7 The Moon is at perigee (356,907 kilometers from Earth), 18h09m UT

8 Full Moon occurs at 2h35m UT

14 The Moon passes 1.2° south of Pluto, 22h UT

Last Quarter Moon occurs at 22h56m UT

The Moon passes 2° south of Jupiter, 23h UT

15 The Moon passes 2° south of Saturn, 9h UT

16 The Moon passes 2° south of Mars, 5h UT

17 Venus passes 10° north of Aldebaran, 20h UT

19 The Moon passes 4° south of Neptune, 7h UT

20 The Moon is at apogee (406,462 kilometers from Earth), 19h00m UT

23 New Moon occurs at 2h26m UT

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

The Moon passes 0.1° north of asteroid Vesta, 11h UT

Pluto is stationary, 13h UT

The Moon passes 6° south of Venus, 15h UT

27 Venus is at greatest brilliancy (magnitude –4.7), 18h UT

30 First Quarter Moon occurs at 20h38m UT