EXPLORE JUPITER'S TROJAN ASTEROIDS UP CLOSE p. 28

JUNE 2018

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White dwarf stars shed new light on possible life-bearing planets p. 22

DISCOVER GALAXIES in Coma Berenices p. 52

BEHIND THE SCENES at Chicago's great astro sites p. 44

IMAGING for three nights at Pic du Midi p. 58

FIELD-TESTED A hot new CCD camera p. 64

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BONUS ONLINE CONTENT CODE p. 4

Vol. 46 • Issue 6

SKY-WATCHER SIZZLING SUMMER SAVINGS

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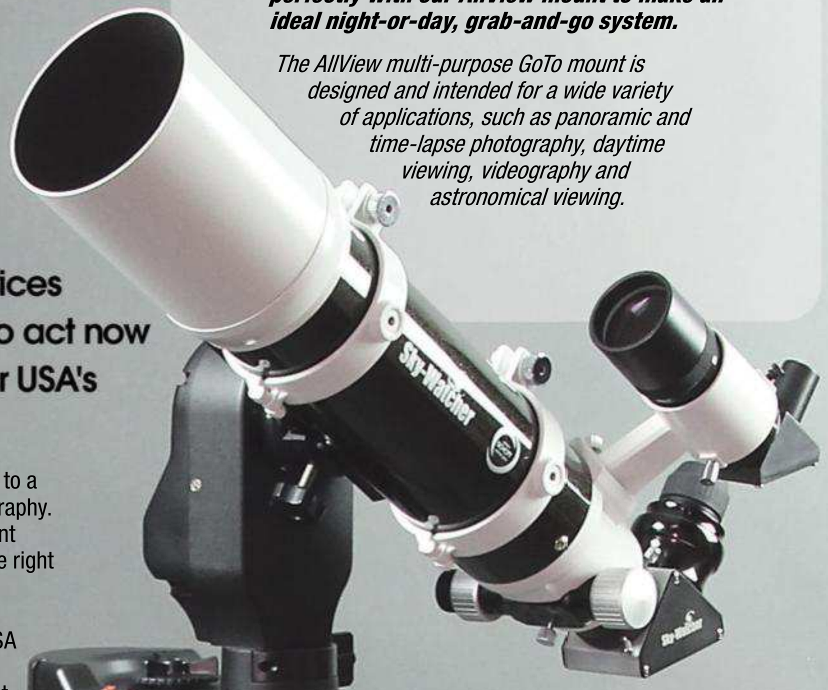

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CONTENTS

28

JUNE 2018
VOL. 46, NO. 6

MARK GARLICK

ON THE COVER

Astronomers are finding watery worlds orbiting stars around us — and the way some of those worlds get their water is surprising.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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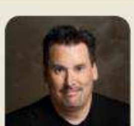

Dave's Universe
The inside scoop from the editor.

Venus Globe
Get the hottest globe around.

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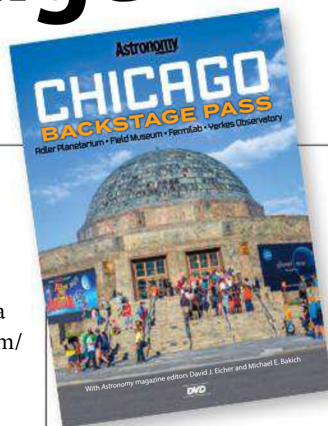
Answers to all your cosmic questions.

Sky This Week
A daily digest of celestial events.

FROM THE **EDITOR**

BY DAVID J. EICHER

Your backstage pass is here



As *Astronomy* approaches its 45th anniversary, we're not only looking for ways to continuously bring you the best coverage of astronomy in the magazine, but we're also creating some exciting new products we hope you'll enjoy.

The latest offering results from a trip Senior Editor Michael Bakich and I took to the Chicagoland area earlier this year. We visited four stellar astronomical institutions in and around Chicago, and filmed several hours of amazing stuff. Nothing like this exists in our field, and there are many exciting things to share. And video allows us to describe what's going on at these places and share the excitement in a unique way.

Our new DVD, *Astronomy Backstage Pass: Chicago*, takes you on a behind-the-scenes tour of the treasures in these four hallowed places: Adler Planetarium, the Field Museum, Fermilab, and Yerkes Observatory. Read about the basics of what we saw on p. 44.

The story is just a taste of what we glimpsed: The three-hour video shows everything in spectacular detail. This product will be exciting for those who can't travel to see the astro sites in Chicago, or even for those who have been there — we saw many treats locked away and not shown to daily visitors!

You can find details about the DVD and order a copy at myscienceshop.com/BackstageChicago

At Adler, Michael and I saw the Gemini XII capsule, the oldest telescope outside of Europe, a copy of Johannes Kepler's most famous work (inscribed by Kepler!), and the amazing star theaters of the first planetarium in the Western Hemisphere. We also saw a 1788 telescope made by William Herschel, the famous Dearborn refractor, and books owned by the Herschel family. We examined at length Adler's incredible antique instrument collection, one of the finest in the world, with its numerous sextants, celestial globes, and astrolabes.

At the Field Museum, we explored the inner vault containing one of the greatest meteorite collections in existence. We beheld countless large specimens of Allende, lunar meteorites larger than our hands, incredibly rare pieces of Mars, and some genuinely scarce fragments of asteroids that were old, historic falls.

At Fermilab, the United States National Accelerator Lab, we checked out its conversion from a particle smasher to chiefly a neutrino detector, and we spoke with several key scientists about the tricky problem of resolving the nature of dark matter.

And at Yerkes, we basked in the amazing history of the institution. We saw the 40-inch refractor, the world's largest; the plate vault containing historic images made by E.E. Barnard and others; the offices used by Chandrasekhar and other greats; and artifacts belonging to a who's who of American astronomy: Hale, Morgan, Keeler, Adams, Struve, Hubble, and many others.

If you love astronomy, enjoy traveling and visiting great places, want to see hidden gems of astronomy's past, or explore the research and possibilities of future research, I suggest you check out this unique DVD. I predict you will gain hours of enjoyment from the "backstage pass" tour you will receive from it.

Yours truly,

David J. Eicher
Editor

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Astronomy

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MALLINCAM LIVE-VIDEO CCD CAMERAS

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The MallinCam UNIVERSE

The MallinCam UNIVERSE is a colour CCD camera capable of live-video downloads for full-frame views on your computer monitor. The live-video CCD camera system displays a nonstop new image at every exposure.

The MallinCam UNIVERSE is USB 2.0 controlled. A deep-cooling system with a sealed argon-gas-filled sensor chamber allows cooling to reach –45°C to ensure the lowest dark current noise, and in most cases, a dark frame is not required.

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The new MallinCam UNIVERSE can also be switched from colour mode to black and white with a click of the mouse. Live processing is done on the fly using features such as full histogram adjustment, full gamma range, full contrast range and auto white balance or manual RGB colour balance. Live stacking, dark-field correction binning of 1 x 1, 2 x 2, 3 x 3 and 4 x 4, all in colour, and many more features allow the MallinCam UNIVERSE to deliver a total variable gain of up to 26.06+ db, a dynamic range and an excellent signal-to-noise ratio.

The MallinCam UNIVERSE comes complete with a 15-foot USB cable, a 2" threaded adapter, a T mount, a 120-volt AC to 12-volt DC power supply and the driver and software for Windows on a USB stick.

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ASTRO**LETTERS**

Amazing shadow bands →

Stephen James O'Meara, the photo at the top of your February 2018 article on shadow bands immediately caught my eye. It was an instant reminder of a shot I took on Galveston Island in Texas in 2013. It was a day that started out rainy and overcast, but then turned brilliantly clear. Thank you for all your wonderful articles. **— Tom Loyd,** Columbia, MO

TOM LOYD

Discovered or recognized?

"The Real Music of the Spheres" in the January 2018 issue brings up an interesting point about the early history of quasars. The article talks about CTA-102 and its connection with popular music in the 1960s, but also shows a picture of quasar 3C 273 without any mention of it in the main text.

The article says that CTA-102 was "found" in 1959, and according to online literature, 3C 273 was featured in the *Third Cambridge Catalogue of Radio Sources* that same year, but was not recognized as a quasar until 1962. I assume this means that it was identified with an optical counterpart in the early 1960s. There seems to be some confusion in literature between being "discovered/found" and being "recognized" as a quasar. Perhaps a table outlining when a radio frequency was discovered compared to the discovery of its optical counterparts, giving its date of quasar designation, would have been helpful. I would love to see an article in *Astronomy* that clarifies the early history of quasars for us laypeople. **— Robert Walty,** Stephens City, VA

Chile's extraterrestrial landscape

The delightful article on ALMA and its revelations in the December 2017 issue really hit home for me. In 2012, I climbed the south side of Cerro Toco, the snowy peak in the background of p. 57, with a guide from an adventure company in Santiago. The photo perfectly depicts the bizarre and utterly barren landscape in this part of the Andes.

The area is a unique product of extreme aridity and altitude, with some fantastic coloration from the ubiquitous volcanic rocks. (Everything in that photo is volcanic.) It's a surreal landscape that I can only describe to friends as "another planet in another galaxy." As a geologist, I was in hypoxic heaven! And from the plains of Chajnantor, a plateau on the stratovolcano's south side, we could even see the beginnings of construction at the telescope site, which was closed to the public for obvious reasons. **— Bob Michael,** Fort Collins, CO

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.*

Don't forget about Bruno

The August 2013 edition of *Astronomy* features the article, "40 greatest astronomical discoveries." But the greatest of all was neglected! Deserving credit was given to Copernicus for his heliocentric model, even though he was wrong in thinking that the Sun was the center of the universe. Bruno disputed Copernicus' model four centuries ago. He theorized that there is no center of the universe, and that every star is a Sun with its own planetary system, which is the definition of the universe that we recognize today. When Einstein hypothesized gravitational waves, it took scientists an entire century to discover them, but it took four whole centuries to discover the exoplanets that Bruno hypothesized. He should be given a posthumous Nobel Prize.

The next time you put out such an article, please don't forget about Bruno! **— Hugh Cedric,** Beijing

Jupiter's details left undefined

I found the photo of Jupiter's polar cyclones on p. 15 in the February 2018 issue to be incredible. For most of my 58 years, I have associated Jupiter with its distinct colors and big red spot, and I now have another great image. However, I wish there were a better description of the photo. It describes the oval-shaped cyclones, but there are so many things going on in the photo that it's difficult to figure out which ovals you mean. It would have been nice to have a more detailed description or some annotations in the photo to help us out. **— Thomas Ray,** Woodbridge, VA

Man vs. universe

Every time I open an issue of *Astronomy*, I am utterly amazed at what's out there. I am truly in awe of the people who have devoted their careers and lives to answering one looming question: How does it all work? That has brought me to my own conundrum. In the fight of man vs. universe, who wins? Do humans have any chance of ever answering all of the looming questions? Or does the universe — with its limitless time, space, and the ability to make matter out of nothing — send all life-forms to their graves still wondering … how? **— Sam Davis,** Rosedale, MD

QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES >>

TRENDING TO THE TOP

FLARE-UP
On March 24, 2017, Proxima Centauri experienced a huge stellar flare, calling the habitability of its planet into question.

