**SPACE CLOUDS: TAKE A 3D LOOK INSIDE NEBULAE** p. 44

MAY 2020

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## COSMIC MYSTERY

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**EXPLORE EDGE-ON AND FACE-ON GALAXIES** p. 56

**How V.M. Slipher discovered the expanding universe** p. 30

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## ON THE COVER

Some 13.8 billion years ago, the Big Bang commenced a process that filled the universe with galaxies like M31. But we're still trying to determine how it all happened. TONY HALLAS

## FEATURES



## COLUMNS



## IN EVERY ISSUE



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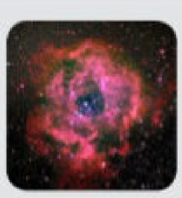

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Gorgeous photos from our readers.

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A daily digest of celestial events.

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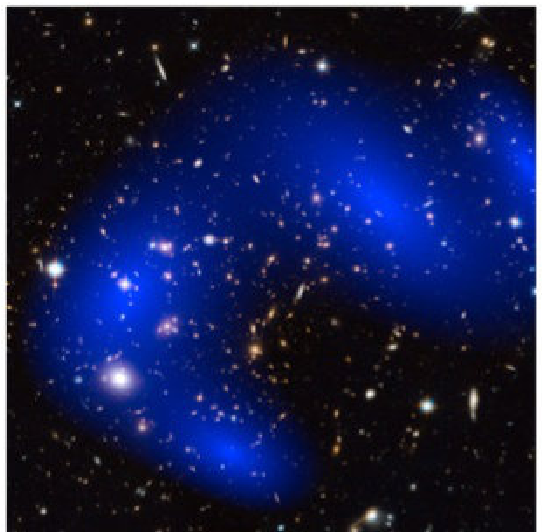
FROM THE EDITOR

# Galaxies, the Big Bang, and existence



The blue light in this image of MACS J0717.5+3745 shows the arrangement of dark matter in this galaxy cluster. Despite the ubiquity of dark matter in the universe, astronomers still have no good idea what it is made of. NASA/ESA/D. HARVEY (ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE)/R. MASSEY (DURHAM UNIVERSITY)/H. EBELING (UNIVERSITY OF HAWAII)/J.-P. KNEIB (LAM)

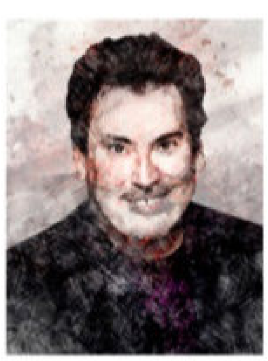
When I talked with my friend Dan Hooper at Fermilab a few months ago, we decided that it was high time to do a "state-of-the-art" story on where we stand with dark matter. When Dan started writing the story, however, he evolved it into a summary of a much bigger dilemma: "Holes" in the Big Bang theory of the origin of the universe are increasingly leaving some astronomers unsettled. So his story, "Is the Big Bang in crisis?" describes the problems astronomers must yet overcome.

When the universe began to assemble matter, it preferred to lump it into galaxies — huge clouds and wheels of stars, gas, and dust. As I was growing up — when we weren't even sure that the Big Bang was the correct model of the universe — one of my favorite books was Tim Ferris' classic *Galaxies*. Since its publication in 1980, what we know about galaxies, the basic units of matter in the cosmos, has been completely revolutionized. I've written my own book, *Galaxies: Inside the Universe's Star Cities*, to explain exactly what we know about these majestic structures now. You can order copies of this new book, just out, from MyScienceShop.com.

This issue features stories on galaxies, too. Veteran observer Steve O'Meara describes how you can observe face-on and edge-on galaxies, and lists challenging objects in each category to target. We have a historical story I've done on the great astronomer V.M. Slipher, who discovered in 1912 that the universe is expanding.

And we have an excerpt from another brand-new book, *Cosmic Clouds 3-D: Where Stars Are Born*, which I wrote along with Brian May, my book-writing partner and founding member and guitarist of the rock group Queen. This book features the incredible work of Finnish photographer J.-P. Metsävainio, who is a master at analyzing the data of distant nebulae and creating realistic 3D images showing the relative distances of stars and gas clouds surrounding them. You can also order this book from MyScienceShop.com.

On a staffing note, please join me in congratulating Alison Klesman on her promotion to Senior Associate Editor. Since joining the magazine in 2016, Alison has taken on an increasingly larger and more varied workload and has produced very nice stories that I know you have enjoyed. You'll treasure her work for a long time to come.



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Yours truly,

David J. Eicher
Editor


# Astronomy

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K2-18 b is a super-Earth exoplanet, discovered in 2015.

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

### Remembering 2019

Your January issue was spectacular. The "Top 10 space stories of 2019" shows what was accomplished this past year. The overload of information is overwhelming, but the article on black holes took my breath away.

In his editor's note, David Eicher masterfully expresses the death and birth of stars as the grandest recycling program. Little did I know what lurks behind the beautiful "like a diamond in the sky" stars at night.

But the most exhilarating story was in Quantum Gravity. It covered the mighty super-Earth exoplanet, K2-18 b, and its signs of habitability. I'm looking forward to another astronomical year! **—Shobha Kaicker,** Mississauga, Ontario

### Forever teaching

Each month I look forward to receiving *Astronomy*. I had the wonderful experience of teaching high school astronomy for the final six years of my 35-year career.

The article in the January 2020 issue indicating water vapor has been identified on planet K2-18 b includes the information: "The researchers were able to tease out the undeniable fingerprint of water vapor in the atmosphere." This line was an opportunity to inform your readers that the "teasing out" was done by the researchers' use of spectroscopic analysis. Adding that information to the article would certainly benefit your readers. **—Frank Lock,** Gainesville, GA

### A job well done

I appreciate Senior Associate Editor Alison Klesman. Not only were her answers in January's Ask Astro clear and concise, I noticed she was the sole expert providing all of the answers. I hope Alison's colleagues give her a well-deserved pat on the back. **—Jim McLeod,** Charlotte, NC

### Televised eclipse

Thank you for the fine article "Astronomy's electronic revolution" in the February issue. I can relate to it as I used an RCA TK11 television camera, which had an image orthicon as the pickup device, to televise a lunar eclipse in 1960. **—Bob Zuelsdorf,** Grass Valley, CA

SNAPSHOT

# ANATOMY OF A COSMIC SWAN

## Infrared light reveals a famous object's piecemeal past.

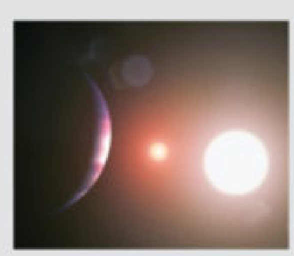
The Omega Nebula, also called the Swan Nebula, is a massive star-forming region about 5,000 light-years away. Hidden within its opaque, dusty clouds are more than 100 newly formed stars as well as clues to the region's past, including how the nebula itself formed over time. Using the Stratospheric Observatory for Infrared Astronomy, or SOFIA, astronomers have peered deeper into the region than ever before to discover nine new massive protostars — collapsing sections of gas and dust that will soon ignite into suns.

SOFIA's observations also show that different areas of the nebula have different ages. Rather than forming all at once or sequentially from top to bottom, the central region of the nebula formed first, followed by the northern portion, while the southern part of the nebula is youngest. By studying the nebula and how it is put together, astronomers hope to learn more about the conditions in which the galaxy's most massive stars are born.

— ALISON KLESMAN

## HOT BYTES

**NEW NAME**
The Large Synoptic Survey Telescope, under construction on Cerro Pachón, Chile, is now called the National Science Foundation Vera C. Rubin Observatory — the first national U.S. observatory named for a woman.



**TWIN SUNS**
On January 6, researchers announced that NASA's TESS planet-hunting spacecraft had spotted its first planet with two suns. The world, called TOI 1338 b, orbits its binary stars every 93 to 95 days.

**BIG SOLO**
In April 2019, LIGO spotted the second-ever gravitational wave signal generated by a binary neutron star merger. It is the first confirmed event seen with only one gravitational wave detector, LIGO Livingston.

NASA/SOFIA/LIM, DE BUIZER, & RADOMSKI ET AL., ESA/HERSCHEL, NASA/JPL-CALTECH. BOTTOM FROM LEFT: RUBIN OBSERVATORY/AURA/NSF; NASA'S GODDARD SPACE FLIGHT CENTER; NATIONAL SCIENCE FOUNDATION/LIGO/SONOMA STATE UNIVERSITY/A. SIMONNET

# FOUND: CRATER FROM 790,000-YEAR-OLD ASTEROID STRIKE

The massive but elusive impact rained down ash over 10 percent of Earth's surface, leaving a mark far beyond the site of the hit.

**INCOMING.** Large asteroids rarely end up on a collision course with Earth. But smaller impactors, like the one seen in this artist's concept, can still wreak havoc around the world. URIKYO33 (PIXABAY)

» The blinding flash of light came first, followed by a shock wave and massive earthquake. Only later did the hailstorm of black, glassy debris begin, a rocky rain that fell on 10 percent of Earth's surface.

That's the scene that followed a massive asteroid impact 790,000 years ago. The rocky remains it scattered, called tektites, have been found from Asia to Antarctica. For decades, scientists have searched for the elusive resting place of the impactor. And now, they think they've found it.

## ELUSIVE CRATER

A report published January 21 in the *Proceedings of the National Academy of Sciences* says that the meteorite likely struck in the Bolaven Plateau in southern Laos, carving a 10.5-by-8-mile (17 by 13 kilometers) crater that's now covered by an ancient lava flow. After identifying the potential impact site via satellite imagery, researchers excavated the area and found the lava dated to around the same time as the impact, while the surrounding sediments were older. This evidence was bolstered by gravity measurements that hinted at a crater hiding below.

By finding the site of the asteroid strike, researchers have been able to reconstruct some of the chaos that ensued after the impact, says study co-author Kerry Sieh, a geologist at Nanyang Technological University in Singapore. The finding could also illustrate some of what we could expect if a similarly large asteroid were to strike Earth again.

## ANATOMY OF AN APOCALYPSE

Roughly 1.25 miles (2 km) wide, the impacting rock would have gouged a hole larger than San Francisco in just seconds. The meteorite's speed and force would have been enough to send pillow-sized boulders careening through the air at almost 1,500 feet (460 meters) per second — faster than the speed of sound. "It would not have been a healthy thing to be on the receiving end of that," Sieh says.

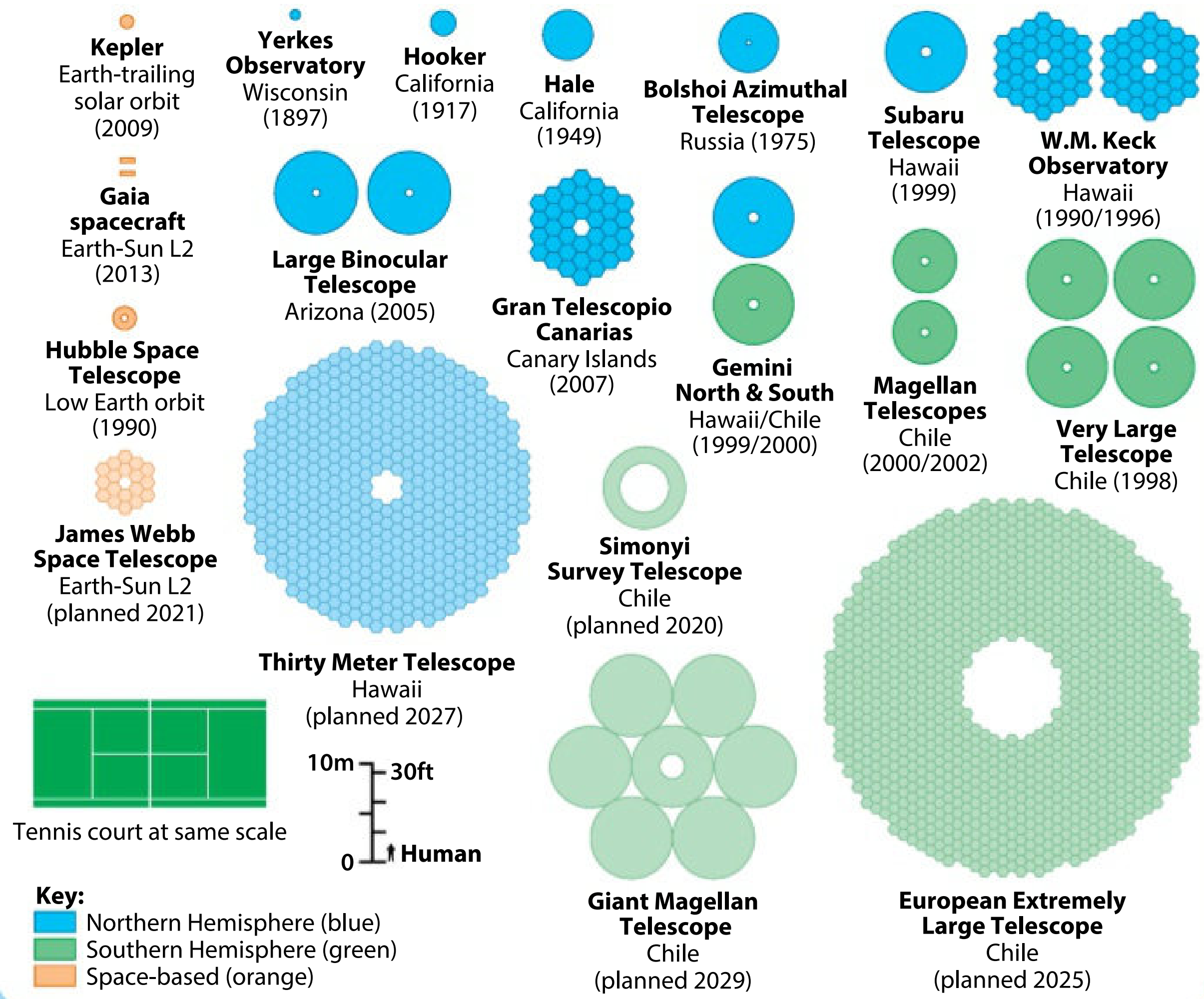
Next, Sieh wants to focus on some of the ashy material surrounding the meteor's debris. The impact would have incinerated all plant and animal life within 300 miles (480 km) of the impact site, and Sieh is curious how that kind of settling dust would affect all of us today, if such an event were to occur in modern times.

The odds of such an impact in our lifetimes are extremely low, but the prospect still fascinates Sieh. "I've never worked on meteorites before," he says, "but I got sucked into this with my curiosity." — LESLIE NEMO, JAKE PARKS

# THE NEXT GENERATION OF TELESCOPES

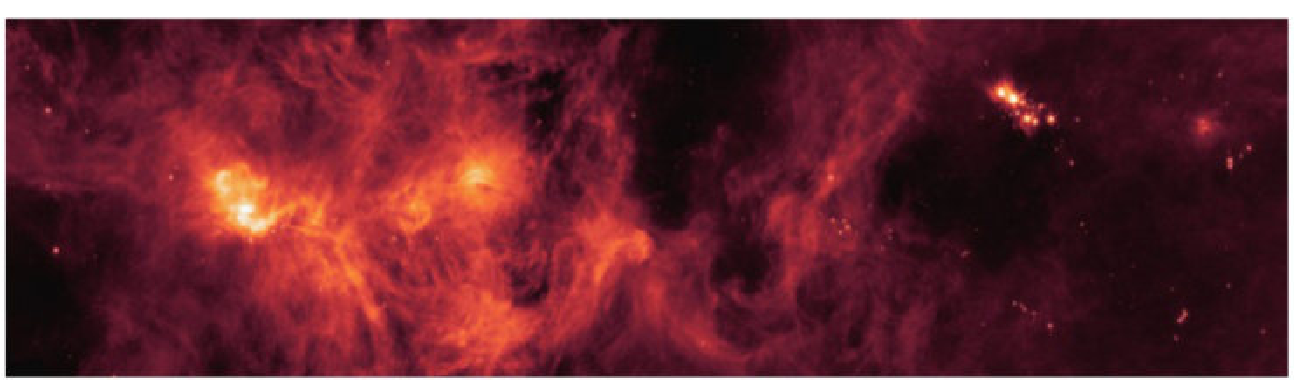
**FAST FACT**

The three smallest ground-based scopes shown here were the world's best for nearly a century.




ASTRONOMY: RICK JOHNSON, AFTER CMGLEE/WIKIMEDIA COMMONS

**OPTICAL EVOLUTION.** Mount Wilson's famous 100-inch (2.5 meters) Hooker Telescope reigned as the world's largest from 1917 until Palomar Observatory's 200-inch (5 m) Hale Telescope was pressed into service in 1949. Although the primary mirrors of both Hooker and Hale were modern marvels during their times, the telescopes of a century ago will look like toys in comparison to the goliath observatories now being built. When the European Extremely Large Telescope sees first light around 2025, its mirror will stretch a truly mind-boggling 129 feet (39.3 m) from edge to edge. – ERIC BETZ, J.P.



NASA/JPL-CALTECH

# Spitzer captures a stellar playground

The Perseus Molecular Cloud, seen here, abounds with young stars. Located about 1,000 light-years from Earth, the expansive collection of dust and gas stretches some 500 light-years across and is home to a number of intriguing targets — including the young star cluster IC 348 (the bright clump on the left) and the reflection nebula NGC 1333 (upper right). This image, taken about 10 years ago with NASA's now-retired Spitzer Space Telescope, captures the infrared radiation streaming from the cloud. – J.P.

## QUICK TAKES

### HELLO, NEIGHBOR

NASA'S planet-hunting TESS telescope has discovered a habitable Earth-sized exoplanet candidate just 100 light-years from Earth — close enough that its atmosphere could be targeted by the upcoming James Webb Space Telescope.

### BLACK HOLE BULLIES

Tidal Disruption Events (TDEs) — which occur when a black hole tears an unlucky star into a disk of hot, glowing gas that is eventually consumed — may come in two flavors: complete and partial. New research suggests the light curves of TDEs can help astronomers know at which type they're looking.

### EARLY BIRD SPECIAL

A distant, giant galaxy seen as it existed 1.5 billion years after the Big Bang appears to have finished forming stars at its center. The find implies that other ancient and massive galaxies might have also completed star formation in their cores early in the universe's history.

### SPACE TRIAGE

An unnamed astronaut discovered they had a blood clot in their jugular vein while carrying out a vascular study aboard the ISS. The clot was successfully managed with a treatment of blood thinners, and though it was still present 24 hours after landing on Earth, it was gone 10 days later.

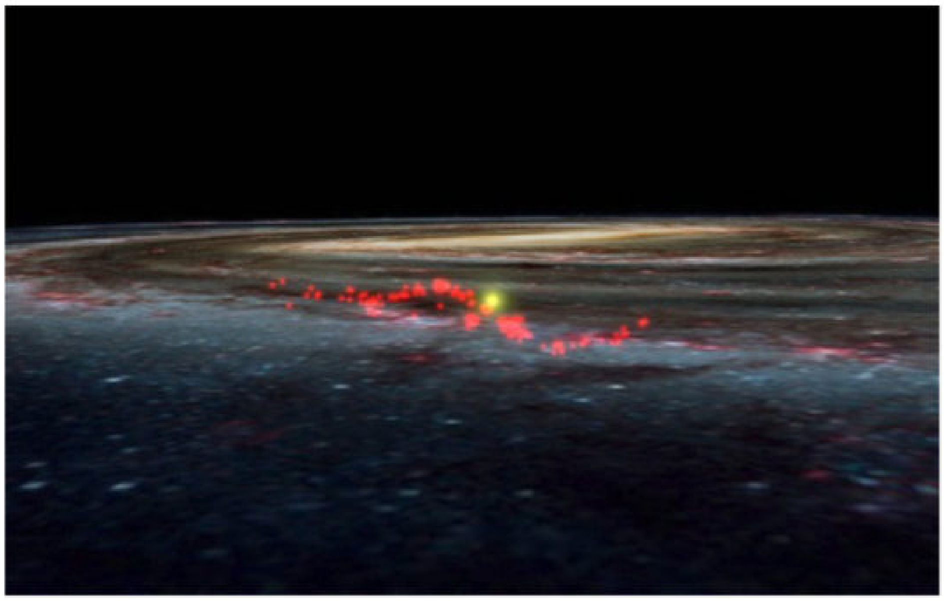
### REMIND ME LATER

Astronomers expect a pair of stars known as V Sagittae, which are on a spiraling collision course with one another, to coalesce and go nova around 2083 — give or take about 10 years. The event is expected to briefly make V Sagittae the brightest star in the night sky.

### BAKER'S DOZEN

Thirteen supermassive black holes were recently found within dwarf galaxies more than 100 times less massive than the Milky Way. Half were in the center, as expected. But half the black holes were located in the outskirts of their host galaxies, meaning researchers may need to expand their hunt for supermassive black holes in dwarf galaxies beyond just their cores. – J.P.

# Giant wave of star-forming clouds lies near the Sun



**DO THE WAVE.** The Radcliffe Wave is a recently discovered 9,000-light-year-long structure composed of star-forming regions, colored red in this artist's rendition, which also shows the Milky Way Galaxy and the Sun (yellow). Although astronomers aren't sure what caused the ripple-like structure, they do know it has interacted with the Sun in the past. ALYSSA GOODMAN/HARVARD UNIVERSITY

Our local arm of the Milky Way Galaxy is doing the wave. Harvard University astronomers recently uncovered a strange, wave-shaped structure within 500 light-years of the Sun, made up of several interconnected stellar nurseries. Taken as a whole, the wave is 400 light-years wide and 9,000 light-years long, snaking 500 light-years above and below the plane of the galaxy. Findings regarding the wave — dubbed the Radcliffe Wave in honor of the Radcliffe Institute for Advanced Study at Harvard, where the discovery was made — were published January 7 in *Nature*.

Researchers found the Radcliffe Wave while analyzing data from the European Space Agency's Gaia mission, which is tasked with charting the location and motion of stars within our galaxy. Combining that information with other observations as well as simulations and data visualization, they discovered the undulating structure in the spiral arm of the Milky Way closest to our solar system.

According to the team, the wave looks long and straight from above, but from the side, it appears to bob up and down out of the plane of the galaxy. "The wave's very existence is forcing us to rethink our understanding of the Milky Way's 3D structure," said study co-author Alyssa Goodman, co-director of the Science Program at the Radcliffe Institute for Advanced Study, in a press release.

In particular, the wave's discovery disproves the existence of a feature known as "Gould's Belt," which astronomers believed was a ring-shaped structure of star-forming regions circling the Sun. Many of the regions previously thought to reside in parts of this belt are instead part of the Radcliffe Wave, the team found, while other regions associated with the belt now appear to be unrelated to either the wave or any ring structure. "For a long time, people have been trying to figure out if these molecular clouds actually form a ring in 3D," said lead author João Alves of the University of Vienna. "Instead, what we've observed is the largest coherent gas structure we know of in the galaxy, organized not in a ring but in a massive, undulating filament. … It's been right in front of our eyes all the time, but we couldn't see it until now."

Now, thanks to the team's efforts, we can see it, and the information will allow astronomers to better understand the properties of the star-forming clouds of gas and dust that are part of the wave. That's because calculating the size and mass of such clouds relies on knowing their distance, which until now has been difficult to measure. Additionally, the data combination techniques used by the team can set the stage for even more, perhaps also surprising, findings about the structure of the Milky Way. —A.K.

X-RAY: CHANDRA: NASA/CXC/SAO/E. O'SULLIVAN. XMM: ESA/XMM/E. O'SULLIVAN. OPTICAL: SDSS

## SHOCKING SCENE

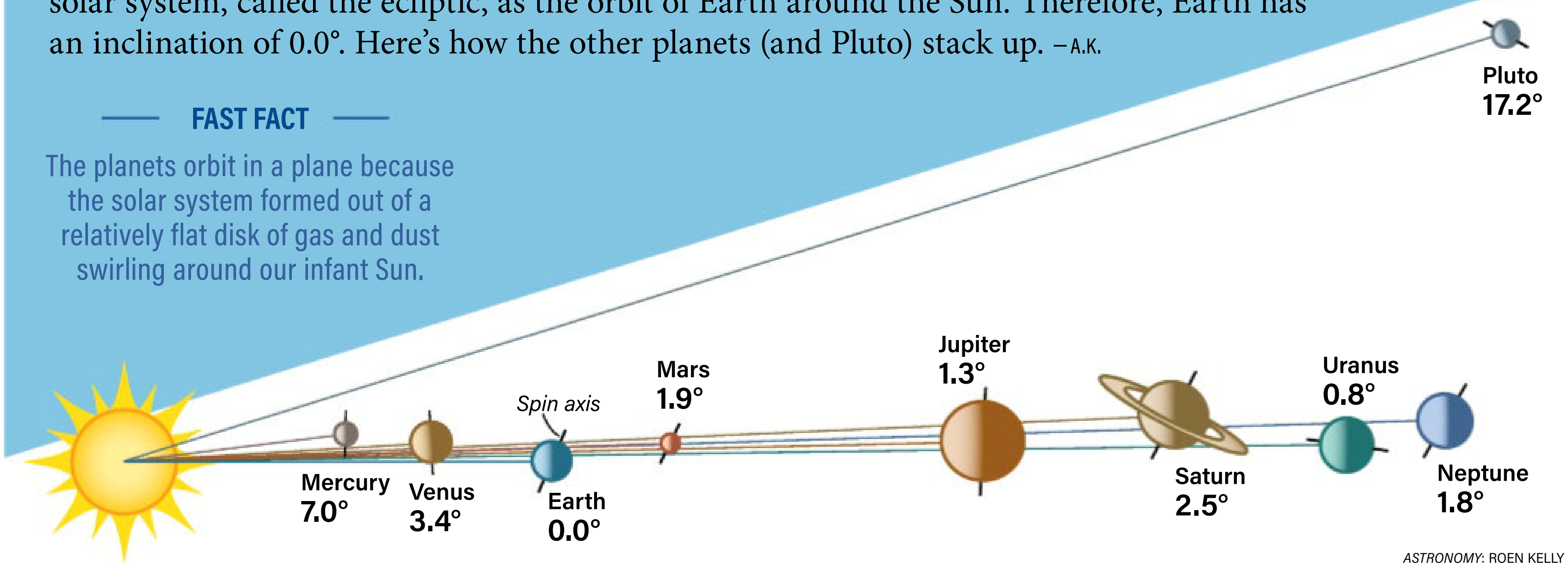
Galaxies rarely live alone. Pulled together by gravity, they congregate into groups that, over time, can merge into larger clusters. That's what's happening in NGC 6338, where two galaxy groups are rushing toward each other at about 4 million mph (6.4 million km/h). This composite image shows the scene of the impending smashup in X-rays and optical light. The hottest gas, with temperatures over 36 million degrees Fahrenheit (20 million degrees Celsius) is colored red. Cooler gas in the cores of the two groups appears blue, while stars and galaxies shining in optical light are white. The thin strip of hot gas between the cores, as well as the gas around them, has been heated by shocks generated during the collision, similar to the sonic booms made by supersonic aircraft. Although this pattern of shocked gas has been predicted by simulations in the past, NGC 6338 is the first galaxy group merger that shows clearly this effect. —A.K.

# HOW THE PLANETS LINE UP

**TILT-A-WHIRL.** The planets orbit our Sun in a relatively flat plane. But the key word here is *relatively* — some planets lie closer to this plane than others. The amount a planet's orbit is tilted, or inclined, away from the plane is called its inclination. As earthbound observers, we have defined the plane of the solar system, called the ecliptic, as the orbit of Earth around the Sun. Therefore, Earth has an inclination of 0.0°. Here's how the other planets (and Pluto) stack up. – A.K.

**FAST FACT**

The planets orbit in a plane because the solar system formed out of a relatively flat disk of gas and dust swirling around our infant Sun.



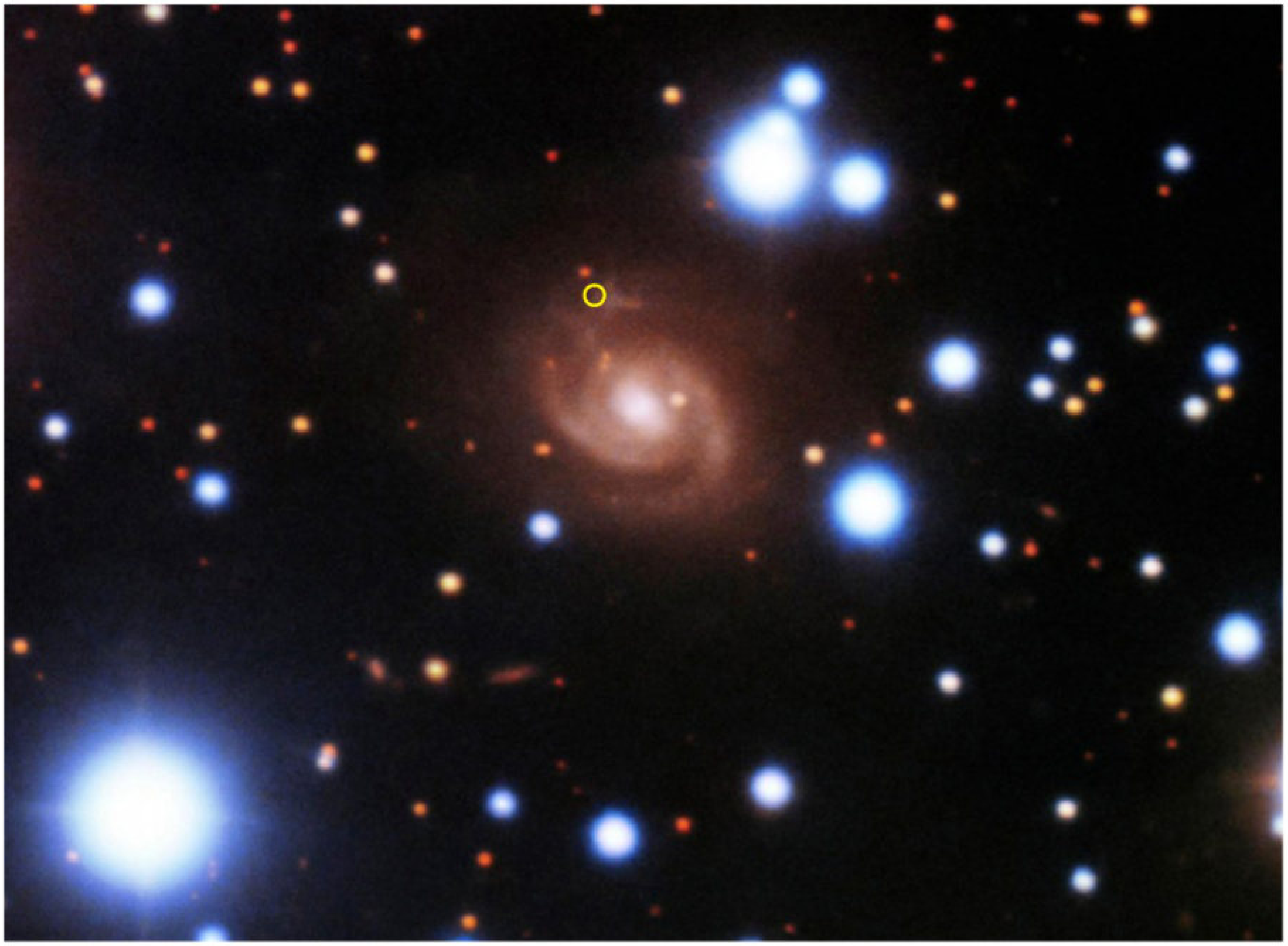

*ASTRONOMY*: ROEN KELLY

## Our nearby gentle giant

The spiral galaxy UGC 2885, also called Rubin's Galaxy, is something of a local legend. At 232 million light-years away, it is the largest galaxy known in our nearby universe, spanning more than twice the width of the Milky Way and containing 10 times as many stars. But astronomers aren't sure how it got so large. Galaxies typically grow by consuming or smashing into other galaxies. But UGC 2885 is alone in space, apparently having undergone neither process to gain its heft. Instead, researchers believe it may have grown by calmly siphoning gas from intergalactic space. One way to read the galaxy's past is to study the globular clusters of stars around it. These clusters often survive collisions and assimilations, revolving around the final result. Astronomers are now looking to count up the globular clusters around UGC 2885 to see whether it has more than it should, which would hint that it's eaten other galaxies in the past. – A.K.

NASA, ESA, AND B. HOLWERDA (UNIVERSITY OF LOUISVILLE)

**$58,000** The total, in USD, awarded by the Planetary Society, in varying amounts, to six amateur astronomers focused on discovering and characterizing near-Earth asteroids.



**UP IN ARMS.** FRB 180916 lies in a Milky Way-like spiral galaxy 500 million light-years away. The location of the FRB (circled) in one of the galaxy's star-forming spiral arms challenges astronomers' ideas about the origin of these mysterious bursts. GEMINI OBSERVATORY/NSF'S NATIONAL OPTICAL-INFRARED ASTRONOMY RESEARCH LABORATORY/AURA

# Second repeating fast radio burst tracked, deepening mystery

Fast radio bursts (FRBs) are short, powerful blasts of energy that originate outside our galaxy. Only a few repeat, while most pop off only once. For more than a decade, astronomers have sought to understand these strange flashes and, in recent years, have begun to trace some FRBs back to their origins. In a paper published January 6 in *Nature*, researchers announced they have tracked yet another FRB to its host galaxy. It is the fifth time an FRB has been traced to its origin, and only the second time a repeating FRB has been pinpointed.

Combining observations from eight separate telescopes, a team of astronomers tracked the burst, which is called FRB 180916.J0158+65, to a spiral galaxy nearly half a billion light-years away. It is the closest FRB tracked to date and lies within an outer arm of its host galaxy, where stars are rapidly forming. The spiral host is similar to our own Milky Way, however, making it unlike any other galaxy in which an FRB has been found before. The only other repeating FRB that astronomers have tracked, FRB 121102, comes from a tiny, distant dwarf galaxy 3 billion light-years away — a dramatically different environment than a spiral galaxy near our own.

"This object's location is radically different from that of not only the previously located repeating FRB, but also all previously studied FRBs," said study co-author Kenzie Nimmo of the University of Amsterdam in a press release. And that has implications, the team says, for the types of conditions that cause FRBs, repeating and nonrepeating.

The current leading theory is that FRBs are produced by neutron stars, the highly magnetized remnants of massive stars. While this could be the case for some FRBs, it may not be the cause of all of them. The more FRBs astronomers identify and track, the more diverse the population becomes. "It may be that FRBs are produced in a large zoo of locations across the universe and just require some specific conditions to be visible," Nimmo said.

The team, along with many others, aims to track an increasing number of FRBs to their hosts. They hope more information on where FRBs originate will ultimately reveal what's causing these strange flashes of energy. —A.K.

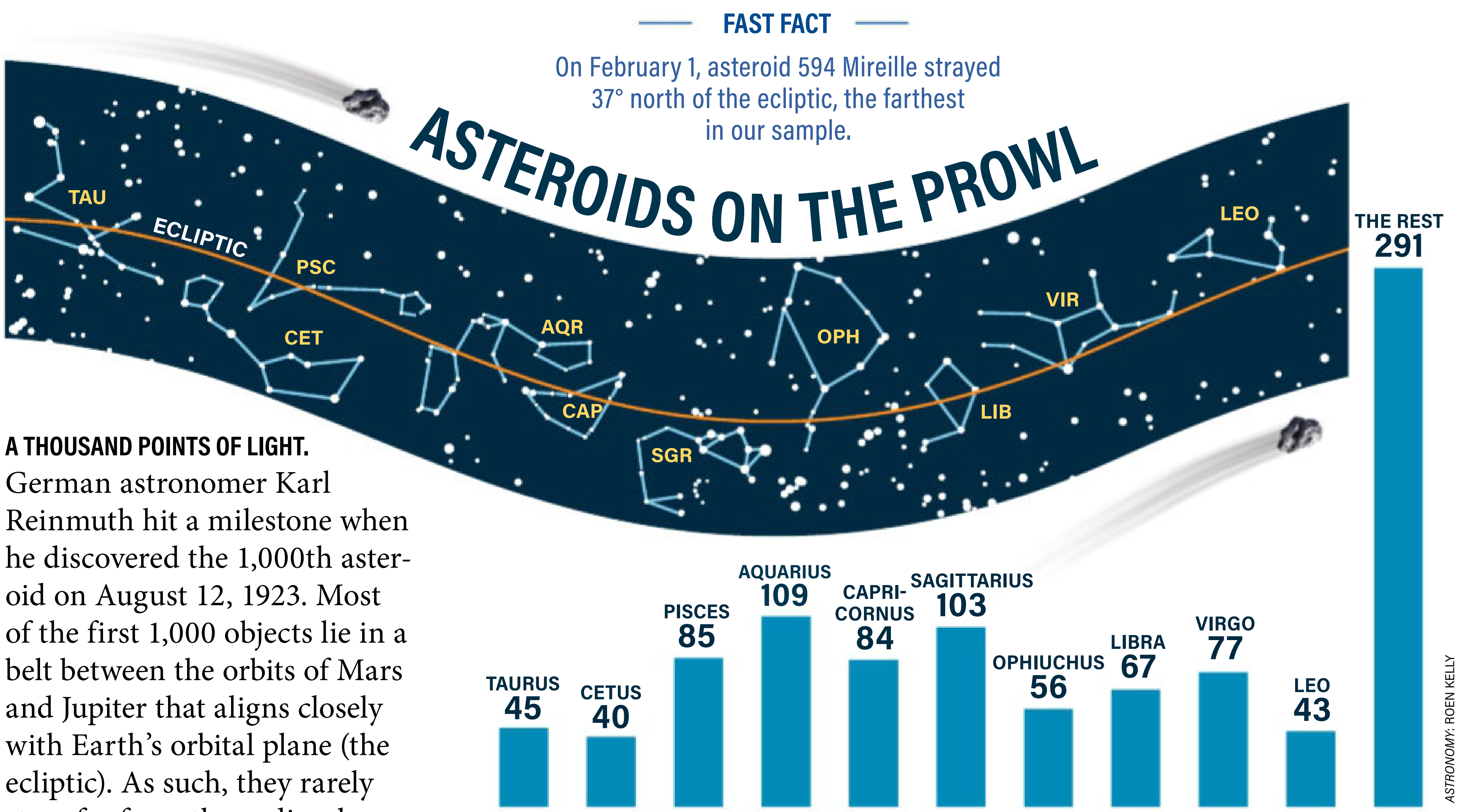
# NASA astronauts graduate with eye toward Artemis

The first class of NASA astronauts slated for the Artemis program graduated January 10. And after more than two years of basic training, the 11 NASA astronauts, in addition to two Canadian Space Agency (CSA) astronauts, are now eligible for missions to the space station, the Moon, and eventually Mars. Selected from a record-setting pool of more than 18,000 applicants, this cosmic class includes some of the best and brightest our country has to offer. The next-gen astronauts are (top row, left to right) Matthew Dominick, Kayla Barron, Warren Hoburg, Joshua Kutryk (CSA); (middle row) Bob Hines, Frank Rubio, Jennifer Sidey-Gibbons (CSA), Jasmin Moghbeli, Jessica Watkins; (bottom row) Raja Chari, Jonny Kim, Zena Cardman, and Loral O'Hara. Congratulations, graduates! – J.P.

NASA

**7,800** The temperature, in degrees Fahrenheit (4,300 degrees Celsius), on the surface of the hottest-known exoplanet, KELT-9 b.

## ASTEROIDS ON THE PROWL



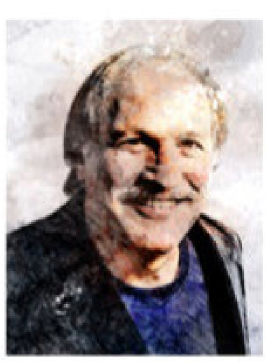

ASTRONOMY: ROEN KELLY

**A THOUSAND POINTS OF LIGHT.** German astronomer Karl Reinmuth hit a milestone when he discovered the 1,000th asteroid on August 12, 1923. Most of the first 1,000 objects lie in a belt between the orbits of Mars and Jupiter that aligns closely with Earth's orbital plane (the ecliptic). As such, they rarely stray far from the zodiacal constellations where the major planets reside. The graph above shows the positions of these 1,000 asteroids on February 1, 2020. More than 70 percent of them resided in just 10 constellations. – RICHARD TALCOTT

# Observatory odds and ends

Don't give up on your backyard astronomy dreams.

The author's new observatory in upstate New York, as seen from his kitchen window. The rural landscape is free of lights and houses. But there's no cell service or mail delivery, either. BOB BERMAN



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

In some alternate universes, astronomy is free. But around here, perusing these pages filled with tempting gadgets and gleaming telescopes, many of us have expensive dreams.

I'm familiar with the drooling-craving syndrome. For me, it started with airplanes. During my three post-college years in Asia, some of my Peace Corps friends discovered cheap lessons at government-run flight schools. Count me in! In 1985, I finished my training in the U.S., but what do you do after you've obtained a pilot's license? Everyone's biggest aspiration is to own a plane.

It seemed a pipe dream for this writer, married to a kindergarten teacher. But, it turned out, good used four-seaters are not crazy expensive, and the next three decades were peppered with fairy-tale aerial adventures.

The parallels to our astronomy passion are obvious. A private observatory may seem impossibly opulent and utterly unworkable for urbanites. Nonetheless, many stubbornly harbor the dream of owning one.

**A private observatory may seem utterly unworkable for urbanites. Nonetheless, many stubbornly dream of owning one.**

As someone who has traveled that road and managed to make every possible mistake in the process, let me share some hard-won lessons.

First is the issue of "where?" You might think a city would be out of the question. But I watched a physician in light-polluted Kingston, New York, construct a dome on his Victorian rooftop. And, as Dudley Observatory in the Albany, New York, metro area and Matt Francis' Prescott Observatory south of that city in Arizona show, an imperfect sky is no reason to forgo such a project.

True, this eliminates most deep-space objects. However, the endless realm of double stars, as well as Moon and planet explorations, can keep you and your visitors enthralled forever. Those crowd-pleasers are immune to light pollution.

Of course, when galaxies and nebulae are important, you must have a dark site. If, like me, you already live far out in the boonies, your home environment might be perfect. Otherwise, if you can commute, buy some land in the middle of nowhere, where real estate is inexpensive. Solar panels and battery storage can preclude the need to spend a fortune erecting poles to connect to the grid. Don't close until you've spent a night camping there. If one sky-direction must be blocked, sacrifice the north.

Next decision: type and size. I built a big roll-off roof observatory in the mid-'80s. No one helped me, and I made major mistakes. I put the roof on swiveling casters. Don't do that. I had to jack it up and replace everything. I also thought the roof's wheels would roll on the wooden wall tops. Wrong again. When parked, the heavily loaded casters created depressions and wouldn't readily climb out of them. I jacked everything up again and topped the walls with thin steel plates. It was harder than it sounds.

I also learned that everything needs to be periodically greased. And that a reversible half-horsepower DC motor was best for moving the enormous weight. And to use chains, not cables. Also, the 12-by-20-foot (3.7 by 6 meters) building was excessive. Do yourself a favor and go smaller.

Then, last year, having moved to even darker skies and now significantly less poor, I gladly paid Explora-Dome to install an 8-foot (2.4 m) motorized dome on their square building. Everything all together — the dome, building, and labor — totaled under $10K. Another few thousand covered the masonry foundation and pier, and the end result was my big f/6 equatorial reflector in one observatory (the roll-off) and apochromatic refractor in the dome.

Shuttling back and forth from a dome to a roll-off provides a great A/B comparison. Yes, a dome looks cool. But a roll-off exposes the entire sky, letting occupants stargaze or use binoculars while waiting their turn at the scope. You can't do that in a dome.

The bottom line is: Don't ever abandon your observatory dream.

I've skipped the part about how snakes like to nest in them.

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# Rekindling dreams

When will humankind leave the cradle?

When Gene Cernan snapped this photo of Jack Schmitt on the lunar surface, along with the Apollo 17 rover, no one yet appreciated how long it would be until humans returned to the Moon. NASA/JSC

It is hard to say whether I truly remember Mercury astronauts being bolted into tiny capsules and blasted into space, or whether I only remember remembering. Regardless, those images are there in my mind. That is where my lifelong love affair with science, engineering, and exploration took root.

Even as a young kid, I understood that spaceflight was about pushing the limits of human experience. Maybe I became aware of the danger when Gemini VIII tumbled out of control after the first-ever docking of two spacecraft in orbit. A quick-thinking Neil Armstrong and David Scott narrowly averted tragedy by using the reentry system to wrestle the capsule back under control.

Or maybe it all became real with the Apollo 1 fire.

Along with much of the world, I was glued to the TV waiting for Apollo 8 to emerge from behind the Moon on Christmas Eve 1968. As a 10-year-old, I listened when Armstrong again demonstrated his skill as a seat-of-the-pants pilot, landing on the Moon with only 15 seconds of fuel to spare.

By all accounts, Apollo 13 should have ended in tragedy. I recall shocked amazement when I first saw a picture of the hole blasted in the side of the Service Module when an oxygen tank exploded. Twenty-five years later, I was visiting Fermilab when a freshly minted particle physics graduate student scoffed at the "preposterous" plot of the newly released Tom Hanks movie. I'm not sure that he believed me when I told him it was a true story.

I cried when I watched Apollo 17 lift off from the Moon, knowing that the last three planned missions had been canceled. I now understand why that decision was inevitable. To the people calling the shots, Apollo was never really about exploration. We went to the Moon to one-up the Soviets in the eyes of the world. Having accomplished that end, each additional flight put that political victory at risk with little perceived gain in status.

But for a generation of young people who watched that drama and went on to become scientists and engineers, Apollo didn't go to the Moon to beat the Soviets. Apollo went to the Moon for us.

**Is all of the recent talk about sending humans to the Moon and Mars a pipe dream?**

I was saddened by the disaster of space shuttle *Columbia*. I was livid when it became clear that space shuttle *Challenger* exploded because someone thought political expediency was more important than physical reality.

I never saw eye to eye with colleagues who bemoaned dollars spent on human spaceflight. While robotic exploration of space is one of humanity's grandest accomplishments, for many, including myself, robots aren't enough. It matters that humans see, feel, experience, and push limits. It always has, and it always will. Had you told me at 12 years old that half a century would pass without a return to the Moon, much less a trip to Mars, I probably would have spit in your face. But here we are.

Personally, I can't really complain. As a kid (and, to be honest, as an adult, too) I devoured books by the likes of Ray Bradbury, Isaac Asimov, and Arthur C. Clarke. Experiences like working in the Mission Operations Center as STS-61 astronauts installed WFPC2, the camera that saved Hubble, offered small tastes of what that future might have been like.

But do dreams from childhood ever really die? Call me a romantic, but apparently the answer is no.

When two reusable SpaceX Falcon Heavy boosters landed side by side, I felt hope and longing as much as I did excitement. And, face it: It takes a certain *je ne sais quoi* to launch your cherry-red electric sports car into Mars-crossing solar orbit with a spacesuit-clad mannequin named Starman in the driver's seat.

Those were teases; September's rollout of the shining, bullet-shaped Starship prototype took my breath away. How could the cover artists for all of those 1940s and '50s science fiction magazines have known?

Robert Heinlein's *The Man Who Sold the Moon* was pure fiction, but could Elon Musk become The Man Who Sold Mars? While SpaceX is careful not to say too much about schedules publicly, there is talk on the street of the possibility of a Mars landing within the next five years or so. One even hears that a base could be up and running within the decade. If and when that happens, it seems clear that Musk has no intention of walking away.

This is a struggle. Is all of the recent talk about sending humans to the Moon and Mars a pipe dream? Can Musk — or, for that matter, NASA or Blue Origin — make it so? After a lifetime of resignation, should I again let myself dream of seeing humans on another world?

Could I stop myself if I tried?

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

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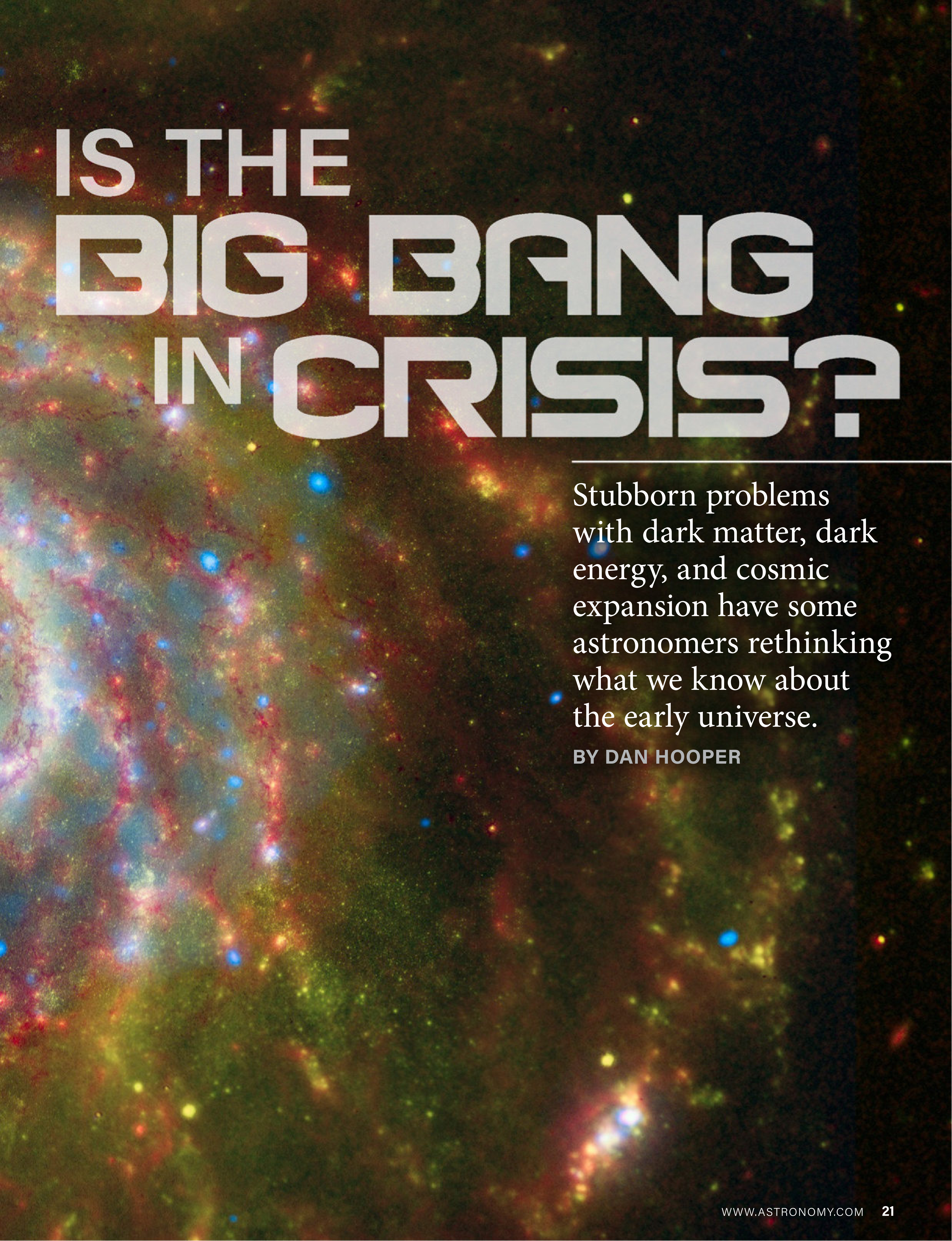
Spiral galaxy M101 harbors hundreds of Cepheid variables that scientists use to measure the universe's expansion rate, though the value differs from that deduced from the cosmic microwave background. M101 also harbors vast amounts of mysterious dark matter. Enigmas such as these have cosmologists questioning their ideas on cosmic evolution. This composite image combines visible light (yellow), infrared radiation (red), and X-rays (blue). NASA/ESA/CXC/SSC/STScI



# IS THE BIG BANG IN CRISIS?

Stubborn problems with dark matter, dark energy, and cosmic expansion have some astronomers rethinking what we know about the early universe.

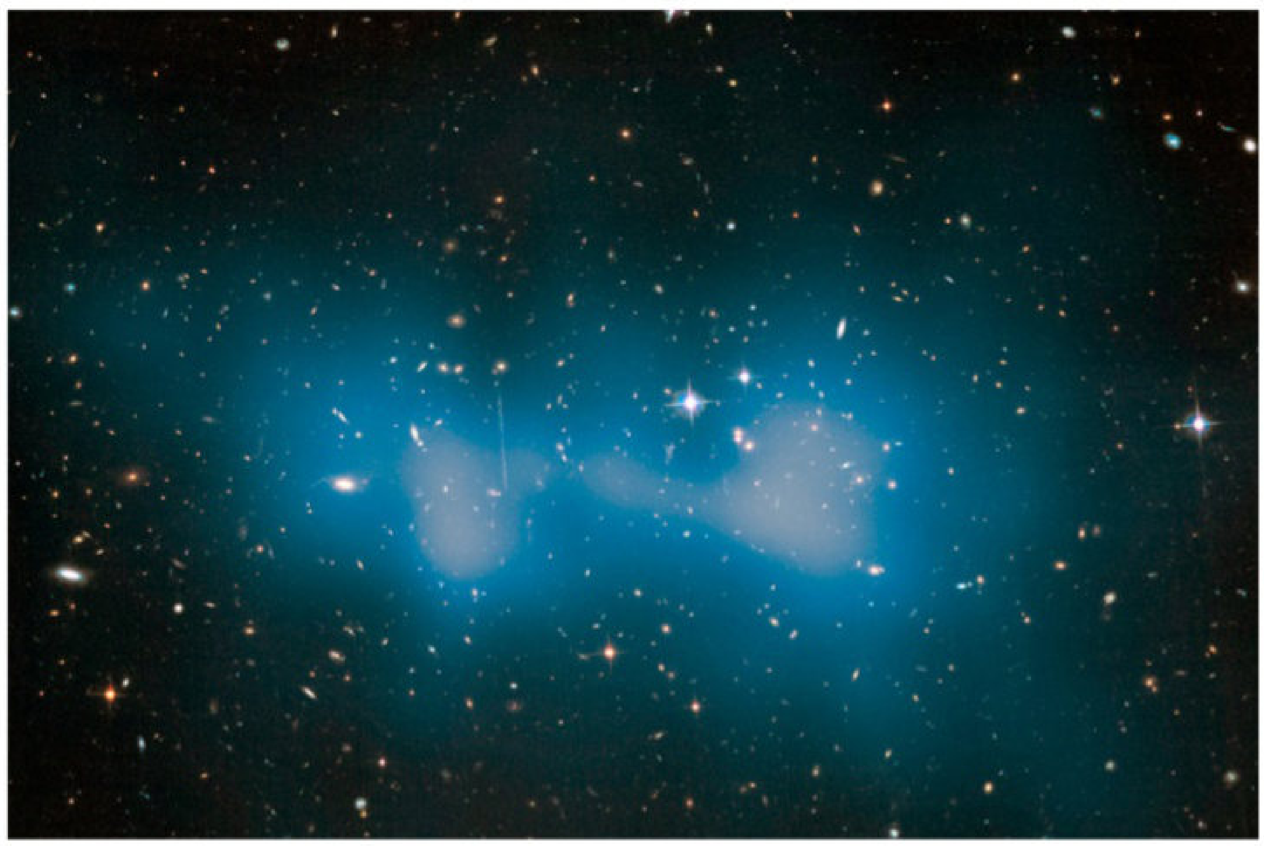
BY DAN HOOPER

With a diameter 2.5 times that of the Milky Way and containing 10 times as many stars, UGC 2885 ranks among the largest spiral galaxies in the local universe. But there's more here than meets the eye: Invisible dark matter accounts for some 85 percent of UGC 2885's mass. Vera Rubin discovered dark matter in this galaxy during her pioneering study of this mysterious material. NASA/ESA/B. HOLWERDA (UNIVERSITY OF LOUISVILLE)

A series of powerful observations has made it clear that our universe has expanded for billions of years, emerging from the hot, dense state we call the Big Bang. Over the past several decades, new types of precise measurements have allowed scientists to scrutinize and refine this account, letting them reconstruct the history of our universe in ever greater detail. When we compare the results from different kinds of measurements — the expansion rate of the universe, the temperature patterns in the light released when the first atoms formed, the abundances of various chemical elements, and the distribution of galaxies and other large-scale structures — we find stunning agreement. Each of these lines of evidence supports the conclusion that our universe expanded and evolved in just the way that the Big Bang theory predicts. From this perspective, our universe appears to be remarkably comprehensible.

But cosmologists have struggled — if not outright failed — to understand essential facets of the universe. We know almost nothing about dark matter and dark energy, which together make up more than 95 percent of the total energy in existence today. We don't understand how the universe's protons, electrons, and neutrons could have survived the aftereffects of the Big Bang. In fact, everything we know about the laws of physics tells us that these particles should have been destroyed by antimatter long ago. And in order to make sense of the universe as we observe it, cosmologists have been forced to conclude that space, during its earliest moments, must have undergone a brief and spectacular period of hyperfast expansion — an event known as cosmic inflation. Yet we know next to nothing about this key era of cosmic history.

It's possible that these puzzles are little more than loose ends, each of which will be resolved as cosmologists continue to



TOP: This galaxy cluster, nicknamed El Gordo (Spanish for "The Fat One"), ranks as the largest known cluster in the distant universe. Composed of two individual clusters colliding at more than 1 million mph (1.6 million km/h), this structure holds a mass equivalent to 3 quadrillion Suns. ESA/HUBBLE & NASA/RELICS

ABOVE: The blue color added to this image maps the distribution of dark matter in the El Gordo galaxy cluster. Astronomers traced the presence of this shadowy substance by looking at how it distorts the appearance of more distant objects. NASA/ESA/J. JEE (UNIVERSITY OF CALIFORNIA, RIVERSIDE)

investigate our universe. But so far, these problems have proven to be remarkably stubborn and persistent. With the goal of identifying the individual particles that make up dark matter, scientists have designed and built a series of impressive experiments — yet no such particles have appeared. Even powerful particle accelerators like the Large Hadron Collider have revealed nothing that moves us closer to resolving any of these cosmic mysteries. And despite having measured the expansion history and large-scale structure of the universe in ever increasing detail, we have not gained any substantively greater understanding of the nature of dark energy, the force that seems to be accelerating the expansion of the cosmos.

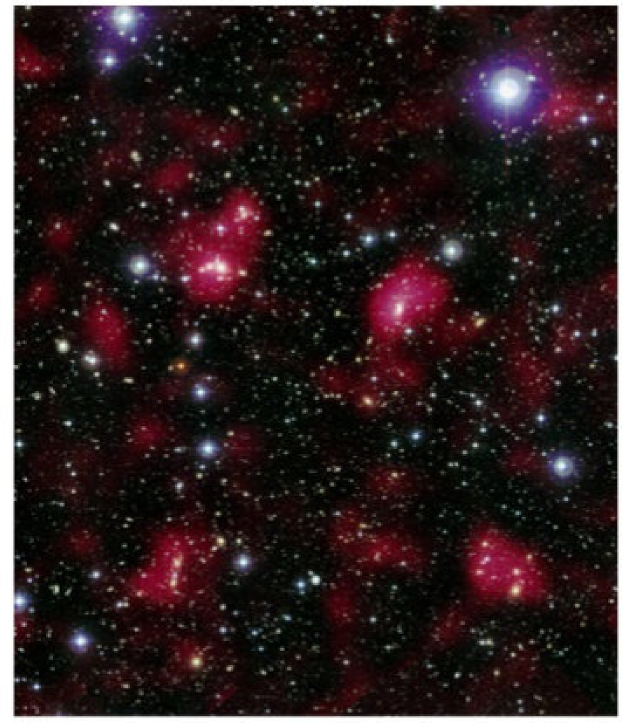
It is from this perspective that some cosmologists have found themselves asking whether these cosmic mysteries might be symptoms of something more significant than a few loose threads. Perhaps these puzzles are not as unrelated as they might seem, but are instead collectively pointing us toward a very different picture of our universe and its earliest moments.

## What we've learned by *not* discovering dark matter

Dark matter is likely the most celebrated problem facing modern cosmologists. Astronomers have determined that most of the matter in our universe does not consist of atoms or any other known substances, but of something else — something that does not appreciably radiate, reflect, or absorb light.

Despite not knowing much about the nature of dark matter, cosmologists often

The Coma Cluster packs thousands of galaxies into a sphere measuring more than 20 million light-years across. Fritz Zwicky discovered dark matter in this cluster in the 1930s when he deduced that the galaxies are moving too fast to stay together unless the cluster contains nearly 10 times as much matter as what can be seen. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)



The supercluster Abell 901/902 holds hundreds of galaxies and massive amounts of dark matter. The magenta-tinted clumps show the dark matter's distribution, derived from Hubble Space Telescope observations, overlaid on a ground-based image of the supercluster. HUBBLE DATA: NASA/ESA/C. HEYMANS (UNIVERSITY OF BRITISH COLUMBIA) ET AL./THE STAGES COLLABORATION. GROUND-BASED IMAGE: ESO/C. WOLF (OXFORD UNIVERSITY) ET AL./THE COMBO-17 COLLABORATION

speculate about the kinds of particles that might make up this substance. In particular, researchers have long recognized that if dark matter particles interact through a force that is approximately as powerful as the weak nuclear force (which governs radioactive decay), then the number of these particles that should have emerged from the Big Bang would roughly match the measured abundance of dark matter found in the universe today. With this in mind, weakly interacting massive particles — WIMPs — became the best guess for dark matter's nature.

One initially appealing aspect of WIMPs was that scientists thought they knew how to detect the particles and study their properties. Motivated by this goal, physicists engaged in an ambitious experimental program to identify these WIMPs and learn how they were forged in the Big Bang. Over the past couple of decades, researchers have deployed a succession of increasingly sensitive dark matter detectors in deep-underground laboratories that are capable of detecting individual collisions between a dark matter particle and the atoms that make up the target.

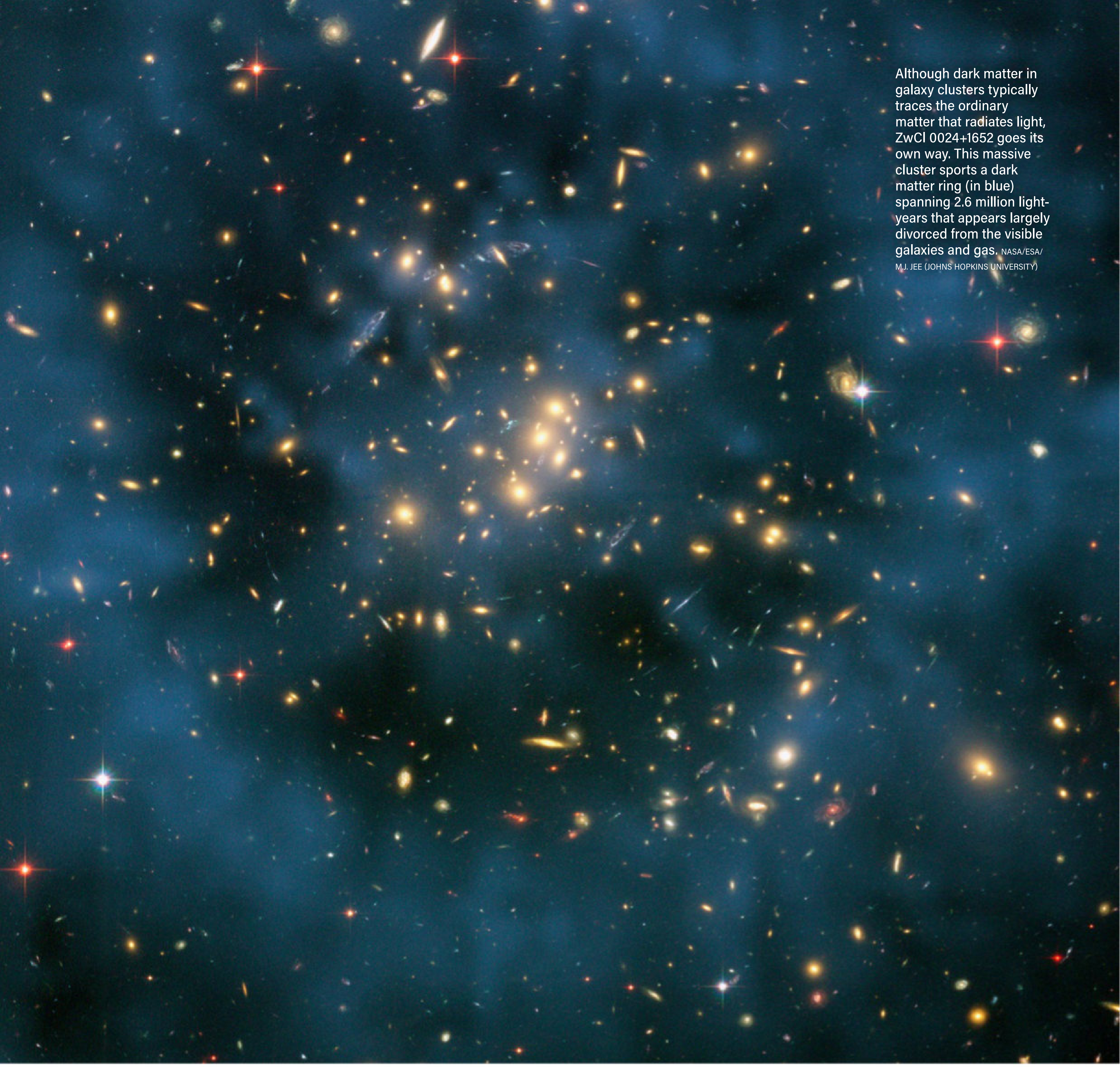
These sophisticated experiments performed beautifully — as well as or better than designed. Yet no such collisions have been observed. A decade ago, many scientists were optimistic that these experiments would bear fruit. But dark matter has turned out to be very different, and far more elusive, than we had once imagined.

Although it's still possible that dark matter could consist of some form of difficult-to-detect WIMPs, the lack of any signal from underground experiments has led many physicists to shift their focus toward other dark matter candidates. One such contender is a hypothetical ultralight particle known as an axion. Axions are predicted according to a theory proposed by particle physicists Roberto Peccei and Helen Quinn in 1977. Although scientists are searching for axions in experiments that use powerful magnetic fields to convert them into photons, these investigations have yet to place very strict constraints on the properties of these particles.

The blue light in this image of MACS J0416.1–2403 shows the arrangement of dark matter in this galaxy cluster. Despite the ubiquity of dark matter in the universe, astronomers still have no good idea what it is made of. NASA/ESA/D. HARVEY (ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE)/R. MASSEY (DURHAM UNIVERSITY)/HST FRONTIER FIELDS

Another possibility that could explain why dark matter has been so difficult to detect is that the first moments of the universe may have played out much differently than cosmologists have long imagined. Take the case of the conventional WIMP. Calculations show that the fledgling universe should have produced vast quantities of these particles during the first millionth of a second or so after the Big Bang, when they reached a state of equilibrium with the surrounding plasma of quarks, gluons, and other subatomic particles. The number of WIMPs that could have survived these conditions — and ultimately contributed to the dark matter found throughout today's universe — depends on how, and how often, they interacted. But when carrying out calculations such as these, scientists generally assume that space expanded steadily during the first fraction of a second, without any unexpected events or transitions. It is entirely plausible that this simply was not the case.

Although cosmologists know a great deal about how our universe expanded



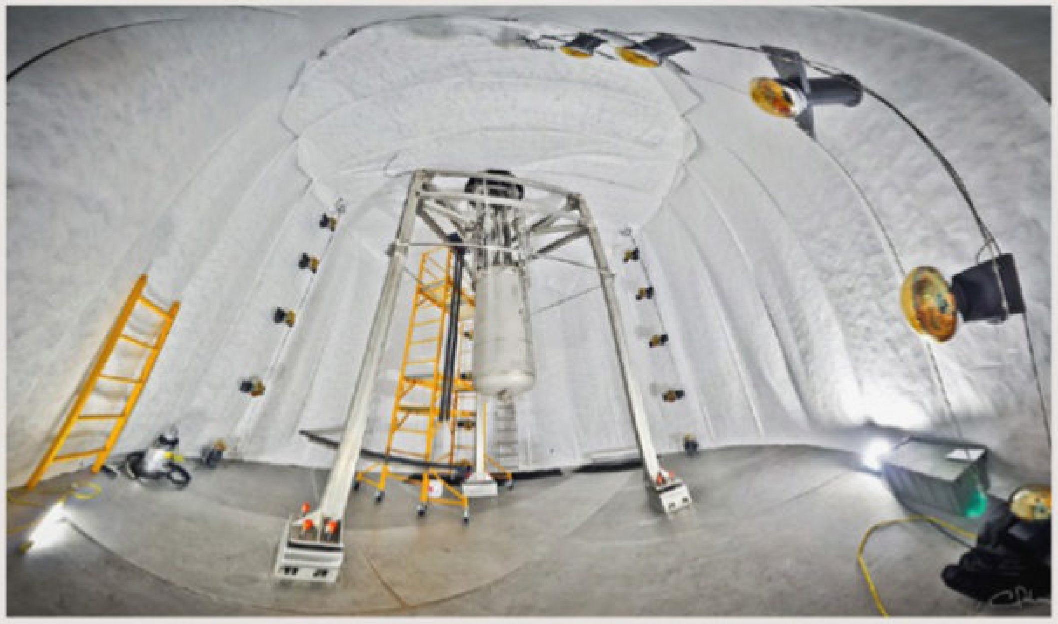
Although dark matter in galaxy clusters typically traces the ordinary matter that radiates light, ZwCl 0024+1652 goes its own way. This massive cluster sports a dark matter ring (in blue) spanning 2.6 million light-years that appears largely divorced from the visible galaxies and gas. NASA/ESA/M.J. JEE (JOHNS HOPKINS UNIVERSITY)

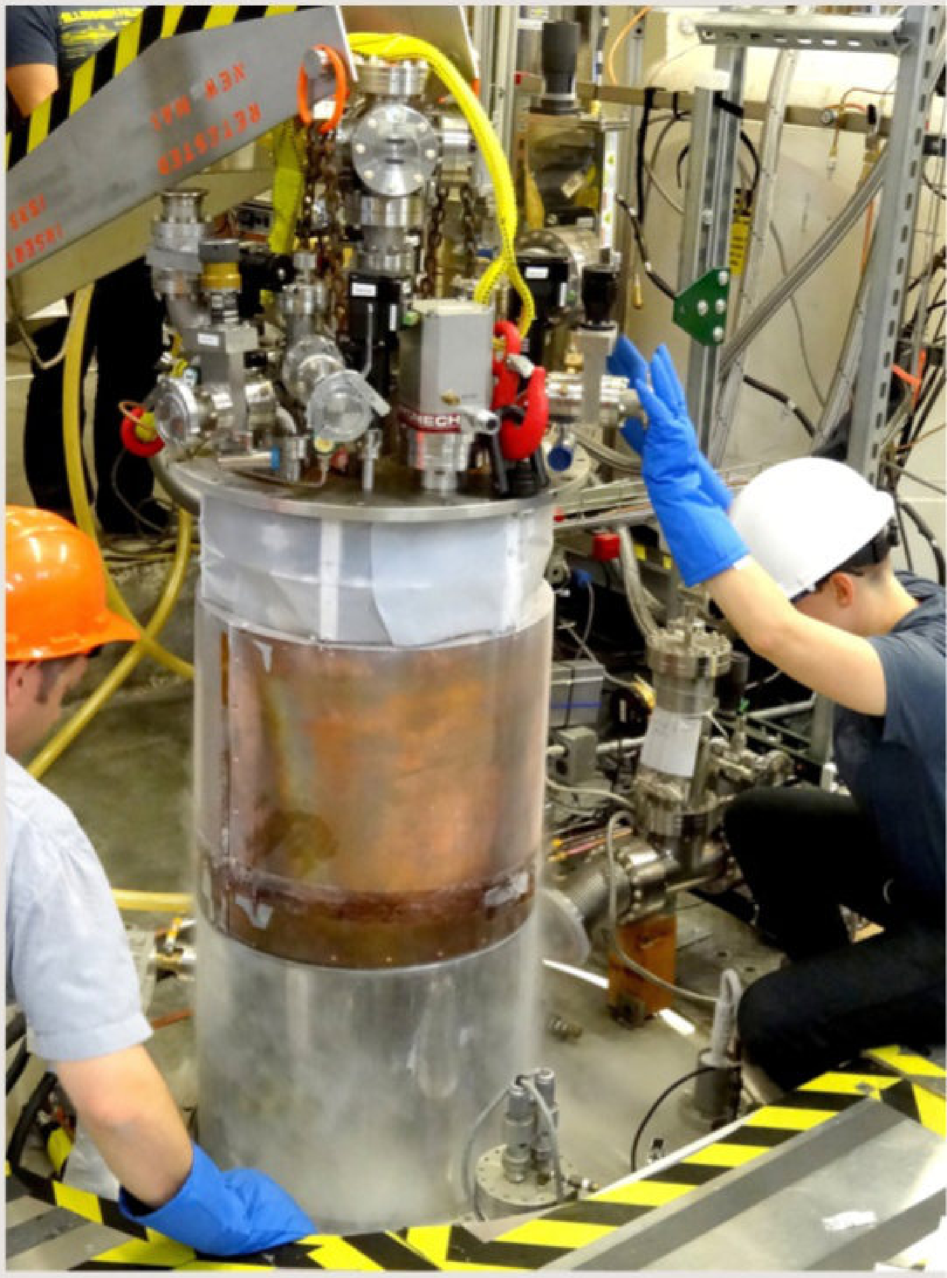
and evolved over most of its history, they know relatively little about the first seconds that followed the Big Bang — and next to nothing about the first trillionth of a second. When it comes to how our universe may have evolved, or to the events that may have taken place during these earliest moments, we have essentially no direct observations on which to rely. This era is hidden from view, buried beneath impenetrable layers of energy, distance, and time.

Our understanding of this period of cosmic history is, in many respects, little more than an informed guess based on inference and extrapolation. Look far enough back in time, and almost everything we know about our universe could have been different. Matter and energy existed in different forms than they do today, and they may have experienced forces that have not yet been discovered. Key events and transitions may have taken place that science has yet to illuminate. Matter likely interacted in ways that it no longer does, and space and time themselves may have behaved differently than they do in the world we know.

With this in mind, many cosmologists have begun to consider the possibility that our failure to detect the particles that make up dark matter might be telling us not only about the nature of dark matter itself, but also about the era in which it was created. By studying dark

## Earthbound experiments on the hunt for dark matter





COUNTERCLOCKWISE FROM TOP LEFT: The IceCube Neutrino Observatory sits under South Pole ice, hunting for cosmic neutrinos. Some of these subatomic particles could come from the decay of weakly interacting massive particles — a prime candidate for dark matter — though none has been detected yet. MARTIN WOLF (ICECUBE/NSF)

The Large Underground Xenon experiment (LUX) attempted to detect interactions between weakly interacting massive particles and 816 pounds (370 kg) of liquid xenon inside this tank. The experiment, which operated from 2013 to 2016 in an old mine in the Black Hills of South Dakota, turned up none of these dark matter particles. A successor, the 7-ton LUX-ZEPLIN, should begin taking data in 2020. CARLOS FAHAM/WIKIMEDIA COMMONS

The Axion Dark Matter Experiment looks for hypothetical axions when they decay into microwaves in the presence of a strong magnetic field. Here, technicians install the superconducting magnet in a lab at the University of Washington. LAMESTLAMER/WIKIMEDIA COMMONS

matter, scientists are learning about the first moments after the Big Bang.

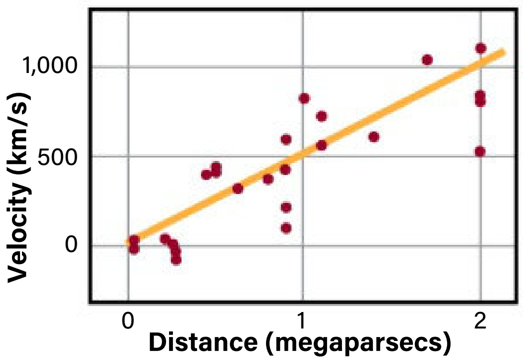
### How fast is space expanding?

In 1929, Edwin Hubble discovered that galaxies are moving away from us at speeds proportional to their distances. This provided the first clear evidence that our universe is expanding. Ever since, the current rate of this expansion — the Hubble constant — has been one of the key properties of our universe that cosmologists study.