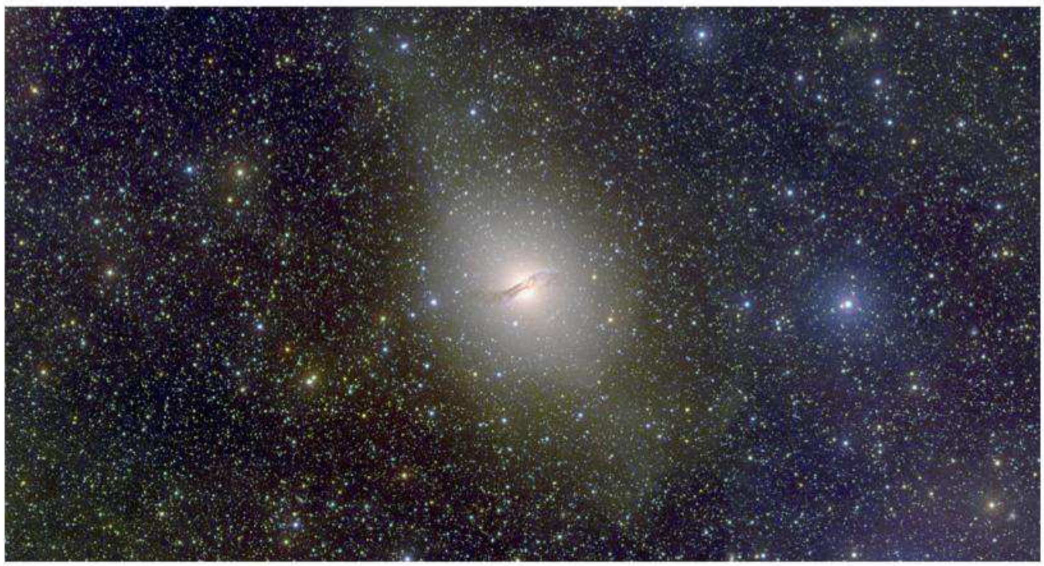
RED DAWN
The Opportunity rover has now witnessed more than 5,000 sunrises on Mars.

GOLDEN AGE
NASA's Global-scale Observations of the Limb and Disk (GOLD) satellite powered up January 28, despite a launch anomaly that will delay arrival in its final orbit.

SNAPSHOT

Centaurus A contradicts dark matter models

New observations confirm what astronomers have seen elsewhere … and challenge current dark matter theories.



ORDERED MOTION. Centaurus A is an elliptical galaxy whose satellites orbit in an ordered fashion on a well-defined plane — an observation at odds with predictions from dark matter models.

CHRISTIAN WOLF & SKYMAPPER TEAM/AUSTRALIAN NATIONAL UNIVERSITY; TOP FROM LEFT: ROBERTO MOLAR CANDANOSA/CARNEGIE INSTITUTION FOR SCIENCE, NASA/SDO, NASA/JPL; NASA/JPL-CALTECH/CORNELL/ARIZONA STATE UNIV./TEXAS A&M; NASA GODDARD'S CONCEPTUAL IMAGE LAB/CHRIS MEANEY

Large galaxies, including our own, maintain systems of smaller satellite galaxies through gravity. According to the current standard cosmological model, these satellites orbit within a halo of dark matter stretching far past the visible portion of the parent galaxy. Satellites also should be randomly distributed in orbit and positioned around their parent galaxy — but new observations have just shown, for the third time, that this is not the case.

The results, published February 2 in *Science*, show that the satellite galaxies surrounding Centaurus A (NGC 5128), an elliptical galaxy 13 million light-years away, are not orbiting randomly. Instead, they are orbiting in a nice, orderly fashion in a well-defined plane. Such observations confirm what astronomers have already seen around the Milky Way and the Andromeda Galaxy, but fly in the face of the standard model, which says that such ordered systems of satellites should be rare — as in, 0.5 percent of galaxies should have them. Instead, astronomers have now seen them in 100 percent of observed systems.

Of course, outliers that don't follow the current model's predictions should exist. And three galaxies is an incredibly small sample. Even so, these new observations now confirm that satellites are much more likely to orbit in an orderly fashion than believed. "Coherent movement seems to be a universal phenomenon that demands new explanations," said Oliver Müller of the University of Basel in Switzerland, and lead author of the study, in a press release.

Müller's team discovered that Centaurus A's satellites appear arranged neatly on a thin plane seen edge-on when viewed from Earth. Such an orientation means any Doppler shifting of the light received from the satellite galaxies is due to their motion around the galaxy's center. Of 16 satellite galaxies observed in the study, 14 are rotating together around the center of the galaxy. This is consistent with previous observations of the distribution and motion of satellites around the Milky Way and Andromeda.

The ultimate conclusion is that it's much more common for satellite galaxies to move together than current dark matter models predict. While these results put added force behind a blow to astronomers' understanding of dark matter, they don't necessarily mean that dark matter is no more. What they do mean, however, is that current models of the way dark matter interacts with normal matter are not completely correct — which makes sense, given that astronomers have yet to detect it directly. Challenges to current models are the best way to hone and improve those models, pushing them to better match the universe we observe. —**Alison Klesman**

1942–2018

The world suffered an immeasurable loss when Stephen Hawking died March 14, 2018. ANDRÉ PATTENDEN/COURTESY STEPHEN HAWKING

REMEMBERING
Stephen Hawking

Science received a heavy blow this year with the loss of its leading luminary. **by David J. Eicher**

If you felt the world of science collectively shudder this spring, it was because the field lost its most brilliant mind. Stephen William Hawking — theoretical physicist, mathematician, philosopher, author, and genius — died in his home in Cambridge, England, at age 76. In this terrible event, humanity lost perhaps its most brilliant and original thinker. The world is certainly now a darker place.

Born in Oxford in 1942, Hawking was the son of parents who worked in medical research. Schooled in London, he showed interest and aptitude in science and leaned toward a scientific career when he began studying at the University of Oxford. He emerged socially, and developed interests in classical music and science fiction.

Hawking took up graduate studies at the University of Cambridge in 1962. Interested in relativity theory and cosmology, he was initially disappointed that he drew Dennis Sciama as a supervisor rather than the more famous Fred Hoyle. At this time, suddenly, he began to feel alarming symptoms and was diagnosed with motor neuron disease, an increasing paralysis and loss of muscular control similar to Lou Gehrig's disease (or ALS). This put Hawking into a depression; he had to fight through the debilitating symptoms to carry on with any hope of his career. Initially, doctors proclaimed he had perhaps two years left to live.

In June 1964, Hawking began to stand out from his young colleagues, not because of his disease but because of his unusual brilliance. He publicly called out the great Hoyle at a lecture, questioning his ideas. Hoyle was a proponent of the so-called steady state model, which suggested that the cosmos could collapse on itself eventually and then rebound in a series of expansions and contractions. The other leading cosmological idea, the Big Bang, was gaining traction during this time, and Hawking supported it. In this model, the cosmos would expand forever, without a cyclic contraction. Shortly thereafter, in fact, Bell Labs astronomers Arno Penzias and Robert Wilson discovered the so-called cosmic microwave background radiation, the faint, omnipresent echo of the Big Bang. Hawking's determination for the Big Bang was turning out to be correct.

Hawking, of course, became immensely famous in the years to come through his brilliant studies of astrophysics and cosmology. He finished his Ph.D. in 1966 on the topic of "Properties of Expanding Universes," and it shared top physics honors that year with a paper written by one of his distinguished professors, Roger Penrose.

Along with Penrose and others, Hawking picked up the mantle of Einstein, investigating many cosmological ideas during the early years of his professorship at Cambridge. He eventually took on the title of Lucasian Professor of Mathematics at the venerable institution, occupying the same chair once held by Isaac Newton centuries earlier.

> **The world will never be the same. But now Stephen is with the stars he loved.**

Most of Hawking's work during the late 1960s and 1970s focused on black holes, and this led to his great friendship and collaboration with Caltech's Kip Thorne. Aside from deciphering the physics of black holes, Hawking postulated what came to be known as Hawking radiation — that black holes, in some cases, could leak radiation over long time intervals, and possibly evaporate. His immense grasp of mathematics, despite increasing illness and inability to easily communicate, stunned the science world.

The theoretical physics of black holes was one thing; finding them was another. Postulated in the 18th century, these regions of intense gravity were very hard to identify. In the early 1970s, the best candidate was Cygnus X-1. Hawking made a bet with Thorne. If Cyg X-1 turned out to be a black hole, Stephen would owe Kip a magazine subscription. If the opposite were true, Kip would owe Stephen. By 1990, the verdict was in, and Cygnus X-1 was determined to be the first confirmed stellar black hole. Hawking had requested a subscription to *Popular Mechanics*; Thorne had wagered a subscription to *Penthouse*. Stephen anted up and sent the magazines to Pasadena.

Hawking's research rocketed onward in many areas, focusing on cosmology and theoretical astrophysics. He established his reputation of being the smartest guy around by extending and confirming many of Einstein's ideas. And all of this was accentuated by his terrible disease, which progressively pushed him into being aided ever more by sophisticated wheelchairs, supplemented by speech therapy computers that would allow him to produce sentences with eye and mouth movements, and to program and deliver spectacular talks that would amaze his colleagues and fascinate the public.

I was fortunate enough to meet Stephen as a fellow member of the Starmus Festival Board of Directors. A good friend of the festival's founder and director, Garik Israelian, Stephen was a profound supporter of this celebration of science and music. He really loved music and was extremely funny, as anyone who saw one of his talks knows.

Stephen taught me to never be afraid again. After I delivered an hourlong talk on astrophysics with Stephen and his nurses in the front row, I thought, my goodness, that's it. The fact that he liked it and was such a kind person, so concerned about Earth and all its creatures, made the recent news harder to hear.

I was in Costa Rica staring at the sky when someone ran by and shouted out the terrible news. The world will never be the same. But now Stephen is with the stars he loved.

David J. Eicher *is Editor of* Astronomy *and a member of the Starmus Festival Board of Directors, which also included Stephen Hawking.*

STRANGE**UNIVERSE**

BY BOB BERMAN

Spin cycles

There's a deeper meaning behind the way things rotate.

Many things on Earth and in the heavens move in circles or ellipses. But the direction in which they spin is also important.

Spin is something we don't always notice. For example, when you're standing to the left of a car and it starts moving forward, which way do the wheels turn — clockwise or counterclockwise? Everyone should be able to figure this out in a few seconds, yet not everybody gets it right. And when it comes to the larger universe, the motion of celestial bodies often seems downright mysterious.

Let's start with things on our planet. Which way do you turn a doorknob to enter a room? Which way does water spiral when you flush the toilet? OK, these are trick questions. In both cases, either way is the answer. That business about toilets flushing in opposite directions in Earth's Northern and Southern hemispheres is totally bogus. The Coriolis effect influences only large-scale items like weather systems; it has no effect on toilets. Instead, the way water swirls down a basin or bowl is determined by the direction the water entered, the levelness of the basin, or any residual water motion when the plug is pulled.

Let's move to real issues. In the Northern Hemisphere, which way does the wind circulate around a nice-weather, high-pressure system? If you said clockwise, you are correct. It's counterclockwise for lows, meaning storms. That's why we can trust the old mariners' rule: When you face into the wind, your right arm points toward the storm.

What about the sky? When you face the North Star, all the stars and constellations slowly circle it during the night. Polaris is like the middle of a giant vinyl record. But which way does the record turn? Think for a moment. The answer is counterclockwise.