It's fair to say that the Hubble constant has long been difficult to measure. Hubble's original determination was plagued with systematic errors that led him to overestimate the expansion rate by a factor of 7. As recently as the 1990s, textbooks often quoted values ranging from as low as 50 to as high as 100 kilometers per second for every million parsecs separating two points in space — usually written as 50 to 100 km/s/Mpc. (One megaparsec [Mpc] equals 3.26 million light-years.) Although the precision of these measurements has improved considerably over the past two decades, no consensus yet exists regarding the correct value for this quantity. In fact, as these measurements have improved, the results from different methods seem to disagree with one another even more.

One way to determine the Hubble constant is to directly measure how fast objects are moving away from us, just as Hubble did in 1929. For his measurements, Hubble used a special class of pulsating stars known as Cepheid variables, whose intrinsic luminosities track nicely with the periods over which they brighten and fade. Modern cosmologists continue to use Cepheids for this purpose, but they also employ other classes of objects, including type Ia supernovae — exploding white dwarfs that all have the same approximate luminosity. When researchers combine the latest data, they find that the universe is currently expanding at a rate of about 72 to 76 km/s/Mpc.

## GALAXIES IN MOTION




Edwin Hubble discovered the expanding universe in 1929, when he first plotted the velocities of individual galaxies relative to their distances. (The line gives the best fit to the data.) Although his estimated distances were a factor of nearly 10 too small, he got the basic relationship right. *ASTRONOMY*: ROEN KELLY, AFTER EDWIN HUBBLE/*PNAS* (MARCH 15, 1929)

But that's not the end of the story. Cosmologists also can infer the value of the Hubble constant by studying the primordial light released when the first atoms formed some 380,000 years after the Big Bang. The detailed temperature patterns of this light — known as the cosmic microwave background — serve as a map that shows how matter was distributed throughout the universe at that time.

When scrutinized, this map reveals many details about our young universe, including how much matter and other forms of energy were present, as well as how fast space was expanding. It also tells us that the Hubble constant is about 67 km/s/Mpc — a significantly smaller value than cosmologists have found through more direct measurements.

What does this mismatch mean for our universe? Assuming that these studies have correctly accounted for all the systematic uncertainties inherent in the observations, these two ways of determining the Hubble constant appear to be incompatible — at least within the context of the standard cosmological model. To make these discrepant results mutually consistent, astronomers would be forced to change how we think the cosmos expanded and evolved, or to reconsider the forms of matter and energy in the universe during the first few hundred thousand years following the Big Bang.

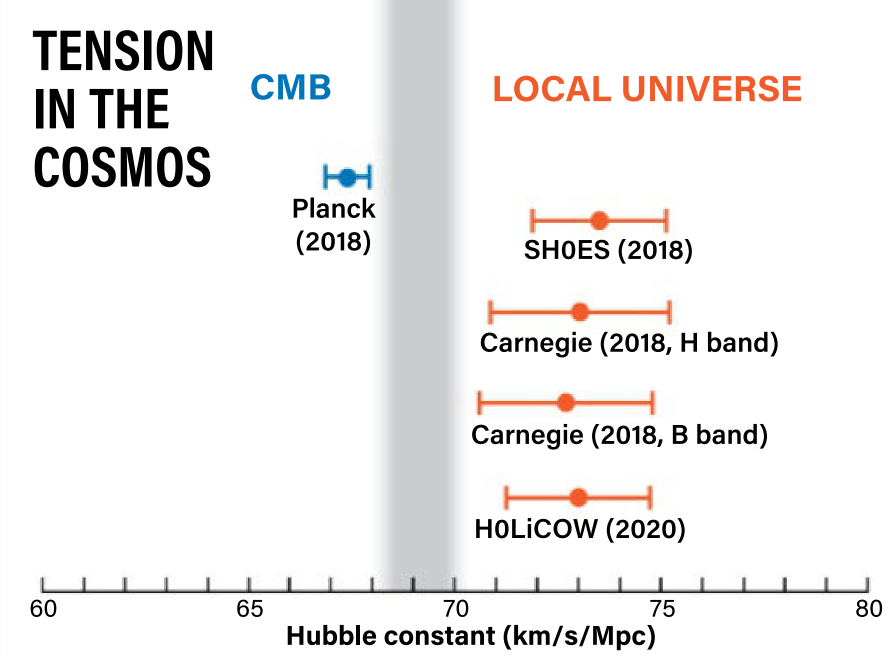
According to Einstein's general theory of relativity, the rate at which space expands depends on the density of

The Antennae Galaxies (NGC 4038 and NGC 4039) are two interacting spirals located 65 million light-years from Earth. Host to many Cepheid variable stars as well as a type Ia supernova, the pair is one of a handful of systems that possess both types of standard candles and thus forge a link between the two. ESA/HUBBLE & NASA

Spiral galaxy NGC 3972 forms a key link in the cosmic distance ladder. The galaxy contains dozens of Cepheid variables, which astronomers use to gauge distances to relatively nearby galaxies, and in 2011 hosted a type Ia supernova, an exploding white dwarf that serves as a vital link to finding distances to more remote galaxies. Scientists need both markers to pin down the Hubble constant. NASA/ESA/A. RIESS (STScI/JHU)

Spiral galaxy MCG+01-38-005 (the lower member of this galaxy pair) harbors a water megamaser — amplified microwave emission from water molecules — orbiting the supermassive black hole at its center. The microwave emission provides an independent way to measure the galaxy's distance and thus helps astronomers refine values for the Hubble constant. ESA/HUBBLE & NASA

A type Ia supernova exploded in the grand design spiral M100 in early February 2006. (The supernova is the brighter of the two stars to the lower right of the galaxy's center.) Supernovae of this type, which arise when a white dwarf accumulates too much mass from a binary companion, all have the same intrinsic brightness and thus make excellent distance indicators. ESO/IDA/DANISH 1.5 M/R. GENDLER, J.-E. OVALDSEN, C.C. THÖNE, AND C. FÉRON



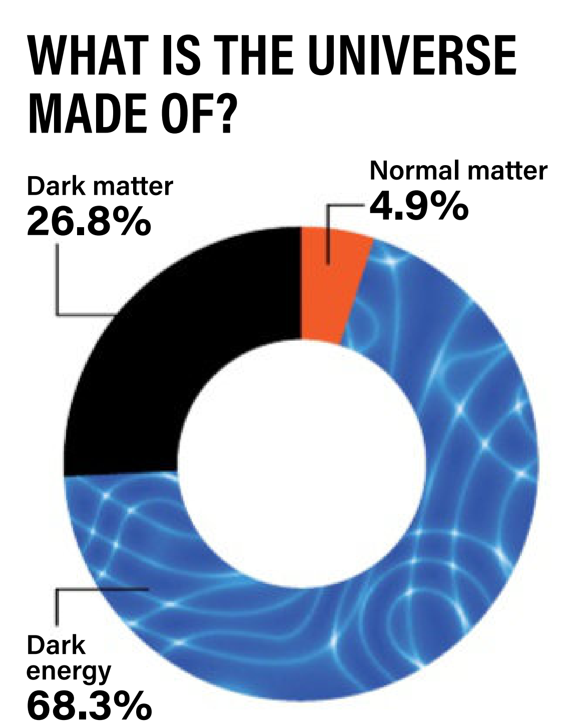

Astronomers have been trying to determine the expansion rate of the cosmos for nearly a century. Although measurements of this so-called Hubble constant have grown more precise over the years, different methods yield different results. Direct observations of relatively nearby galaxies give significantly higher values than those deduced from observations of the cosmic microwave background. *ASTRONOMY*: ROEN KELLY

matter and other forms of energy it contains. When cosmologists infer the value of the Hubble constant from the cosmic microwave background, they have to make assumptions about the amounts of dark matter, neutrinos, and other substances that were present.

Perhaps the simplest way to explain the tension between the different measurements of the Hubble constant would be to hypothesize that the cosmos contained more energy than expected during the first hundred thousand years or so following the Big Bang. This energy might have taken the form of an exotic species of light and feebly interacting particles, or of some kind of dark energy associated with the vacuum of space itself that has long since disappeared from the universe. Or perhaps there is something else we don't understand about this era of cosmic history. We simply do not yet know how to resolve this intriguing mystery.

## Is a revolution coming?

As I said earlier, it's possible that the various puzzles cosmologists face today are little more than a few trivial threads that scientists will tie up nicely in the years ahead with the help of new experiments and observations. But lately, it seems the more we study the universe, the less we understand it. Despite decades of effort, the nature of dark matter remains unknown, and the problem of dark energy seems nearly intractable. We do not know how the particles that make up the atoms in our universe managed to survive the first moments of the Big Bang, and we still know little about cosmic inflation, how it played out, or how it came to an end — assuming that something like inflation happened at all.

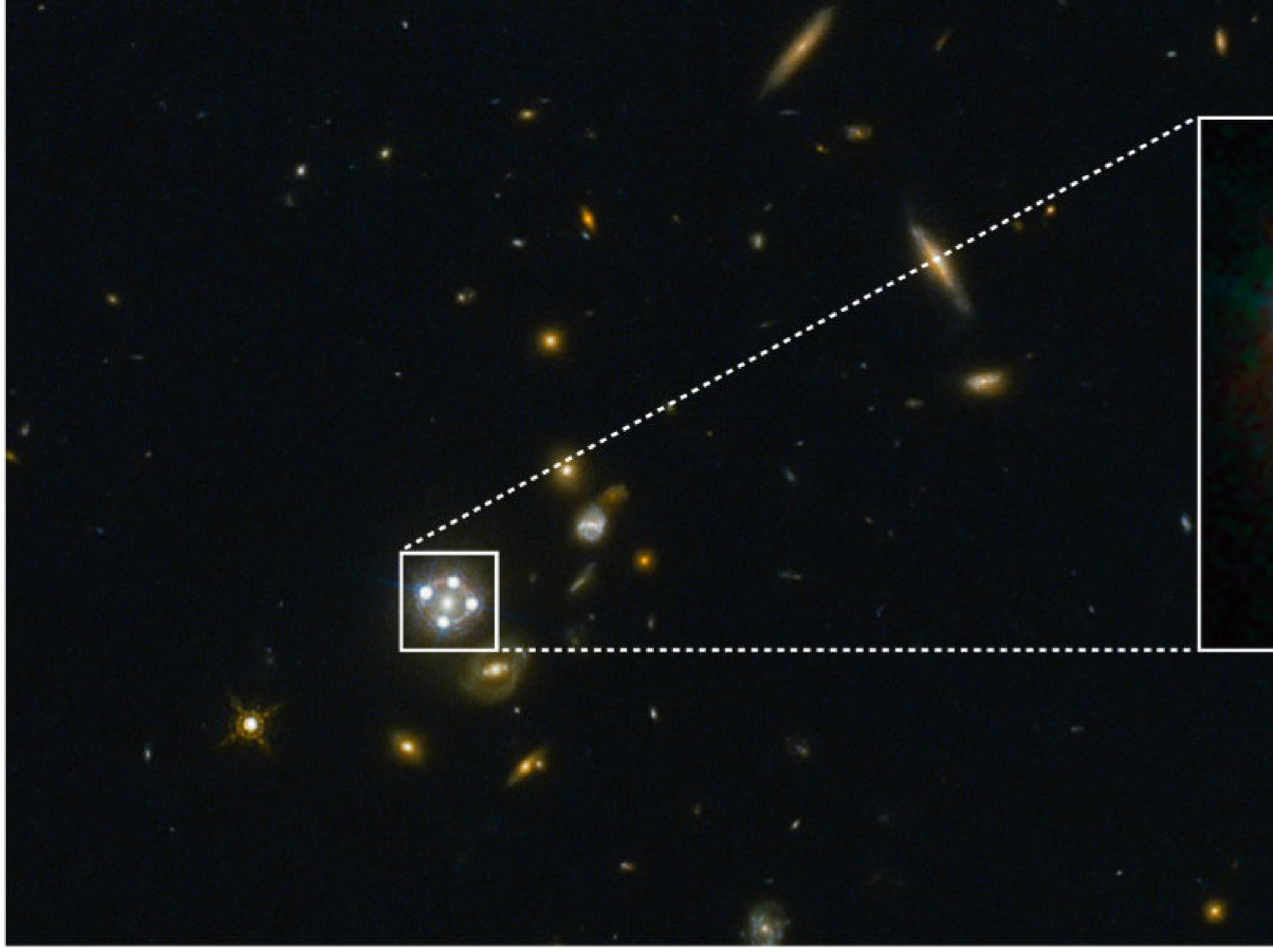
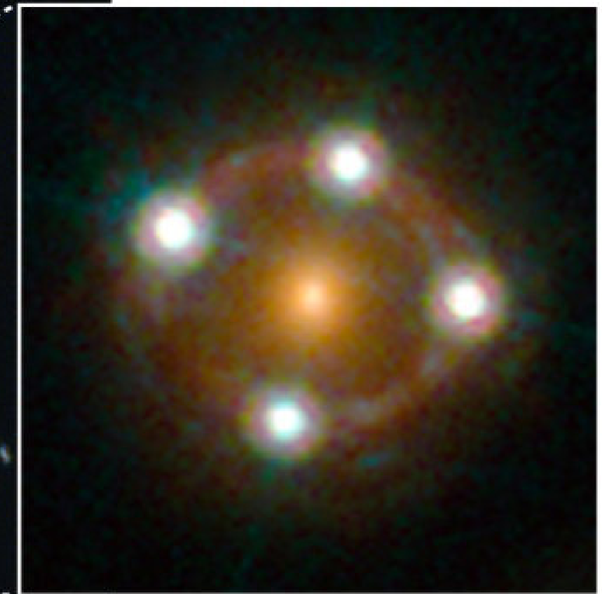



The atoms that make up stars, planets, and people add up to less than 5 percent of the universe's constituents. Invisible dark matter contributes more than five times as much, while the dark energy that powers the accelerating cosmos accounts for more than two-thirds of the total. *ASTRONOMY*: ROEN KELLY

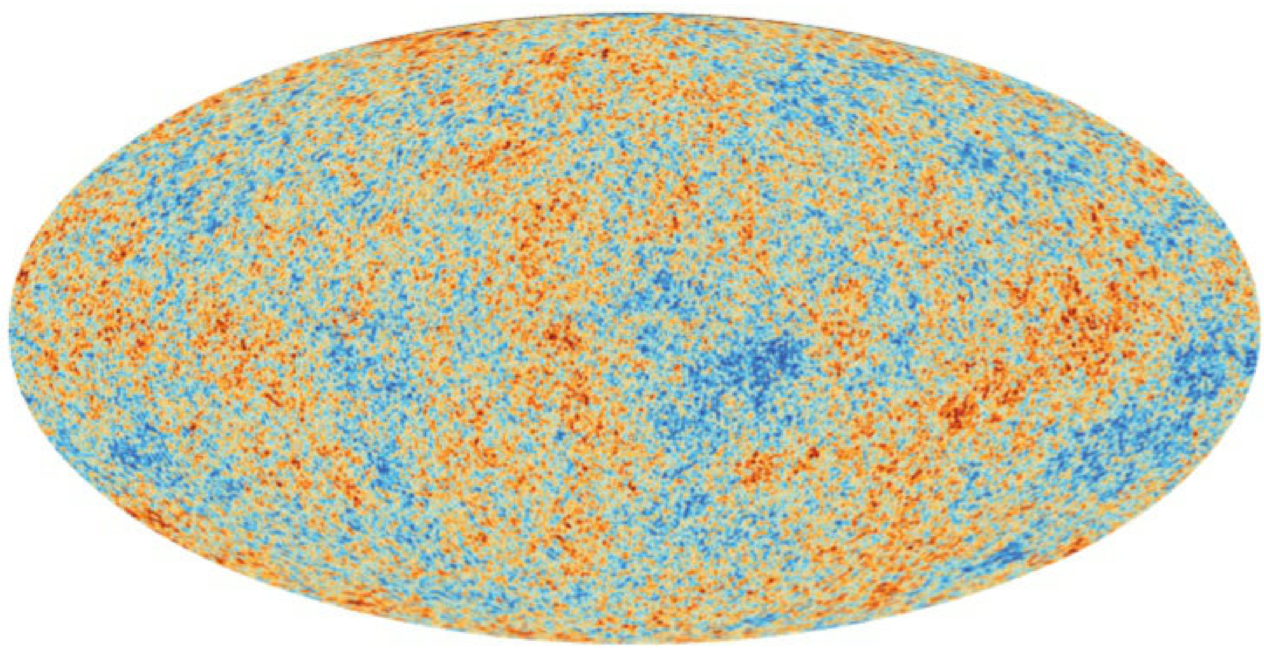
It is from this perspective that I sometimes find myself considering whether these mysteries might represent something greater than a few open and unrelated questions. Perhaps they are telling us that the earliest moments of our universe were far different from what we long imagined them to be. Perhaps these problems represent the beginning of a revolution for the science of cosmology.

Sometimes I wonder whether we might be on a significant precipice of scientific history, similar to what we experienced in 1904. At that time, physics had never before seemed to be on such solid footing. For more than two centuries, the principles of Newtonian physics had been applied successfully to problem after problem. And although physicists expanded their knowledge into areas such as electricity, magnetism, and heat, these aspects of the world were really not so different from those Newton had described hundreds of years earlier. To the physicists of 1904, the world seemed well understood. There was little reason to expect a revolution.

Similar to the situation cosmologists confront today, however, the physicists of 1904 had not yet been able to address a few challenges. The medium through which they believed light traveled — the luminiferous ether — should have induced variations in the speed of light, and yet light always moves through space

The gravitationally lensed quasar HE 0435–1223 offers an independent method for determining cosmic distances. The close-up view reveals the foreground galaxy that creates the four nearly identical images of a more distant quasar. The galaxy lies about 4.8 billion light-years from Earth, while the quasar resides twice as far away. NASA/ESA/HUBBLE/S. SUYU (MPIA) ET AL.



The European Space Agency's Planck satellite has captured the best data on the cosmic microwave background radiation. Combining these results with the standard model describing the universe produces a Hubble constant that is slightly but unequivocally smaller than that gleaned from nearby galaxies. ESA/PLANCK COLLABORATION

at the same rate. Astronomers observed the orbit of Mercury to be slightly different from what Newtonian physics predicted, leading some to suggest that an unknown planet, dubbed Vulcan, might be perturbing Mercury's trajectory.

Physicists in 1904 had no idea what powered the Sun — no known chemical or mechanical process could possibly generate so much energy over such a long time. Lastly, scientists knew various chemical elements emitted and absorbed light with specific patterns, none of which physicists had the slightest idea how to explain. In other words, the inner workings of the atom remained a total and utter mystery.

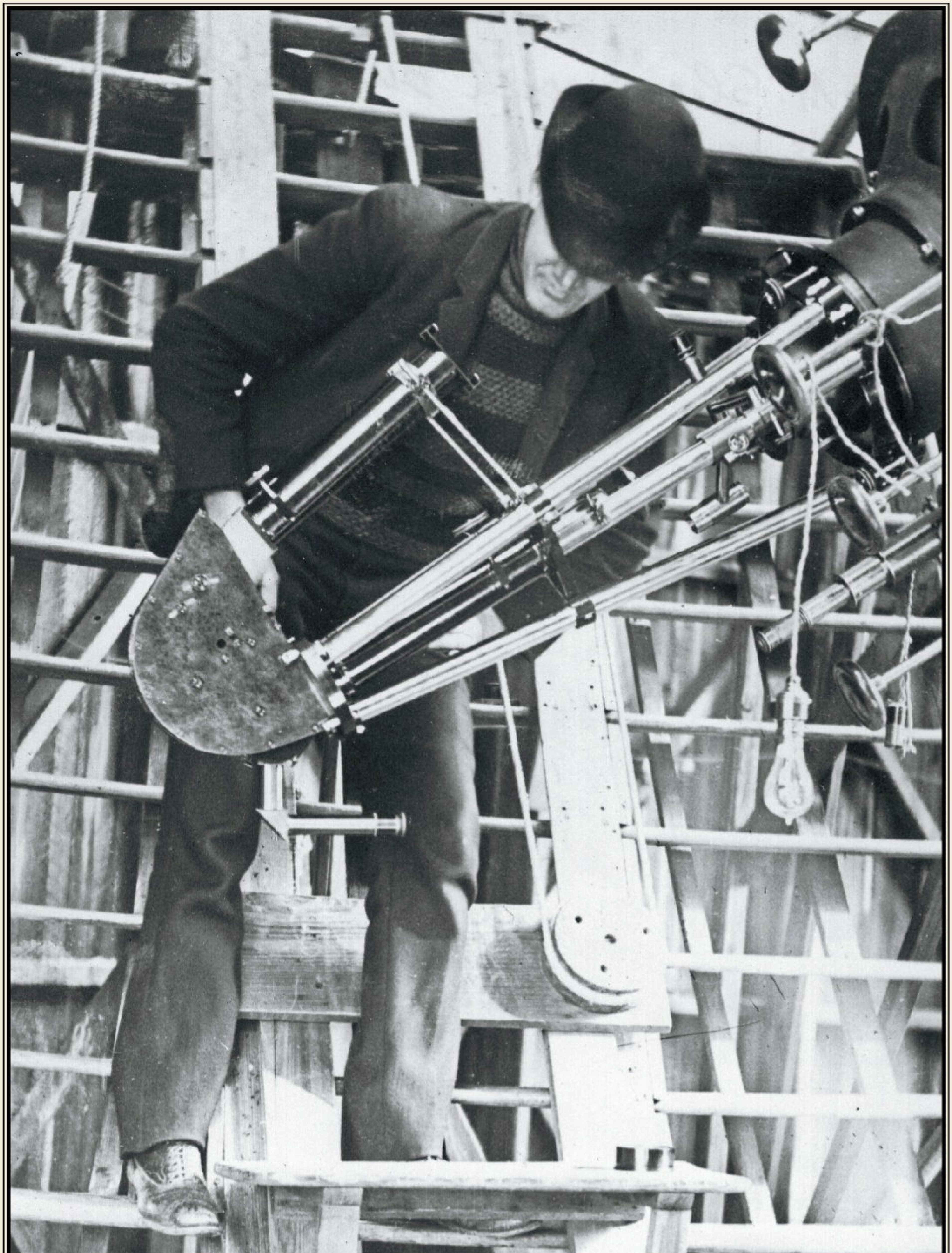
Although few saw it coming, in hindsight, it's clear that these problems were heralds of a revolution in physics. And in 1905, the revolution arrived, ushered in by a young Albert Einstein and his new theory of relativity. We now know that the luminiferous ether does not exist and that there is no planet Vulcan. Instead, these fictions were symptoms of the underlying failure of Newtonian physics. Relativity beautifully solved and explained each of these mysteries without any need for new substances or planets.

Furthermore, when scientists combined relativity with the new theory of quantum physics, it became possible to explain the Sun's longevity, as well as the inner workings of atoms. These new theories even opened doors to new and previously unimagined lines of inquiry, including that of cosmology itself.

Scientific revolutions can profoundly transform how we see and understand our world. But radical change is never easy to see coming. There is probably no way to tell whether the mysteries faced by cosmologists today are the signs of an imminent scientific revolution or merely the last few loose ends of an incredibly successful scientific endeavor.

There is no question that we have made incredible progress in understanding our universe, its history, and its origin. But it is also undeniable that we are profoundly puzzled, especially when it comes to the earliest moments of cosmic history. I have no doubt that these moments hold incredible secrets, and perhaps the keys to a new scientific revolution. But our universe holds its secrets closely. It is up to us to coax those secrets from its grip, transforming them from mystery into discovery.

**Dan Hooper** *is a senior scientist at the Fermi National Accelerator Laboratory in Illinois and a professor of astronomy and astrophysics at the University of Chicago. He is author of* At the Edge of Time: Exploring the Mysteries of Our Universe's First Seconds*.*



# V.M. Slipher's expanding universe

The Lowell Observatory astronomer's revolutionary findings include the expansion of the universe and the discovery of the interstellar medium. BY DAVID J. EICHER

**EDWIN HUBBLE REVOLUTIONIZED ASTRONOMY IN 1923** when he discovered that the "Andromeda Nebula" was actually a distant island galaxy full of stars, gas, and dust. That breakthrough helped set the cosmic distance scale and the overall nature of the cosmos. But fewer astronomy enthusiasts know that a decade before Hubble's discovery, a little-known astronomer at Lowell Observatory in Flagstaff, Arizona, discovered the expanding universe.

## Indiana youth

Vesto Melvin Slipher was born on a farm in Mulberry, Indiana, on November 11, 1875. Invariably known as "V.M. Slipher," he had an unspectacular childhood in the American Midwest, with few details of his youth ever recorded. Certainly growing up on a farm kept Slipher in robust shape. Many years later, astronomers remarked on his ability to climb mountain peaks, staying well ahead of those who were much younger. Slipher had a brother, eight years his junior, Earl C. Slipher, who would also grow up to be an astronomer and work at Lowell Observatory.

But during Slipher's youth, this was all a distant future dream. Slipher graduated from high school, taught briefly at a country school, and then enrolled at Indiana University in Bloomington. One of his professors was Wilbur Cogshall, who had worked as an astronomer at Lowell in 1896 and 1897. Another professor was John Miller, an astronomer who later became director of Sproul Observatory in Pennsylvania. It was Miller who turned Slipher's interests toward the heavens and Cogshall who introduced him to the idea of moving west to work at an observatory.

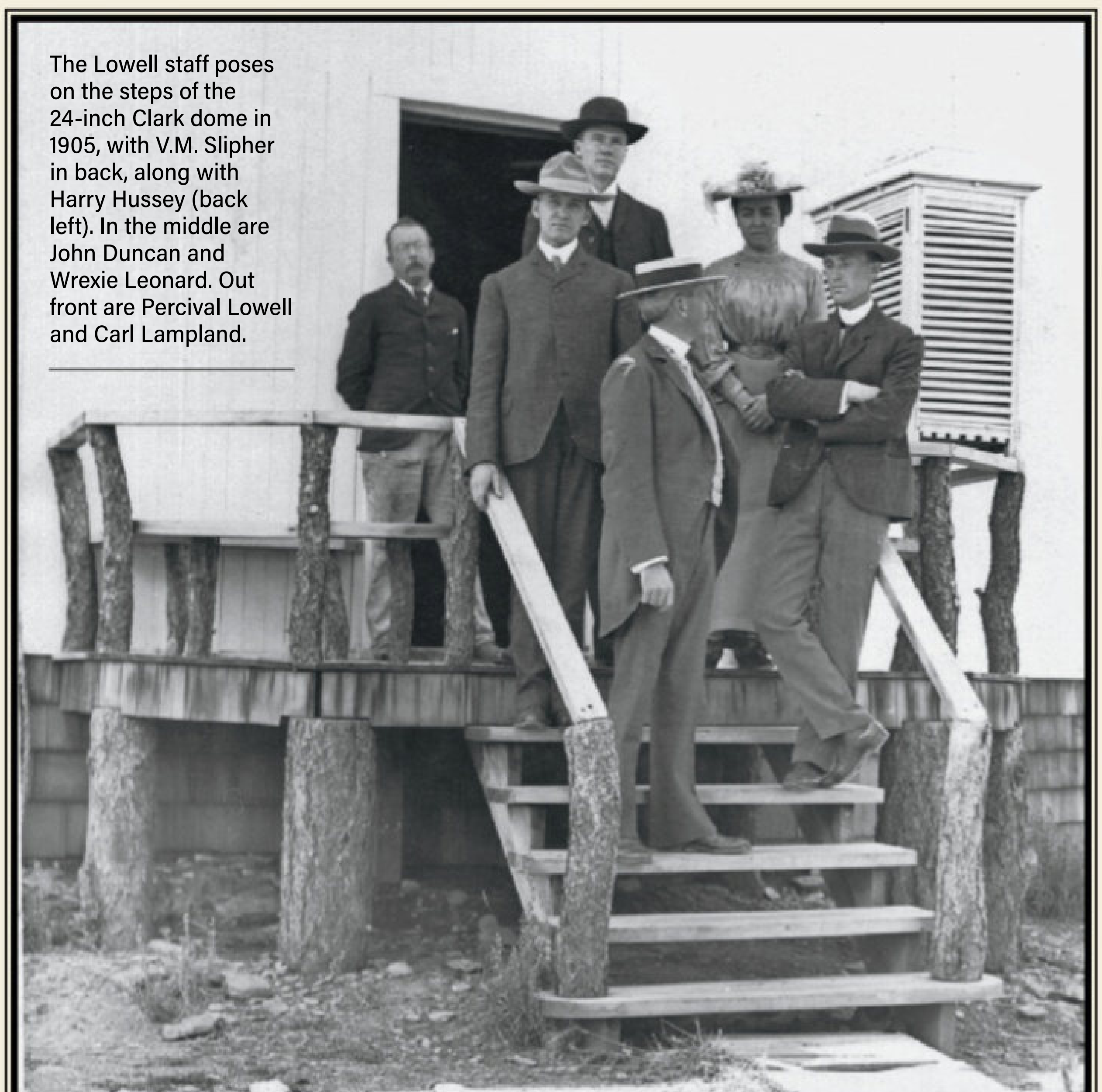
## Called to the West

At the time, Lowell Observatory was a fledgling institution less than a decade old, overseen by its founder, the wealthy Boston adventurer-scientist Percival Lowell.

At first, Lowell was reluctant to seek Slipher's help, but Cogshall persuaded him to bring on the young astronomer. The year was 1901, and as far as Lowell was concerned, the association would be temporary. In the end, however, Slipher would stay at the observatory for 53 years. In 1915, he became assistant director, and when Lowell died the following year, Slipher became acting director and then director by 1926. He served as the observatory's chief until retiring in 1954 at age 79.

This iconic image of V.M. Slipher shows the astronomer with his famous spectrograph on the 24-inch Clark telescope, with which he discovered the expanding universe and the interstellar medium. ALL PHOTOS: LOWELL OBSERVATORY

Revolutionary astronomer V.M. Slipher (third from left) sits inside the 24-inch Clark refractor dome at Lowell Observatory in 1905 with Harry Hussey, Wrexie Leonard, Percival Lowell, Carl Lampland, and John Duncan.



The Lowell staff poses on the steps of the 24-inch Clark dome in 1905, with V.M. Slipher in back, along with Harry Hussey (back left). In the middle are John Duncan and Wrexie Leonard. Out front are Percival Lowell and Carl Lampland.

Slipher's astronomical studies went in several simultaneous directions. Shortly after his arrival in 1901, the observatory received a state-of-the-art spectrograph made for the 24-inch Clark refractor, the institution's main instrument. By 1902, Slipher had worked out the bugs with this tricky piece of equipment and made some spectrograms of Mars, Jupiter, and Saturn worthy of sharing with the astronomical community. His own work focused on radial velocities of stars and the discovery of binary stars by measuring shifts in the spectra of the visible component.

Slipher began to use this spectrograph exhaustively. He studied planetary atmospheres, such as that of Mars, and examined the rotation period of Venus. He also studied the spectra of the giant outer planets Uranus and Neptune. Attempting to determine the rotation periods and detection of various substances — such as chlorophyll on Mars — took up much of his research.

**The discovery of matter among the stars of the Pleiades was a big one. This put Slipher on the map, with a legitimate claim to a major discovery in astrophysics.**

During his time spent on planetary research, Slipher also managed to keep investigating spectroscopic binary stars. His work here led to a major breakthrough, hailed by astronomers as a milestone. He found that certain spectral lines in the otherwise blurred spectra of some stars were sharp and stationary, and noted this phenomenon in a variety of stars in Scorpius, Perseus, and Orion. From this he concluded in 1909 that interstellar gas must exist in widely separated regions of space, producing what he called "selective absorption of light in space." Some astronomers congratulated Slipher for this conclusion, but many others ignored the findings for a long time. Observations in the 1920s would finally prove Slipher correct.

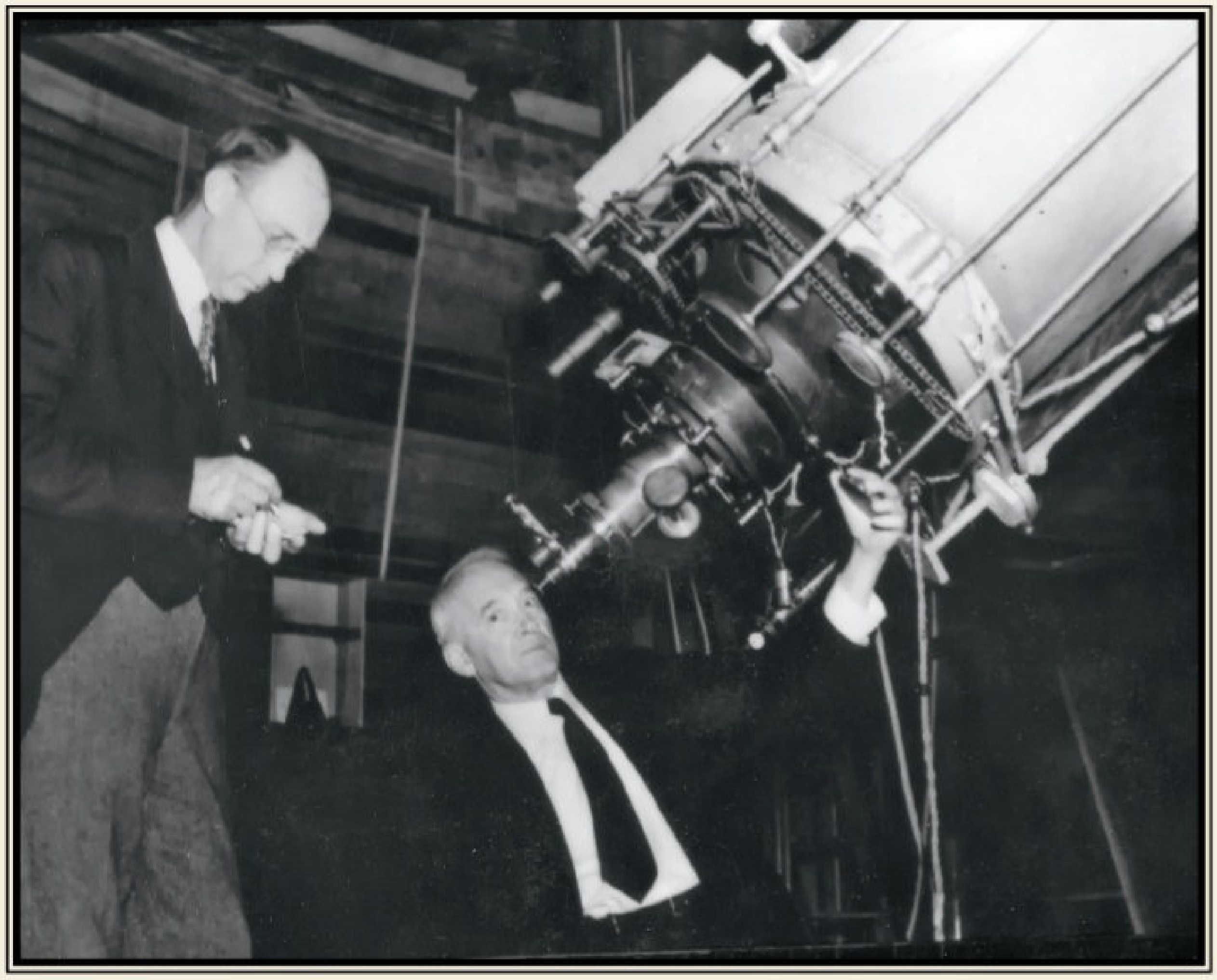
Moreover, in December 1912, Slipher used the spectrograph to discover the presence of dust — or "pulverulent matter," as he termed it — between the stars of the famous Pleiades Cluster. Proving that the dust near the star Merope in this cluster was shining only by reflected light demonstrated the existence of stuff between the stars; that stuff came to be called the interstellar medium.

## The breakthrough

The discovery of matter among the stars of the Pleiades was a big one. This put Slipher on the map, with a legitimate claim to a major discovery in astrophysics. He then turned toward solving the biggest mystery of the age, the nature of so-called spiral nebulae. These numerous, faint, diffuse objects had remained mysterious for a century and a half. The German natural philosopher Immanuel Kant had suggested they were separate, large "island universes" of matter as early as 1755. But the evidence of their nature

LEFT: The Slipher and Lampland families roll out in the Lowell Stevens-Duryea car, with Verna Lampland, Emma Slipher, and Marcia Slipher in the back seat, and V.M. Slipher (driving), David Slipher, and Carl Lampland in the front seat.

BELOW: V.M. Slipher made this image of a solar eclipse expedition at Syracuse, Kansas, in 1918.



V.M. Slipher (bottom) accompanies Carl Lampland at the business end of the 24-inch Clark refractor, in an undated image.

**Although Slipher was a cautious thinker, he adopted some of the more aggressive and controversial ideas of his employer, Percival Lowell, throughout the early part of his career.**

was slow in coming. Some thought they were within the Milky Way, embryonic planetary systems in their early stages of formation.

In 1909, Slipher began recording spectra of spiral nebulae, urged on by Lowell, who thought they might show spectral similarities to our solar system. This task was difficult, however, because these objects were faint. Nonetheless, Slipher consulted with astronomers at other observatories and experimented with equipment, including faster lenses and observing techniques that might minimize the difficulty.

In the fall of 1912, Slipher recorded a plate of the "Andromeda Nebula" that he felt was sufficiently good to obtain its radial velocity. No radial velocities of nebulae were known at that time. He recorded better plates in November and December 1912, and still a better result on the nights of December 29, 30, and 31, and into the predawn hours of New Year's Day 1913. He measured the plates over the first half of January, finding that the nebula was moving three times faster than any previously known object in the universe.

Confusion ensued, and Slipher spent more time measuring the plates. On February 3, 1913, he wrote to Lowell that the Andromeda Nebula was approaching Earth at the unheard-of velocity of 186 miles per second (300 kilometers per second), still an accurate value. "It looks as if you had made a great discovery," wrote Lowell. "Try some other spiral nebulae for confirmation."

Slipher next went after what we now call the Sombrero Galaxy (M104) in Virgo. He found its spectral lines shifted far toward the red, indicating that it is receding from Earth at 620 miles per second (1,000 km per second). By the 1914 American Astronomical Society meeting in Evanston, Illinois, Slipher was able to announce results for 15 spirals. Nearly all were receding at high velocities. Three years later, Dutch astronomer Willem de Sitter theorized that the universe is expanding. It was Slipher's observations of the so-called spiral nebulae that established this fact.

## Slipher's varied work

In addition to discovering that the spiral nebulae were receding at great velocities, Slipher found that radial motions existed within the spiral nebulae themselves. That is, they were rotating. These first discoveries again included what we now know as the Andromeda and Sombrero galaxies. This finding contradicted what astronomer Adriaan van Maanen of Mount Wilson Observatory had reported earlier, that the spiral arms of these objects were unwinding. This would suggest they were close and not at great distances, or such a detection would be impossible.

As with many aspects of astronomy, debates ensued, and most astronomers took the side of van Maanen rather than Slipher. Another decade passed before the realization came that Slipher was right and van Maanen wrong. By the end of World War I, other astronomers reinforced Slipher's work on spiral nebulae with their own observations, and the tide of belief began to turn. And then in 1923 came Hubble's discovery of the nature of galaxies. By 1929, Hubble derived his crucial velocity-distance relationship for galaxies, using, as Hubble wrote Slipher, "your velocities and my distances." Slipher and Hubble had together uncovered the expanding universe, the nature of galaxies, and a way to measure extragalactic distances.

Slipher also conducted critical work on aurorae and on the phenomenon known as sky glow, the brightness of the night sky. He turned to these areas in part because he had mostly exhausted the research capability of the 24-inch

ABOVE: In 1947, V.M. Slipher (left) poses with Carl Lampland in front of the Lowell Observatory administration building.

TOP RIGHT: In 1955, during the centennial celebration of Percival Lowell's birth, V.M. Slipher (left) and Stanley Sykes lay a wreath on Lowell's tomb.

RIGHT: V.M. Slipher (right) and Al Wilson pose in Lowell Observatory's reading room about 1955.

Clark telescope for further studies of nebulae. Before World War I was finished, he studied spectral lines in aurorae and found a "permanent aurora." By this, he meant that the night sky was not absolutely dark. He discovered many new features in the spectrum of the sky, revealing ionized elements in Earth's upper atmosphere. Later, in the mid-'30s, Slipher extended his analyses of the sky to the zodiacal light, studying that glow from dust particles in the plane of the solar system.

In addition, Slipher led two eclipse expeditions, in 1918 to Syracuse, Kansas, and in 1923, to Ensenada, Mexico. He also made spectral studies of unusual objects like the Crab Nebula, Hubble's Variable Nebula, and the unusual nebula NGC 6729. He supervised the search for a new outer solar system planet, bringing on board Clyde Tombaugh, a young Kansas farm boy, who would in 1930 find Pluto.

Although Slipher was a cautious thinker, he adopted some of the more aggressive and controversial ideas of his employer, Percival Lowell, throughout the early part of his career. He did not question the possibility of life on Mars, and believed that the cosmos contained millions of planets that could support some sort of life.

But Slipher will be remembered for his discoveries relating to spiral nebulae and the expanding universe. When he received the Royal Astronomical Society's Gold Medal in 1933, the president said: "In a series of studies of the radial velocities of these island galaxies he laid the foundation of the great structure of the expanding universe. ... If cosmogonists today have to deal with a universe that is expanding in fact as well as in fancy, at a rate which offers them special difficulties, a great part of the blame must be borne by our medalist."

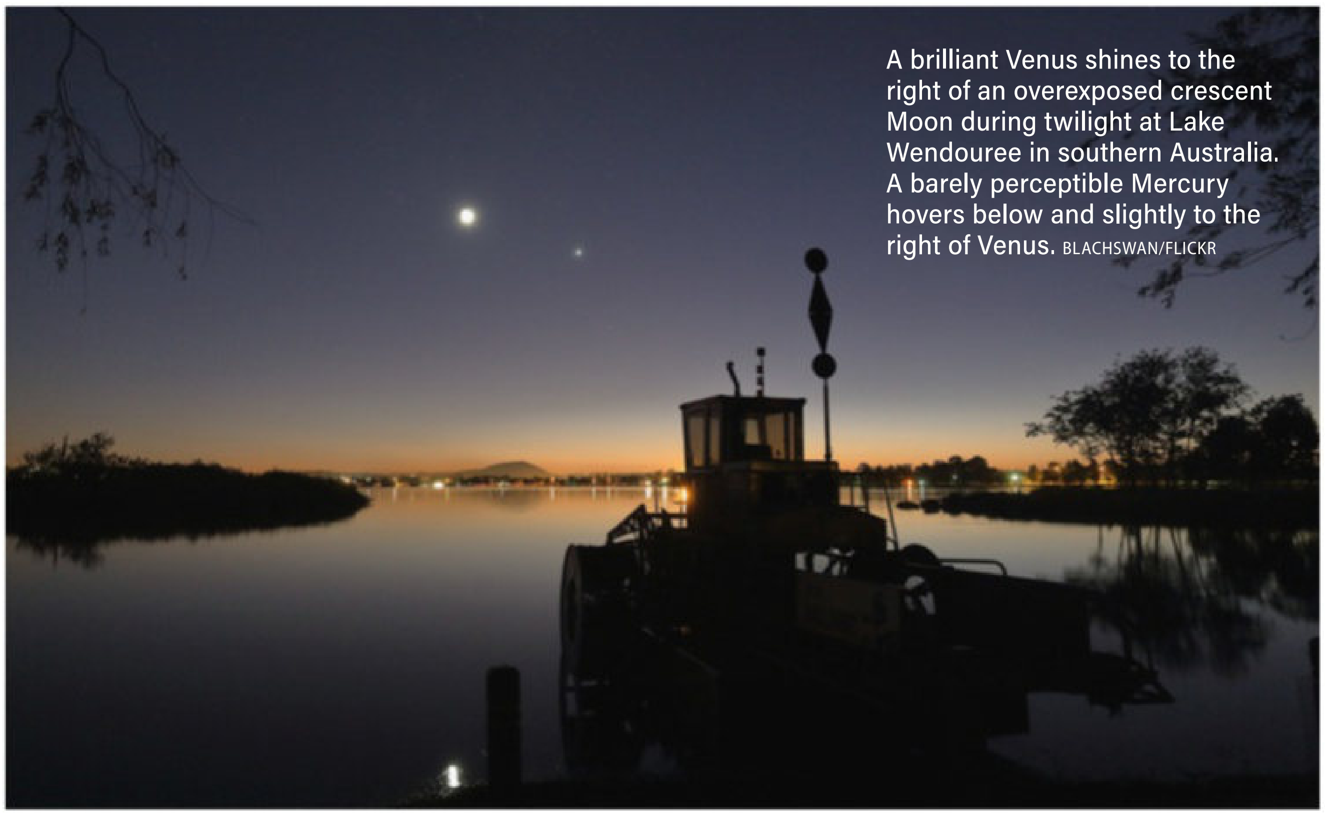
When it comes to the expanding universe, the rotation of galaxies, the discovery of the interstellar medium, important studies of aurorae and sky glow, and other areas, we should not forget the name V.M. Slipher. Edwin Hubble helped us define galaxies. His associate Slipher gave us universal expansion, a concept that governs the mighty cosmos.

**David J. Eicher** *is editor of* Astronomy *and the author of 23 books on science and history.*

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

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
**BY MARTIN RATCLIFFE AND ALISTER LING**

# MAY 2020 Venus meets Mercury



A brilliant Venus shines to the right of an overexposed crescent Moon during twilight at Lake Wendouree in southern Australia. A barely perceptible Mercury hovers below and slightly to the right of Venus. BLACHSWAN/FLICKR

Whether you prefer evening or morning observing — or both — May has you covered. Venus and Mercury appear in the night sky this month, offering fine views during evening twilight. Meanwhile, the morning sky holds the magnificent trio of Jupiter, Saturn, and Mars. All three planets are improving as they approach their respective oppositions later this year, which results in larger disks when viewed with a telescope. But first, let's begin with the inner planets in the evening sky.

**Venus** is the brilliant beacon hanging in the western sky soon after sunset. Shining at magnitude –4.7, it dazzles near the northern horn of Taurus the Bull. During the first week of May, the Hyades and Pleiades sit low near the horizon before disappearing in twilight. Look west an hour after sunset to catch these open clusters before low altitude fades them.

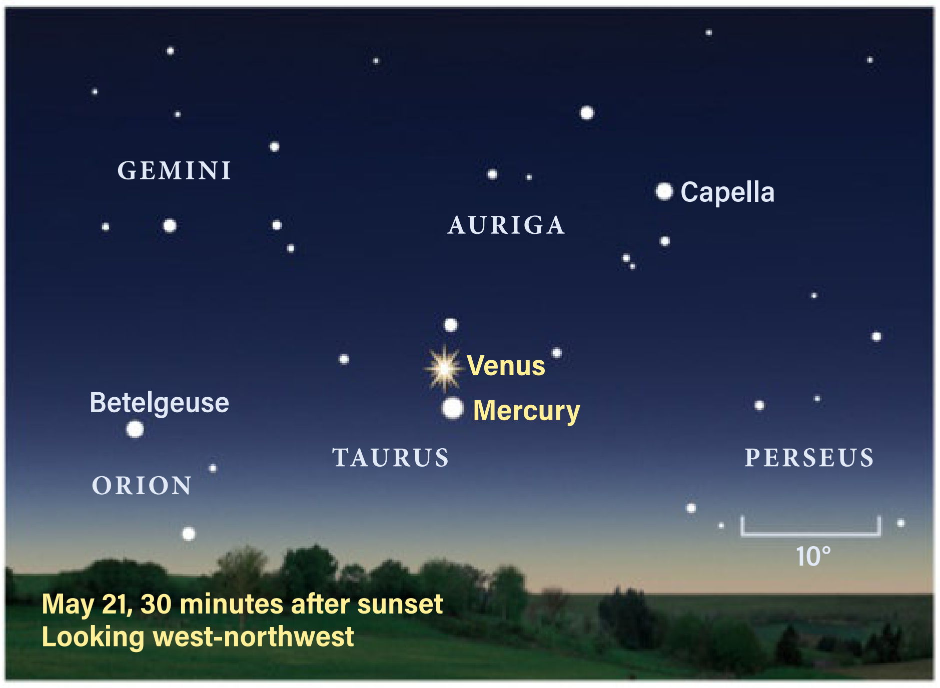
Venus sits 37° east of the Sun on May 1, and stands 23° above the western horizon an hour after sunset. Its beautiful, 24-percent-lit crescent disk spans 39" when viewed through a telescope. The world maintains a reasonable altitude through the middle of May as its separation from the Sun diminishes. And on May 16, it stands 11° high an hour after sunset. By then, the disk of Venus has grown to 50" wide, but it's even more slender, just a 10-percent-lit crescent. As the month presses on, Venus rapidly descends deeper into twilight and its altitude falls as it nears June's inferior conjunction.

However, there's one more event that observers may want to catch: a conjunction with Mercury, which is moving on the far side of the Sun in the opposite direction of Venus. **Mercury** passes through superior conjunction May 4 and reaches conjunction with Venus on May 21/22. Their closest approach occurs during the early morning of May 22, so the best time for U.S. observers to target the pair is on the previous evening, May 21, when they stand slightly more than 1° apart one hour after sunset. At this point, Mercury shines at magnitude –0.6 and Venus at magnitude –4.4.

Telescopic views of Mercury reveal a tiny 6"-wide disk that's 69 percent lit. This vividly contrasts with the Venusian crescent, which spans 53" as a 6-percent-lit crescent. Within days, Venus descends out of view. But at the same time, Mercury climbs higher along the ecliptic, making it relatively easy to spot the rest of the month. Look to the west-northwest in a clear sky May 31 to find the innermost planet hovering 8° high an hour after the Sun goes down, shining at magnitude 0.1.

**Jupiter** rises close to 2 A.M. across mid-northern latitudes May 1, and by May 31, it is up by midnight. Look for the gas

### The innermost planets share the evening sky




The innermost planets stand only about 1° apart above the west-northwestern horizon shortly after sunset May 21. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

## OBSERVING HIGHLIGHT

**VENUS** and **MERCURY** cross paths this month, and they stand just 1° apart an hour after sunset May 21.

giant rising above the southeastern horizon as Altair in the Summer Triangle reaches an altitude of 20°. Saturn rises 20 minutes later, standing less than 5° from Jupiter.

Jupiter begins the month at magnitude –2.3 and brightens to –2.6 by May 31. Saturn glows at magnitude 0.6 in early May before brightening by 0.2 magnitude by May 31. Both planets slow their eastern track against the background stars as the month goes on, with Saturn reaching its stationary point May 11 and Jupiter May 14.

The beautiful pair remain less than 5° apart all month, straddling the border of Sagittarius and Capricornus. Check out the field of view with binoculars — can you spot the dim (magnitude 9.5) globular cluster M75 forming an isosceles triangle with the planetary duo? It lies less than 2° south of a line between the two planets. A waning gibbous Moon stands 3° south of Jupiter on the morning of May 12.

Thanks to Jupiter's southerly declination, it remains at a relatively low altitude for the rest of the year. It reaches its highest elevation of about 30° above the southern horizon (depending on your latitude) during morning twilight, when it's located in eastern Sagittarius. Jupiter is just two months away from

*— Continued on page 42*

## RISING MOON | Cracks, craters, and domes

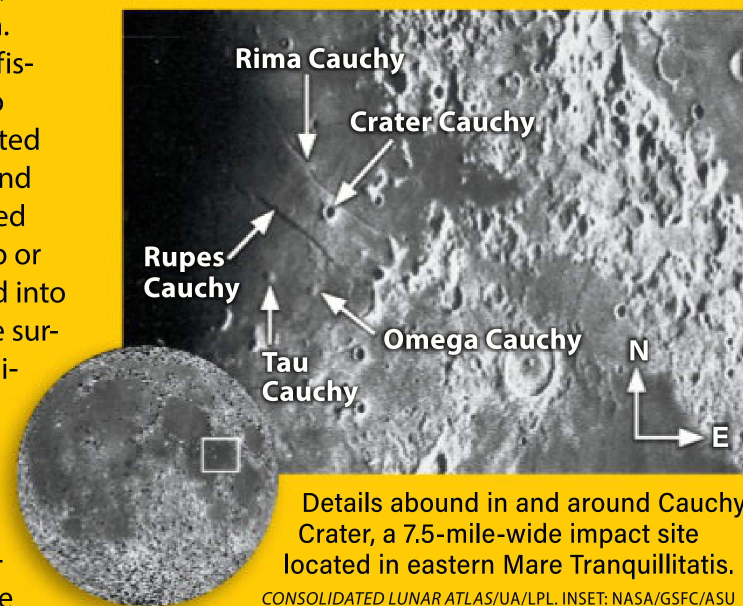
**TODAY'S SEA OF TRANQUILLITY** was once quite untranquil. It began 4 billion years ago, when a giant impact excavated a large basin. Millions of years later, lava erupted through fissures in the basin floor. The cracks tended to be oriented along stress lines that were created by other large impacts. During a second round of upwelling lava, the terrain unevenly heaved from below, causing the formation of a scarp or fracture. In other places, lava tubes collapsed into rilles. Nearby, some volcanoes made it to the surface, but the failed ones created domes. Mini-asteroids that slammed into the surface millennia later added the final touch of texture.

On May 26, roughly four days after New Moon, the Sun rises on the fascinating region of crater Cauchy, just north of the terminator's midpoint. The terminator is the line that divides lunar day and night, but at such a young age, the dark face of our sister Luna might be modestly lit by the gray glow of earthshine, which is sunlight reflected from Earth's dayside.

Crater Cauchy itself is a modestly small, 7.5-mile-wide, simple impact feature with nice, sharp edges that reveal its relative youth. Immediately to Cauchy's north is a prominent rille named Rima Cauchy, where years of tiny impacts have softened its edges. Within a couple of Earth days, the higher angle of the Sun shines light directly into the rille, wiping out the shadows and making it all but invisible. South of Cauchy is a prominent fault scarp called Rupes Cauchy, which lies parallel to the rille. Well known to lunar aficionados, the fault is second only to the famous Straight Wall. When the Sun rises over the region, the scarp casts a sharp shadow westward, but the dark line disappears a couple of Earth evenings later.

As an added bonus for this region, a pair of lava domes sit at the edge of Mare Tranquillitatis. Look for the small, light-dark pairing caused by these hills protruding up in the sunlight. The eastern dome, cataloged as Omega, is likely a shield volcano, while the western one, Tau, appears to have been formed by uplifting from below.

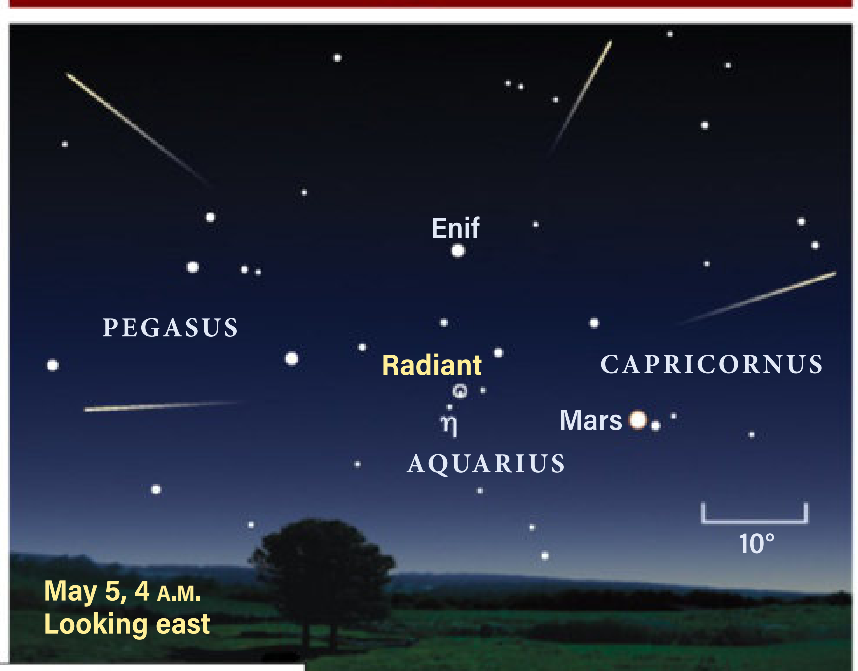
### Crater Cauchy and its companions




Details abound in and around Cauchy Crater, a 7.5-mile-wide impact site located in eastern Mare Tranquillitatis.
CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

## METEOR WATCH | Comet Halley returns to Earth's sky

### Eta Aquariid meteor shower




Partly due to the low altitude of the Eta Aquariids' radiant when viewed from northern latitudes, the shower is not considered one of the year's best. But with Mars hovering in the nearby sky this year, it's worth taking the time to view it.

**ETA AQUARIID METEORS**

**Active dates:** April 19–May 28
**Peak:** May 5
**Moon at peak:** Waxing gibbous
**Maximum rate at peak:** 10 meteors/hour

**MAY'S MAIN METEOR SHOWER** is heavily affected by a nearly Full Moon that remains visible most of the night. The Eta Aquariids is one of two showers associated with Halley's Comet, which has spent eons littering its path with debris that results in the yearly shower (the Orionids in October is the other).

The Aquariids sport a maximum observable rate of about 10 meteors per hour under perfectly dark skies. However, with a bright Moon present, you'll be lucky to spot five streaks per hour in most urban locations. The first few days of May after the Moon sets (4 A.M. on May 2) is a good time to catch the few early shower members streaking through the sky. A New Moon on May 22 offers dark skies for viewing sporadic meteors, as well as the occasional straggler of the Eta Aquariid shower.

# STAR DOME

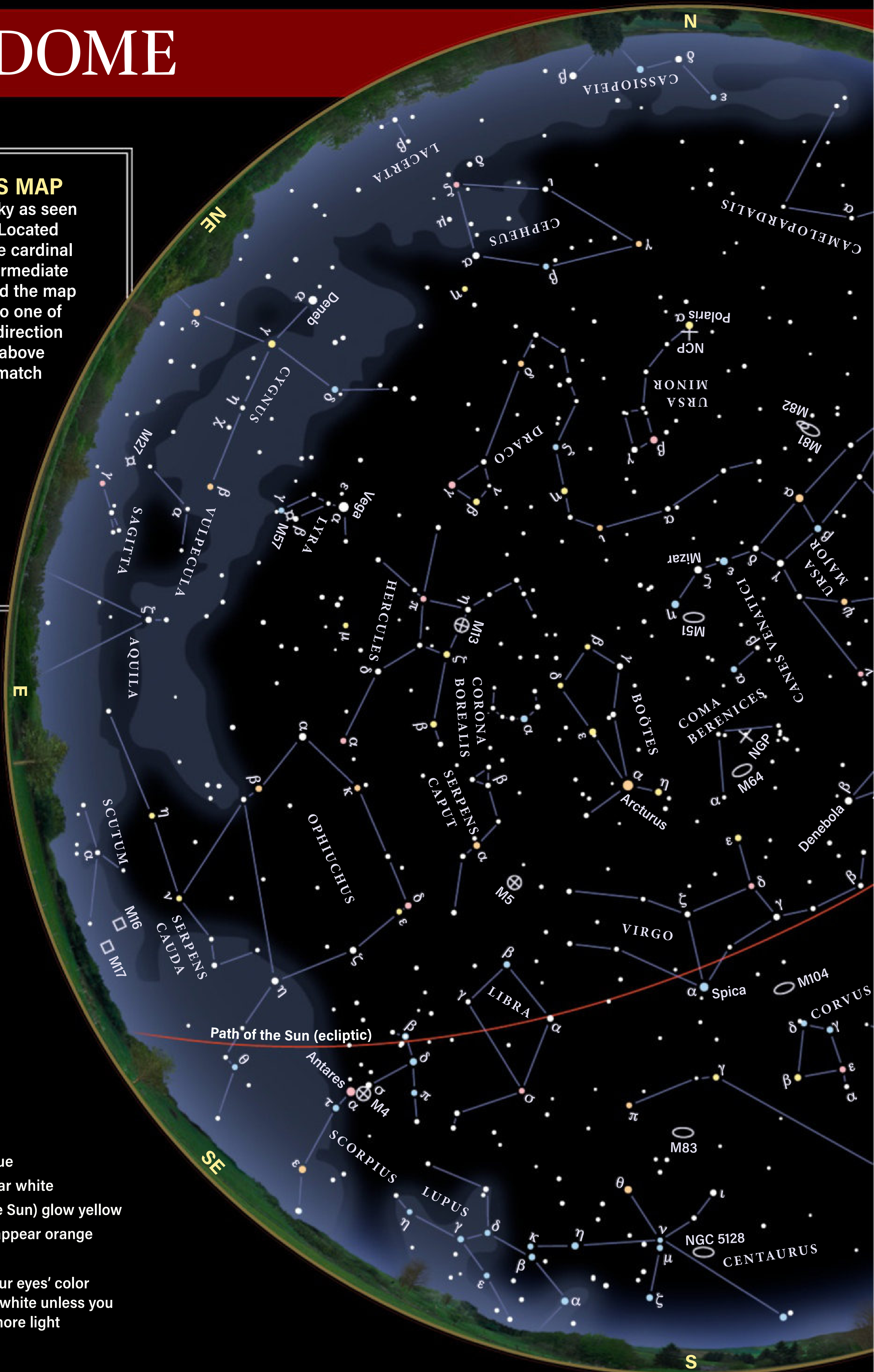
## HOW TO USE THIS MAP

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

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

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

Planets are shown at midmonth




## MAP SYMBOLS

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

## STAR MAGNITUDES

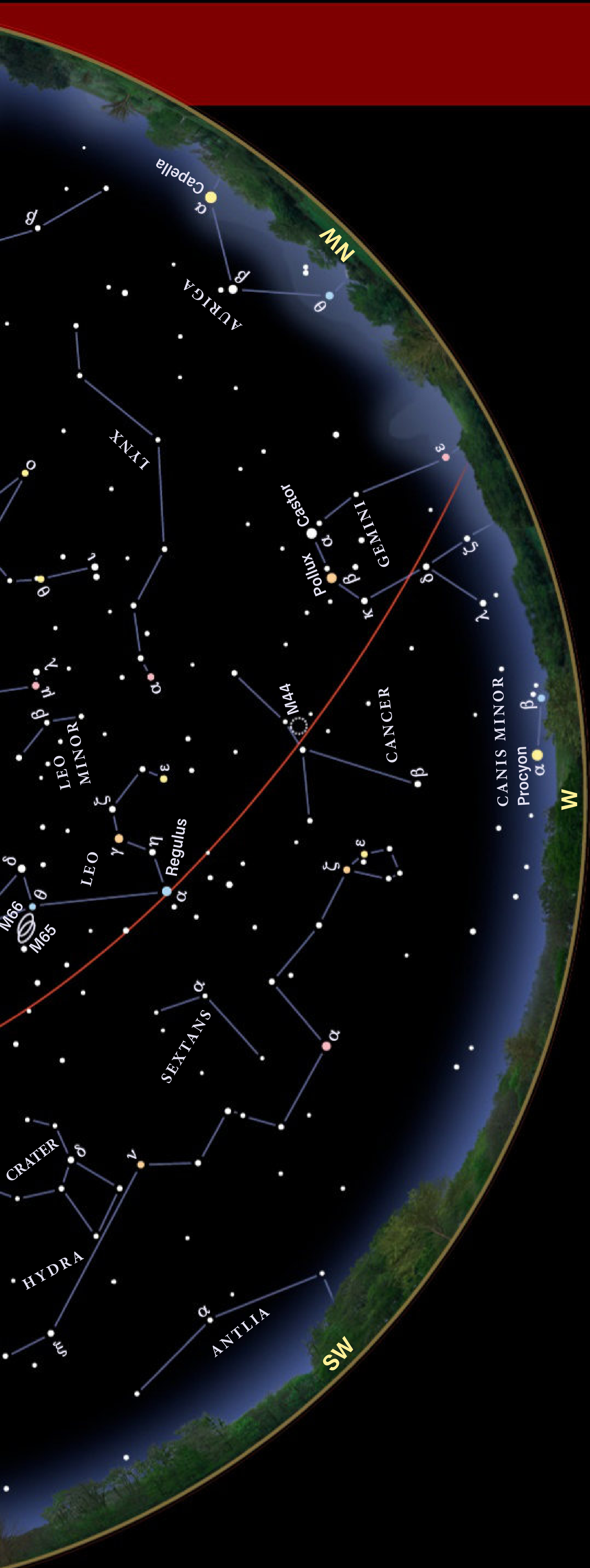
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

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

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




# MAY 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 |
| 31 | | | | | | |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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

## CALENDAR OF EVENTS

**4** Mercury is in superior conjunction, 6 P.M. EDT

**5** Eta Aquariid meteor shower peaks

The Moon is at perigee (223,478 miles from Earth), 11:03 P.M. EDT

**7** Full Moon occurs at 6:45 A.M. EDT

**11** Saturn is stationary, 5 A.M. EDT

Asteroid Pallas is stationary, 7 A.M. EDT

**12** The Moon passes 2° south of Jupiter, 6 A.M. EDT

The Moon passes 3° south of Saturn, 2 P.M. EDT

**13** Venus is stationary, 6 A.M. EDT

**14** Last Quarter Moon occurs at 10:03 A.M. EDT

Jupiter is stationary, 2 P.M. EDT

The Moon passes 3° south of Mars, 10 P.M. EDT

**16** The Moon passes 4° south of Neptune, 11 A.M. EDT

**17** Mercury passes 7° north of Aldebaran, 5 A.M. EDT

**18** The Moon is at apogee (252,018 miles from Earth), 3:45 A.M. EDT

**20** The Moon passes 4° south of Uranus, noon EDT

**22** Mercury passes 0.9° south of Venus, 4 A.M. EDT

New Moon occurs at 1:39 P.M. EDT

**23** The Moon passes 4° south of Venus, 11 P.M. EDT

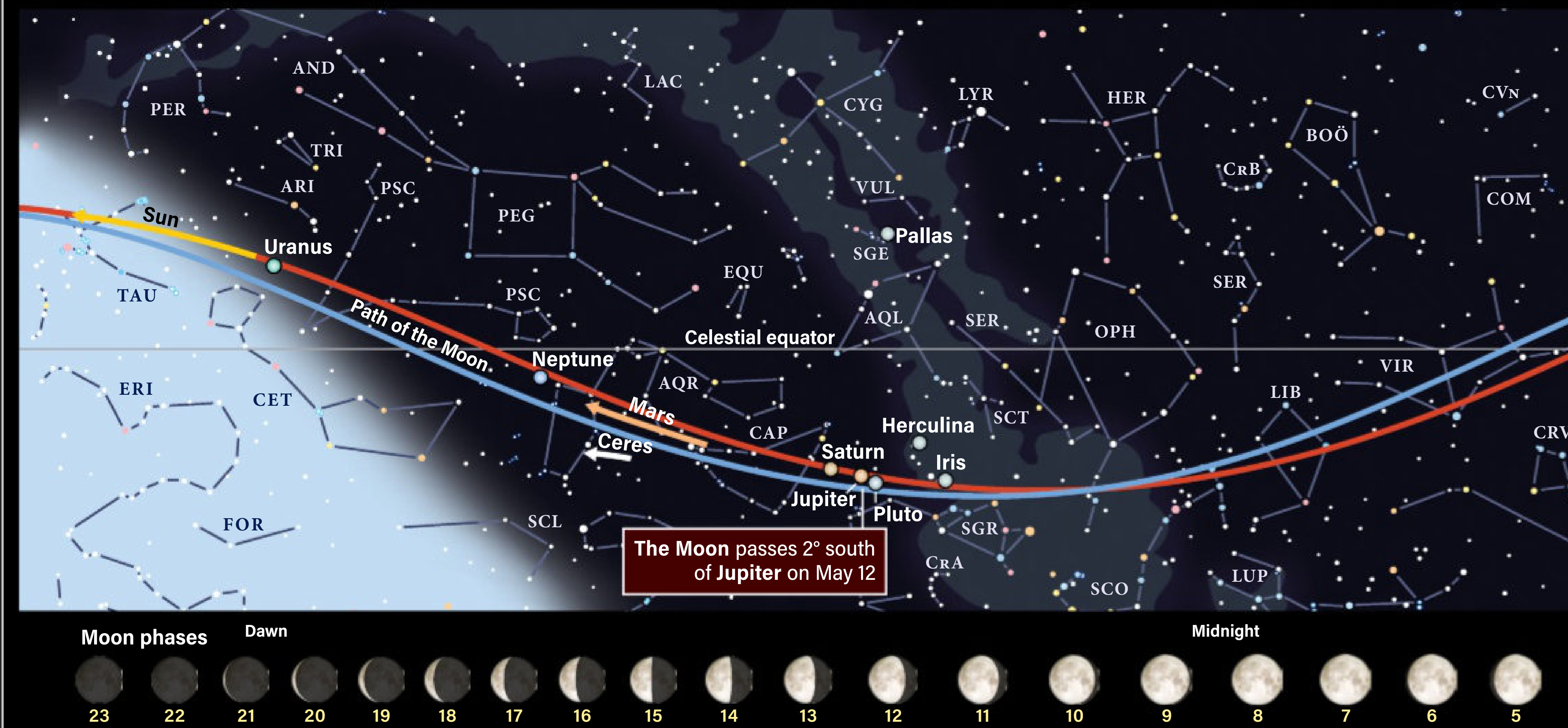
**24** The Moon passes 3° south of Mercury, 7 A.M. EDT

The Moon passes 0.6° north of asteroid Vesta, 11 A.M. EDT

**27** Asteroid Juno is stationary, 10 A.M. EDT

**29** First Quarter Moon occurs at 11:30 P.M. EDT

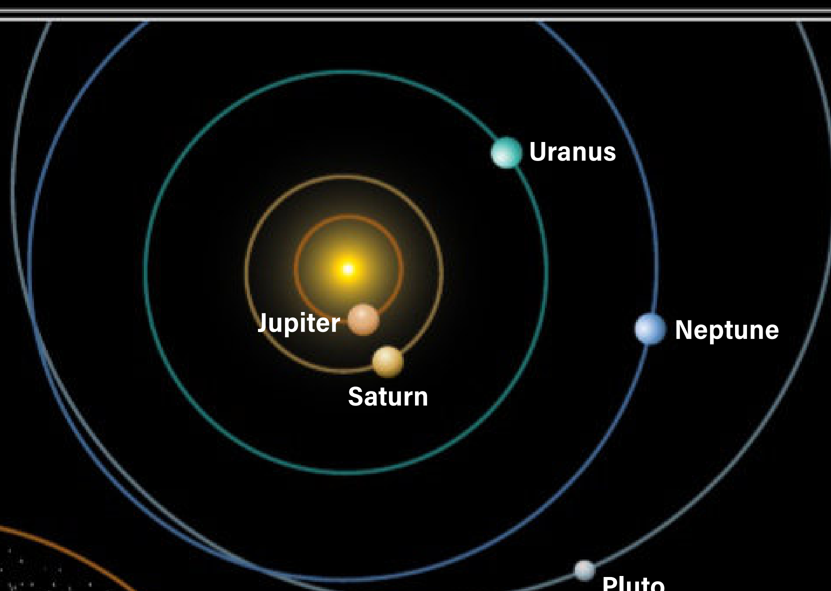
# PATHS OF THE PLANETS

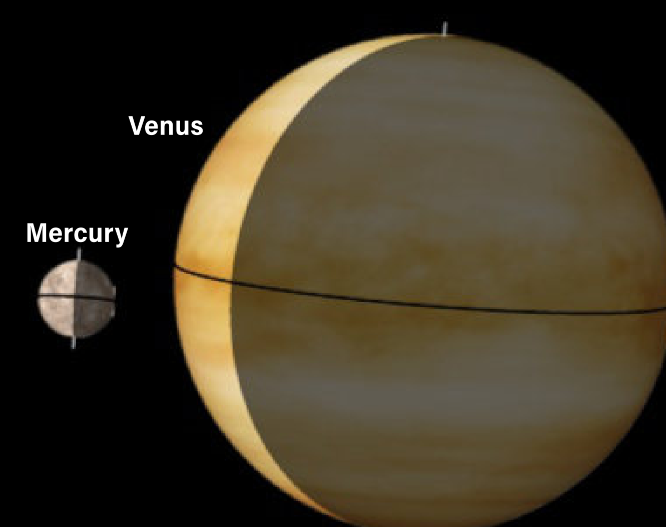


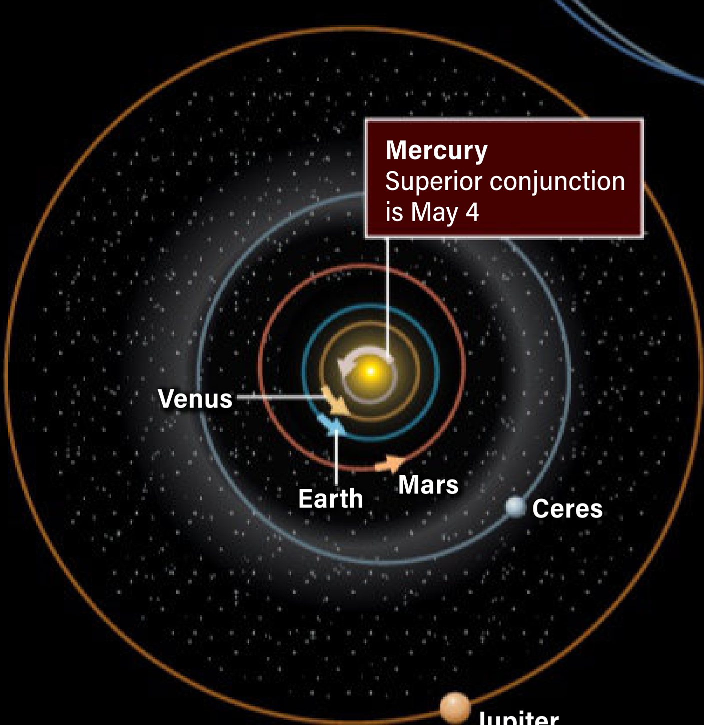

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

## THE PLANETS IN THEIR ORBITS

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



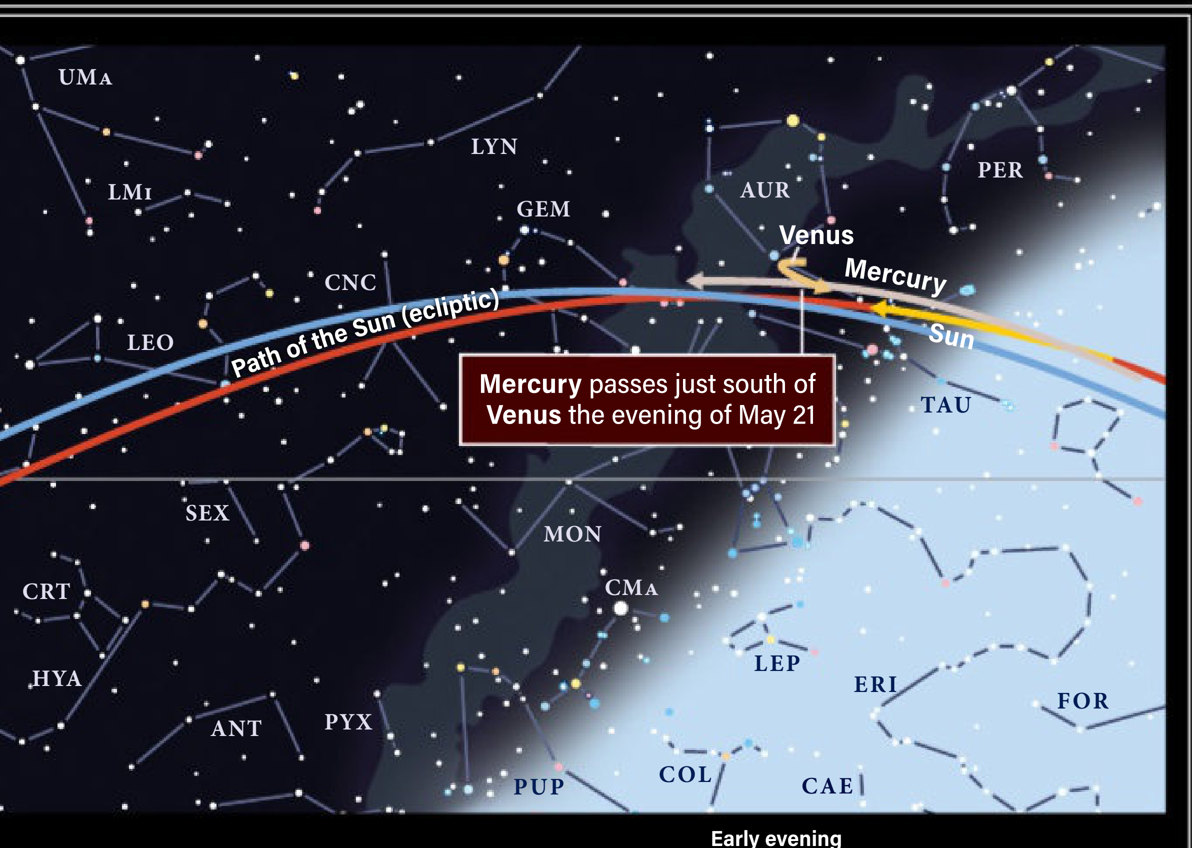




| PLANETS | MERCURY | VENUS |
|---|---|---|
| Date | May 31 | May 15 |
| Magnitude | 0.0 | –4.6 |
| Angular size | 7.4" | 48.5" |
| Illumination | 47% | 12% |
| Distance (AU) from Earth | 0.910 | 0.344 |
| Distance (AU) from Sun | 0.397 | 0.723 |
| Right ascension (2000.0) | 6h11.7m | 5h21.9m |
| Declination (2000.0) | 25°28' | 27°14' |