What if you were an astronaut or alien floating north of the solar system? Which way do all the planets revolve around the Sun? Again, the answer is counterclockwise. Since asteroids orbit that same way too, it's obvious that a collision between an asteroid and Earth likely won't be a terribly high-speed affair.

But now consider comets. Their orbits are random. Some of the most famous revolve around the Sun clockwise. Result: These would devastatingly collide with us head-on. Comets with such retrograde orbits include the ones responsible for the annual Perseid, Orionid, and Leonid meteor showers: Swift-Tuttle, Halley, and Temple-Tuttle. That's why their meteors are superfast. So, clockwise vs. counterclockwise can be the deciding factor in a mass extinction.

When it comes to the larger universe, the motion of celestial bodies often seems downright mysterious.

What about our galaxy's rotation? Spiral galaxies typically rotate with their arms trailing the direction of spin. But that doesn't help us because we can't look at our galaxy from the outside.

Over the course of the night, the stars near the North Star travel in a circle. Which way do they rotate about Earth's northern axis? PIXABAY

How about this clue: When you're under the summer sky and the Milky Way's center is to your right in Sagittarius, you are facing the direction of the galaxy's rotation. You're now looking east where the star Deneb is rising these nights. Facing Deneb means looking in the exact direction the Sun and Earth are heading as our galaxy spins. If you can then picture where the North Star is situated, you can work out whether this is counterclockwise or clockwise. It may be easier to Google a 21-centimeter radio map of our galaxy's hydrogen clouds, which trace the spiral arms, and remember we rotate opposite the trailing arms.

During winter days in the north, the Sun's path is a giant rainbow-shaped arc across the southern sky. If we visualize this as the top segment of a circle, then daily Sun motion is indeed either clockwise or counterclockwise. Which is it? During our annual tours to the Southern Hemisphere, the strangest sky feature is that the Sun moves through the northern sky in the reverse direction from back home. In the United States, Canada, and Europe, the Sun moves clockwise along that arc, meaning rightward. Down there, it's counterclockwise. It feels deeply weird.

Backward stuff always does. For example, during last August's total solar eclipse, the Moon's shadow swept across the United States from upper left to lower right, from Oregon to the Carolinas. And yet all observers saw the Moon cross the Sun's face from upper right to lower left. How can you possibly explain this? Think about it.

Maps of the United States are always oriented with north up. But at the time of the eclipse, the Sun was in the southern sky. So we were all standing with our backs to the north. Thus, everything was reversed, and the backward motion is explained.

Sometimes you gotta keep your directions straight, or your mind goes in circles.

Join me and Pulse of the Planet*'s Jim Metzner in my new podcast,* Astounding Universe*, at* **http://astoundinguniverse.com.**

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

COSMIC EXPANSION. Astronomers used Hubble to take the most precise measurement yet of the universe's expansion rate, and confirmed it is expanding faster than expected.

QUICK TAKES

LOOKING FOR LIFE
NASA's planetary protection officer suggested aggressively exploring Mars' most promising regions for signs of life.

●

SCIENTIFIC HANDOFF
A consortium headed by the University of Central Florida will now manage Arecibo Observatory in Puerto Rico.

●

POSITIVE OUTLOOK
New research suggests humans would react positively to the discovery of microbial life on another world.

●

NEW APPOINTMENT
President Donald Trump recently nominated former astronaut James Reilly to lead the U.S. Geological Survey.

●

THE FLOOR IS LAVA
The Chicxulub meteor that struck Earth 66 million years ago triggered the release of magma from seafloor ridges all over the world.

●

WORKING TOGETHER
The Very Large Telescope's ESPRESSO spectrograph has combined light from all four 8.2-meter Unit Telescopes for the first time.

●

BRIGHT BEACONS
Computer simulations show the oldest stars in the Milky Way can act as tracers for invisible dark matter.

●

IGNORANCE IS BLISS
Contrary to current theory, star-forming gas in the galaxy WISE 1029 is not affected by strong outflows from its supermassive black hole.

●

DEEP FREEZE
Asteroids can function as "time capsules" that preserve molecules from the early solar system and help scientists reconstruct the origins of life on Earth.

●

BY THE STARS
Swedish researchers have shown that nocturnal animals can use light from stars and the glow of the Milky Way to navigate at night.

●

PULSING LIGHTS
Scientists have proven that pulsating aurorae occur when waves of plasma flow from the magnetosphere down into Earth's atmosphere. —**J.P.**

Supernova snapshot is 1 in 10 million

Catching a glimpse of a supernova is tricky business. Not only do you need the right equipment, but you also need to have some incredible luck. Fortunately for amateur astronomer Víctor Buso, September 20, 2016, was apparently his lucky day.

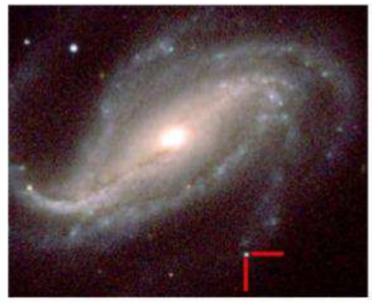
Buso was testing a new camera mounted on a 16-inch telescope at his home rooftop observatory in Rosario, Argentina. Under a dark sky, he pointed his scope at NGC 613 — a spiral galaxy about 70 million light-years away in the constellation Sculptor — to take a series of short-exposure photographs.

To ensure his new camera was functioning properly, Buso examined the images right away. He noticed that a previously invisible point of light had appeared on the outskirts of NGC 613, and that the point was quickly growing brighter as he moved from one image to the next.

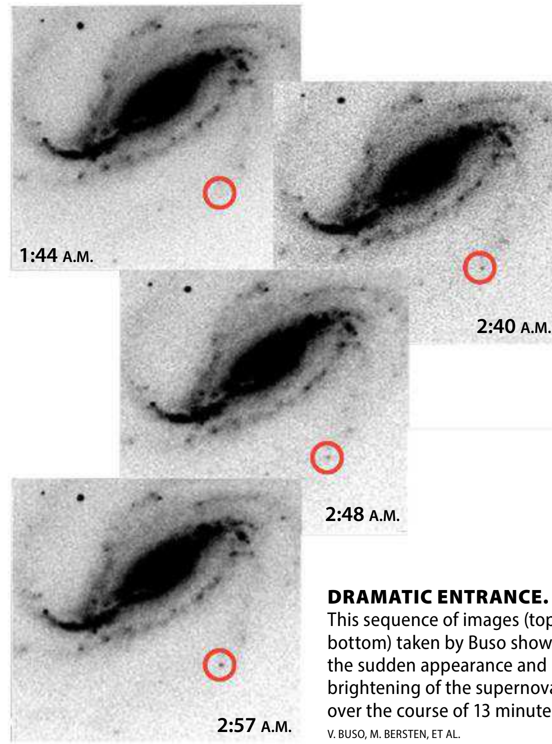
With the help of fellow amateur Sebastian Otero, Buso prepared an international alert, an online notification reporting transient night-sky events. Within no time, astronomer Melina Bersten and her colleagues at the Instituto de Astrofísica de La Plata spotted the report and immediately realized that Buso had caught the initial burst of light from a massive supernova explosion — an extremely rare event. According to Bersten, the chances of making such a discovery are between 1 in 10 million and 1 in 100 million.

"Professional astronomers have long been searching for such an event," said University of California, Berkeley astronomer Alex Filippenko, whose follow-up observations were critical to analyzing the explosion, in a press release.

"Observations of stars in the first moments they begin exploding provide information that cannot be directly obtained in any other way," Filippenko added. "It's like winning the cosmic lottery."
— Jake Parks



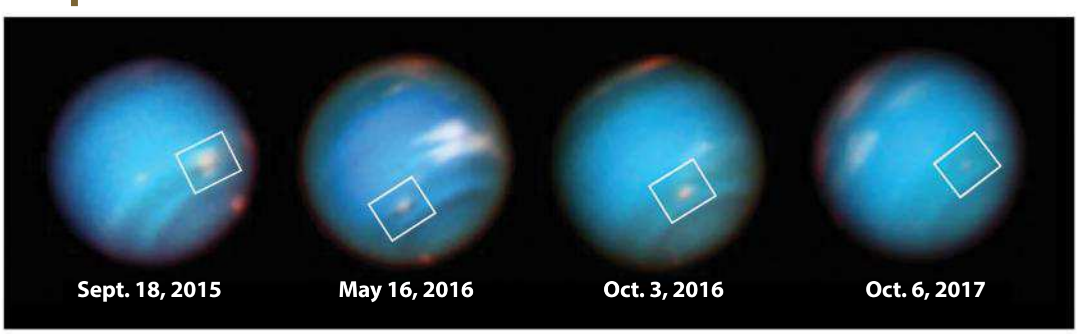
LUCKY SHOT. Supernova 2016gkg (indicated with red lines) occurred in the spiral galaxy NGC 613, about 70 million light-years from Earth. On September 20, 2016, amateur astronomer Víctor Buso captured the initial burst of light from this supernova, a first. CARNEGIE INSTITUTION FOR SCIENCE, LAS CAMPANAS OBSERVATORY



DRAMATIC ENTRANCE. This sequence of images (top to bottom) taken by Buso shows the sudden appearance and brightening of the supernova over the course of 13 minutes. V. BUSO, M. BERSTEN, ET AL.

39,000 The distance from Earth, in miles, at which asteroid 2018 CB passed on February 9. This is less than a fifth of the Earth-Moon separation.

Neptune's dark storm weakens further



NASA, ESA, AND M.H. WONG AND A.J. HSU (UC BERKELEY)

SMELLY STORM. Dark storms on Neptune were first spotted by Voyager 2 in 1989. Using the Hubble Space Telescope, astronomers have continued to track similar features. A recent massive storm, found by Hubble in 2015 and believed to consist of unpleasant-smelling hydrogen sulfide, is slowly fading away. Once roughly 3,100 miles (5,000 kilometers) across, the storm now measures only 2,300 miles (3,700 km) in diameter. Researchers had believed that an eruption of cloud activity would occur as the vortex approached Neptune's equator, but instead, it's shrinking calmly before our eyes. **— Amber Jorgenson**

OBSERVING**BASICS**

BY GLENN CHAPLE

Let’s even the score with M102

Though most lists of Messier objects contain 109 targets, the inclusion of NGC 5866 brings the total to an even 110.

This image of M102 (the Spindle Galaxy) was created by combining 60 minutes’ worth of sub-exposures taken with a 32-inch f/6 telescope. MARIO E. MOTTA, M.D.

I hate odd numbers! If I’m putting gas in my car and the pump stops at $23.87, I’ll squeeze out enough gas to make it an even $24.00. When I’m out fishing and keeping a count of my catch, I’ll stubbornly keep casting until I’ve reached an even 10 or 20. Three Little Pigs? Bah! I would have added a fourth and housed him in a two-story, steel- and cement-reinforced condo.

I’m the same with sports stats, particularly baseball. I wince when a pitcher finishes the season with 19 wins or a batter ends up hitting .299. If only they had wound up with an even 20 wins or a .300 batting average! Last year, Miami Marlins outfielder Giancarlo Stanton hit 59 home runs. Were I the Major League Baseball commissioner, I would have extended the season until he hit No. 60.