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

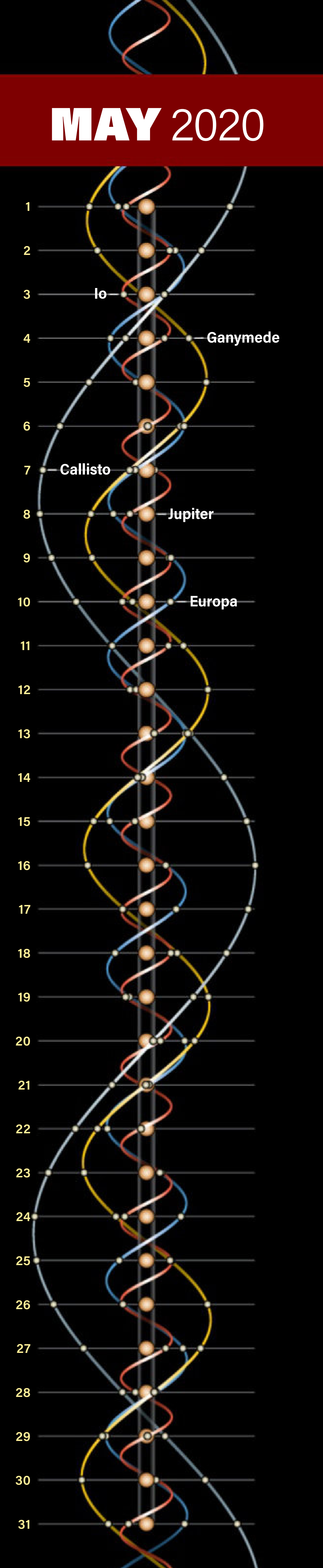
# MAY 2020





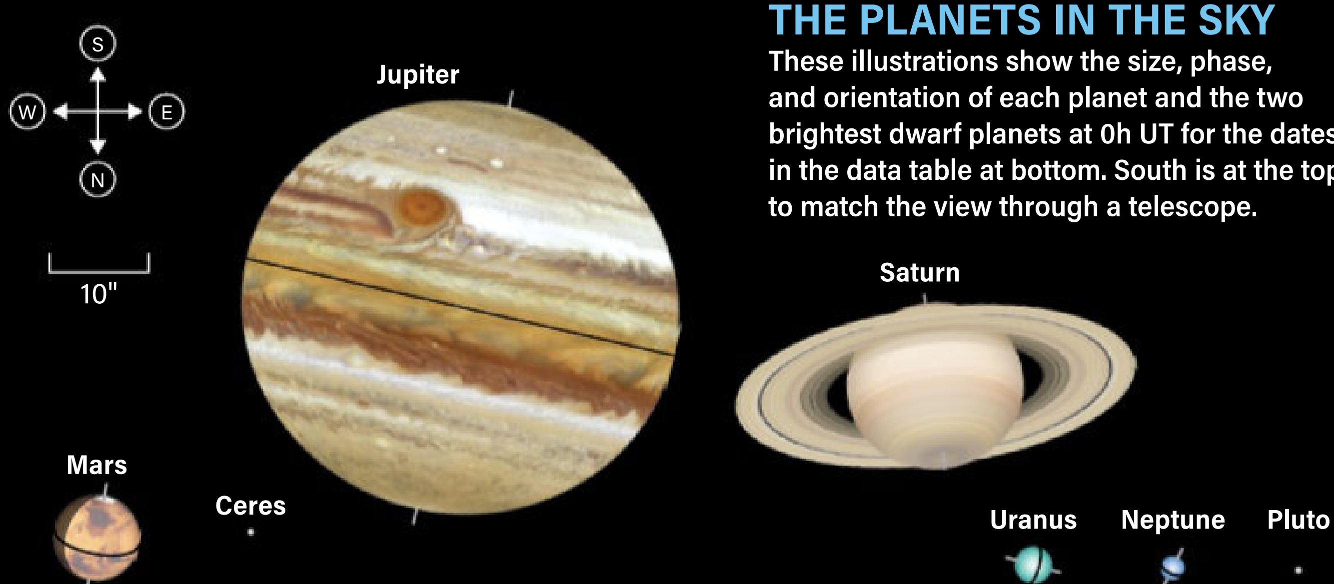

## JUPITER'S MOONS

Dots display positions of Galilean satellites at 5 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



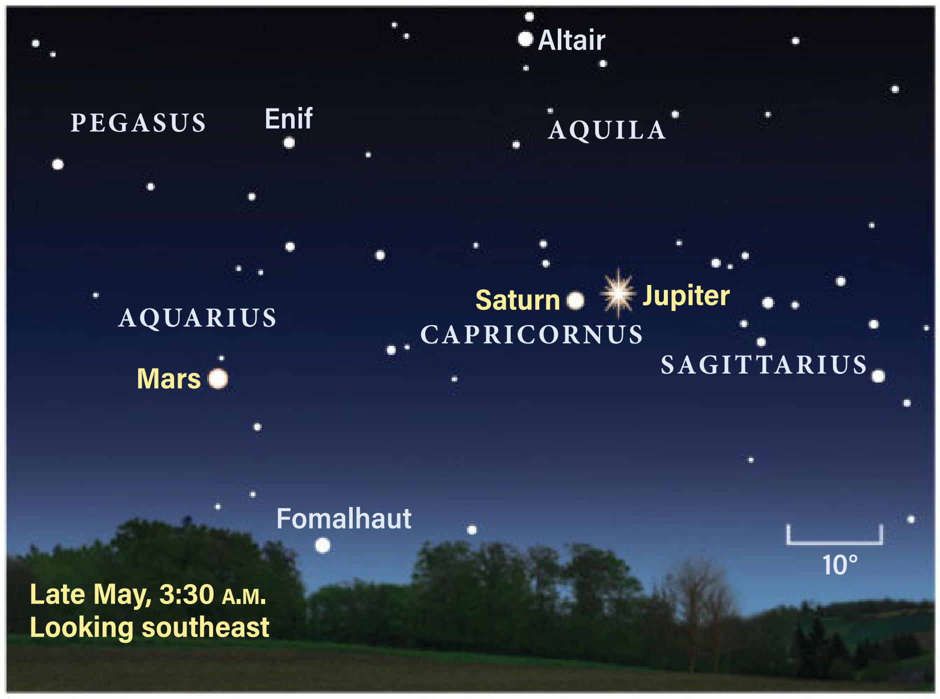

## THE PLANETS IN THE SKY

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.




| MARS | CERES | JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|---|---|
| May 15 | May 15 | May 15 | May 15 | May 15 | May 15 | May 15 |
| 0.2 | 9.1 | –2.4 | 0.5 | 5.9 | 7.9 | 14.7 |
| 8.3" | 0.4" | 42.5" | 17.3" | 3.4" | 2.2" | 0.1" |
| 85% | 97% | 99% | 100% | 100% | 100% | 100% |
| 1.127 | 2.992 | 4.635 | 9.586 | 20.766 | 30.359 | 33.527 |
| 1.425 | 2.970 | 5.178 | 10.019 | 19.802 | 29.931 | 34.039 |
| 22h14.9m | 22h42.4m | 19h56.1m | 20h15.8m | 2h20.7m | 23h25.9m | 19h46.9m |
| –12°57' | –17°34' | –20°56' | –19°55' | 13°33' | –4°49' | –22°04' |

**Morning planets**




A trio of planets — Mars, Jupiter, and Saturn — will grace the southeastern sky a few hours before sunrise this month.

opposition, and a telescope will reveal its growing apparent size. During May, it expands from 41" to 45", just 5 percent shy of its opposition peak.

The dramatic display of atmospheric belts and zones are Jupiter's main attraction. Most obviously, a pair of dark equatorial belts straddle Jupiter's equator. Other features are more delicate, however, and the dazzle of the planet can drown them out for casual observers. Let your eye become accustomed to its brilliance for a minute before seeking out finer details. The view of Jupiter is exquisite when our turbulent earthly atmosphere calms for a second or two and enables a beautiful spacelike view of the solar system's giant planet.

In addition to the appeal of the cloud belts, Jupiter's four Galilean moons offer an ever-varying display, including occultations, eclipses, and transits. Individual events occur throughout May, and occasionally dual events occur within minutes of each other. One such back-to-back display occurs the morning of May 3, when Callisto casts its large shadow onto Jupiter's northern temperate cloud tops as Ganymede begins to disappear behind the same limb, south of the southern equatorial belt. As Jupiter rises, Callisto's shadow is already on the jovian disk while Callisto itself lies to the east of the planet. Ganymede lies west of Jupiter, and during a couple of hours, Callisto's shadow nears the western limb of Jupiter while Ganymede approaches. Both events occur almost simultaneously at 4:49 A.M. CDT (in the eastern time zone, it's already twilight, though the event is still observable). Ganymede's disappearance takes just seven minutes, while Callisto's shadow ambles off the disk over the course of 20 minutes. This is because Callisto is in a wider, slower-moving orbit — illustrating the laws of planetary motion.

On May 6 and May 22, Io and its shadow traverse the jovian disk. And a notable trifecta of events occurs the morning of May 21, when Ganymede itself and Europa's shadow are both visible soon after 2 A.M. CDT before being joined by a transiting Europa at 3:23 A.M. CDT.

Before moving on to Saturn, it's worth pointing out that **Pluto** sits just 2.1° west of Jupiter throughout May. But at magnitude 14.7, you'll need a large scope and ideal viewing

## WHEN TO VIEW THE PLANETS

**EVENING SKY**
Mercury (northwest)
Venus (northwest)

**MORNING SKY**
Mars (southeast)
Jupiter (south)
Saturn (south)
Uranus (east)
Neptune (east)

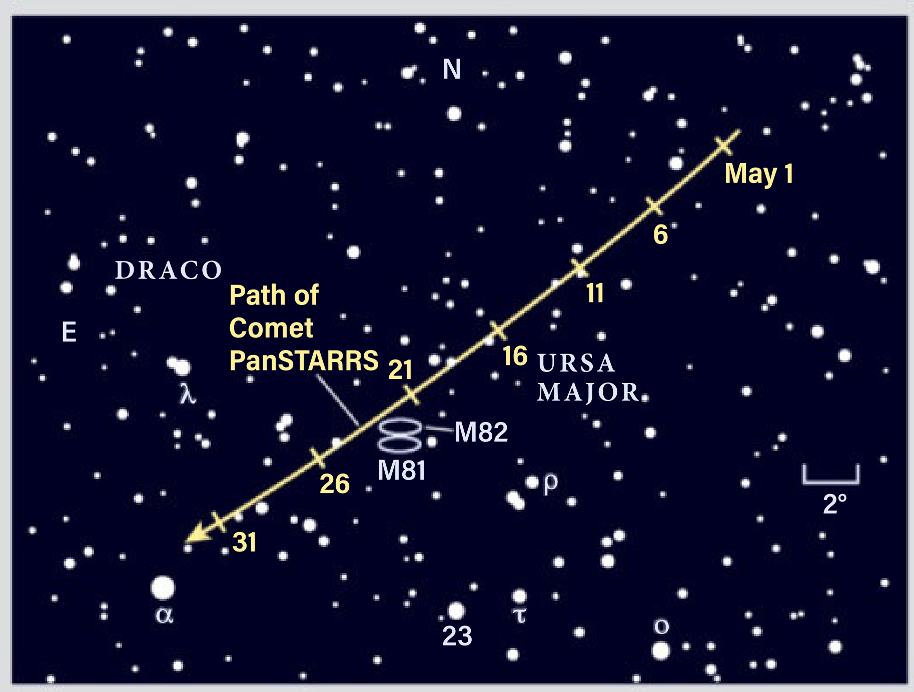
## COMET SEARCH | Peaking near a cigar

**HIGHLIGHT OF THE YEAR:** Comet PanSTARRS (C/2017 T2) shares a low-power field with the Cigar Galaxy (M82)! As ideal as modest-telescope comets get, PanSTARRS hits a peak brightness of 8th or 9th magnitude while sailing high in the northern sky. The comet makes its closest approach to the Sun, or reaches perihelion, May 4, at a distance of 149 million miles. On the plus side, PanSTARRS crests near Polaris, making it accessible to northern observers all night.

New Moon occurs May 22, which is perfect timing because PanSTARRS lies only ¾° from M82 the following weekend. PanSTARRS is just barely visible with binoculars; it will show up better in a 4-inch scope, and will likely sport some green when viewed through a 12-inch scope.

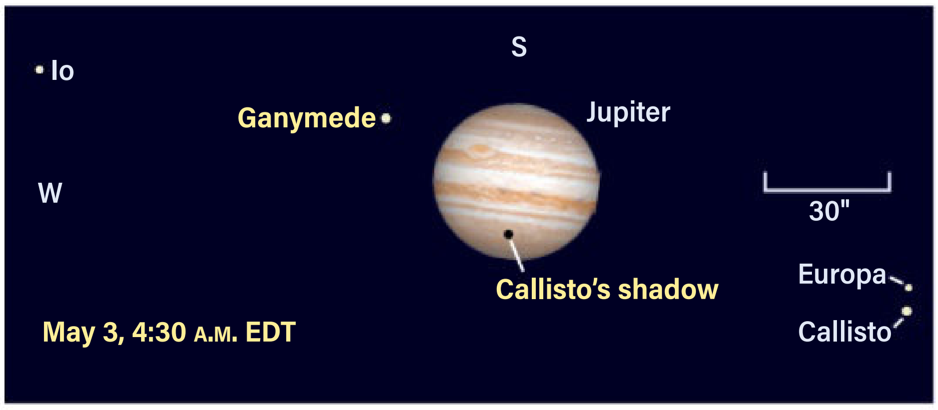
From May 24 to May 26, make sure to look for a double-spike. The comet's short, fan-shaped tail flattens to edge-on when Earth passes through the orbital plane, so as long as our visitor from the Oort Cloud produces a decent amount of both gas and dust, we can expect to see a green or blue streak on the leading edge and an "anti-tail" knife blade of white on the other. If you can, take a peek every other night to catch the whole transformation. For the rest of the apparition we get more and more of a top-side view.

**Comet PanSTARRS (C/2017 T2)**




It takes roughly 15 minutes for light from the comet to reach us, but about 12 million years for light from the Cigar Galaxy to get here.

## Jupiter's moons




On May 3, Callisto's shadow traverses Jupiter's northern cloud tops as Ganymede begins to disappear behind the gas giant.

conditions to spot it without photographic equipment.

**Saturn** sits just 5° east of Jupiter every evening in May. The planet's disk spans 18" and its expansive rings stretch 40" wide by the end of May. Any telescope will reveal Saturn's rings. The minor axis of the rings is just 14", narrower than the planet itself, so you'll notice the northern pole of Saturn arcs above the far ring edge.

It's also worth observing Saturn's moons, including its largest and brightest, Titan. This intriguing world orbits Saturn once every 16 days, and stands due south of the planet May 5 and 21, and due north May 13 and 29. At magnitude 8.6, it will remain the brightest object near Saturn unless a rare field star joins in. Shining between magnitude 10 and 11, the moons Tethys, Dione, and Rhea orbit closer to Saturn and with shorter periods. Their relatively quickly changing positions are easy to follow with modest telescopes.

May is also a great month to spot Iapetus. This odd saturnian moon changes brilliance between eastern and western elongations depending on whether its bright or dark hemisphere faces us. Iapetus shifts between magnitude 10 and 12 and reaches the middle of this range May 11 when it's at inferior conjunction (48" due south of Saturn). Iapetus is brightest at western elongations, like the one it reaches May 31, when it shines at about magnitude 10.5 and stands about 9' due west of the planet.

**Mars** is best viewed in the hour before dawn during May. On the 1st, it stands 15° above the southeastern horizon by 4:45 A.M. local daylight time, and it climbs to 26° high at the same time May 31. Still far from its October opposition, Mars' apparent size continues to grow during May, expanding from 8" to 9". This is still too tiny for small scopes to resolve much detail, but the better resolution of 10-inch scopes and larger will reveal fine details. This is a good time to begin practicing video imaging, as it will enhance details not visible to the eye.

Mars continues to climb to higher declinations as it crosses into Aquarius. It begins the month at 15° south in northeastern Capricornus, which puts it 2.7° from 3rd-magnitude Deneb Algiedi. The Red Planet then shines at magnitude 0.4. It crosses into Aquarius on May 9, passing less than a Moon's-width from Iota (ι) Aquarii May 11/12. By the end of May, the planet shines at magnitude 0.0 and is at a declination of –9°, putting it 2° south-southeast of Lambda (λ) Aquarii.

**Neptune** returns to the night sky by late May. On May 31, it sits 8.6° east-northeast of Mars and 3° east of 4th-magnitude Phi (ϕ) Aquarii. To spot Neptune with binoculars, use Mars as a guide. Neptune shines at magnitude 7.9, but at just 15° high an hour before twilight, its low altitude makes it more difficult to spot than later in the year.

Meanwhile, **Uranus** rises with the onset of twilight and remains difficult to spot throughout May. So your best bet is to hold off until next month before trying to pick out its blue-green glow from the starry background.


**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.*


## LOCATING ASTEROIDS | Double feature

**WHEN IT COMES TO ASTEROIDS,** luck works both ways. Rather than one bright asteroid all by itself, May brings two fainter ones almost side by side. During midevening from the Northern Hemisphere, the blue-white luminary Spica shines in the southeast. If you then look about 15° east (1 hour of right ascension), you'll spot 4th-magnitude Iota (ι) Virginis — the anchor star for this month's pair of space rocks. Both 23 Thalia and 40 Harmonia sport a diameter of about 67 miles and lie beyond the orbit of Mars in the inner asteroid belt.

Correctly identifying both asteroids will take a bit more care and patience than usual, as they stand in front of many background stars glowing at 10th magnitude. Despite being far from the Milky Way's bulge, the lack of dust clouds here lets light from many distant stars shine through. If you want to risk the weather, you can sketch the star field May 15 or 16 with 40 Harmonia on the southern edge of the field, then return May 29 through 31 to pinpoint the extra dot on the northern edge that is 23 Thalia.

During the month, the two asteroids are never closer than about 2°, but that is actually an easier shift than you might think. If your telescope uses a diagonal, take a picture of the chart and flip it left to right to match the orientation in the eyepiece.

### 23 Thalia shares the sky with 40 Harmonia


The two 10th-magnitude asteroids will take some effort to pick out from a backdrop of similarly bright stars.

# Cosmic

The most observed emission nebula in the Northern Hemisphere is the famed Orion Nebula (M42), lying some 1,300 light-years away. Visible to the naked eye as a misty spot of stars, this cloud of gas is forming an infant star cluster, the four brightest of which are called the Trapezium. This wide-field view shows the Orion Nebula at left with bluish reflection nebulae around it, the brightest of which is NGC 1973-5-7, at right.
TONY HALLAS

# Clouds 3D

A glimpse behind the dusty veil of nebulae reveals the chemistry of the universe.

BY DAVID J. EICHER AND BRIAN MAY; STEREO IMAGES BY J.-P. METSÄVAINIO

The universe is a magical place. Many people don't know this; they are born, go through their lives, and perish without ever realizing it.

I'm not talking about magic the way you might think. The universe is not a supernatural place. It's not full of tricks. There are no violations of the natural order of the cosmos, no validity in amulets, curses, spells, miracles, or occultism.

Rather, the universe is a place dominated by natural magic — by nature's own laws that make it an amazing wonder in itself. The truth about the universe is far stranger and more incredible than the petty imaginary stories we concoct every day on our little blue planet Earth.

## The universe's building blocks

Consider the very stuff you're made from, for example. The average human has 7 octillion atoms in their body. That's 7 times 10 to the 27th power. Put another way, it's 7 billion billion billion atoms. Suffice to say, it's a lot. These very same atoms were created in the early stages of the universe or in the bellies of exploding

The Eagle Nebula (M16) in Serpens resembles the widespread wings of a majestic bird. It contains bright emission nebulosity, a young star cluster, and towering pillars of dust that gravity is compressing into stars. The dust features in this nebula gave rise to the name "Pillars of Creation" in images made with the Hubble Space Telescope. This big nebula lies some 7,000 light-years away. ADAM BLOCK

The story of elements in nature, of why we are here, of our cosmic roots, is strongly tied to the story of stars in our galaxy and universe.

stars long ago. As the great astronomer Carl Sagan said, "The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of starstuff."

Right now, you have at least traces of 60 chemical elements within you. By mass, oxygen is the most abundant; carbon follows second, and then hydrogen and nitrogen. But you also have heavier elements such as calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium. And, yes, you even have naturally occurring radioactive elements within you — again, all natural.

The elements, of course, are the basic atomic building blocks of the cosmos, from which all normal matter is composed. Consider, just for a moment, our discovery and understanding of them. Organized by their properties in the periodic table, the 118 known elements display a wide range of characteristics. The Russian chemist Dmitri Mendeleev created the first detailed periodic table in 1869 to understand and organize the elements. The first 94 elements occur naturally, and the last 24 have been synthesized in labs or nuclear reactors but are not yet observed in nature.

The first known elements were metals, dating back to the last part of the Stone Age, when copper was discovered around 9000 B.C. in the Middle East. However, beads found in Çatalhöyük, Anatolia, in what is modern Turkey, suggest clear manufacturing of copper goods dating to 6000 B.C. This is highly interesting, as Çatalhöyük is one of the first and most important protocity settlements on Earth. Clear evidence of copper smelting dates to at least 5000 B.C., from Belovode in the Rudnik Mountains of what is now Serbia.

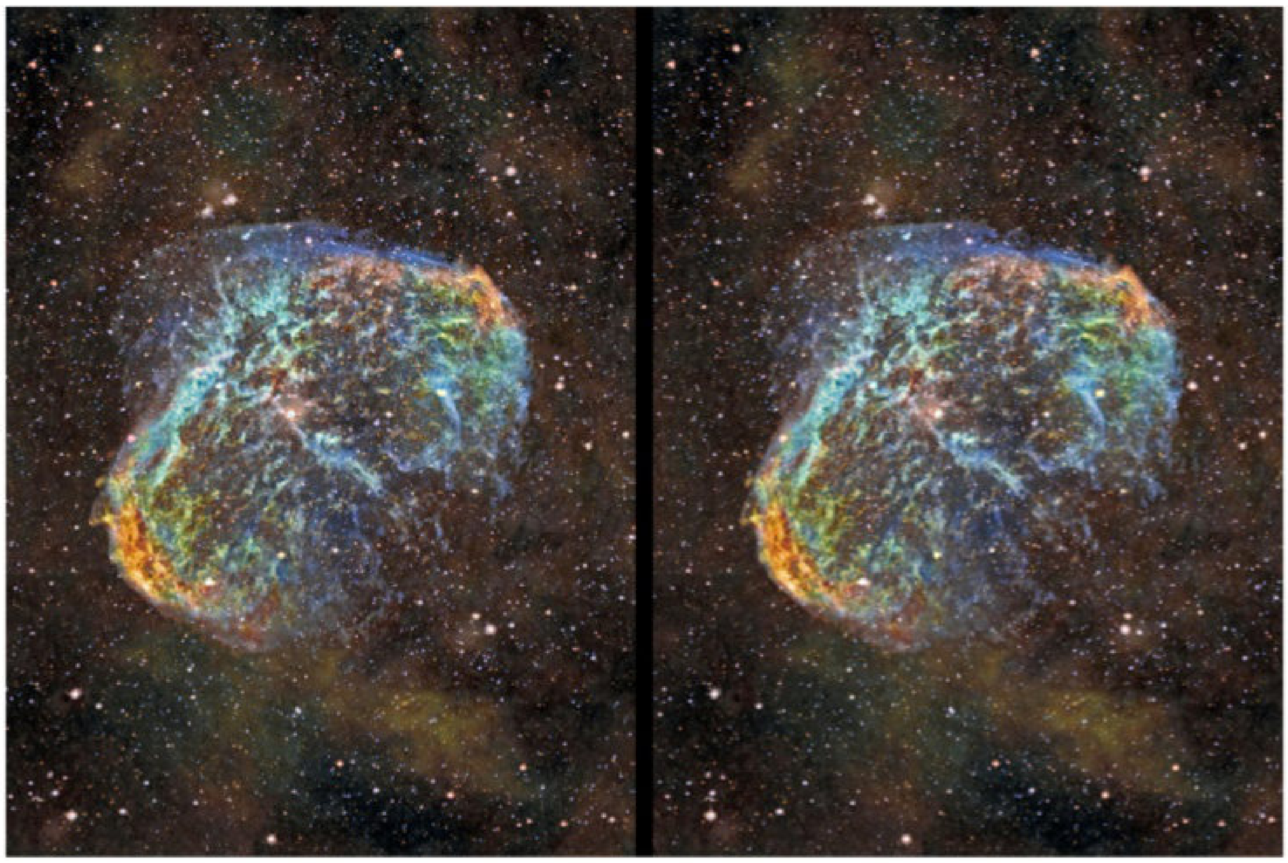
By 6000 B.C., humans were also smelting and using lead and gold. Silver and iron came next, before 5000 B.C. By the time of the Egyptians, alchemists had discovered carbon. The smelting of tin by 3500 B.C. led to the Bronze Age, combining tin with copper to fashion the hardy alloy that gave the epoch its name.

Important elements have been found in modern times, too. Hydrogen, the most abundant element, was discovered by the English natural philosopher Henry Cavendish in 1766. The Swedish-German chemist Carl Wilhelm Scheele uncovered a variety of elements during the 1770s, including oxygen, chlorine, manganese, and tungsten. (The English natural philosopher Joseph Priestley and French chemist Antoine Lavoisier also discovered oxygen at about the same time.)

So, where did the elements that make up our stars, our planets, and even us, come from? The creation of the first atomic nuclei took place immediately following the Big Bang itself, the origin of the universe some 13.8 billion years ago. That process, called Big Bang nucleosynthesis, created mostly hydrogen, deuterium (an isotope of hydrogen), and helium, with trace amounts of other elements like lithium.

Long after Big Bang nucleosynthesis, more complex elements formed through a variety of processes. Stars are nuclear fusion reactors — engines that fuse lighter elements together into heavier

The spectacular Helix Nebula (NGC 7293) in Aquarius is one of the closest planetary nebulae, lying nearly 700 light-years away. The curling form of the gas is reminiscent of the DNA double helix, leading to its distinctive name. The central star that gave rise to the nebula is plainly visible in backyard telescopes, and astronomers believe the nebula formed about 10,000 years ago. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



A stereo view of the Crescent Nebula (NGC 6888) shows an oblate bubble of gas encapsulating its hot central star, with blebs of multicolored nebulosity aligning here and there to form the three-dimensional cloud.

ones. The process of fusion itself creates many more elements on the periodic table, up to iron and nickel. Exploding stars — supernovae — are the dying carcasses of massive stars far heavier than the Sun. Their bombastic blasts create heavier elements still, and the blasts send them far out into the surrounding galaxy. These processes, over vast amounts of time, have created and spread the variety of elements, most far heavier than hydrogen and helium, that we know of today, including the stuff that makes up our bodies.

The cosmic origins of the elements, then, are varied. About two dozen elements originate from dying low-mass stars. These include carbon, nitrogen, strontium, and tin. Another two dozen or so elements come mostly from supernovae. These include oxygen, potassium, sodium, arsenic, and aluminum. Two elements arise from cosmic ray fission — when energetic particles from space impact Earth's atmosphere and surface. This process creates boron and beryllium.

About another two dozen elements are created largely from merging neutron stars — the clashes of super-dense, dying stellar remnants made mostly of packed neutrons. These include iodine, xenon, cesium, platinum, and gold. And a small number of elements are created, or at least can be created, by exploding white dwarf stars, the final, decayed ultra-dense remnants of stars like the Sun. These include titanium, vanadium, chromium, manganese, iron, and nickel.

These are incredible facts to ponder as you walk out under a starry sky on a clear, moonless night. Look deep toward the shimmering glow of the Milky Way, and you'll see many twinkling stars and the unresolved light from millions more that make up the hazy band running across our sky. That oldest of all human questions — "Why am I here?" — actually has an answer. You're here because atoms created in the Big Bang and in the bellies of stars have recombined in a way to make you, billions of years after their creation — with a big thank you to your parents as well.

## The story of the stars

The story of elements in nature, of why we are here, of our cosmic roots, is strongly tied to the story of stars in our galaxy and universe. And that means exploring the lives of stars, how stars come to be, what happens during their lifetimes, and how they, too — like humans — eventually die. We may not all know it, but we are part of the biggest recycling program that exists: the birth, life, and death of stars.

Stars are born in great clouds of gas called nebulae. The word *nebula* comes from Latin and means "cloud" or "fog." These clouds exist between the stars and consist of mostly hydrogen and helium, along with some other gases. They are typically ionized, meaning they are excited — energized — by hot stars inside and nearby them, which causes these clouds to glow. Thankfully, because of this process, we can see nebulae from very large distances, across our galaxy and even in other nearby galaxies. Interstellar clouds also contain various amounts of dust. Astronomers believe these veils of dust in the universe were formed in supernova explosions.

Observations of the universe have shown that not only is the cosmos expanding, as we have known for more than a century, but that the universal expansion also is accelerating over time.

On large scales, everything is moving away from everything else, and the universe is getting bigger. But various forces are at work in the universe. One of the most important, the very force that keeps us on Earth's surface, is gravity. The

In stereo, a close-up view of the Elephant's Trunk Nebula within IC 1396 reveals a complex multilayering of the many regions of dust and gas within this giant star-forming region.

The Bubble Nebula (NGC 7635) is an object seemingly custom-made for a stereo view. An incredible curtain of nebulosity wisps throughout the entire field of view, as the bubble itself takes on an eerie, cocoonlike quality, the hot star forming it nestled within. Foreground stars pepper the field.

attraction of gravity means that even though the universe is expanding, things that are near each other are drawn together because of their mass. Galaxies close to each other can merge together as one. It also means that new stars can be born, as gravity causes the gas and dust in nebulae to condense into smaller volumes. As this process occurs, enough hydrogen, helium, and other elements are compressed so that a critical mass is reached, and a new nuclear fusion reactor — a star — is born.

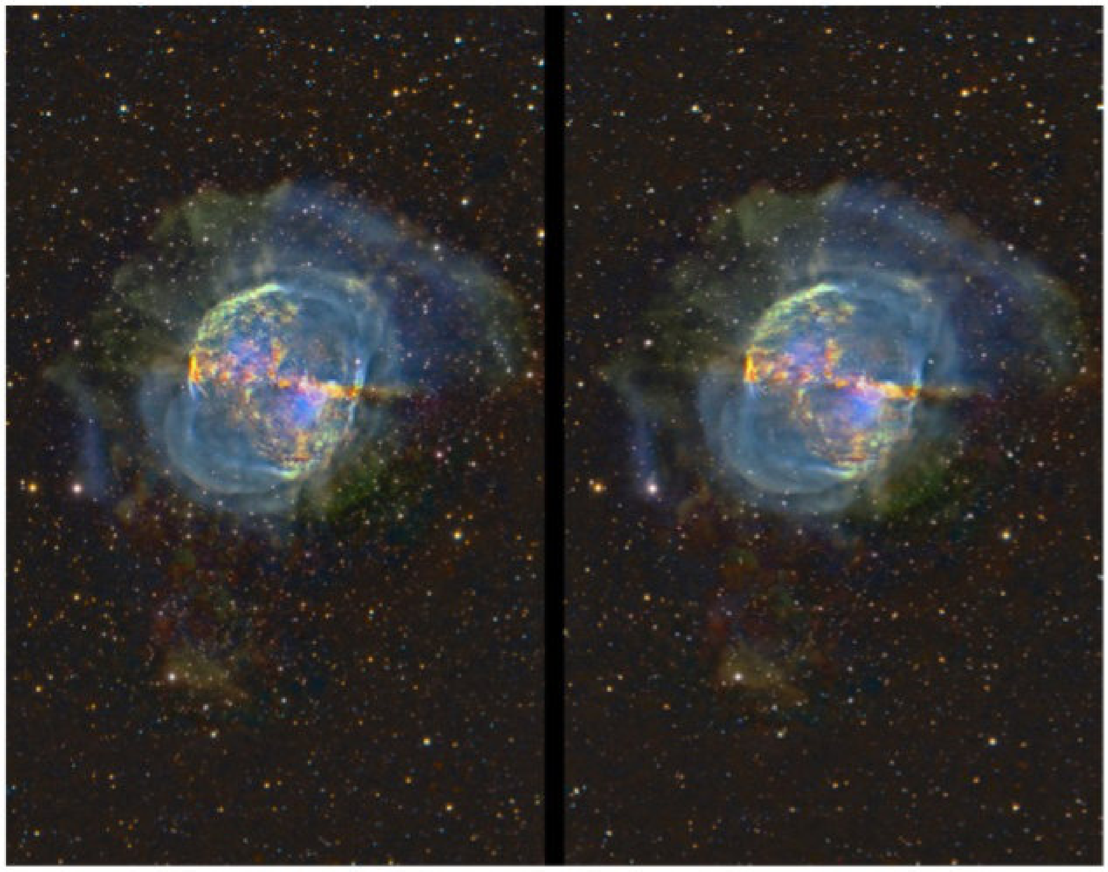
So, the majority of nebulae we see scattered across our sky, almost all belonging to our Milky Way Galaxy, are cauldrons that make possible the births of new stars. They are stellar nurseries, and that's why they are frequently intermingled with clusters of young stars. By observing nebulae, we are peering into the world of infant suns, seeing a process that for our own Sun took place some 4.6 billion years ago.

This is an important story to understand and appreciate, because it truly allows us to see where we came from and why we're here on a planet orbiting one rather ordinary star in the Milky Way. To understand the universe is paramount for the billions alive now, but it's also vital to spread this knowledge for the unborn billions to come.

The majority of nebulae in our sky are stellar nurseries. But not all of them. Some are simply blobs of gas that are not energized and glowing of their own accord, but are rather reflecting the light from nearby bright stars toward our line of sight. Others are truly dark, composed of dusty, black grains, and obstruct the light from stars beyond them. Thus, we see them in outline as ghostly clouds of darkness, floating in the immense void of space. And some glowing nebulae are the remnants, the torn-away insides, of massive stars that have violently exploded as a cosmic bomb. These leavings glow for a short cosmic time before dissipating into invisibility. Still other types of nebulae are the endpoints of ordinary stars like the Sun, shells of softly glowing gas that cocoon outward, belched away by the dying remains of their progenitor stars within. Each of these types of nebulae offers numerous varieties and you can see many examples on these pages, in both stereo and mono imagery, for your visual pleasure.

One of the sky's best-known dark nebulae is the Horsehead Nebula (B33), so named for its distinctive equine shape. Dark nebulae are composed of dust grains, making them visible only when backlit by brighter objects. The Horsehead lies in the constellation Orion, at a distance of about 1,400 light-years, and is a difficult object to spot visually in backyard telescopes. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Exploring the world of nebulae offers an eye-opening understanding of the cosmos at large. We're able to understand a great deal about the universe because of chemistry. Specifically, spectroscopy is a vital and powerful tool for astrophysicists. By carefully analyzing the spectra, or patterns of light, from various objects, astronomers can understand the chemistry of the target they're looking at. Countless millions of spectral



When one views the distinctive Dumbbell Nebula (M27) in stereo, the two-dimensional dumbbell shape transforms into the object's true shape: a three-dimensional bloated sphere. Such planetary nebulae form from low-velocity gas belched away from the parent star, which is followed by higher-velocity ejections. The collision between the gas clouds helps to light them up, giving us such a majestic view.

observations of stars, planets, galaxies, and so on have demonstrated that chemistry is uniform throughout the cosmos. That is, it works the same way in a galaxy 10 billion light-years away as it does in your backyard. And that's a crucially important fact that astronomers use to understand how the universe works.

## Chemistry all around us

Chemistry is everywhere in the cosmos. All matter that exists in the universe is made of chemicals. The only thing we experience every day that's not made of chemicals is thought — but our thoughts are themselves byproducts of chemical interactions within the brain.