When it comes to the Messier catalog, I’m also odd-number phobic. After all the historic studies and revisions, Messier’s number stands at 109 — but I round up to 110. (This is also why I selected 110 stellar duos for my Double Star Marathon.) And though I’m not alone in citing 110, most of the Messier lists that do recognize 109 objects (including the one used by *Astronomy*) discard M110 — a late addition that elevated one of the bright satellite galaxies of M31 to Messier status.

Other Messier lists fall short of 110 entries because of the controversy over the existence of Messier 102, which was reported by Messier’s contemporary Pierre Méchain early in 1781. Méchain later retracted his discovery, stating that it was a duplicate observation of M101.

But was it? In his original notes, Méchain described his find as a “nebula between the stars Omicron Boötis and Iota Draconis.” It’s possible that Méchain meant Theta Boötis, not Omicron. The Greek letters omicron and theta (ο and θ, respectively) look similar. Omicron Boötis is more than 40° away from Iota Draconis, while Theta Boötis lies about 11° to the southwest. And, lo and behold, if you look about one-third of the way from Iota Draconis to Theta Boötis, you’ll come across the 10th-magnitude galaxy NGC 5866. This is quite likely the object Méchain found.

When it comes to the Messier catalog, I’m also odd-number phobic.

A detailed article on the M102 controversy, written by Hartmut Frommert, appears on the SEDS Messier website at www.messier.seds.org/m/m102d.html. In it, Frommert presents a compelling argument that NGC 5866 is indeed Messier’s 102nd object. My argument is far more simplistic. NGC 5866 (an even number, by the way) brings the Messier catalog total to 110 — even number perfection!

One of my first goals as a fledgling backyard astronomer was to notch all the objects in the Messier catalog. M102 was one of the last. I captured it the evening of July 25, 1978, with a 3-inch f/10 reflector and a magnifying power of 30x. Next to a sketch of the galaxy, I wrote, “With averted vision, surprisingly easy! Accompanied by a star of ~11th magnitude. Slightly oval, it seems.” At the time, I was observing under 6th-magnitude skies.

Working with slightly murkier magnitude 5 skies three decades later, I revisited M102, this time with a 4.5-inch f/8 reflector and a 150x eyepiece to improve contrast. The galaxy was still visible, as was its long oval form. This shape, being wider in the middle, has garnered NGC 5866/M102 the nickname the “Spindle Galaxy.”

To Méchain and Messier, that nebula near Iota Draconis was little more than a fake comet. To me and my little backyard scopes, it was a patch of faint fuzz. However, it means much more to astronomers who have studied it with larger and more sophisticated telescopes. M102 is actually an edge-on lenticular galaxy bisected by a distinct dark dust lane. The dust lane gives M102 a striking photographic resemblance to another dusty edge-on galaxy, M104, the Sombrero Galaxy.

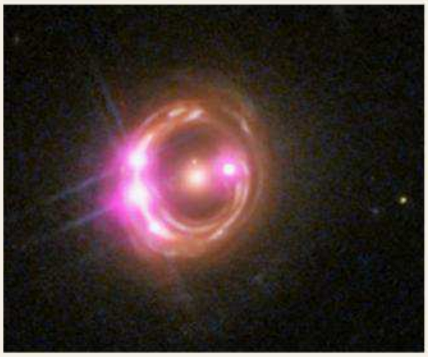
Further study adds an awe-inspiring dimension to the 4.5'-by-2' patch of fuzz that is M102. It lies some 50 million light-years away, which translates to a true diameter of roughly 60,000 light-years. When you peer into the eyepiece, the light you’re seeing first left M102 during Earth’s early Eocene epoch, when our planet was embraced by a pole-to-pole tropical climate. Ancestral whales were in the process of abandoning a terrestrial existence, horses were dog-sized and had padded feet, and human ancestors were little more than tree-dwelling primates. Had Messier and Méchain known this, they might have abandoned comets and turned their attention solely to nebulous objects that didn’t change position.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Another messy Messier mystery. Clear skies!

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

BROWSE THE “OBSERVING BASICS” ARCHIVE AT **www.Astronomy.com/Chaple.**

Free-floating extragalactic planets found



X-RAY: NASA/CXC/UNIVERSITY OF MICHIGAN/R.C. REIS ET AL.; OPTICAL: NASA/STScI

DISTORTED LIGHT. RXJ 1131–1231 is a distant quasar that appears as four bright spots when viewed in X-ray emission (pink). It is lensed by an intervening galaxy 3.8 billion light-years away (yellow, optical), in which astronomers have discovered a population of up to 2,000 free-floating planets.

Microlensing occurs when light from a background source is distorted by a foreground object, such as a star or planet. The amount of distortion reveals clues about the intervening (or "lensing") object, including information about its mass.

Microlensing allows astronomers to detect small, dim objects, such as planets that are smaller and more distant than those accessible via other methods. Two astronomers at the University of Oklahoma recently used this method to serendipitously discover possibly thousands of extragalactic planets.

The discovery, published February 2 in *The Astrophysical Journal Letters*, focuses on the lensed quasar RXJ 1131–1231 and the elliptical galaxy between it and Earth. The intervening lens galaxy is 3.8 billion light-years away, too far for astronomers to probe for planets via other methods. But while attempting to explain a shift in the light coming from the background quasar, the team's models showed that the best explanation is a group of up to 2,000 rogue exoplanets with masses ranging between the Moon and Jupiter within the lensing galaxy.

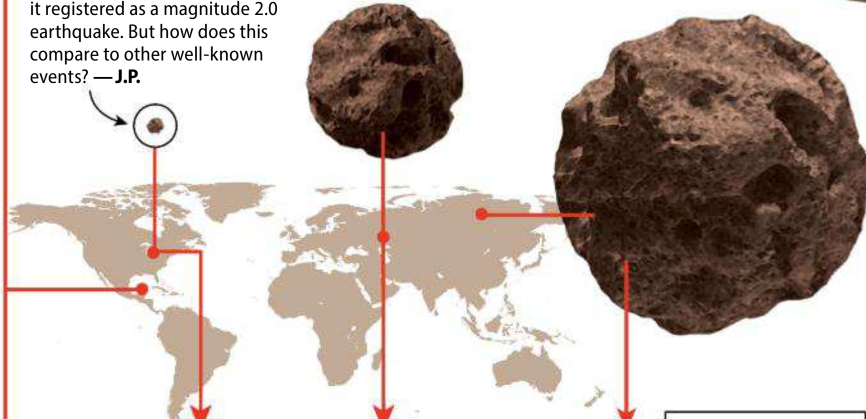
Rogue planets are not bound to a star, and instead freely float through space. Little is known about these objects, even in the Milky Way, because they are difficult to detect. If they can be characterized through microlensing, astronomers might be better able to quantify this population in our own galaxy.

"This is an example of how powerful the techniques of analysis of extragalactic microlensing can be," said Eduardo Guerras of the University of Oklahoma and the second author on the paper, in a press release.

"There is not the slightest chance of observing these planets directly, not even with the best telescope one can imagine," he added. "However, we are able to study them, unveil their presence, and even have an idea of their masses. This is very cool science." **—A.K.**

How big was the Michigan meteorite?

SMALL POTATOES. A meteor exploded over southeastern Michigan on January 16, 2018. Although NASA estimates the object was only 6 feet (2 meters) in diameter, the U.S. Geological Survey said that its sonic boom was so powerful, it registered as a magnitude 2.0 earthquake. But how does this compare to other well-known events? **—J.P.**



NOTABLE METEORITES	Southeast Michigan	Chelyabinsk, Russia	Tunguska, Russia	Chicxulub, Yucatán Peninsula
DATE	January 16, 2018	February 15, 2013	June 30, 1908	66 million years ago
DIAMETER	6 feet (2 meters)*	60 feet (20 meters)*	120 feet (40 meters)*	6 miles (10 kilometers)*
ENERGY	100 tons of TNT*	1 megaton*	15 megatons*	100,000,000 megatons*
FREQUENCY	Every 5 years	Every 100 years	Every 200 to 1,000 years	Every 50 to 100 million years

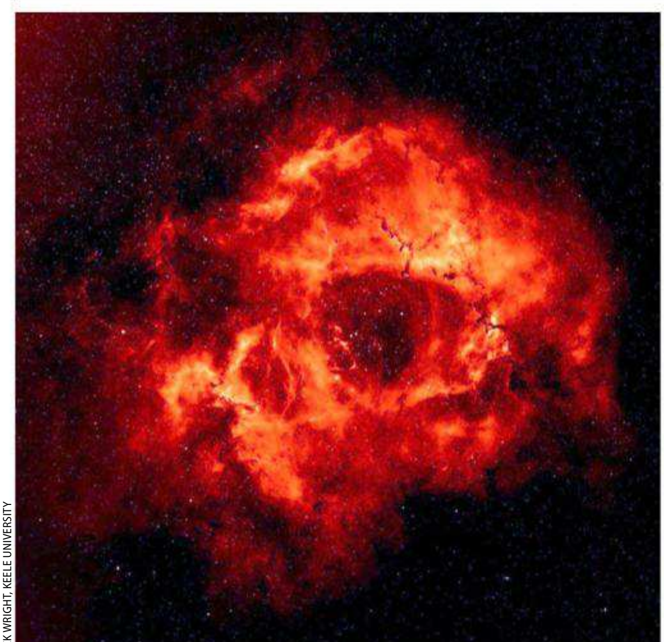
Meteorites not to scale with world map

* Numbers based on estimates

ASTRONOMY: ROEN KELLY

FAST FACT

The Tunguska meteor (roughly 15 times the diameter of the Michigan meteorite) exploded above the sparsely populated region of Tunguska in eastern Russia, flattening 500,000 acres (2,000 square kilometers) of forest.



NICK WRIGHT, KEELE UNIVERSITY

Inside the heart of the Rosette

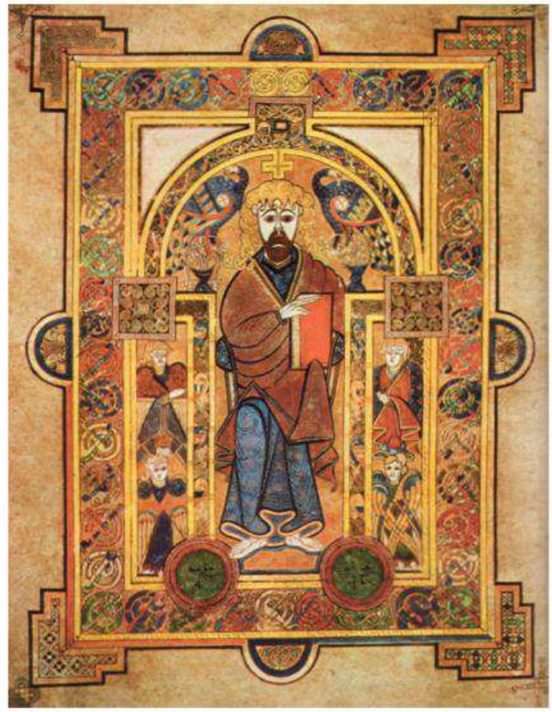
DELICATE BLOOM. The elegant Rosette Nebula's central hole is caused by stellar winds blasting from massive stars in the heart of the cloud. But given the age of the stars, the nebula's cavity should be much larger. A study led by the University of Leeds simulated different nebula formation scenarios, and found the nebula formed as a thin disk with the strongest stellar winds focused away from its center, resulting in the cavity's small size. **—A.J.**

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Narnia fading

The slow twilight of medieval thought.



This image of Jesus of Nazareth from the Irish *Book of Kells* dates from the late eighth century. In some ways, world culture has never moved beyond a medieval world model of the universe, although long ago scientific knowledge left it far behind. WIKIMEDIA COMMONS

In his last book, *The Discarded Image: An Introduction to Medieval and Renaissance Literature*, C.S. Lewis explores how Europeans before the Scientific Revolution thought about the world. Rather than intellectual creativity, Lewis relates, medieval Europe was all about wrapping up the elements of its culture into a nice, clean, tidy package: "At his most characteristic, medieval man was not a dreamer nor a wanderer. He was an organizer, a codifier, a builder of systems." Lewis went so far as to jokingly say, "Of all our modern inventions I suspect that they would most have admired the card index."

It would be wrong to mistake Lewis' humor for derision. On the contrary, Lewis found the medieval world and its mindset captivating. Reading Lewis's *The Chronicles of Narnia*, it's hard to escape the feeling that something was lost as the medieval world gave way to the modern. Lewis appreciated the appeal of a clearly articulated and universally accepted conception of the world. He understood the power of what he called "the medieval synthesis itself, the whole organization of their theology, science and history into a single complex, harmonious mental model of the universe."

That "model" of which Lewis spoke was far more than a literary device. Every question had an answer, and that answer was to be found by appealing to authority. Such a feeling of certainty comforts a place deep within us. As I've discussed in earlier columns, we can't even perceive the world without a mental model into which things, including ourselves, fit. And once we latch onto a mental model of the world, we hold on for dear life.

Therein lies the rub. Within a single lifetime we have learned more about life, the universe, and what it is to be human than our ancestors could have begun to imagine. Much of that is radically different from what our medieval ancestors would have considered certain knowledge.

Today, science sees humans as part of a universe vast and ancient beyond what we will ever feel in our guts, but not beyond the reach of our rational minds to explore. There are roughly a trillion galaxies in the part of the universe that we can see, each consisting of tens or hundreds of billions of stars. Quoting Douglas Adams from *The Hitchhiker's Guide to the Galaxy*: "Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space!"

Even at that, the universe we can observe is still only a tiny bubble within a far larger universe, which itself may be only one of a potentially infinite number of universes. While not (yet?) a statement of scientific knowledge, many see modern physics and cosmology as pointing inevitably toward a multiverse in which all possibilities play themselves out, each as real as the others.

All of that can be hard to take in or to stomach, even for scientists. Erwin Schrödinger, who helped lay the foundation of quantum mechanics, was appalled by the success of his own work. His eponymous cat was intended not as an illustration of the counterintuitive nature of quantum mechanics so much as an expression of his horror at the theory's implications. "I don't like it, and I'm sorry I ever had anything to do with it!" he said.

But regardless of the hand-wringing, Schrödinger's horrifying theory does a truly remarkable job of telling us how reality behaves. What remains as hard, objective fact is that quantum mechanics has never made an incorrect prediction. In a post-medieval world, objective facts beat Schrödinger's unease hands down.

Which brings us back to C.S. Lewis. In *The Chronicles of Narnia*, Peter, Susan, Edmund, and Lucy are torn between the magical land of Narnia and the hard realities of wartime Britain. That storyline echoes today's tension between Lewis' harmonious but profoundly flawed medieval model of the universe and an ever more successful schema that shatters the very foundations of traditional concepts. On the one hand, we long for certainty and the easy comfort of prepackaged answers. On the other hand, we are challenged to set aside cherished notions, accept uncertainty as a precondition of knowledge, and repudiate time-honored authority in deference to objective evidence.

It is little wonder that transition is difficult! In his autobiography, Max Planck observed, "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die."

Cultural echoes of medieval thought remain strong, even today. But as they surrender their hold, a new harmonious model of the universe — beautiful, elegant, and emotionally satisfying in its own right — is finding form and voice.

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

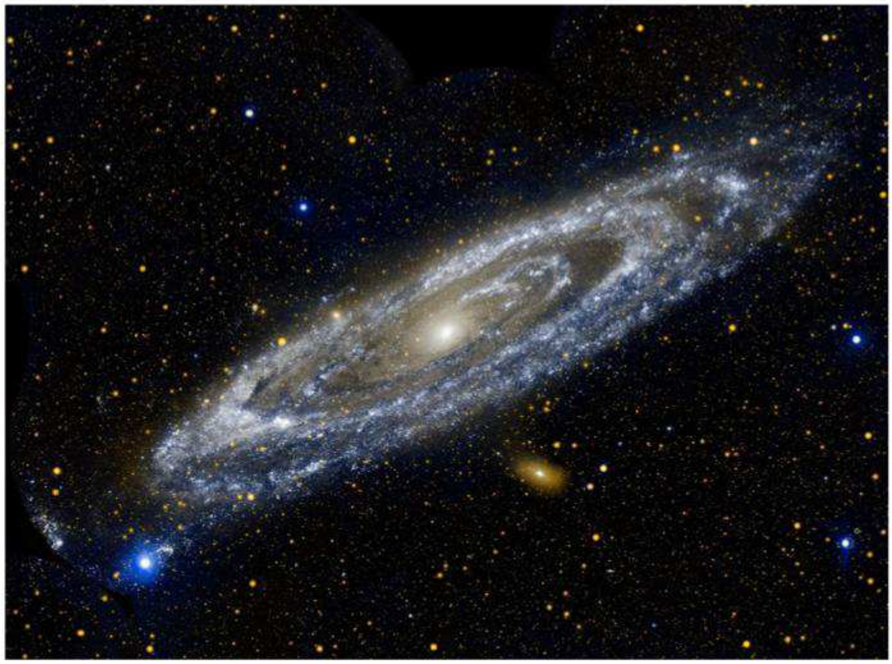
BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

LONE STAR. S2, a star that will test general relativity when it swings by our galaxy's supermassive black hole this year, does not have a significant binary companion. If such a companion had existed, it may have complicated measurements.

SIZING UP ANDROMEDA

The Milky Way and the Andromeda Galaxy (M31) are giant spiral galaxies. And in about 4 billion years, they will collide in a gravitational sumo match that will ultimately bind them forever. Previously, astronomers believed that Andromeda would dominate with a mass up to three times that of the Milky Way. But new research suggests we've overestimated our opponent.

In a study published February 14 in the *Monthly Notices of the Royal Astronomical Society*, a team of Australian astronomers announced that Andromeda is not actually the heavyweight we once thought it was. Instead, they found that our nearest large galactic neighbor is more or less the same mass as the Milky Way — some 800 billion times the mass of the Sun.



NASA/JPL-CALTECH

MATCHING MASS. The Andromeda Galaxy, shown here in an ultraviolet image from NASA's Galaxy Evolution Explorer, is roughly the same mass as the Milky Way, not three times as massive, as previously thought.

To determine Andromeda's mass, the team studied the orbits of high-velocity planetary nebulae, which contain aging stars moving at high speeds. They coupled their observations with a technique that calculates the speed required for a quick-moving star to escape the gravitational pull of its host galaxy. The speed needed for ejection is known as escape velocity.

"When a rocket is launched into space, it is thrown out with a speed of 11 kilometers per second [6.8 miles per second] to overcome the Earth's gravitational pull," Prajwal Kafle of the University of Western Australia branch of the International Centre for Radio Astronomy Research said in a press release. "Our home galaxy, the Milky Way, is over a trillion times heavier than our tiny planet Earth, so to escape its gravitational pull, we have to launch with a speed of 550 kilometers per second [342 miles per second]. We used this technique to tie down the mass of Andromeda."

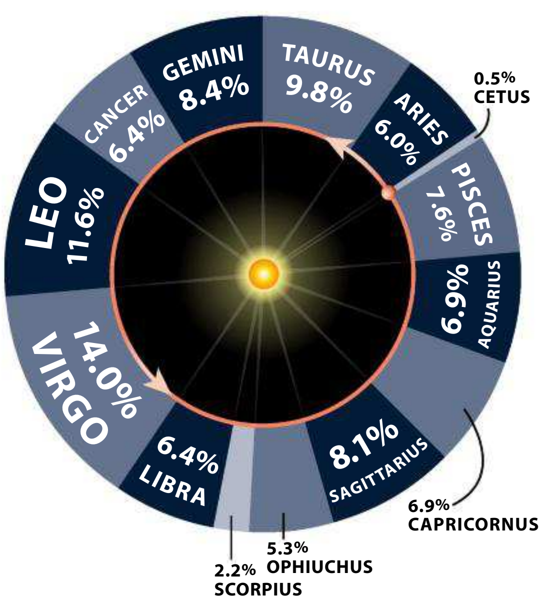
This is not the first time a galaxy's mass has been recalculated based on its escape velocity. In 2014, Kafle used a similar technique to revise the mass of the Milky Way, showing that our galaxy has much less dark matter — a mysterious form of matter that has gravity but does not interact with light — than previously thought.

Much like the 2014 study, this paper suggests that previous research has overestimated the amount of dark matter present in the Andromeda Galaxy. "By examining the orbits of high-speed stars, we discovered that [Andromeda] has far less dark matter than previously thought," said Kafle.

Although revising down Andromeda's overall mass may seem like it should help the Milky Way out during our eventual collision, the researchers say that new simulations are first needed to determine exactly how the galaxies' eventual meeting will go down. But no matter what happens in 4 billion years, Kafle says the new finding "completely transforms our understanding of the Local Group" of galaxies, which is dominated gravitationally by Andromeda and the Milky Way.

For now, it appears we can take solace in the newfound knowledge that the Milky Way is not nearly as overpowered by Andromeda as we once thought. As University of Sydney astrophysicist Geraint Lewis said, "We can put this gravitational arms race to rest." —**J.P.**

MARS IN MOTION



ASTRONOMY: ROEN KELLY

A ZODIACAL JOURNEY. The Red Planet takes 1.88 years to circle the Sun. During a typical orbit, Mars spends the most time in the constellation where it executes its retrograde loop — the apparent backward motion that occurs when Earth overtakes the outer planet around the time of opposition. To average out this effect, here we chart the percentage of time Mars spends in each constellation along the zodiac during the 21st century's first half. — **Richard Talcott**

FAST FACT

Mars reaches opposition 24 times during this 50-year period, with the most (four) coming within the borders of Leo the Lion.

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Satellite 'fake out'

In honor of NFL training camps starting in July, let's compare an Earth-orbiting satellite to a running back.

A common trick in American football is for a ball carrier to take a quick step forward in one direction — making it appear he's heading that way — only to change direction at high speed, thereby confusing the defender to avoid being tackled. It's called a "fake out," and it not only works on the playing field, but also in the night sky with some pretty shifty satellites.

A visual trickster

It doesn't matter how skilled we are as observers, satellites have no shortage of visual tricks to confuse our brain as they sail across the playing field of the night sky. While satellites look like "stars" that move at a steady clip in one direction, it's common for them to appear to gently weave among the other stars like a running back heading for the end zone.

The slight weaving is a well-known optical illusion that results from our eye-brain system. This complex mass of receptors and nerves has difficulty fixing on a moving point of light (satellite) at night, especially when seen against a jumble of other points of light (stars) whose orientations change with the turn of the head.