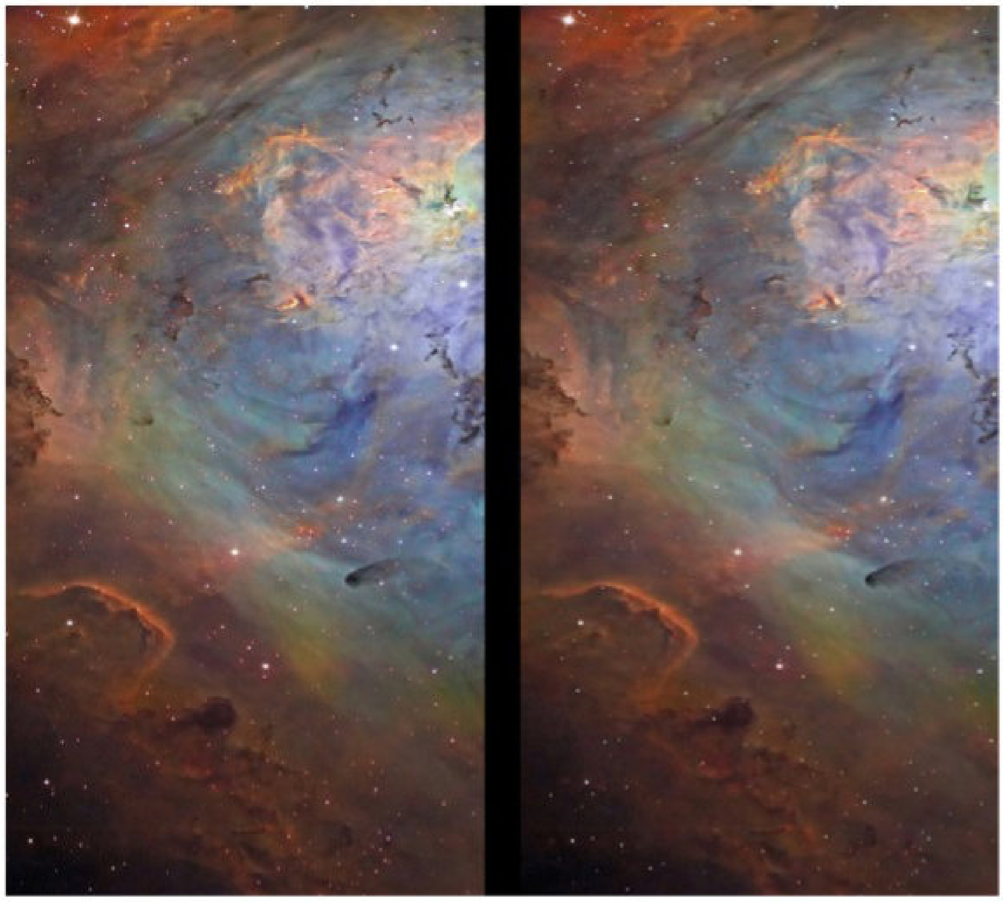
Let's step away from ourselves for a moment to consider how matter goes together. Again, there's no magic involved in the way the universe assembles things. Consider some of the most abundant objects on our planet: rocks and minerals. There's no randomness here, nor any magical behind-the-scenes thought or preordained control. A simple pyrite crystal builds itself when iron and sulfur atoms are in solution in the right abundances. The atoms are electrochemically attracted to each other, and they assemble in a lattice in just the right way to create a crystal. The more solution that's available, the larger the crystal can grow. The same is true of the whole spectrum of about 5,400 known minerals, including emeralds, diamonds, quartz, garnets, wulfenite, rhodochrosite, and many others.

Holding a mineral specimen in your hand can be a special experience because of what spectroscopy tells us. From that technique, as stated, we know that chemistry and physics are consistent throughout the universe. Temperatures, pressures, and many other local conditions could be wildly variable, but countless other worlds throughout our galaxy and the universe might contain minerals very much like the ones we

## HOW TO VIEW OUR 3D IMAGES

There are two ways to view the images printed in 3D. To free view the images with no mechanical assistance, let your eyes relax as you view the photos as though focusing on a point behind them. At first, you will see the two images split into four; as your eyes focus at the correct distance, the middle two images will combine to create a single, crisp 3D image. The outer two images will remain on either side of the 3D image and become blurry.

Alternatively, you can use a 3D viewer, such as the Lite OWL viewer designed by Brian May and included with the *Cosmic Clouds 3-D* book, to view images in 3D. Only 5.3 by 2.5 inches (134 by 64 millimeters) and 0.1 inch (3 mm) thick, the Lite OWL viewer is designed for easily viewing 3D images in books, magazines, modern and vintage stereocards, and even video or other VR content on your smartphone. You can purchase individual Lite OWL viewers separately at **www.MyScienceShop.com**



A stereo view of the Lagoon Nebula (M8) shows it as bright nebulosity buried within a cave that encloses a shell of fainter gas and appliqués of dark nebulosity stretching into the foreground.

**Exploring the world of nebulae offers an eye-opening understanding of the cosmos at large.**

have on Earth. So, mineral specimens give us a window into faraway worlds that we will never see up close.

That's intriguing, because the more we look around our area of the Milky Way Galaxy, the more we have discovered that many other planetary systems exist around nearby stars. Our galaxy consists of several major parts, but the most recognizable and distinctive is the Milky Way's disk — the brightest portion where most of the stars, gas, and dust reside. The Milky Way contains some 400 billion stars spread across this flattened disk, some 100,000 light-years across. Our Sun is just one of the roughly 400 billion stars.

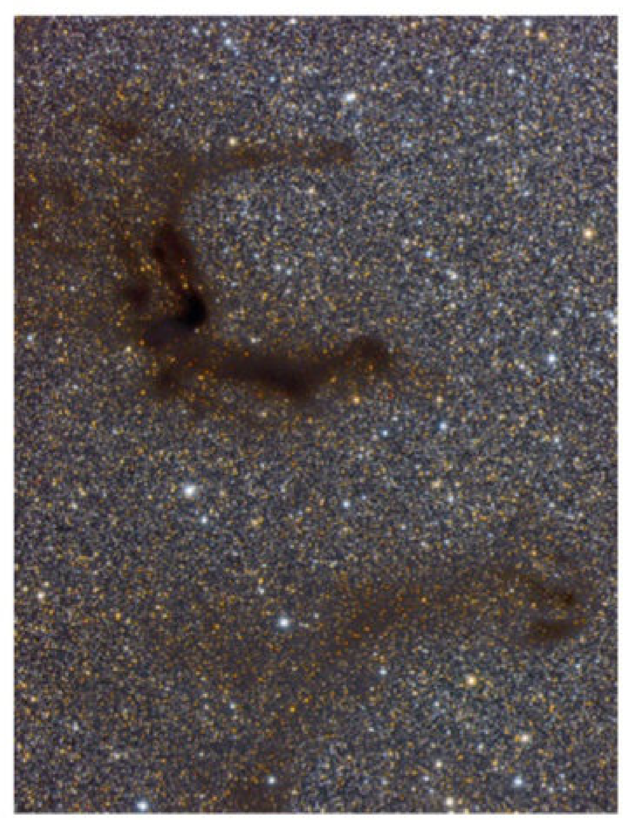
We've known about our own planetary system since ancient times, of course, when ancient skywatchers named the naked-eye planets after gods because they had the power to move night to night relative to the fixed stars. We've been all the way through the discovery of Pluto in 1930 and its demotion to dwarf planet in 2006, and understand the huge population of smaller bodies in our solar system: dwarf planets, Kuiper Belt objects, comets, and asteroids. They are almost countless, and many thousands are cataloged and named.

Only in recent times have astronomers had the power to discover planets orbiting stars other than the Sun. Technological advances in telescopes and observing methods brought the first confirmed discovery of an exoplanet — shorthand for extrasolar planet — in 1992. As of January 2020, we now know of about 4,100 exoplanets in more than 3,000 systems, and astronomers have only reached out to relatively nearby space in our galaxy.

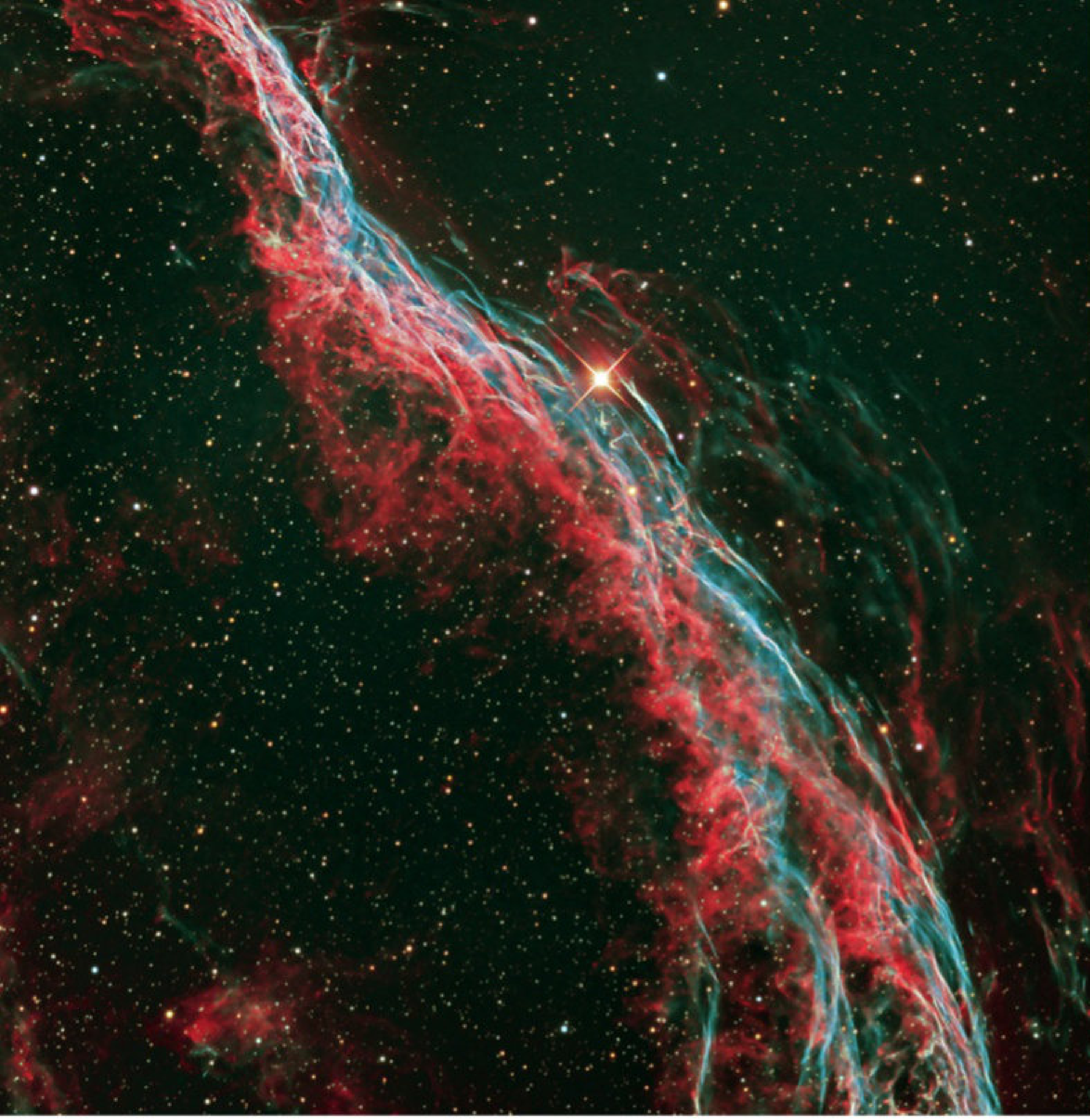
Because of the difficulty of detecting planets orbiting stars from enormous distances, many of these planets are massive, so-called "hot Jupiters" that are relatively close to their suns. The most productive planet-hunting instrument was the Kepler Space Telescope, which trailed Earth in its orbit around the Sun and cataloged exoplanets from 2009 through 2018. This magnificent telescope studied a relatively small area of sky and found more than 2,600 of the roughly 4,100 known exoplanets. A newer telescope, TESS, was launched in 2018 and has begun another epoch of exoplanet detection.

As we look out into the galaxy surrounding our solar system, it's not surprising to see lots of nearby planetary systems. Astrophysicists believe that stars form as cosmic clouds — nebular stellar nurseries — collapse and stars wink on inside them. The leftover detritus from the collapse, swirling slowly around the infant suns, make a cadre of planets and smaller bodies surrounding the new star.

And we are only in the pioneering days of being able to see farther out into the galactic neighborhood that surrounds us. Understanding that stars are so numerous and that planetary systems are plentiful is exciting. After all, the most basic driving question everyone would like to answer is at the foundation of it all: "Are we alone? Is there other life in



Rarely do cosmic clouds create letters suspended in the sky, but such is the case with a pair of dark nebulae, B142 and B143 in Aquila, which seem to form a capital letter E. It is nicknamed Barnard's E because the nebulae were discovered by astronomer E.E. Barnard. Set off by a particularly rich Milky Way star field, this nebula can be glimpsed in small telescopes on a dark night. BERNHARD HUBL



NGC 6960 is the westernmost portion of the great Veil Nebula in Cygnus, one of the sky's best supernova remnants. Appearing to slice right through the bright star 52 Cygni, the nebula actually lies far behind the star. Sometimes called the Witch's Broom, this nebula sits some 1,470 light-years away and is expanding into the surrounding medium, causing the ionized shock front that we see. DON GOLDMAN

the solar system? In the Milky Way? In other galaxies?"

We just don't yet know. The numbers are staggering. By taking very deep exposures of small areas of sky with the Hubble Space Telescope, astronomers have estimated that something like 100 billion galaxies must exist in the universe. And that's in the visible universe, which may not represent the whole universe that exists. But for simplicity's sake, let's say that it does. Let's say that an average galaxy contains 100 billion stars, as many dwarfs are smaller than our galaxy. Multiplying that out gives us the approximate number of stars in the universe as something like 10,000 billion billion. That's an awful lot of stars.

Is it possible that our little blue planet Earth is the only place in the entire universe with life? Or with a civilization? It would seem almost completely unbelievable. Our whole heritage of discovery in astronomy has commenced with Earth being at the center of everything, the most special place there is, and finding out how disastrously wrong that idea is. Now we know that chemistry is uniform throughout the cosmos, and that complex organics, the stuff of life, exist in all manner of places out in space.

And yet we know, thus far, of just one planet in the cosmos that hosts life: ours. The story of nebulae, these cosmic clouds, can lead us on an exciting exploration of all these questions, of why we're here on a watery little world, how we got to be where we are, and what the universe holds at large. After all, the very atoms that make up our bodies were born in the Big Bang and in the explosions of massive stars. We are indeed children of the cosmos.

## EXPLORE FROM HOME

*Cosmic Clouds 3-D: Where Stars Are Born* by David J. Eicher, Creative Director Brian May, and 3D images by J.-P. Metsävainio, presents a new and unique story of the life cycles of stars and nebular clouds, where they are born, and how they die.

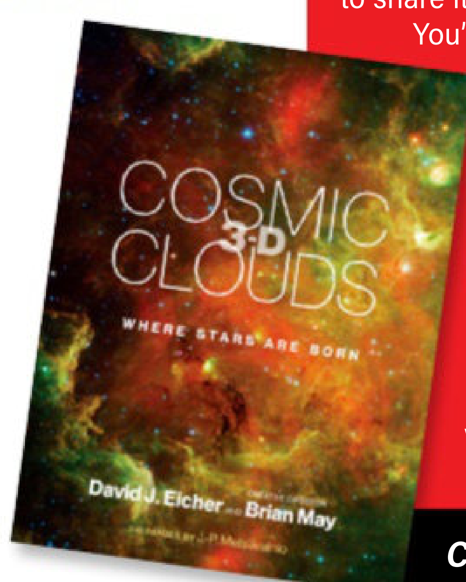
This visually amazing volume, with text and 3D images, takes readers inside the birthplaces of stars — the cosmic clouds called nebulae. Seen in the night sky, they glow, energized by the new stars within and around them. *Cosmic Clouds 3-D* offers hundreds of magnificent images of nebulae captured by ground-based and space telescopes. Along with the high-resolution views of nebulae are unique stereo views that show the nebulae in three dimensions.

The story of elements in nature, of why we are here, and of our cosmic roots, is strongly tied to the story of stars in our galaxy and universe. And that means exploring the lives of stars, how stars come to be, what happens during their lifetimes, and how they, too — like humans — eventually die. We may not all know it, but we are part of the biggest recycling program that exists — the birth, life, and death of stars.

This is a detailed story, and we aim to share it with you in this unique book.

You'll learn about many aspects of the universe as you travel through the tale of cosmic clouds. Our tale involves detours of science, history, and maybe even a bit of philosophy.

A 3D viewer, designed by astrophysicist (and lead guitarist with the rock group Queen) Brian May, is included with the book.



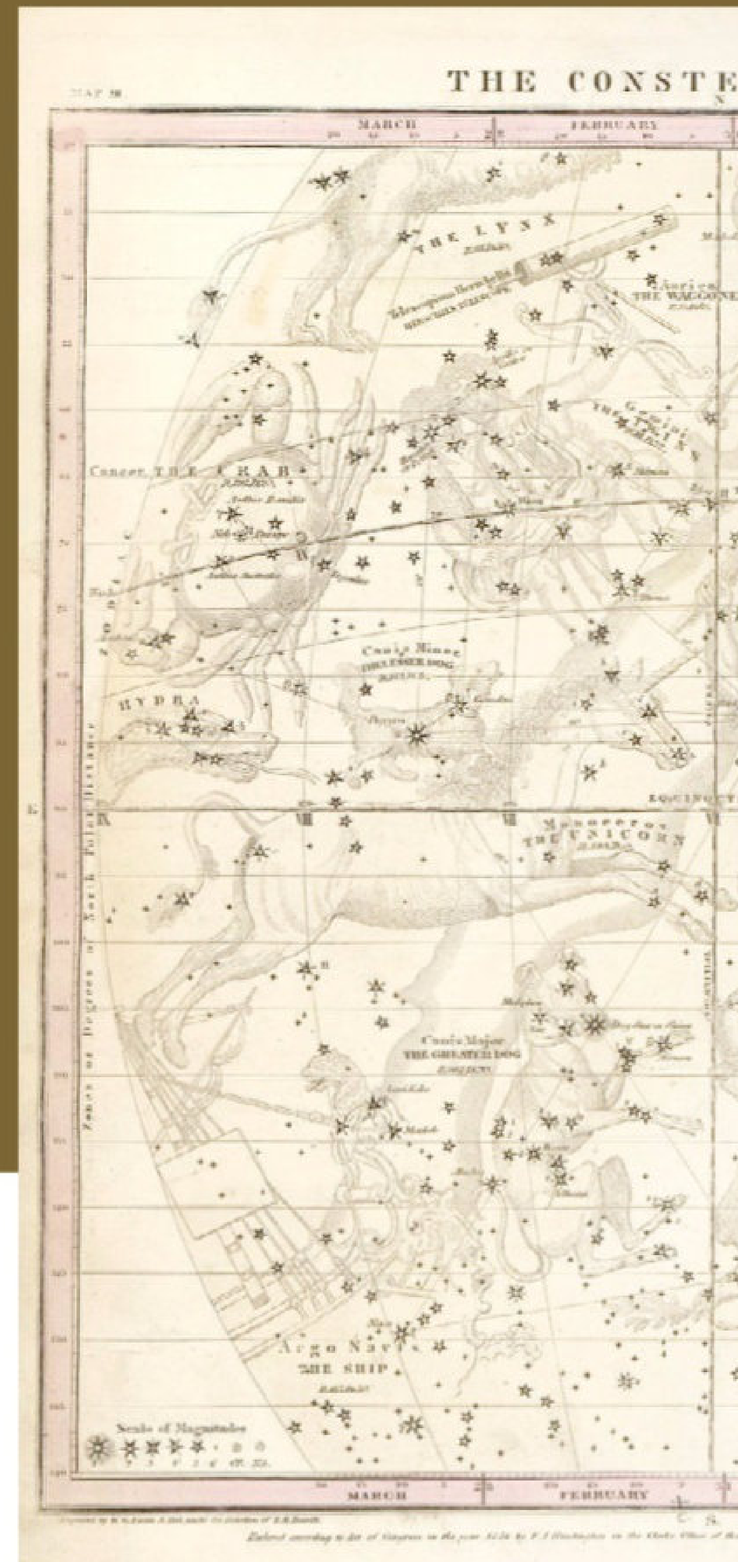

***COSMIC CLOUDS 3-D***
IS AVAILABLE ONLINE AT
**www.MyScienceShop.com**

Astronomy *Editor* **David J. Eicher** *is the author of 25 books on science and history.* **Brian May** *is an astronomer and founding member and guitarist of the legendary rock band Queen.*

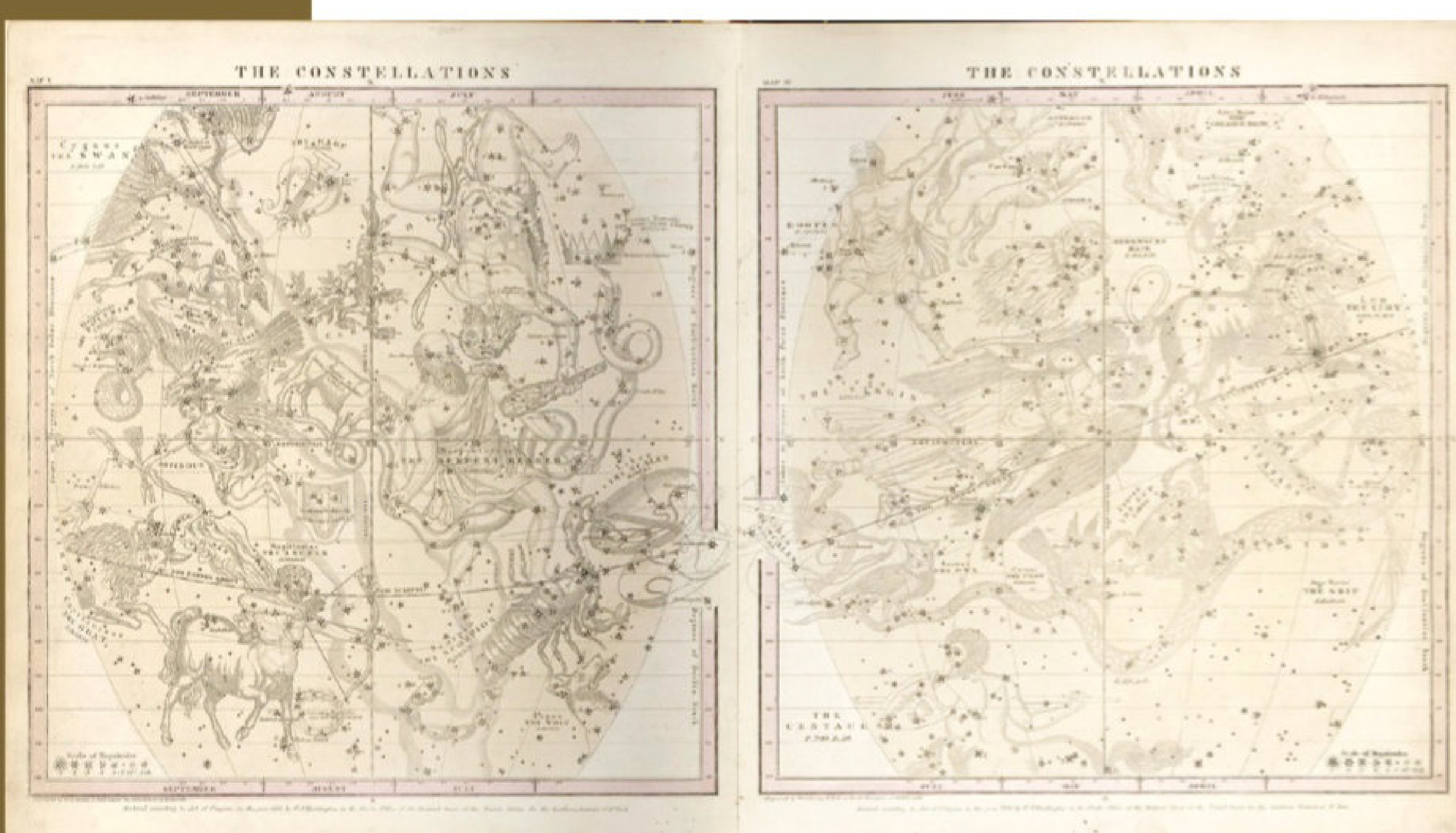
*This story is adapted from* Cosmic Clouds 3-D: Where Stars Are Born, *by David J. Eicher, Creative Director Brian May, and 3D images by J.-P. Metsävainio, © 2020 by London Stereoscopic Co. and MIT Press, Boston.*

# CHARTING THE 19TH-CENTURY HEAVENS

Schools and colleges throughout America regarded *The Geography of the Heavens* as a valuable tool for teaching astronomy. **BY MICHAEL E. BAKICH**




*The Geography of the Heavens,* along with the atlas designed for it, appeared in 1833 and single-handedly changed the landscape of astronomy education. Its author, Elijah Hinsdale Burritt, wrote in a more understandable style than was common in the textbooks of the day. More importantly, he stressed observation over theory. Burritt created this combination textbook and set of maps specifically to get students out under the stars.




ABOVE: The stars and constellations of winter (left, Map III) and fall (Map II) are the first pair a student would encounter in Burritt's *Atlas*. As in the sky, Orion the Hunter stands out on the winter map. Note that some regions of the figures, which should share the central borders of the maps, are missing.

ALL IMAGES: LIBRARY OF CONGRESS

LEFT: The summer (far left, Map V) and spring (Map IV) star figures join better than the previous pair. The "shadow" drawing of Libra the Scales forms the main connecting point.


Despite being relatively easy reads, the two publications carried impressive titles: *The Geography of the Heavens, or Familiar Instructions for Finding the Visible Stars and Constellations*; *Accompanied by a Celestial Atlas, with a View of the Solar System, Illustrated by Engravings* and *Atlas Designed to Illustrate Burritt's Geography of the Heavens*. Each cost $1.25 in 1833, a bit pricey for the textbook, but a steal for the atlas.

The set was a smash hit. In the 16th edition, published in 1876, the preface stated that more than 300,000 copies had been sold. That number makes it the most popular star atlas of the 19th century. In fact, it wasn't surpassed in sales until the mid-20th century, after numerous editions of Arthur Philip Norton's *Star Atlas and Reference Handbook*, first published in 1910, had appeared.

## Who was Burritt?

Elijah Hinsdale Burritt (his middle name was his mother's maiden name) was born April 20, 1794, in New Britain, Connecticut. He was the first of 10 children.

When he was 18, Burritt ventured to a nearby town to study for two years to become a blacksmith. Unfortunately, he suffered an accident. That, along with motivation from his friends, caused him to enroll in Williams College in Williamstown, Massachusetts, where he studied astronomy, a subject he'd read a lot about during his recovery.

After a year, his finances forced him to take up a teaching job in 1817 to earn money to continue his studies. He then went back to college, but in 1819, he left to teach school (among other pursuits, including editing a weekly newspaper) in Milledgeville, Georgia. He remained there for 10 years before moving back to New Britain. While in

**Burritt created this combination textbook and set of maps specifically to get students out under the stars.**


Map VI in the *Atlas* displays the stars and constellations around the North Celestial Pole. Note the presence of the defunct constellation Quadrans Muralis ("Mural Quadrant" on the map). In its boundaries was the radiant of the Quadrantid meteor shower (thus the name). That point now lies in Boötes. Another now-defunct constellation is also present: Gloria Frederica.

Georgia, he married Ann Williams Watson, with whom he had five children.

Upon returning to Connecticut, he converted some property he owned, called the Stone Store, into a school. As part of the conversion, Burritt installed an observatory, featuring a telescope he had purchased, on the top floor.

## Geography

Once back in Connecticut, Burritt began writing *The Geography of the Heavens*. He had one major book under his belt already, having authored *Logarithmick Arithmetick* in 1818. The first half of this work was a textbook on arithmetic. He followed it with a section on astronomy, and devoted the final 40 pages to a table of logarithms from 1 to 10,000, each calculated to seven decimal places. Burritt also included a method for students to calculate the logarithms of numbers up to 10 million.

In 1821, Burritt wrote a 28-page pamphlet: *Astronomia, or directions for the ready finding of all the principal stars in the heavens which are named on Carey's Celestial Globe*. He followed this work in 1830 with another pamphlet that showed how to compute interest, both simple and compound.

The book that made Burritt famous, however, was *The Geography of the Heavens*. He wanted to call it *Uranography*, but his publisher (probably wisely) insisted on *Geography*. Apparently buying into this notion, Burritt writes in the preface that he wants the book to be to the heavens what geography is to Earth.

Burritt devotes the main part of the book to the constellations. He describes each star figure, recounts its mythology and history, and lists the brightest stars it contains, giving their magnitudes and other facts.

The next section deals with the solar system, followed by a number of problems for readers (mainly students) to solve, and then an appendix with 13 astronomical tables.

The *Atlas* contains seven maps. Four of them show constellations in the equatorial regions by season, two illustrate the star figures in the polar regions, and one is an all-sky chart that shows the Sun's position on the ecliptic throughout the year. Burritt drew all the maps and supervised their engravings. But although he drew them, he didn't create them — he copied all the constellation figures from English astronomer Francis Wollaston's *A portraiture of the heavens, as they appear to the naked eye: constructed for the use of students in astronomy*, which appeared in 1811. Later editions of the *Atlas* included an additional spread showing the relative sizes and distances of the Sun, Moon, and planets, along with many other solar system facts.

Burritt also added material to the second (1835) and third (1836) editions of the textbook, but he died before further editions were printed. The next four editions (1841, 1844, 1846, and 1849) were reissues of the third edition. In 1852, American astronomer Hiram Mattison revised the *Geography*, and added two pages containing 80 drawings of double stars, comets, clusters, and nebulae to the *Atlas*. Mattison produced nine editions, the last one in 1876.

## Gone too soon

Burritt died January 3, 1838, in Galveston, Texas. Late in the previous year, he had organized and led a group of 30 colonists, which included one of his sisters and a brother, to Houston, Texas, to settle there. In 1836, Texas seceded from Mexico and became an independent republic. It wouldn't become part of the U.S. until 1845. Burritt was drawn to Texas because the government had passed laws that granted colonists generous plots of land.

Burritt's group chartered a ship and, after a 28-day voyage, landed at Galveston — well, sort of. A storm caused the ship to wreck on a sandbar, which delayed the actual landing by several days. The journey to Houston took just a few more days, but once they arrived, the party had to live in tents because nobody was expecting them. Within a week, yellow fever broke out and wiped out nearly the entire group, including Burritt, who died in Houston just a few weeks later.

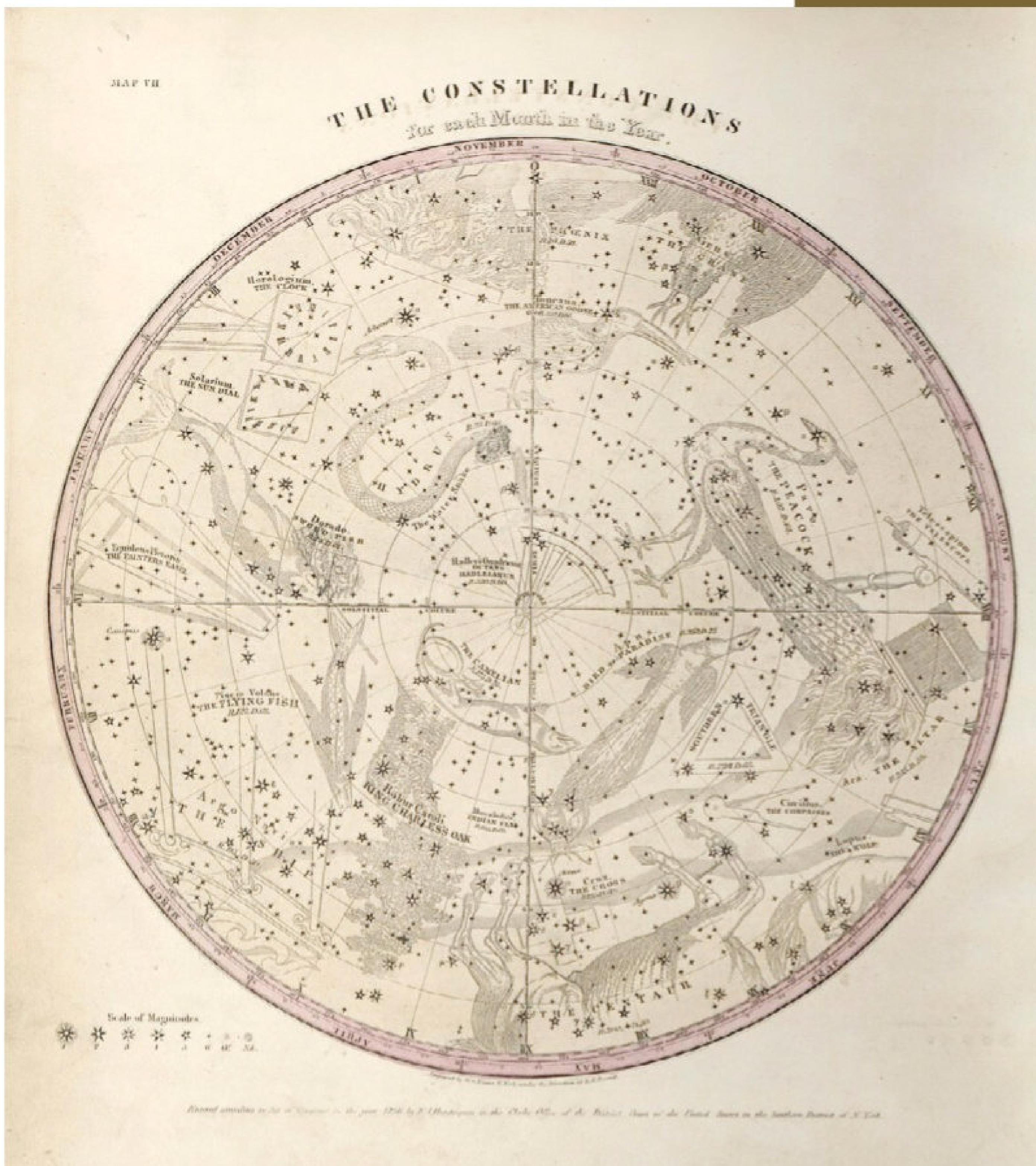
## Testimonials

I have owned a copy of the original 1833 edition of *The Geography of the Heavens* for many years, as well as a set of Burritt's 1835 constellation maps, which I had framed in the 1980s. When I began collecting 19th-century first-edition astronomy books, this set was one of the top 10 items I set out to acquire. But I wasn't the only one who thought highly of Burritt's work.

The famous double-star discoverer Sherburne Wesley Burnham became interested in the stars after purchasing a copy of Burritt's *Geography* at an auction in 1862 in New Orleans, where Burnham was a shorthand reporter in Maj. Gen. Benjamin Butler's Union Army headquarters. After studying the constellations shown in the *Atlas*, Burnham began to identify them in the sky. He held positions at several observatories and finished his career as an astronomer at Yerkes Observatory.

Praise also came from outside the field of astronomy. In a letter dated January 1, 1915, to Maurice Winter Moe, American horror author H.P. Lovecraft cited his admiration for Burritt's work, a copy of which he inherited from his grandmother: "Her copy of Burritt's *Geography of the Heavens* is today the most prized volume in my library."

For the simplicity of the text, the beauty of the illustrations, and the sheer number of sales, *The Geography of the Heavens* is rightly hailed as a terrific teaching tool. Likewise, Elijah Hinsdale Burritt deserves his place as one of the great popularizers in the history of astronomy.




The final map (Map VII) in the *Atlas* displays the stars and constellations around the South Celestial Pole. Several defunct constellations are visible, including Robur Caroli and Solarium.

**Michael E. Bakich** *is a contributing editor of* Astronomy *whose library once contained 475 first-edition 19th-century astronomy books.*

# TARGET

## EDGE-ON AND FACE-ON GALAXIES

Hunting pins and needles in the deep sky will give your observing some pizzazz.

BY STEPHEN JAMES O'MEARA

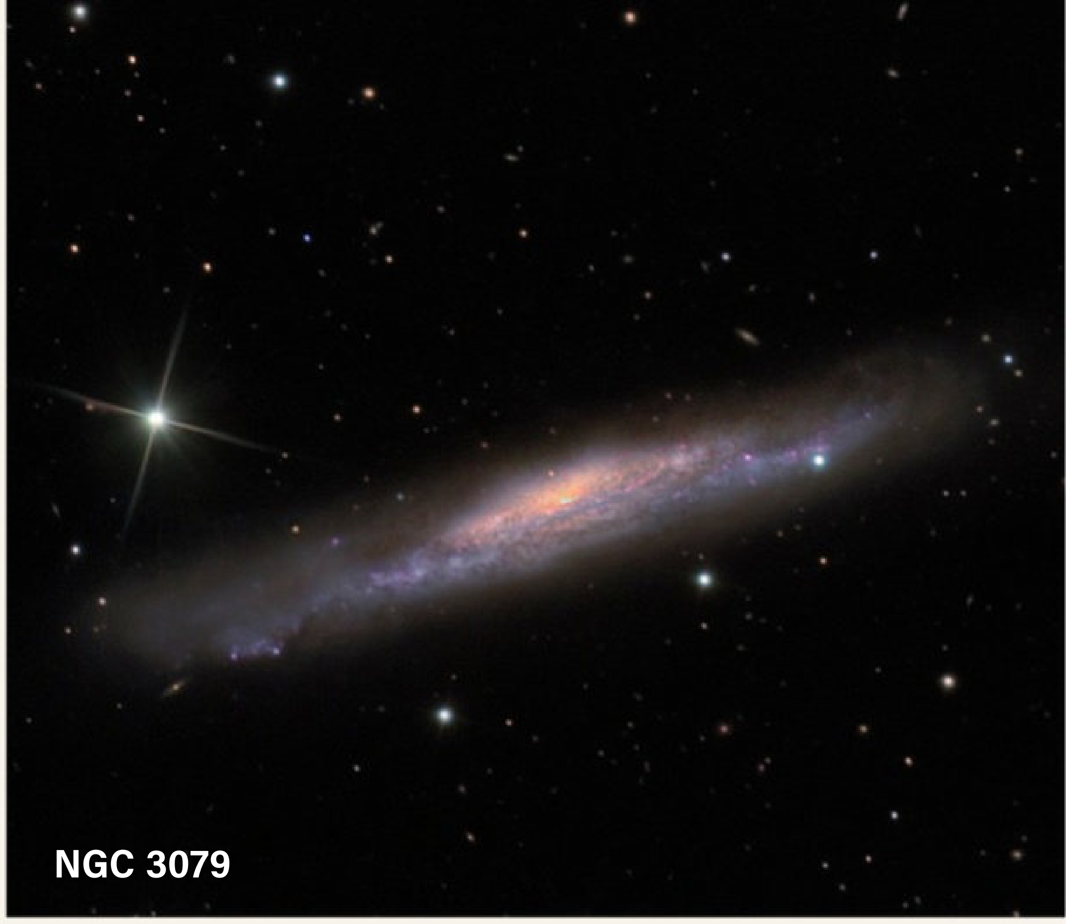
This month, we'll visually thread our way through the extragalactic haystack that's now prominent along the meridian. We'll focus on three types of spiral galaxies: grand-design (those with striking spiral arms), flocculent (those that appear "fluffy"), and edge-on or near-edge-on (those whose orientation doesn't allow us to see their disks). I call the first two types "pins" and the third "needles."