Now imagine the difficulty the brain has in trying to keep track of the path of a flashing or tumbling satellite, which we only intermittently see as the highly reflective metallic surfaces of these objects send glints of sunlight to our eyes. Spinning satellites (which create rhythmic flashes as the craft rotates) are much easier to follow than tumbling satellites (such as rocket boosters and space junk), which can flash erratically as they topple out of control in a decaying orbit.

Sometimes, the flashes are so erratic in both magnitude and frequency that tracking their path requires a keen knowledge of the night sky. And therein lies the story of my "running back" satellite.

A series of flashes

I have to applaud the rocket booster or fragment of space junk I saw recently because it stopped me in my tracks with its seemingly impossible movements. Had I not persisted in watching it with a critical eye, I may have walked back in the house scratching my head.

> **Now imagine the difficulty the brain has in trying to keep track of a flashing satellite …**

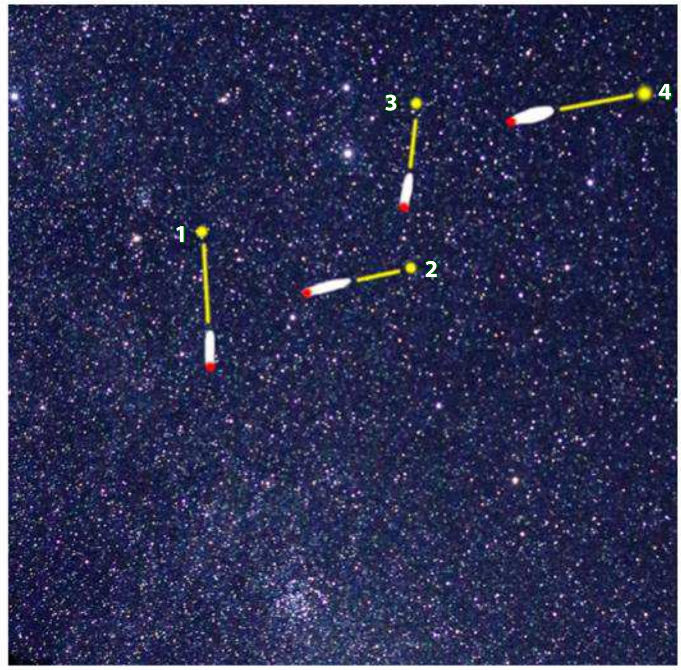
It started with a prolonged, elongated flash lasting long enough for me to detect its direction (along the major axis of the flash). Scanning my eyes in the direction of motion, I waited for the next event. To my surprise, it occurred well below and to the right of the first flash, causing me to believe it was a different object.

The second flash also was elongated, and appeared to travel perpendicular to the first satellite. So, now I had two satellites to follow. A third elongated flash occurred in an unexpected location in the sky, followed by a fourth seemingly unrelated flash.

The first photo-illustration (above, top) shows the location of the flash (red), the direction of elongation (white), and the expected location of the next event (yellow) for each object. After the fourth flash, however, it became clear that the satellite was, in fact, moving as it should: on a straight and steady course, but tumbling in a way so that its rotation axis was not aligned with its principal axis.

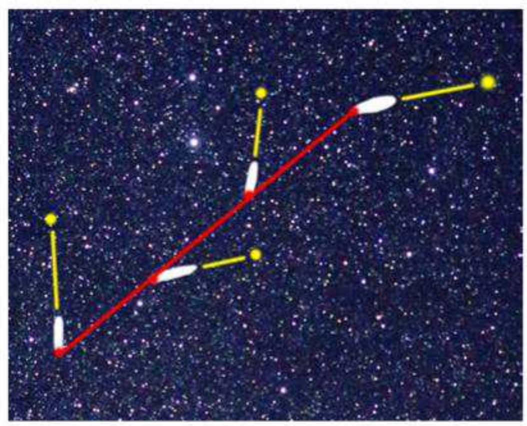
If the object itself were elongated, like a rocket body, this could explain the "fake out," as sunlight slid along the length of the body. The second photo-illustration (above, bottom) shows that if you connect the red dots, the satellite is indeed moving along a straight line.

What's interesting, however, is that if you try to connect the red dots with your eyes alone in the first image, the red dots seem to wiggle a bit. Perhaps, as they say, it's all in your head (and mine!). As always, send your thoughts to sjomeara31@gmail.com.



BOTH ILLUSTRATIONS: STEPHEN JAMES O'MEARA

The author added the colored dots, lines, and numbers to this photograph. The red dots show where the flashes appeared to him. The white lines give the expected direction of motion. The yellow dots show the expected location of the next event for each object.



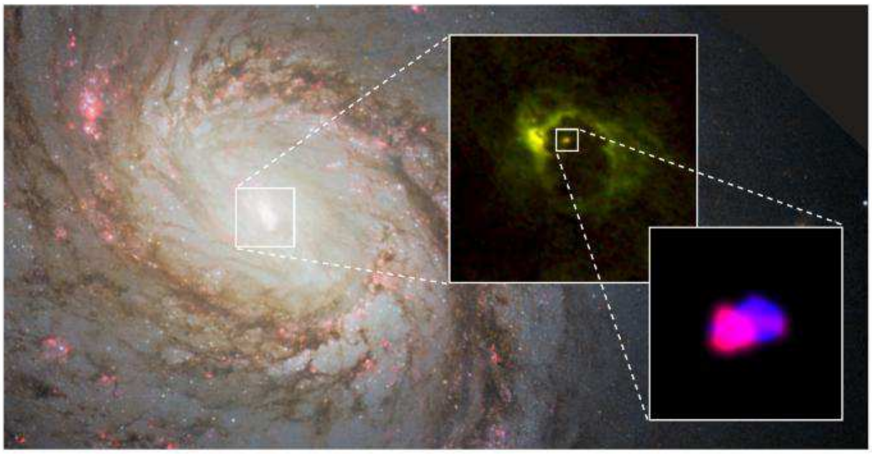
This illustration shows the true path of the satellite (the red line) through the stars. Although the events seemed disjointed to the author, the appearance of each flash (the red dots in the above image) proves the object was moving in a straight line.

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

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

ASTRO**NEWS** **RISING WATERS.** Twenty-five years of satellite data confirm that Earth's sea levels are rising at an accelerating rate.

A black hole's dusty doughnut



ZOOMING IN. ALMA allowed astronomers to image the central region of the galaxy M77, showing a 700-light-year-wide horseshoe-shaped filament of hydrogen cyanide (green) around a compact region of formyl ions (red). Zooming in, astronomers imaged Doppler rotation in the 20-light-year-wide torus directly around the galaxy's supermassive black hole, with red showing gas moving away from Earth and blue showing gas moving toward Earth. ALMA (ESO/NAOJ/NRAO), IMANISHI ET AL., NASA, ESA AND A. VAN DER HOEVEN

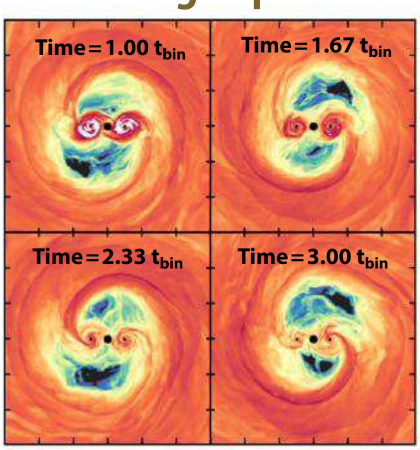
Supermassive black holes sit in the centers of most massive galaxies. Actively accreting black holes are called active galactic nuclei, or AGN. Astronomers use the unified model of AGN to describe these objects as a black hole surrounded by a bright accretion disk of infalling material, all inside a larger doughnut-shaped torus of dusty material.

Now, the resolution afforded by the Atacama Large Millimeter/submillimeter Array (ALMA) has allowed astronomers to clearly image the rotation of a dusty torus around a supermassive black hole for the first time. The target was the spiral galaxy M77, 47 million light-years away. Using ALMA, researchers identified emission from hydrogen cyanide molecules and formyl ions associated with the gas and dust in the center of the galaxy around the black hole, zeroing in on a dense doughnut of material immediately around it. The work was published February 1 in *The Astrophysical Journal Letters*.

The torus spans only about 20 light-years, an extremely small region compared with M77's diameter of about 100,000 light-years. Data showed Doppler shifting of the material in the doughnut, with some material moving away from Earth and some moving toward it — a clear sign of rotation.

While the torus is rotating as expected, it is asymmetric and shows other possible signs of disruption, such as a past merger with another galaxy. These hints support separate observations with the Subaru Telescope indicating M77 merged with a smaller galaxy several billion years ago and explain M77's extremely active AGN, which is at odds with the galaxy's ordered shape. (Galaxies that have undergone recent mergers show obvious signs of disruption in their shapes, but M77 does not.) More work is needed to determine the history of M77 and its AGN, but this first image of a rotating torus is a significant step forward in the study of galaxies and their supermassive black holes. — **A.K.**

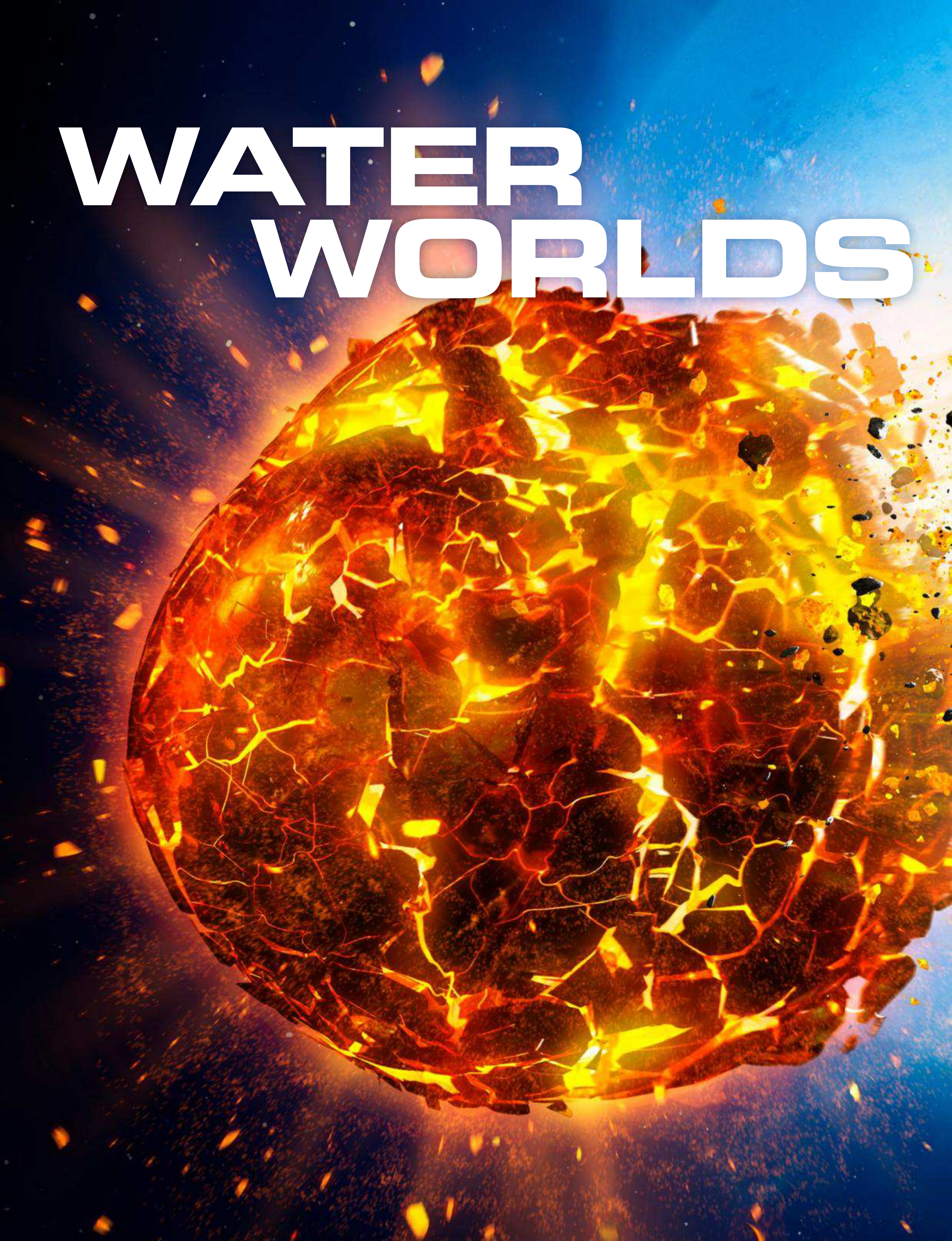
Predicting supermassive black hole collisions



RIT CENTER FOR COMPUTATIONAL RELATIVITY AND GRAVITATION

SMOKE SIGNALS. Rochester Institute of Technology researchers simulated the inward spiral of two supermassive black holes to identify visible signals astronomers might see before such a pair collides. Although the collisions of several stellar-mass black holes have been observed, a pair of colliding supermassive black holes has not. These frames from a time-lapse simulation show two in-spiraling black holes (the black dot at the center of each frame is not part of the simulation) surrounded by individual disks of gas that grow periodically denser and brighter, and then thinner and less bright. Time is measured in units of the binary's orbital period (t_{bin}); areas that are yellow and red are most dense, and those that are blue and black are least dense. Knowing the signature hallmarks of the last dance between supermassive black holes fated to collide can prepare observers to follow up such an event as soon as it is spotted. — **A.K.**

WATER WORLDS



How do planets get their water? Scientists are looking for evidence in the light from white dwarfs. **by Nola Taylor Redd**

in the Milky Way

WHEN IT COMES TO EXOPLANETS, the search for water is paramount, thanks to its vital role in the evolution of life as we know it. However, finding the life-giving liquid on other worlds is an ongoing challenge.

For nearly a decade, scientists have probed the composition of planets as the worlds are shredded and consumed by white dwarf stars. Because heavy elements quickly sink below the hydrogen- and helium-rich stellar surface, any metals (all elements not hydrogen or helium) detected in the star must come from planetary debris falling into it. Thanks to this process, astronomers know more about the interiors of dead exoplanets than they do about Earth's composition.

Uncharted waters

What, then, are scientists looking for? Water is the key ingredient for life on Earth. So, when we search for life on worlds in our solar system, water's presence usually dictates our interest. It's no surprise, then, that astronomers looking for potentially habitable worlds around other stars key in on the possibility of water.

Often, the search for exoplanets focuses on the habitable zone, the region around a star where water could stay liquid on a planet's surface. Unfortunately, it will be a long time before any of our telescopes can resolve the surface of a world light-years away. Instruments like NASA's Hubble Space Telescope probe other worlds, searching for signs of water in their atmospheres. But despite identifying thousands of planets and planet candidates beyond the solar system, scientists can glean only the thinnest of data about them.

Most of the identified planets were originally found and studied using the transit method, which examines how an object blocks light from the star. Unfortunately, this can provide only the size of the world. Others were found using the radial velocity method, which measures how much a planet tugs on its star, thus revealing its mass. If scientists follow up on a transiting world with a radial velocity measurement — and they have in many cases — then they can use the mass and size to calculate the planet's average density, providing a rough estimate of its composition and perhaps a clue whether water is present.

A planet enters the last phase of its death spiral into the white dwarf it has been orbiting. For some years, the resulting debris cloud will change the spectrum of the white dwarf. MARK GARLICK FOR *ASTRONOMY*

A rocky and water-rich asteroid is being torn apart by the strong gravity of the white dwarf star GD 61 in this artist's impression. Similar objects in our solar system likely delivered the bulk of water on Earth and represent the building blocks of the terrestrial planets. NASA/ESA/M.A. GARLICK (SPACE-ART.CO.UK)/UNIVERSITY OF WARWICK/UNIVERSITY OF CAMBRIDGE

Where's the water from?

Despite our familiarity with our own planet, scientists still don't know the source of Earth's water. Although some argue the four rocky inner planets of our solar system could have been born wet, the majority believe the worlds were probably too hot to hold onto water. Somehow, Earth and Mars, and possibly even Venus, went from hot desert worlds to planets with vibrant oceans. While Venus and Mars lost their water again, the liquid remained on Earth, transforming it into a planet rich in life.

But if Earth had formed dry, where did that water come from? For decades, scientists believed that comets were a strong contender. The rocky snowballs of the solar system could have crashed into the inner planets when everything was colliding in the violent early solar system, bringing not only water, but also other volatile materials like carbon and nitrogen. Unfortunately, missions to comets have revealed that the chemical fingerprint of their water doesn't quite match up with Earth's oceans, leading most researchers to shrug them off as a primary water source — although they may have contributed a fraction of our current supply.

Today, asteroids remain the strongest contender for the delivery of water to Earth. In the asteroid belt, water is locked up in minerals. If young Jupiter with its immense gravity stirred up material there, some may have hurtled inward. The collisions and resulting heat would have released the water onto the young Earth.

"Asteroids have enough water in them to give a nice wet surface layer to forming young rocky planets," says Ben Zuckerman, who studies white dwarfs at the University of California, Los Angeles.

So, researchers are unraveling the mystery of how water got to Earth, and they assume a similar process worked for planets around other stars.

The key: white dwarfs

Exoplanets may be shrouded in mystery, but their remains are providing clues about their lives. Over the last decade, scientists have found a way to probe what lies inside an exoplanet, not from the outside in, but from the inside out. Such observations are providing a more detailed look at the composition of these bodies than studies of our closest worlds — including Earth.

"In the solar system, we don't actually have a method to see into the interiors of planets," says Jay Farihi, an astronomer at the University College London. "We don't know, for example, 70 to 80 percent of Earth's composition, even though we are standing on it."

That doesn't mean scientists are blind about Earth's makeup. Studying its density and magnetic field, as well as examining meteorites, has provided a wealth of insights. But no one can dig through to Earth's core and directly identify the layers of the planet.

But in a way Farihi may be able to work around such tactics to study exoplanets. Rather than looking at the worlds themselves, he and his colleagues study white dwarfs — the remains of Sun-like stars that have retained much of their mass but are only the size of Earth. Some of these stars have consumed the worlds that once orbited them.

At the end of its life, when it can no longer fuse helium, a star like the Sun swells to become a massive red giant before releasing its outer layers as a planetary nebula. What's left collapses into a white dwarf. These stellar corpses no longer fuse elements, but their high density and

This illustration depicts the extrasolar planet HD 189733b with its parent star peeking above its top edge. Astronomers used the Hubble Space Telescope to detect methane and water vapor in the Jupiter-size planet's atmosphere. They made the finding by studying how light from the host star filters through the planet's atmosphere. NASA/ESA/G. BACON (STScI)

This artist's impression shows a massive cometlike object falling into the white dwarf WD 1425+540, which lies in the constellation Boötes some 170 light-years away. NASA/ESA/Z. LEVY (STScI)

leftover heat means they'll spend billions of years cooling.

Unlike stars, the atmospheres of white dwarfs are fairly pristine. Astronomers detect only hydrogen and occasionally helium, which rise to the top. Other material sinks quickly. So when scientists see something like carbon or nitrogen polluting the atmosphere, they know something falling onto the star must have delivered it.

"A white dwarf acts like a blank piece of paper," Farihi says. "When stuff falls on there, we can see what it's made of."

And white dwarfs are voracious eaters. As material orbiting them draws closer, the object's intense gravity shreds it. While Sun-like stars produce winds that drive gas away, the dead stars are silent, with no gales that can carry debris to freedom.

"Once you're trapped in the gravitational field of a white dwarf, it doesn't matter what form you're in — eventually, you're going to be gobbled up by that white dwarf," Zuckerman said.

That's when the science starts. Probing the outer layers of white dwarfs reveals the guts of their latest meals, consumed anywhere from 10,000 to 100,000 years earlier. Disks of debris surround white dwarfs. Recently, astronomers spotted a disintegrating Ceres-sized asteroid orbiting a white dwarf, suggesting that much of the material in its atmosphere could have come from the destroyed minor planet.

Because white dwarfs shred objects spiraling into them, it can be challenging to say whether material came from a full planet or just an asteroid-sized chunk. But over the past decade, observations of the last meals of white dwarfs have made it obvious that water is common in dying systems, suggesting it's an ingredient in planets as well.

Minor planet meal

As it became more obvious that white dwarfs were snacking on dying worlds, many scientists wanted another look. In 2012, Farihi and his colleagues captured new images of the white dwarf GD 61, taking a more in-depth look with Hubble and the Keck I and II telescopes in Hawaii. After studying the chemistry of the white dwarf's atmosphere, the team announced that GD 61 had recently eaten a water-rich object. For the first time, water was identified as a major ingredient in an object outside the solar system.

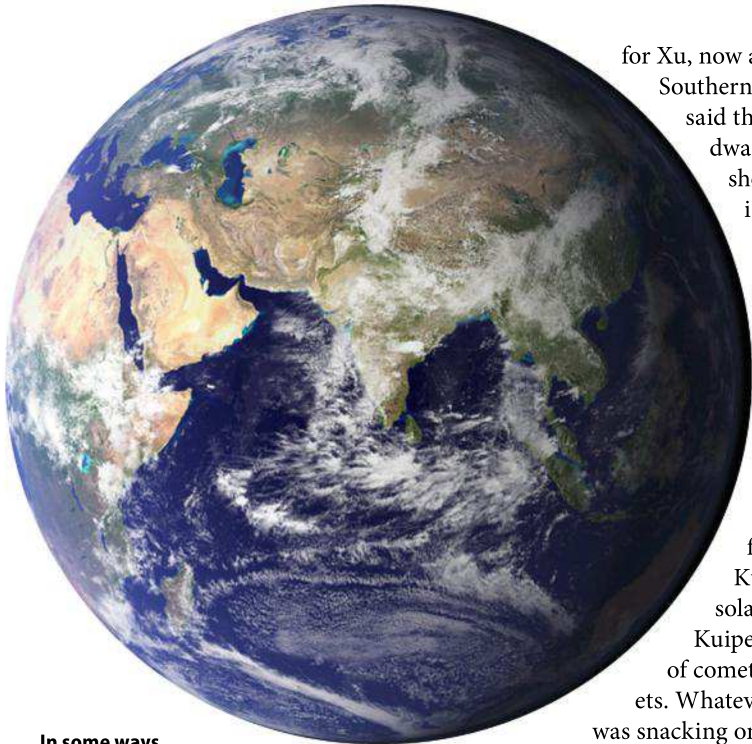
The chemistry of the Vesta-sized object suggested that it was once part of an asteroid belt when GD 61 was a star. While it's impossible to tell if the water arrived as a solid, liquid, or gas, it was most likely trapped inside of rocks.