The galaxies in this hunt run the gamut from striking to elusive. To approach this galactic scavenger hunt in a systematic way, I've divided the sky into four sections. In each section, we'll follow a one-to-one extragalactic stitch pattern — first a needle, followed by a pin — looping our way from one region of sky to the next. (And in an effort to introduce you to some lesser-known beauties, none of the objects discussed below is on Messier's famous list.) Let the needlework begin!

NGC 2683, also known as the UFO Galaxy, is one of the sky's best "needles," running three times as long as it is wide. It lies in Lynx.
ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

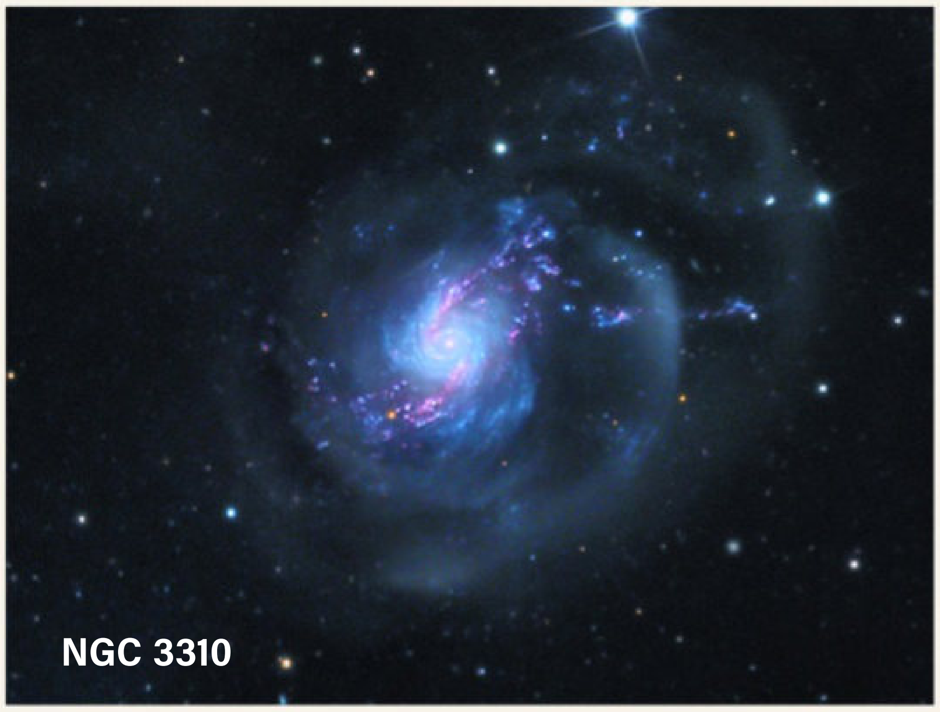
NGC 3184

DAN SMITH/ADAM BLOCK/NOAO/AURA/NSF



NGC 3079

KEN CRAWFORD



NGC 3310

ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

## SECTION 1

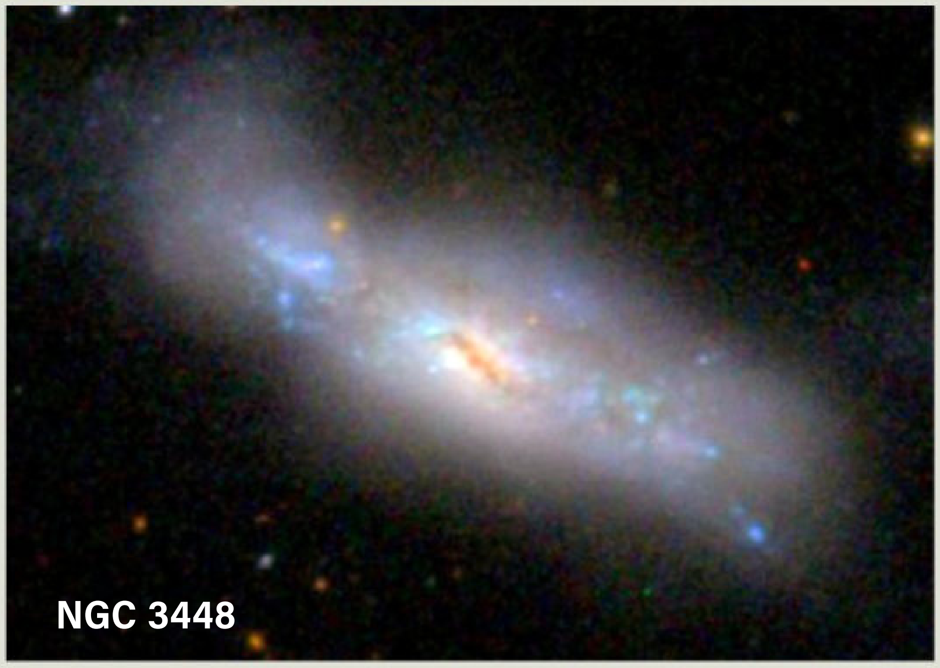
**The first section of sky we'll examine lies in the constellations Lynx and Ursa Major.**

We begin with our first needle, **NGC 2683**, located within the borders of Lynx, but about 1° northwest of magnitude 5.4 Sigma² (σ²) Cancri. This luscious magnitude 9.7 spiral, which tilts just 11° from edge-on, carries the moniker "UFO Galaxy." Through all instruments, it appears as a silver needle (9' by 3') elongated northeast to southwest. It also has a distinct sheen — like moonlight glinting off the blade of a sword.

Now thread your way to Tania Australis (Mu [μ] Ursae Majoris) and look only 45' west for the Little Pinwheel Galaxy (**NGC 3184**). Seen nearly face-on, this magnitude 9.5 circular glow sports a 7'-wide disk hugging a stellar core. At a magnification of 100x, its disk breaks down into delicate waves of impure light. Note that the northern flank is punctured by an 11th-magnitude field star.

Next, turn your attention 2° northeast of Phi (ϕ) UMa to the spectacular edge-on gem **NGC 3079**. This galaxy tilts only 2° from edge-on. It is one of the nearest and brightest Seyfert galaxies, which have both glowing, active cores and clearly visible disks. Visible in a 4-inch scope at 100x, this 8'-by-1.5' streak of light looks like a phantom Frisbee (oriented roughly north to south) near a triangle of stars.

Heading northward, we encounter the peculiar grand-design spiral **NGC 3310**. We see this face-on, 10.8-magnitude starburst galaxy less than 3.5° southwest of 44 UMa. Through a 4-inch telescope at 150x, it resembles a swollen planetary nebula 3.5' across. It is one of the bluest spirals known, and it's also the brightest disturbed galaxy in the late Halton Arp's *Atlas of Peculiar Galaxies*. To see its arms well, however, will require at least a 12-inch instrument.

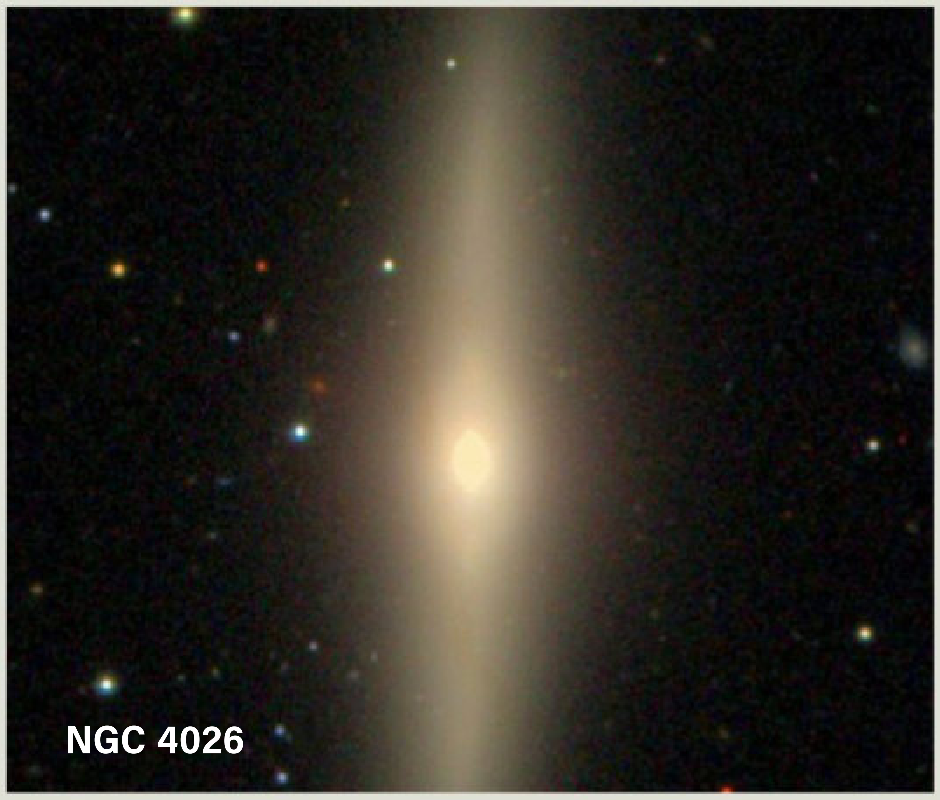


NGC 3448

SLOAN DIGITAL SKY SURVEY

NGC 3631

ESA/HUBBLE/NASA/LUCA LIMATOLA



NGC 4026

SLOAN DIGITAL SKY SURVEY

NGC 3893

BOB UMINSKI/CINDI KRISTOPEIT/ADAM BLOCK/NOAO/AURA/NSF

## SECTION 2

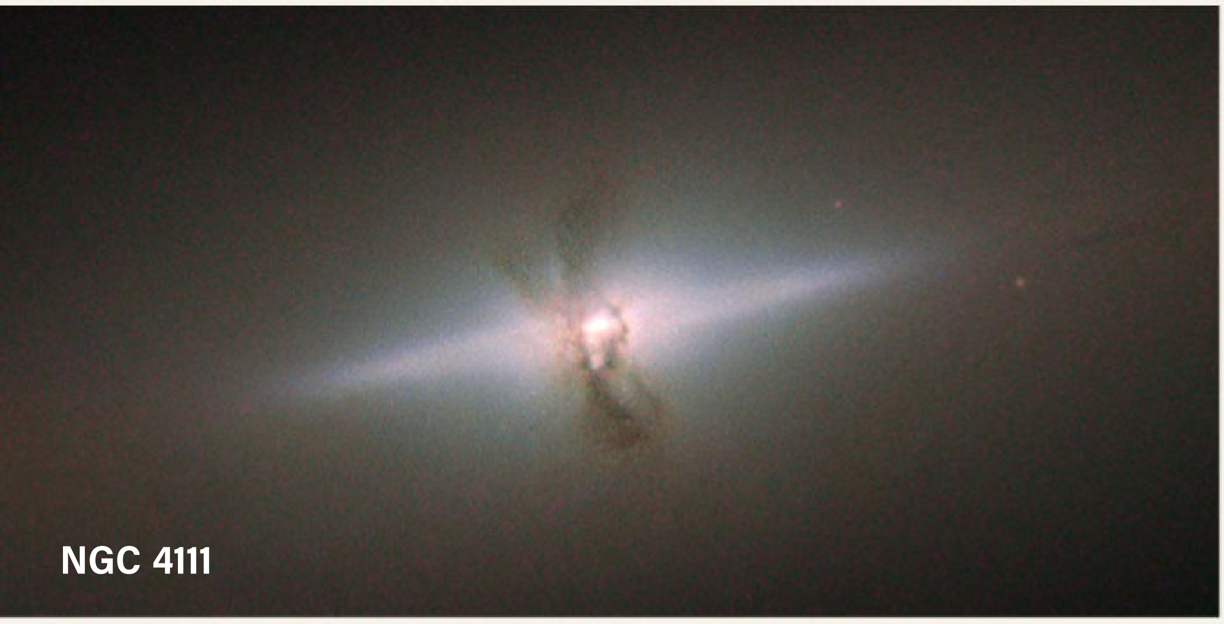
### Our second section lies entirely within Ursa Major.

Here, we come to our first challenge: magnitude 11.5 **NGC 3448**. I call this object the Cigarillo Galaxy because it's an edge-on amorphous galaxy like the Cigar Galaxy (M82), only smaller. This smooth, 5'-by-1.5' sheet of light hugs 44 UMa only 20' to the southeast. Among the galaxies with the highest known rate of star formation per unit mass, NGC 3448 is interacting with UGC 6016, a 14th-magnitude dwarf 3.8' to the west.

Also in this section, nearly 5° west of Phecda (Gamma [γ] UMa), we find the 10th-magnitude grand-design spiral **NGC 3631**. While only 4.5' in extent, this nearly face-on galaxy sports a visual enigma — namely, one "heavy arm," as Arp described it. This peculiar feature originates just north of the galaxy's nucleus and points east. Those viewing through 8-inch or larger apertures should use magnifications of 150x to reveal this hefty appendage.

Visible in a 4-inch scope, **NGC 4026** is a high-surface-brightness magnitude 10.8 edge-on lenticular galaxy in Ursa Major. Look for a starlike core punctuating its 4.5'-by-1' needle-thin disk (oriented north to south), which swells with averted vision. You'll find it about 3° south-southeast of Phecda. Larger scopes will also reveal its faint elliptical halo.

Next, turn your gaze about 1° north-northeast of Chi (χ) UMa for the last target in this section: the magnitude 10.5 grand-design spiral **NGC 3893**. Through a 5-inch telescope, it's an elegant sight. The 4'-by-2' spindle has a soft oval core, as well as fainter arclike extensions. Magnifications of 100x and greater will reveal a tiny nucleus and two high-surface-brightness arms wrapping tightly around the galaxy's core.



NGC 4111

ESA/HUBBLE/NASA/JUDY SCHMIDT

NGC 5033

BERNARD MILLER

NGC 4244

JOE NAUGHTON/STEVE STAFFORD/ADAM BLOCK/NOAO/AURA/NSF

NGC 4414

HUBBLE HERITAGE TEAM (AURA/STScI/NASA/ESA)

## SECTION 3

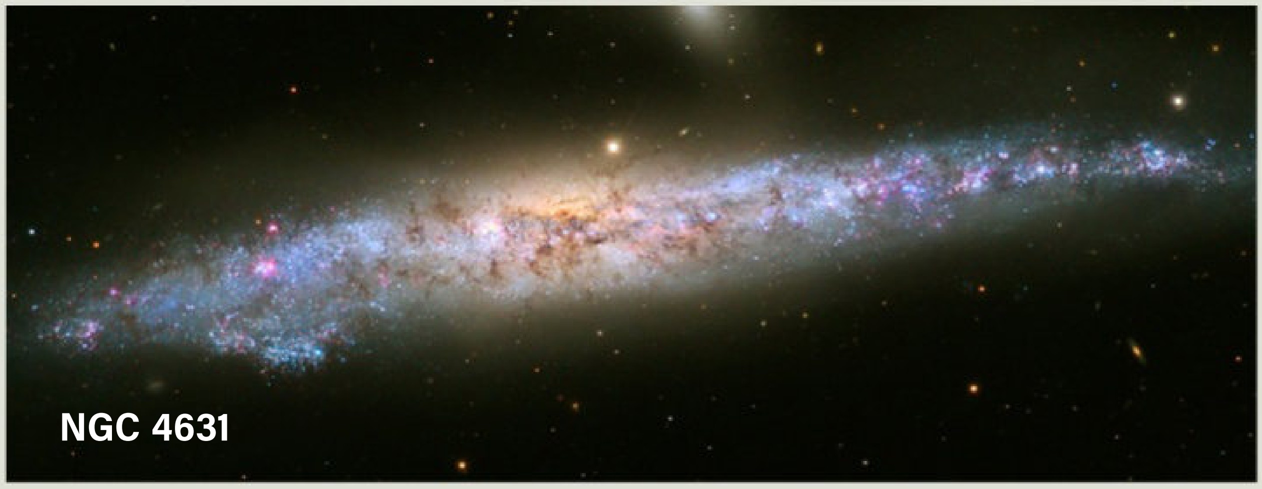
**Our third section lies in two small northern constellations, Canes Venatici and Coma Berenices.**

The first target, **NGC 4111**, lies near the border between Canes Venatici and Ursa Major. This small but fascinating edge-on lenticular galaxy lies about 1° due east of 67 UMa. It cuts a fine line against the night sky. A dark dust lane runs perpendicular to the galaxy's plane, causing a dramatic decrease in brightness between the edge of the bulge and the beginning of the disk. Use at least 100x to see its bright starlike core, eye-shaped bulge, and hyperfine needlelike disk, oriented west-northwest to east-southeast.

Next, thread your way about 1.5° northeast of 14 Canum Venaticorum for the amazing flocculent galaxy **NGC 5033**. Visible with averted vision in 10x50 binoculars, this 10th-magnitude marvel is the visual twin of NGC 5005, which lies 0.5° to the northwest. This 5'-long lens-shaped object becomes increasingly more compressed toward its highly condensed core, a result of the galaxy swallowing a companion sometime in the distant past.

Our third target in the third section is the Silver Needle Galaxy (**NGC 4244**), which glows at magnitude 10.5 about 4½° southwest of Chara (Beta [β] CVn). This galaxy's exactly edge-on disk (15.5' by 1.5') is devoid of a strong central bulge, but it does display a small central concentration. The galaxy orients northeast to southwest and, through a 4-inch scope at 75x, is a compelling ghostly ellipse with an uncanny sharpness to the galaxy's slender shape.

Last but not least in this section, **NGC 4414** is another superb flocculent spiral about 3° north of Gamma Comae Berenices. The 10th-magnitude galaxy's 4.5'-by-3' disk has a relatively high surface brightness and makes a good target for small-telescope users, even under suburban skies. A 5-inch instrument at a magnification of 100x will reveal the inner lens. This feature appears mottled along the major axis, and the outer lens has hints of knotty enhancements along what appears to be a spiral pattern, although nothing is connected.



ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

BOB FERA

R. JAY GABANY

ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

ESA/NASA/HUBBLE

## SECTION 4

**Our final section encompasses parts of Canes Venatici, Coma Berenices, and Virgo.**

For a whale of a view, slide about 3.5° east-northeast of NGC 4414 to **NGC 4631**. Popularly known as the Whale Galaxy, this 9th-magnitude tapered monolith (oriented roughly east to west) is replete with dark vapors in a delicate embrace. Star clumps pepper the 15'-long disk like snowballs on the side of a house. For a triple treat, check out **NGC 4627**, a magnitude 12.5 dwarf elliptical galaxy 3' to the north, and its equally slender partner, the Hockey Stick (**NGC 4656/7**), a magnitude 10.5 edge-on barred spiral 30' to the southeast.

Next is a different sort of pinwheel. **NGC 4725** is a peculiar one-armed spiral — a transition system between a normal spiral and a barred spiral that forms one of the most complete rings of any galaxy known. To find this magnitude 9.5 gem, look 2° south and slightly west of 31 Com, which lies near the North Galactic Pole. Through a 4-inch scope, the galaxy's inner region displays a bar that connects a bright, broken inner ring surrounded by a fainter lens of light.

To find our next treat, travel westward to a point 2° due east of 17 Com. There, you'll find the Needle Galaxy (**NGC 4565**). This magnitude 9.5 wafer of light has two 8'-long threads of light extending from the galaxy's slightly swollen belly — like silk from a spider's abdomen. A 4-inch telescope at high power will resolve NGC 4565's classic dark lane, which cleanly divides the galaxy's bright hub into two distinct ovals.

The last object is the Lost Galaxy (**NGC 4535**). While relatively bright (magnitude 10.5), this barred spiral is of low surface brightness, so it's a challenge to small-scope observers. The 7'-long glow lies 2¼° northwest of 31 Vir and, in a 4-inch scope, shines as a circular patch of ill-defined light. Views through 12-inch and larger scopes bring out the spiral's main, S-shaped arms within what I describe as "extragalactic ectoplasm."

### BONUS: A FINISHING STITCH

We'll end our needlework with magnitude 10 **NGC 4762**, an edge-on system 2° west and slightly north of Vindemiatrix (Epsilon [ε] Virginis). A 5-inch scope shows it as a 9'-by-2' wisp sporting a nuclear bead within an inner lens. Bright dots flank the core, beyond which threads give way to hyperfine extensions. In larger scopes, the thin disk tapers to sharp points.

And with that, our galactic stitchwork is done. But there's an entire universe at your disposal, and I encourage you to sew your own wonders together. As the late hand-knitting expert Elizabeth Zimmermann said, "Properly practiced, knitting soothes the troubled spirit, and it doesn't hurt the untroubled spirit either." Enjoy.

**Stephen James O'Meara** *is a contributing editor and columnist for* Astronomy *who enjoys frequent trips into the deep sky.*

# WE TEST Canon's new astro

## With 30 megapixels of resolution, a full-frame sensor, and a mirrorless body, the EOS Ra camera can help you reveal the night sky in all its glory.

TEXT AND IMAGES BY TONY HALLAS

With all the noise about Sony and Nikon cameras over recent years, I was under the impression that Canon had gone dormant. I could not have been more wrong. Not only has Canon been quietly creating new innovations in camera lenses and design, but they also have been working to improve the overall quality of their products. This is clearly evident with the release of their new EOS Ra camera.

The camera is based on the company's mirrorless R model, with two significant modifications. Instead of the usual 10x magnification, the latest Ra model can go to 30x, allowing you to obtain an extremely precise focus on stars, especially when using a wide-angle lens. Additionally, the Ra model sports a newly designed filter that lets the emission line of Hydrogen-alpha (Hα) at 656.3 nanometers really shine through. This leads to a roughly fourfold increase in the transmission sensitivity of Hα light — enabling you to capture deeper, more vivid reds — for the Ra compared to previous models, yet the window is so precise that the camera can still be used in daylight. Though Canon officials "do not recommend" using the Ra for daytime applications, after two months of daytime use, I have yet to see a bad picture.

The Canon Ra, like the R, has a full-frame, 30.3-megapixel CMOS sensor with an individual pixel size of 5.36 microns. The large pixel size helps it strike a good balance between resolution and light sensitivity, as each of the Ra's pixels absorbs more photons than the smaller pixels found in many other camera sensors. The Ra's electronics incorporate the latest DIGIC 8 image processor, which has powerful noise-suppression capabilities. Images taken in extremely low-light situations and then stretched to look normal show very low noise — on par with the best cameras currently available.

The Ra is a thoroughly modern camera, with most of its main controls accessible via touch screen. This makes adjustments at 2 A.M., when you are half-asleep, a breeze. The rear screen also articulates into any position, unlike many other screens that have limited or no movement. When you're not using the camera, the screen can be folded so its glass face is on the inside, protecting it from damage. And, unique to the Canon R series, when the camera is turned off, the shutter closes, protecting the delicate sensor inside from dust and other contaminants. This also means that changing lenses while the camera is off does not expose the sensor to the environment.

Canon optical engineers also enlarged the Ra's front opening to 52mm. The larger opening facilitates lenses that are sharper to the edge and have less vignetting, helping keep images crisp all the way to the periphery. Lenses that are dedicated to the R series bear the "RF" designation; the RF 70–200mm f/2.8 is a prime example. You can, however, still use older EF lenses with a short adapter, and you can order the adapter with a built-in filter housing. Canon also offers polarizing and variable neutral density filters that you can insert into the adapter

One of the most striking features of the Canon Ra is its vari-angle LCD screen, which makes it a breeze to view your target no matter where the camera points. In this case, the target is the Orion Nebula seen through a 200mm lens.

# camera


Canon's EOS Ra sports a DIGIC 8 processor and a full-frame CMOS chip. Its shutter also closes when the camera is off, protecting the sensor.

— a really neat idea. You'll likewise be able to insert astronomy-related filters as they become available.

As an added bonus, you can assign custom functions to most of the Ra's buttons and its multi-function bar. There's also a ring with click stops for the RF lenses and some EF adapters, which allows you to make additional adjustments. Being a nuts-and-bolts kind of person, I chose to turn the multi-function bar off. Because the ring can only be activated when another button is held down, this negates the chance of any accidental movement.

While I was at the Advanced Imaging Conference in 2019, I had the opportunity to see more of the latest RF lenses made specifically for Canon's R-series cameras. These lenses are wider than a normal lens. And if they are fast, they are also quite heavy. Although they can handle being attached to a tripod or mount, I would not recommend going on a hike with them. For daytime use, my favorite lenses are the 24–70mm f/4 EF with macro and the 70–200mm f/4 IS EF. Both of these are used with an adapter to allow for internal filtering, as mentioned earlier.

The Ra does not come with a built-in intervalometer, so to automatically shoot continuous images, you'll need to buy an external one that plugs into the camera. But if you are shooting three-minute, dithered exposures (by slightly shifting the camera between exposures), the exposure time in bulb mode can be set all the way to 60 minutes. No external timer needed.

I should also say something about how I prefer to image with the Ra. As previously noted, the Ra has very little noise. This means you can get by shooting just a single frame. But to get the most detail out of the sky, nothing beats shooting multiple frames. Through experimentation I've found that longer, low-ISO exposures are better than shorter, high-ISO shots. However, this means you'll need some form of tracking with a small equatorial mount, for instance, or a star tracker like the Vixen Polarie. I typically shoot three- to five-minute exposures at an ISO of 800 to 1600 (depending on the target) and an f-ratio of f/3.5 to f/4. Shooting wide open records the worst the lens can perform and usually leads to heavy vignetting that must be dealt with after the fact.

I always shoot RAW images, taking anywhere from five to nine exposures, dithering between each. I then convert them to Digital Negative Image (DNG) files and import them into Adobe Camera Raw (ACR) for processing. Once I've processed the images in ACR, I save them as 16-bit TIFF files and import those into RegiStar, where the files are aligned and combined — or stacked — to create a master TIFF file. Finally, I import the master file into Photoshop for final adjustments and enhancements.

## Better than a small step

The Canon EOS Ra is a giant leap forward in astronomical imaging. Its combination of high sensitivity, low noise, and good resolution in a modern architecture is a true winner. Plus, the touchscreen menus alone are worth the price of admission. All in all, the camera is a real joy to work with.

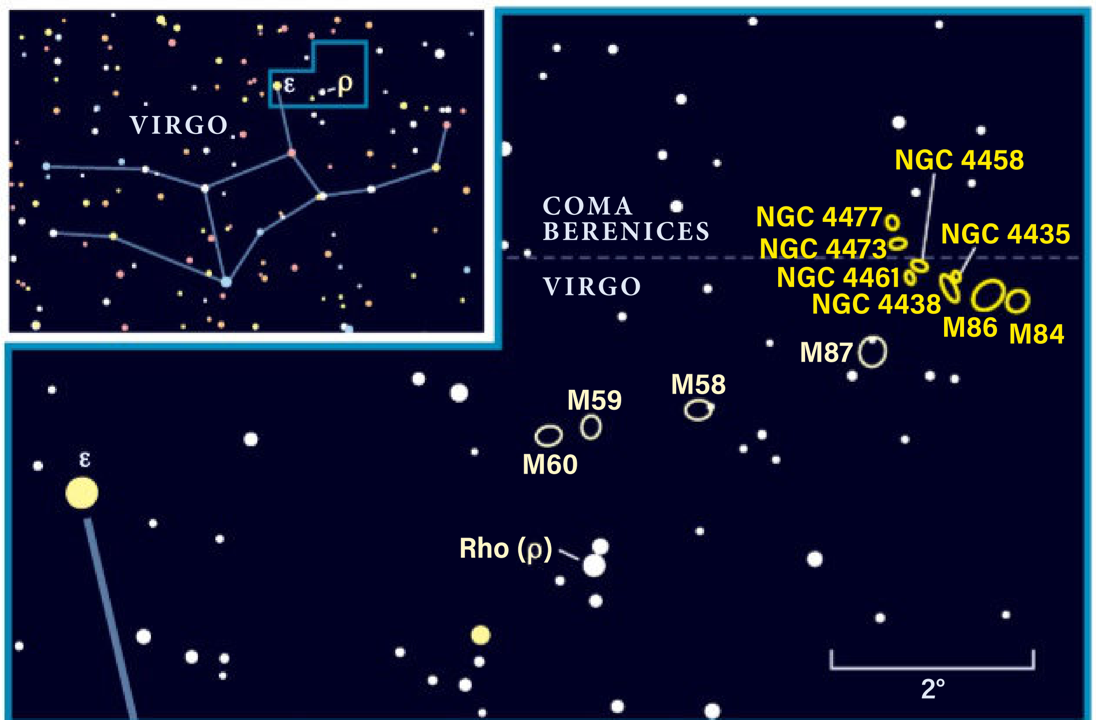
**Tony Hallas** *is one of the world's top astroimagers.*

### PRODUCT INFORMATION

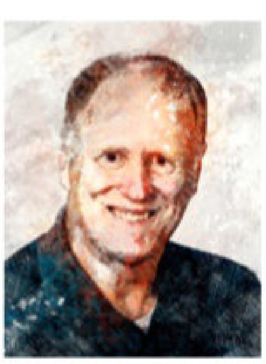
**Canon EOS Ra**
**Type:** Digital single-lens non-reflex
**Sensor:** 30.3-megapixel CMOS
**Format:** Full frame (36 by 24 millimeters)
**Resolution:** 6,720 by 4,480 pixels
**Processor:** DIGIC 8
**ISO range:** 100 to 40000
**Shutter speed:** $\frac{1}{8,000}$ to 30 seconds
**Continuous shooting:** 8 frames/second
**Wi-Fi:** Built in
**Display:** 3.15-inch vari-angle touchscreen LCD
**Dimensions:** 5.35 by 3.87 by 3.32 inches (135.8 by 98.3 by 84.4 mm)
**Weight:** 1.28 pounds (580 grams)
**Price:** $2,499.00 (body only)

# Explore Markarian's Chain

Tour a tightly packed group of gorgeous galaxies.




Markarian's Chain (yellow), located about 50 million to 55 million light-years away, might not look that impressive through a backyard scope. But targeting this many galaxies contained in such a tiny section of the sky is worth the challenge.
*ASTRONOMY*: ROEN KELLY



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

To the passionate deep-sky observer, spring means one thing — galaxies! And nowhere is the number of galaxies greater than in the Virgo Cluster. I featured this galactic swarm in my April 2013 column, but this month, we return to the Virgo Cluster to explore a remarkable group of galaxies within it: Markarian's Chain.

If your scope has go-to capability, you can arrive at the group by entering the coordinates R.A. 12h27m45.6s, Dec. 13°00'31". This will take you directly to NGC 4438, which lies near the center of Markarian's Chain. However, if you opt for this direct route, you'll miss some of the surrounding scenery. I instead suggest you star-hop from the nearby 5th-magnitude star Rho (ρ) Virginis. Rho serves as an ideal "base camp" because it teams up with three surrounding field stars to form a northwest-pointing arrowhead that quickly establishes field and size orientation. Use an eyepiece that yields a 1° or 2° field of view for the scenic journey.

**A nearly straight row of bright Messier galaxies runs from just north of Rho Virginis all the way to Markarian's Chain.**

A nearly straight row of bright Messier galaxies runs from just north of Rho all the way to Markarian's Chain. From Rho, move 1½° northward to the elliptical galaxies M60 and M59. A slight shift westward will bring the barred spiral M58 into view. A sweep from M60 to M58 and extended an equal distance beyond takes us to the elliptical galaxy M87, whose giant black hole was recently targeted by the Event Horizon Telescope. If we continue the M58-to-M87 route another 1½°, we arrive at the side-by-side ellipticals M84 and M86. They mark the western edge of Markarian's Chain.

Once you have M84 (magnitude 9.2; 6.5' by 5.6') and M86 (magnitude 8.9; 8.9' by 5.8') centered in the eyepiece field, gently nudge your scope slightly less than ½° eastward. Here you'll find the close pair NGC 4435 (magnitude 10.8; 3.0' by 2.2') and NGC 4438 (magnitude 10.0; 8.5' by 3.0'). Because of their visual appearance, they're nicknamed the Eyes Galaxies. Switch to a higher magnification if you have trouble seeing them.

Less than ½° east and slightly north of the Eyes is a fainter galactic duo. It's comprised of the elliptical galaxy NGC 4458 (magnitude 11.8; 1.6' by 1.5') and its lenticular neighbor NGC 4461 (magnitude 11.1; 3.4' by 1.4').

The final members of Markarian's Chain, NGC 4473 (magnitude 10.2; 4.5' by 2.5') and NGC 4477 (magnitude 10.4; 3.7' by 3.3'), lie across the border in Coma Berenices. The former is yet another elliptical galaxy, while the latter is a barred lenticular galaxy.

Although M84 and M86 are visible in an ordinary 60mm refractor, spotting the rest of the chain will require larger instruments. All can be glimpsed with an 8-inch scope under dark-sky conditions, while an observer with a keen eye might be able to see them with a 6-inch or smaller scope.

Markarian's Chain is named after the Armenian astrophysicist Benjamin Markarian (1913–1985). However, he didn't discover these galaxies. That honor goes to Charles Messier, who cataloged M84 and M86 in 1781, and William Herschel, who found the rest of the chain's members a few years later. Markarian discovered their common motion in the early 1960s.

Visually speaking, Markarian's Chain is hardly a cosmic masterpiece. Its member galaxies are too far away (an estimated 50 million to 55 million light-years) to appear as much more than fuzzy blobs in most backyard scopes. Still, it's intriguing to see so many galaxies packed in such a small area of sky. The "wow" factor comes from the realization that the photons stimulating your retinal cells as you gaze into the eyepiece started their journey during the early part of Earth's Eocene Epoch, just 10 million years after the extinction of the dinosaurs.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: We explore the "Fadeaway Star." Clear skies!

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# MARKETPLACE

## INDEX *of* ADVERTISERS



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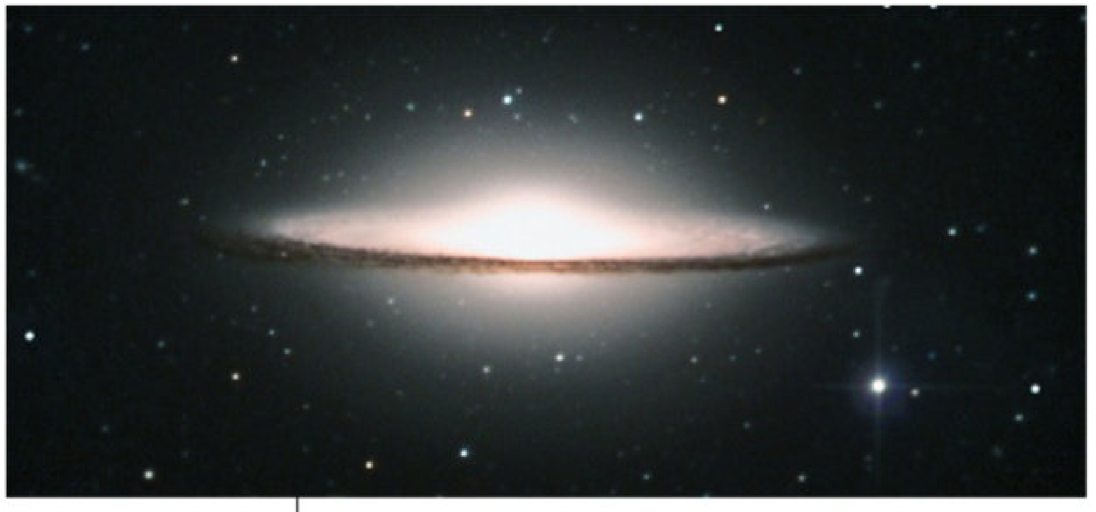
# Curve to Corvus and beyond

The region of the crow hides some pretty cool celestial stuff.



The magnificent Sombrero Galaxy (M104) is a great edge-on spiral, and makes a fine target for any pair of binoculars. R. JAY GABANY

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

One of the first catchphrases we probably all heard when learning our way around the spring sky was that from the handle of the Big Dipper, you "arc to Arcturus, then speed to Spica, and, finally, curve to Corvus." Arcturus and Spica are brilliant stellar beacons, far outshining the handle stars that guide us their way. The four primary stars that make up the trapezoidal body of Corvus the Crow, however, shine at an insipid 3rd magnitude. Despite their modest numbers, those four stars stand out surprisingly well, even under the veil of suburban light pollution.

Let's begin our exploration at **Zeta (ζ) Corvi**, a wide double star within the southern confines of the trapezoid. Shining at 5th magnitude, Zeta shows a subtle hint of blue, while its 6th-magnitude companion, HD 107295, 6' to the west, is yellowish. Whether they form an actual binary star system or just a chance optical double is open to debate. Zeta is projected to be 415 light-years away, while HD 107295 is calculated at 386 light-years distant. Some ambiguity in the data, however, may mean that they are actually much closer to one another.

Corvus also holds a second widely spaced double star about 2° south of the midway point between Beta (β) and Epsilon (ε) Corvi. The brighter of the pair is 6th-magnitude **6 Corvi**, while 5' to its west is **HD 107756**, one magnitude fainter. Both are orange giant stars. Slightly defocus your binoculars to enhance their delicate colors.

By extending an imaginary line from Delta (δ) through Beta Corvi along the trapezoid's western side, and continuing southward for 3½°, you will come to 5th-magnitude HD 109799 in neighboring Hydra. Can you also see a smudge of faint light just to its northeast? That will be **M68**, a rogue globular cluster lying in the Milky Way's outer halo, about 33,600 light-years from us. Owing to its southern position in the sky from midnorthern latitudes, M68's gentle glow can be quickly extinguished by horizon-hugging light pollution and haze. But if you wait for a moonless night, it will reveal itself with just about any binocular. As you strain to see M68, consider that that feeble glow is actually the combined effort of more than 100,000 stars that have been in existence for an estimated 11 billion years.

The long-period variable star **R Corvi** lies within the trapezoid, about 2½° southeast of Gienah (Gamma [γ] Corvi). Like most long-period variables, R Corvi is a red giant that varies dramatically from maximum to minimum. At peak brightness, it reaches magnitude 6.7, while at minimum it drops to magnitude 14.4. A full cycle, from one max to the next, takes approximately 317 days. And, guess what? It's on the rise. Max light is predicted to occur in mid-June, so now is a great time to check it out. It forms a tiny right triangle with two faint stars that it will easily outshine as it ascends. Use the customizable Variable Star Plotter on the American Association of Variable Star Observers' website, www.aavso.org, to create your own finder chart.

Just north of Gamma Corvi, there is an arrow-shaped asterism of eight 6th- and 7th-magnitude stars that points right at our next target, the **Sombrero Galaxy** (M104). What could be more convenient than that? The galaxy is just 2° northeast beyond the arrow's tip, barely across the invisible boundary in Virgo. Although M104 shines at only 9th magnitude, my old 7x35s still reveal its oval disk. Increasing to my 10x50s, that disk grows more prominent, surrounding a stellar core. It takes my 16x70s to reveal why M104 is nicknamed the Sombrero; they reveal a protruding core and broad, flattened disk cleaved by a "brim" of opaque dust.

I always enjoy hearing of your binocular exploits and successes.

Finally, look about halfway between the tip of the arrow and M104. Can you see a tiny triangle of faint stars? If you are viewing through 14x or higher giant binoculars, you might notice that there are six stars here, forming a triangle within a triangle. Nicknamed the **Stargate**, this little object is one of my favorite springtime asterisms.

I always enjoy hearing of your binocular exploits and successes. You can contact me through my website, philharrington.net. Until next time, remember that two eyes are better than one.

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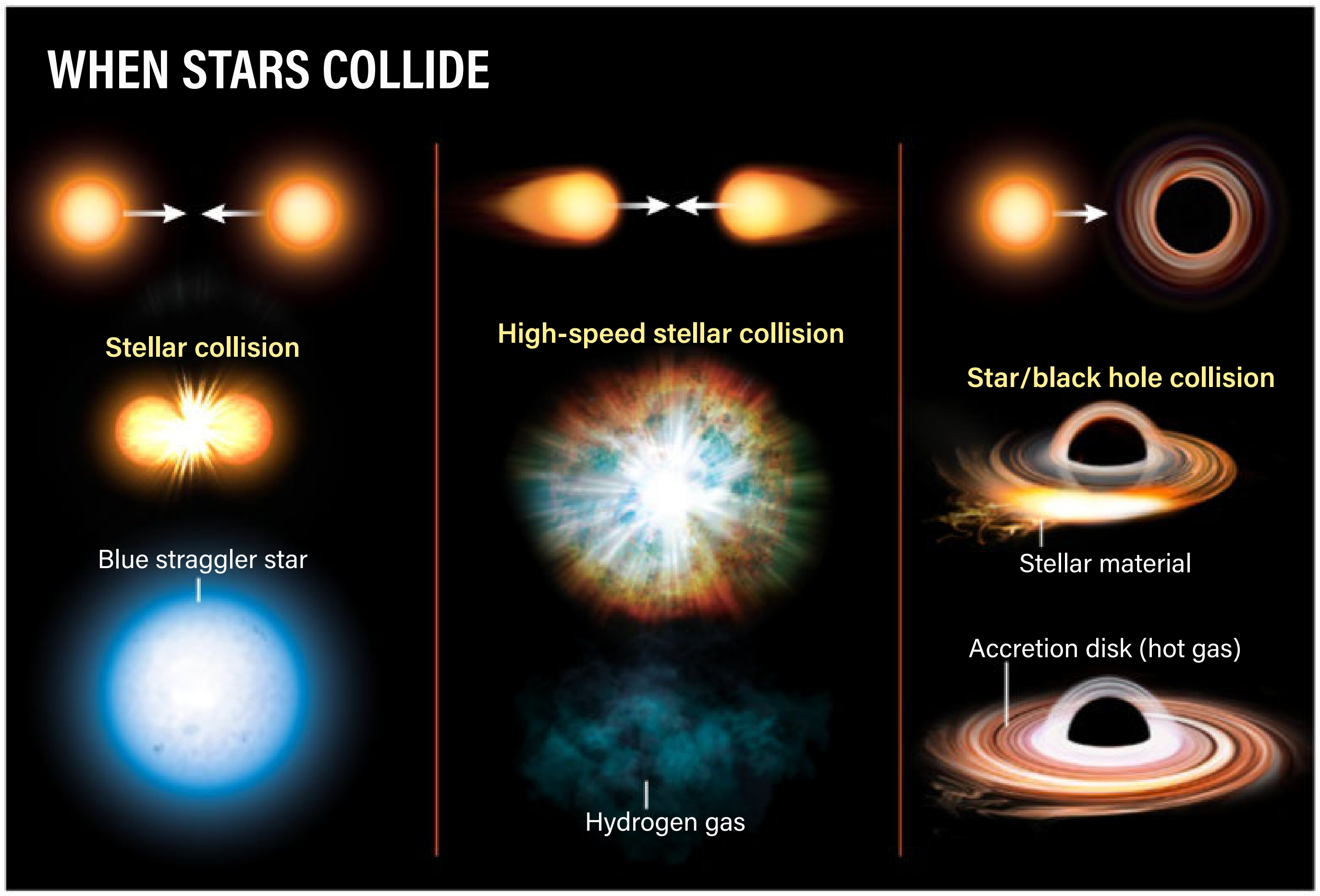


Stars rarely collide, but when they do, the result depends on factors like mass and speed. When two stars merge slowly, they can create a new, brighter star called a blue straggler. If two stars traveling at a fast pace hit, they'll likely leave behind only hydrogen gas. Stars that collide with a black hole are ultimately consumed. *ASTRONOMY*: ROEN KELLY

# Stellar collisions

**Q** | EVERY TIME I READ ABOUT THE ANDROMEDA GALAXY COLLIDING WITH THE MILKY WAY, SOMEONE POINTS OUT HOW UNLIKELY IT IS FOR TWO STARS TO COLLIDE BECAUSE OF IT. BUT WHAT WOULD HAPPEN IF TWO STARS DID COLLIDE?

***Jeremy Strzynski***
*Aurora, Indiana*

**A** | It's rare, but stars do collide in the densest parts of our galaxy: near the center and in massive globular star clusters. The outcome of the collision depends on how fast the stars are moving relative to each other, rather like a car accident. In star clusters, the stars are moving relatively slowly, and so the "fender bender" results in the two stars merging into one new, more massive star that we call a blue straggler. We can identify these stars fairly easily, since they are hotter and brighter than the other stars in the cluster.

The center of the galaxy is more like the interstate, and the stars are moving very quickly. A collision there is much more destructive, and often the aftermath is just "star bits" (that is, mostly hydrogen gas) spread out all over interstellar space. The most exciting collisions happen when a star runs into the central black hole in our galaxy. The star won't survive, of course, but it goes out in a blaze of glory called a tidal disruption event. Some of the star's material gets thrown away, but the rest falls into the black hole and forms a hot disk of gas before it is consumed.

***Alison Sills***
*Professor, Department of Physics & Astronomy, McMaster University, Hamilton, Ontario*

**Q** | SINCE SURFACE ATMOSPHERIC PRESSURE ON MARS IS ROUGHLY EQUIVALENT TO WHAT EXISTS WELL INTO THE STRATOSPHERE ON EARTH, HOW WOULD A HELICOPTER BE ABLE TO GENERATE SUFFICIENT LIFT TO GET OFF THE GROUND?

***John A. Ferko***
*Colorado Springs, Colorado*

**A** | Flying a helicopter on Mars, such as the Mars Helicopter that will be traveling to the Red Planet with the Mars 2020 mission, is a bit of a trade-off. The air pressure at the martian surface is equivalent to the air pressure at about 100,000 feet (30,500 meters) on Earth, but the current height record for helicopters on Earth is roughly 40,000 feet (12,200 m). According to staff at NASA's Jet Propulsion Laboratory (JPL), the softball-sized, 4-pound (1.8 kilograms) Mars Helicopter will compensate for the lower atmospheric density on Mars by using more power and rotating its blades at a higher speed than would be required to lift the craft

The Mars Helicopter's small size and fast rotor rotation will allow it to fly on Mars. This photo shows the helicopter's flight model, as well as the base, crossbeam, and side posts that will protect its delicate legs and attach it to the Mars 2020 rover. NASA/JPL-CALTECH off the ground on Earth. It will spin its two counter-rotating blades at nearly 3,000 revolutions per minute, or about 10 times as fast as a helicopter on Earth, to stay aloft.

The trade-off, JPL says, is that Mars' gravity is about 40 percent the strength of Earth's gravity — so the Mars Helicopter will require less lift to stay airborne. Over the course of 30 days, mission engineers plan to fly the helicopter up to five times, aiming for incrementally longer distances and hoping to reach a distance of a few hundred yards with a maximum flight time of about 90 seconds. Its first flight, however, aims to have the helicopter rise about 10 feet (3 m) straight up and hover for about 30 seconds.

Although the Mars Helicopter project is an exciting one that engineers expect to succeed, there is still a chance that some aspect of this project won't go as planned. But because the helicopter is simply a proof-of-concept test for future helicopters on Mars, even if this helicopter fails, it will not impact the overall Mars 2020 mission.

**Alison Klesman**
*Senior Associate Editor*

## Q | WHEN SIRIUS A EXPANDS INTO A RED GIANT, COULD WHITE DWARF SIRIUS B GO SUPERNOVA BY PULLING GAS FROM SIRIUS A'S OUTER LAYERS AND PRODUCE HEAVY ELEMENTS VIA THE R-PROCESS?

***John Holmes***
*McLean, Virginia*

**A** | The answer is perhaps, but unlikely. The key uncertainties are the speed at which mass is lost from the giant Sirius A, whether the material that lands on the white dwarf explodes on contact, and whether enough mass can be collected by the white dwarf to get close to the Chandrasekhar limit.

Sirius A and B are quite widely separated, by about 25 times the distance between Earth and the Sun. The larger Sirius A is about twice the mass of the Sun and its white dwarf companion is about the same mass as the Sun. As stellar winds blow material off the surface of Sirius A, some mass can be gravitationally captured by the white dwarf.

The effectiveness of this capture is strongly related to the wind speed. As a main sequence star, Sirius A currently loses little mass, which escapes at high speeds, so Sirius B cannot easily capture it. However, when Sirius A draws toward the end of its life, it will swell to become an asymptotic giant branch (AGB) star. These huge red giants have radii as big as the Earth-Sun separation, but still much smaller than the separation between Sirius A and B. AGB stars blow away a lot of their mass — perhaps 75 percent — in the form of a dusty, slow-moving wind, and this can be partially captured by the white dwarf.

Sirius A (left) and B, shown in this artist's concept, are separated by about 25 times the Earth-Sun distance and circle each other once every 50 years. Although it is possible the white dwarf Sirius B might gather enough material from its companion to explode as a supernova, it is not likely. NASA, ESA, AND G. BACON (STScI)

In order to explode as a supernova, the white dwarf must increase its mass to close to 1.4 times the mass of the Sun, known as the Chandrasekhar limit. It seems unlikely that it will be able to do this unless the wind from the AGB star is even slower than expected, especially as the orbit of the two stars will widen as mass escapes from the system as a whole. Even if the white dwarf were to capture this much mass, it may not necessarily stick! The hydrogen-rich material from the giant star can periodically ignite on the white dwarf's surface, causing a more modest explosion, called a nova, which would blow the material back into space and might even reduce the mass of the white dwarf.

So, in summary, in about 500 million years Sirius A will expand dramatically and lose nearly three-quarters of its mass in the form of a slow, dusty wind. A fraction of this will be captured by the white dwarf, but in order to explode as a supernova, it must first accrete enough mass to get close to the Chandrasekhar limit, and, second, must avoid explosively igniting the accreted material prematurely. Based on our current understanding, neither of those two conditions looks likely.

The final part of your question asks about r-process elements. These are elements that are built up by a series of "rapid" neutron captures followed by radioactive decay. Examples of these are precious metals like gold and platinum. There are two probable sites in the universe where r-process elements are made: colliding neutron stars and core-collapse supernovae of massive stars. The supernova caused by the detonation of a white dwarf is quite different. It consists of the explosive ignition of carbon and oxygen, and there is no rich source of neutrons to make r-process elements. So, the elements produced in a white dwarf supernova (known as a type Ia supernova) are mostly the products of oxygen and carbon fusion, like silicon, sulfur, iron, and nickel.

**Rob Jeffries**
*Professor of Astrophysics and Head of Physics & Astrophysics, Keele University, Staffordshire, U.K.*

### SEND US YOUR QUESTIONS

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

# Cosmic portraits

**1. NOT THE MILKY WAY**
The gegenschein (German for "counterglow") is a faint, diffuse patch of light sometimes seen directly opposite the Sun. This view is from Yaha Pass, some 14,800 feet (4,500 meters) above sea level. The mountains include Mount Gongga, the highest peak in Sichuan Province, China. Yellow and green airglow is also visible in the image. ***• Jeff Dai***

**2. NOT IDENTICAL TWINS**
Open clusters M46 (left) and M47 lie in the constellation Puppis the Stern. M47 is the brighter of the two, but M46 offers a bonus — planetary nebula NGC 2438 lies in the same line of sight. The cluster's stars are 5,400 light-years away, while NGC 2438 is a bit less than 3,000 light-years distant. ***• Dean Salman***

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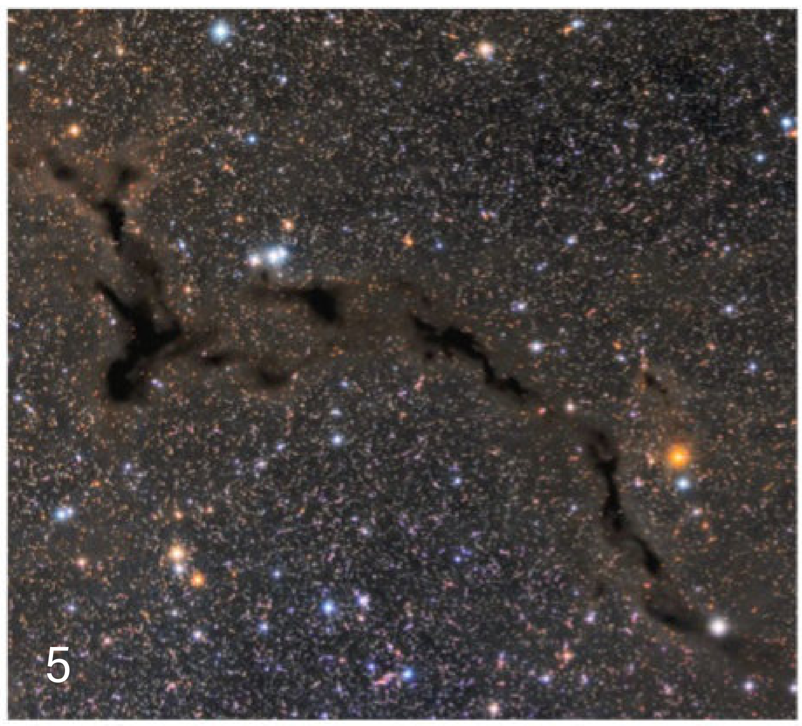

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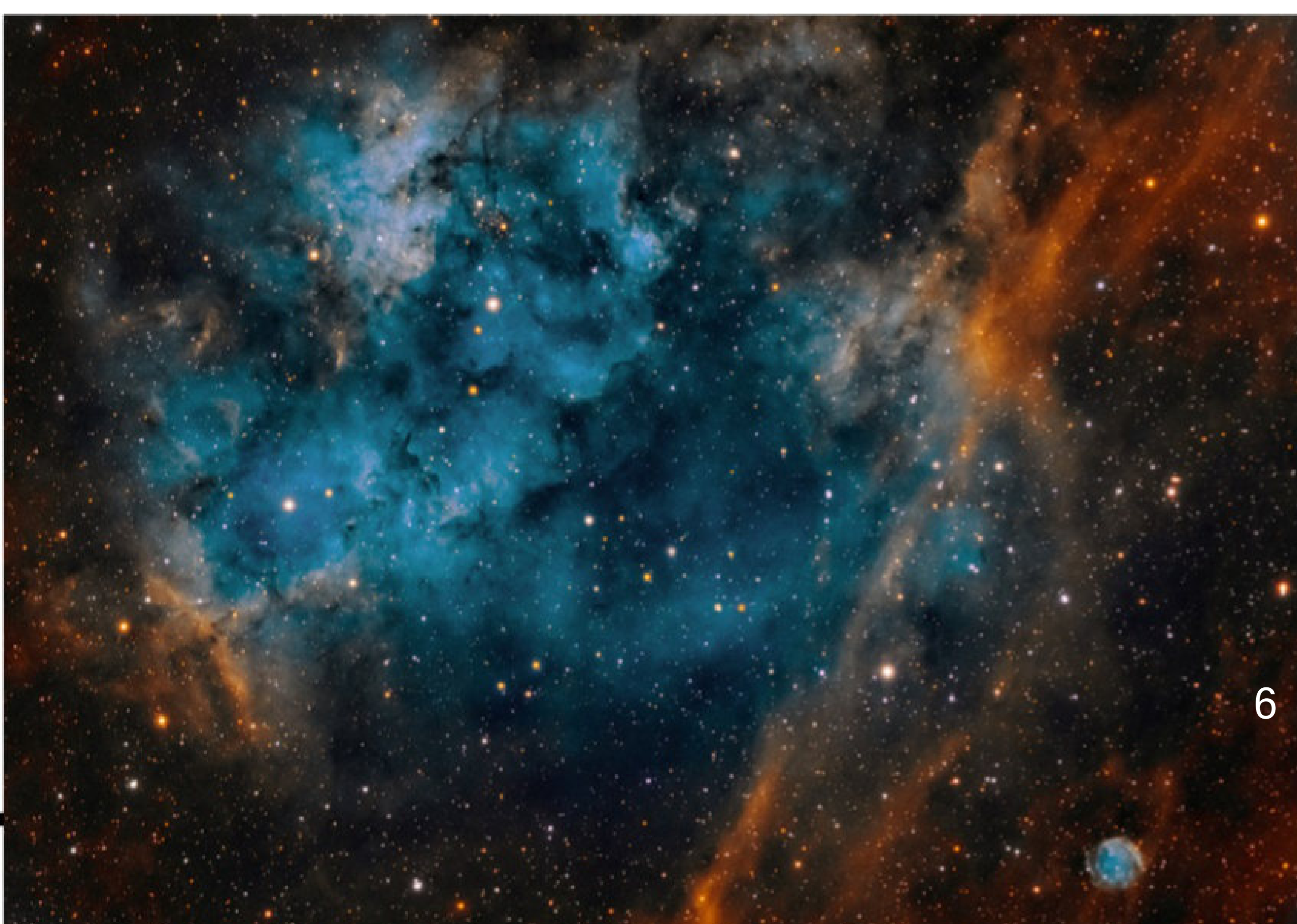

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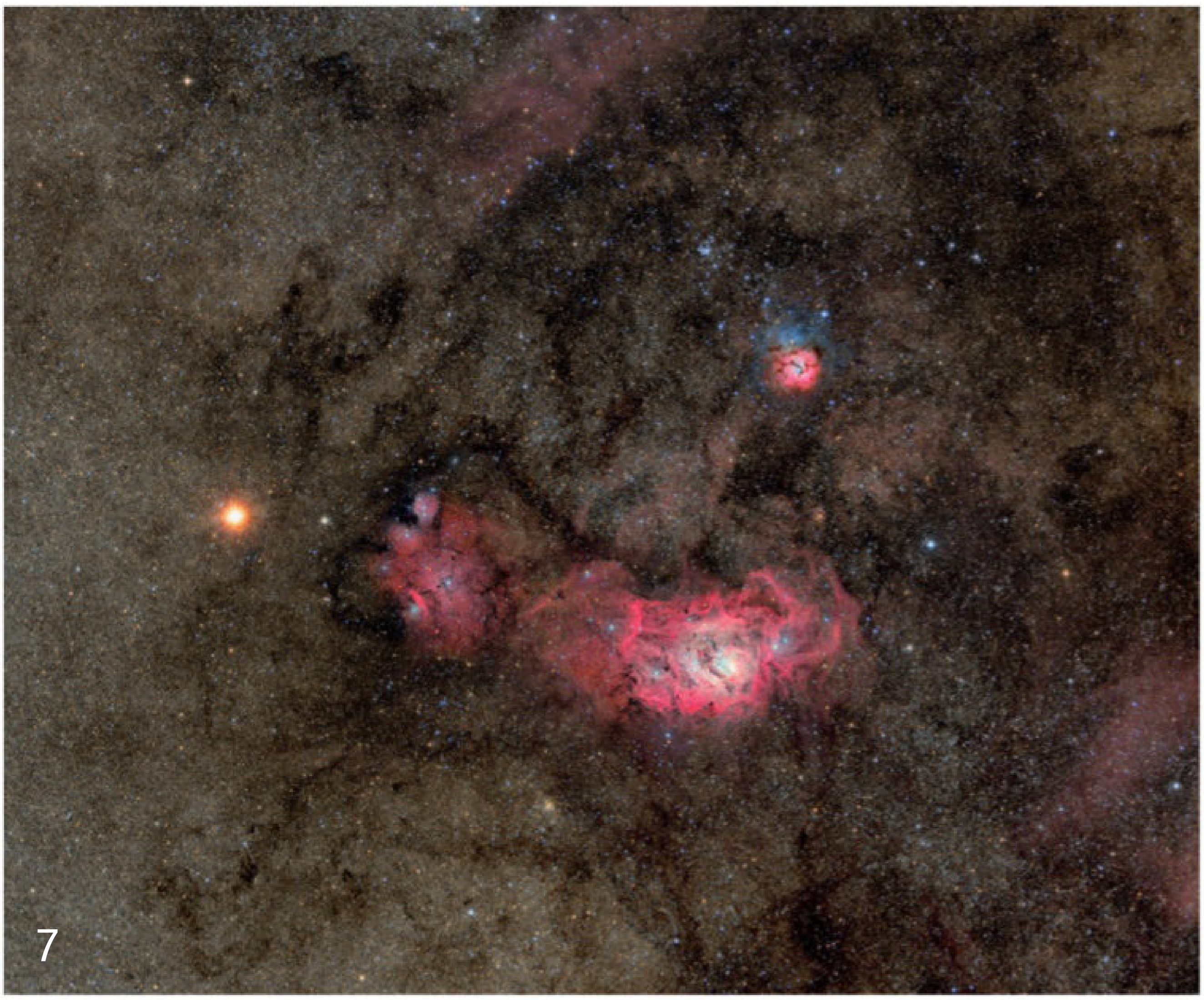
**3. KNIGHT SKY**
The star trails in this image were made by combining 106 exposures of 25 seconds each. They circle above the Castle of Noudar, a medieval castle in Barrancos, Portugal. The smallest trail, that of Polaris, is to the upper right.
**• *Sérgio Conceição***

**4. FERRERO 6**
This faint planetary nebula in Cassiopeia wasn't identified until French amateur astronomer Laurent Ferrero found it in 2013. Its thin, bright outer rim indicates it is strongly interacting with the interstellar medium.
**• *Peter Goodhew***

**5. DARK HORSE**
The Seahorse Nebula (Barnard 150) is a cloud of dust and cold gas in the constellation Cepheus the King. We see it only because of the dense star field behind it. B150 stretches across 1° in apparent length and lies some 1,200 light-years away.
**• *Jeffrey Weiss***

**6. CHECKING IT TWICE**
Sharpless 2–115 is an emission nebula in Cygnus, here imaged in the Hubble palette. Abell 71 (Sh 2–116), the small round object at lower right, is an emission nebula.
**• *Chuck Ayoub***

**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.**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**7. JUST PASSING BY**
Mars (the bright spot to the left) passed through the region of the Lagoon Nebula (M8) and the Trifid Nebula (M20), both of which are in the constellation Sagittarius the Archer, on February 21, 2020. • ***Damian Peach***

**8. CHILLED TO THE BONE**
The Full Moon of December 11, 2019, shines through the Whale Bone Arch in Barrow, Alaska. Barrow is the northernmost city in the U.S. • ***Mark Morris***

**9. DON'T GET PINCHED**
The Lobster Claw Nebula (Sharpless 2–157) is an emission nebula in the constellation Cassiopeia the Queen. The photographer captured 668 two-minute exposures through Hydrogen-alpha and Oxygen-III filters to produce this image. The small open cluster near the top is NGC 7510. • ***Douglas J. Struble***


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## DIVING DEEP INTO THE MILKY WAY'S HEART

On the next clear summer evening, gaze through binoculars toward the center of our galaxy. Under a dark sky, you'll see countless stars interspersed with dark dust lanes. But what would the scene look like without the obscuring dust? The answer appears above. Astronomers at the European Southern Observatory (ESO) lifted the veil by viewing the Milky Way at near-infrared wavelengths, which penetrate all but the thickest dust clouds. The researchers captured more than 3 million stars in their survey of the galactic nucleus using the HAWK-I instrument on ESO's Very Large Telescope. The image achieves a resolution of 0.2 arcsecond, equivalent to seeing a quarter from 16 miles (25 kilometers) away! ESO/NOGUERAS-LARA ET AL.

QHY600 + 3.5nm H-alpha filter, 21 x 20 min RASA11, Captured by Wu Zhen and processed by Dr. Liao



# July 2020

# Jupiter and Saturn at their best

The solar system's two largest planets make a spectacular pair this month. Jupiter and Saturn appear low in the east soon after darkness falls in early July. And not only do they climb higher hour by hour, they also rise earlier as the month progresses.

**Jupiter** shines at magnitude −2.7 and stands out more than its neighbor. The giant planet reaches opposition and peak visibility July 14, when it rises at sunset and climbs highest in the north around midnight local time. You can find it among the background stars of eastern Sagittarius, though truth be told, it's easier to locate the constellation using the planet as a guide than vice versa.

July is the best time this year to observe Jupiter through a telescope. At opposition, its disk spans 48" across the equator and 45" through the poles, a difference that's surprisingly easy to see. Look for an alternating series of bright zones and darker belts that run parallel to the giant planet's equator, as well as fine details that show up during moments of good seeing. Also watch for Jupiter's four bright Galilean moons as they dance around the planet. The best views come when the planet lies high in the sky and its light passes through less of Earth's atmosphere.

**Saturn** follows Jupiter across the sky, reaching opposition just six days after its companion, on July 20. The ringed planet spends the month's first few nights in western Capricornus before crossing into Sagittarius. Glowing at magnitude 0.1 at opposition, it pales in comparison with Jupiter but easily outshines the background stars in these constellations.

Few sights can match the beauty of Saturn through a telescope. As with Jupiter, plan to wait until the ringed world climbs high in the sky. The planet spans 18" while the stunning ring system measures 42" across and tips 22° to our line of sight. This large tilt affords a nice view of the dark Cassini Division that separates the outer A ring from the brighter B ring. Saturn's brightest moons, led by 8th-magnitude Titan, are also a treat.

By late evening, a third bright planet graces the sky. **Mars** rises in the east before midnight local time and climbs highest in the north shortly before twilight starts to paint the sky. The Red Planet begins and ends July among the background stars of Pisces the Fish, but it spends the middle of the month in Cetus the Whale.

Mars continues to brighten rapidly. As July begins, it shines at magnitude −0.5; it appears 75 percent brighter (magnitude −1.1) by month's end. Mars' telescopic appearance improves noticeably as well. Its disk swells from 11.5" to 14.5" across, big enough to show some dusky surface markings.

As Jupiter and Saturn dip low in the west before dawn, **Venus** pokes above the eastern horizon. The brilliant planet rises before twilight starts and climbs high in the northeast as the sky brightens. Venus shines at magnitude −4.7, its brightest for this morning apparition, against the backdrop of Taurus. It spends the first two weeks of July passing in front of the V-shaped Hyades star cluster.

It's worth getting up early to view Venus' lovely crescent through a telescope. On July 1, the inner planet shows a 43"-diameter disk that is just 19 percent illuminated. By month's end, the world appears 28" across and 42 percent lit.

The second half of July also features a brief appearance by **Mercury**. For about a week on either side of its July 22 greatest western elongation, the small planet lies low in the east-northeast during morning twilight. At its peak on the 22nd, the magnitude 0.2 world lies 6° high 45 minutes before sunrise. A telescope reveals Mercury's 8"-diameter disk and 38-percent-lit phase.

## The starry sky

Our view to the south early on these winter evenings features the spectacular Southern Cross and two bright stars nearby: Alpha (α) and Beta (β) Centauri. Just southeast of Alpha Cen, the night sky's third-brightest star, resides the distinctive constellation Triangulum Australe the Southern Triangle. It seems at first glance that Triangulum Australe and Centaurus must share a border, but they do not. Tucked between the two is the tiny constellation Circinus the Compasses.

Don't confuse Circinus with another constellation having a similar common name: Pyxis the Compass. The two represent entirely different instruments. The compass Circinus refers to is the type we all used in school to draw circles. Pyxis, on the other hand, represents a mariner's compass that seafarers use to tell directions.

Circinus covers an area of 93.35 square degrees, making it the fourth-smallest constellation. (With an area of 68.45 square degrees, Crux the Cross is the tiniest.)

French astronomer Nicolas Louis de Lacaille introduced Circinus in the 1750s. On his star chart, he clearly marked the constellation as *le Compas* and described the device as the one used in geometry classrooms. In the wonderful volume *Histoire de l'Académie royale des sciences*, Lacaille described it as *le Compas du Géomètre*, not to be confused with *La Boussole ou le Compas de mer*, which was the mariner's compass we know as Pyxis.

Circinus holds a few objects worth observing through a telescope, though most of them are best viewed with large apertures. One of the nicest subjects for small instruments is the double star Alpha Circini. Its two stars glow at magnitudes 3.2 and 8.6 and are easy to split thanks to their 15" separation.

# STAR DOME

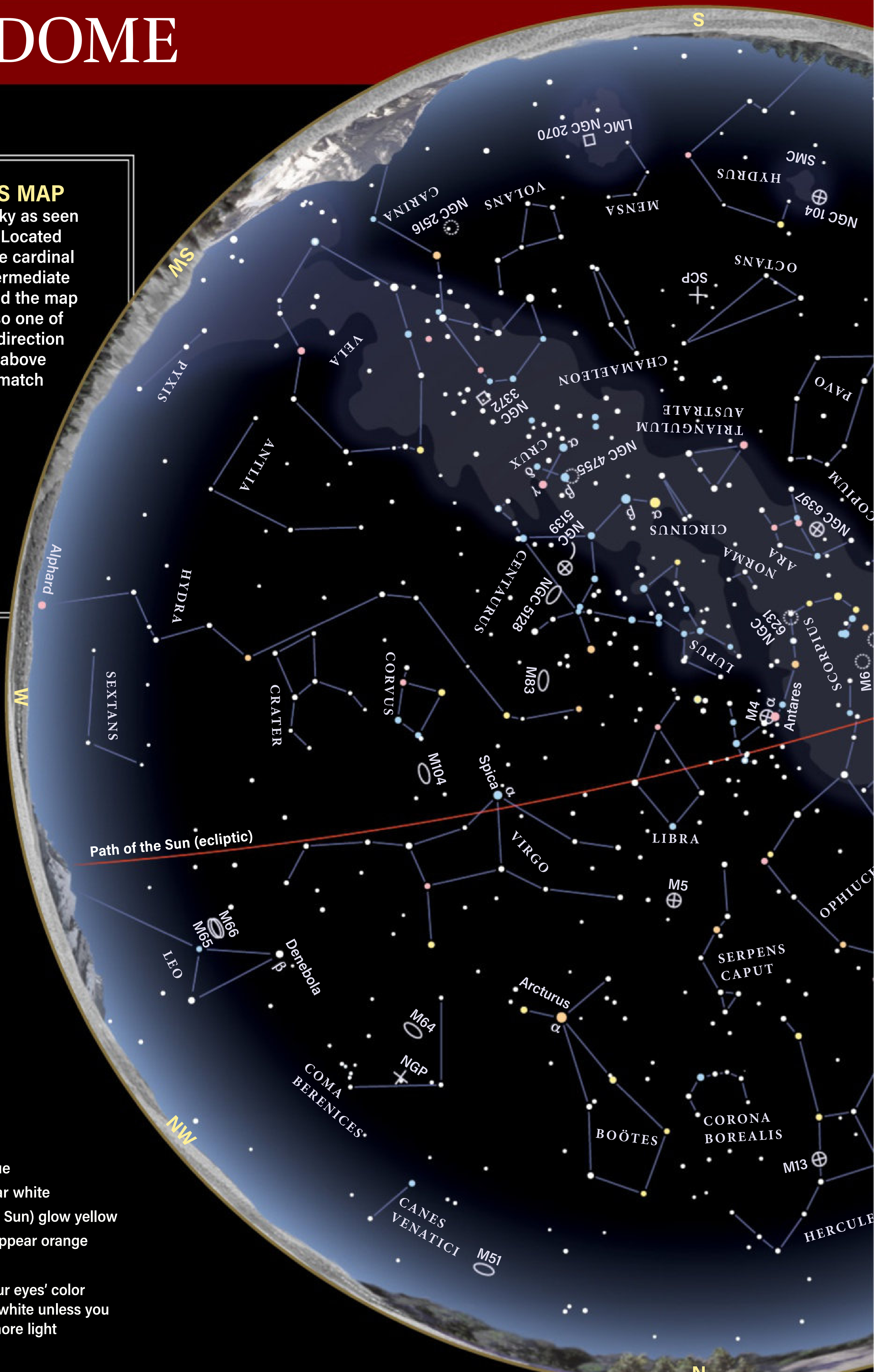
## HOW TO USE THIS MAP

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. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth




## MAP SYMBOLS

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

## STAR MAGNITUDES

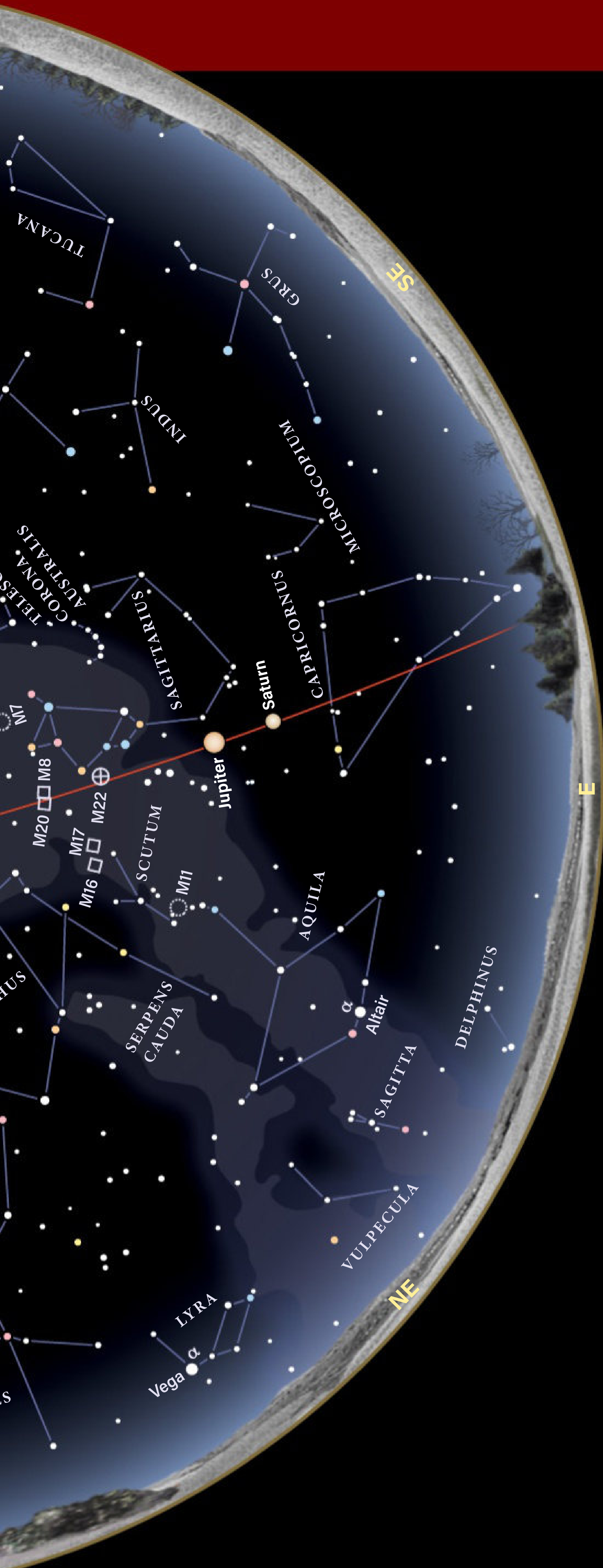
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

## STAR COLORS

A star's color depends on its surface temperature.

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

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




# JULY 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 | 31 | |

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

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

## CALENDAR OF EVENTS

**1** Mercury is in inferior conjunction, 3h UT

**2** Asteroid Herculina is at opposition, 14h UT

**4** Earth is at aphelion (152.1 million kilometers from the Sun), 12h UT

**5** Full Moon occurs at 4h44m UT; penumbral lunar eclipse
Asteroid Vesta is in conjunction with the Sun, 6h UT
The Moon passes 1.9° south of Jupiter, 22h UT

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

**10** The Moon passes 4° south of Neptune, 7h UT
Venus is at greatest brilliancy (magnitude –4.7), 8h UT

**11** The Moon passes 2° south of Mars, 20h UT

**12** Venus passes 1.0° north of Aldebaran, 7h UT
The Moon is at apogee (404,199 kilometers from Earth), 19h27m UT
Last Quarter Moon occurs at 23h29m UT

**13** Dwarf planet Ceres is stationary, 2h UT
Asteroid Pallas is at opposition, 2h UT

**14** Jupiter is at opposition, 8h UT
The Moon passes 4° south of Uranus, 12h UT

**15** Pluto is at opposition, 19h UT

**17** The Moon passes 3° north of Venus, 7h UT

**19** The Moon passes 4° north of Mercury, 4h UT

**20** New Moon occurs at 17h33m UT
Saturn is at opposition, 22h UT

**22** Mercury is at greatest western elongation (20°), 15h UT

**25** The Moon is at perigee (368,361 kilometers from Earth), 5h02m UT

**27** First Quarter Moon occurs at 12h33m UT

**29** Southern Delta Aquariid meteor shower peaks