Uri Malamud and Hagai Perets, researchers at the Israel Institute of Technology, modeled what might happen to water both on and in an asteroid-sized object as its star swells into a red giant.

Researchers are unraveling the mystery of how water got to Earth, and they assume a similar process worked for planets around other stars.

They found that, for all but the most distant rocky bodies, any surface water probably evaporates and is driven off as the star becomes a giant. But water trapped in rocks could survive.

Since GD 61 was found consuming an asteroid-like object, a handful of other white dwarfs have shown the same eating habits. According to Boris Gänsicke, professor of physics at the University of Warwick, the white dwarf snacks spotted before this year all looked like objects from



In some ways, it would be easier to study the composition of a planet like Earth as a white dwarf star destroys it than by probing it from above, as scientists living here now do. NASA

our inner solar system: rocky, iron-rich material that resembled the cores of busted-up planets, with only a handful carrying water. But rocky bodies from distant asteroid belts aren't the only things white dwarfs are consuming.

Outer solar system snack

In early 2017, a team led by Siyi Xu at UCLA found evidence that white dwarfs also have been consuming material from their outer solar systems. Xu has been using the Keck telescope to survey polluted white dwarfs, and she had worked with UCLA's Michael Jura, whom she refers to as "a pioneer in this kind of work." (Jura passed away in 2016.)

One of the objects, WD 1425+540, didn't really stand out from the crowd except for one notable feature. Although it is a helium white dwarf (more about this type of object later), it is rich in hydrogen. When Xu studied the white dwarf with Hubble, she also discovered it is surprisingly rich in carbon and nitrogen, material that is rare close to a star, and that only shows up at distances equivalent to Saturn's position in our solar system.

"Nitrogen is a signpost, or an indicator for low temperatures," Zuckerman says. And where nitrogen exists, can water be far behind?

The high nitrogen content was a signal for Xu, now at the European Southern Observatory, who said that no other white dwarf had previously shown signs of accreting the element. The high quantity of nitrogen in comparison to other elements suggested that the destroyed object came from even farther out than a Saturn-like orbit, perhaps from an extrasolar Kuiper Belt. In our solar system, the Kuiper Belt is the home of comets and dwarf planets. Whatever WD 1425+540 was snacking on was bigger than a comet, weighing in at about the same mass as the Kuiper Belt's most famous inhabitant, Pluto.

"We really don't know the bulk composition [of Pluto]," Xu says. "You don't know it until you smash it up and let us measure it." So, the distant white dwarf may have provided the closest look we'll get at the inside of one of the outermost worlds in our solar system.

But while rocky inner worlds are easily disrupted after a star swells into a red giant, falling inward if they aren't destroyed outright, it can be challenging to figure out how a more distant object gets into the maw of a white dwarf. Xu and her collaborators suspect that the reason may be the gravity of WD 1425+540's companion, a star that orbits more than 2,200 times as far from the white dwarf as Earth orbits from the Sun. Fellow researchers are examining if it's possible for slight perturbations from this companion to move a Kuiper Belt object inward to its doom.

Exo-Kuiper Belts aren't new — scientists spotted them around other stars even before they knew the Sun had a belt of its own. But never before have they been able to peer inside of one.

"Now, for the first time we're actually able to measure the elemental and chemical composition of an object that was once in an extrasolar Kuiper Belt," Zuckerman says.

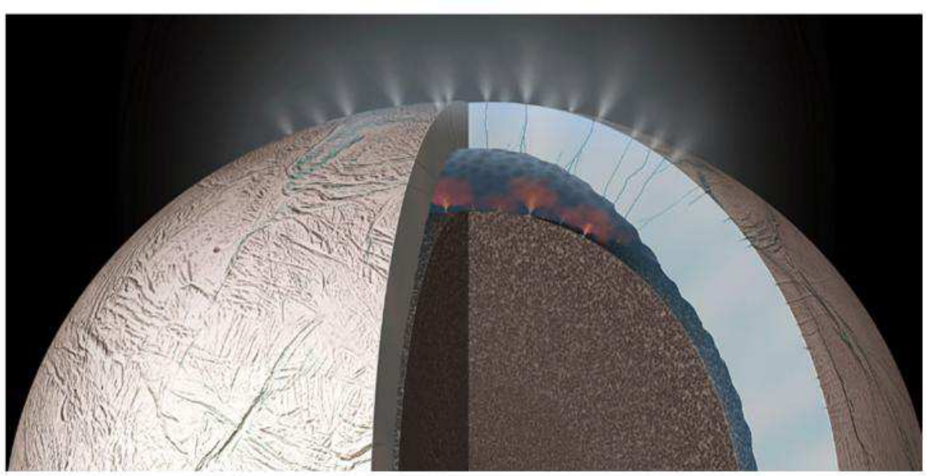
If the Sun's Kuiper Belt tossed comets and other objects toward Earth, seeding it with at least some of the water and elements necessary for life, then an exo-Kuiper Belt rich in the same ingredients provides hope for other systems following a similar track.

The mere fact that such objects rich in volatiles orbit white dwarfs is encouraging. "Earth-like worlds, if they exist, might also have a veneer or surface layer that would be conducive for the origin of life," Zuckerman says.

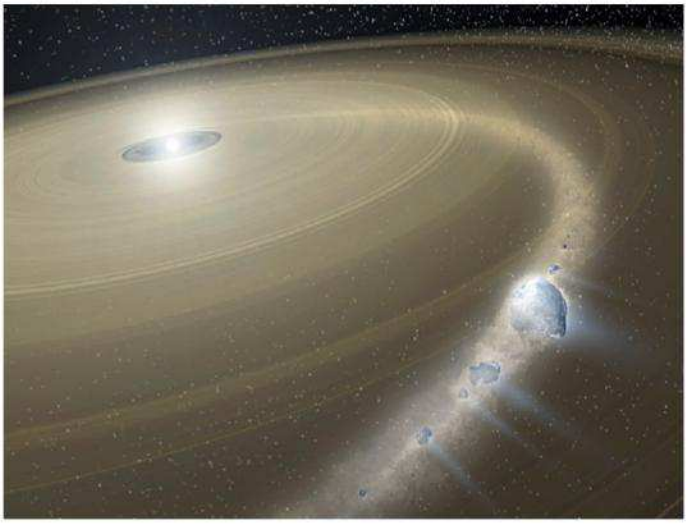
Hydrogen smorgasbord

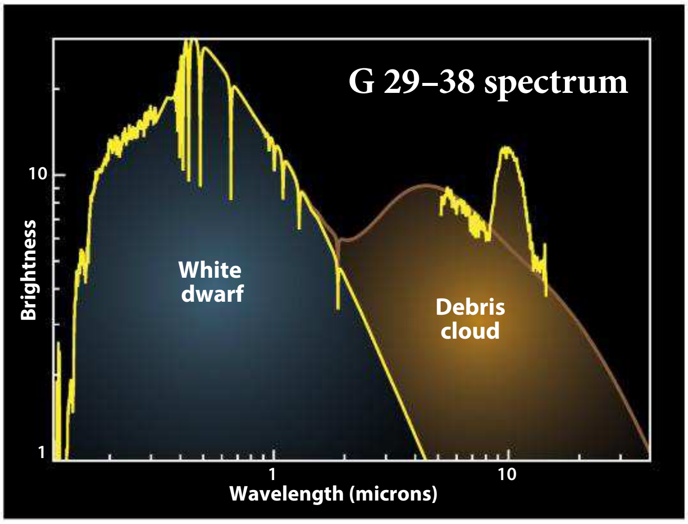
While Farihi and Xu stalk individual white dwarfs for signs of water-rich asteroids and exo-KBOs, Nicola Gentile Fusillo, postdoctoral associate at the University of Warwick, decided to take a step back and survey hundreds of dead stars, focusing on a smaller class known as helium white dwarfs. His findings suggest that water-rich objects are abundant throughout the galaxy.

Helium white dwarfs make up roughly a



One way to find water nearby is to observe a world ejecting it from geysers. Scientists based this illustration (not to scale) of plumes coming from Saturn's moon Enceladus on analysis of data from NASA's Cassini spacecraft, which passed through the plumes in 2015. The discovery of hydrogen in the erupting material provides evidence for hydrothermal activity, making the existence of an underground ocean likely. NASA/JPL-CALTECH





Left: An asteroid heads for its destruction at the hands of white dwarf Giclas 29–38. Right: The Spitzer Space Telescope acquired this spectrum of G 29–38. A normal white dwarf shows a blue-dominated spectral signature like the one on the left side of the chart. G 29–38, however, has another, reddish component scientists think comes from a disk of dust surrounding the star. They believe the debris is the remains of an asteroid that was part of the solar system that existed when G 29–38 was still a Sun-like star. NASA/JPL-CALTECH/W. REACH (SSC/CALTECH)

third of all white dwarfs. Unlike their more plentiful cousins, they have atmospheres rich in helium rather than hydrogen. In fact, their source of hydrogen is something of a mystery. Some researchers contend that these white dwarfs formed with a reservoir of hydrogen that was gradually diluted by the helium atmosphere. Others wonder if the stars might have picked up hydrogen on their surfaces as they passed through interstellar material.

Fusillo and his colleagues recently discovered a new helium-rich white dwarf, GD 17, whose composition strongly resembled GD 61. Both are heavy in hydrogen and rich in other elements. Wondering if the two characteristics might be connected, Fusillo surveyed 729 helium white dwarfs. He found that hydrogen was nearly twice as common in polluted white dwarfs as in their counterparts.

What if the hydrogen in these rich white dwarfs was the only surviving sign of water-rich objects? As with GD 61, an asteroid or KBO may have crashed into the dying star. But while the oxygen, carbon, nitrogen, and everything else would eventually sink out of the atmosphere, the hydrogen would linger. Over time, it would pile up, leaving white dwarfs that had consumed water with an exceptionally thick hydrogen atmosphere.

Consuming planetary debris isn't the only source of hydrogen in helium white dwarfs. Fusillo still thinks that a lot of white dwarfs probably retain traces of a primordial hydrogen atmosphere. But the debris definitely makes an important contribution. "A significant amount of them must have undergone this accretion event," he says.

With no debris disk to provide additional clues, it's impossible to tell if unpolluted hydrogen-rich helium white dwarfs devoured a few large planetlike objects or a wealth of tiny asteroids over their billion-year lifetime. "Hydrogen can look back in history, but that information is lost," Fusillo says. "It could be separate events over time, each carrying a tiny amount of water over long scales of time."

Farihi cautions against the possibility of overstating the link between water and hydrogen-rich atmospheres. With polluted objects like GD 61 and GD 17, it's easier to make the case for water by matching up the signatures of the elements present. Once the elements have sunk into the star, however, all that's left is water.

> "The kind of story that happened in the solar system is quite likely to happen in other planetary systems as well."

Still, Fusillo's co-author and adviser Gänsicke thinks the research reveals that water-rich planetesimals — big or small — are frequent in other planetary systems. "It's exciting in a sense, but maybe actually natural, because we know in the solar system that water occurs in many places, some of them unexpected," he says. After all, water shows up in the shadowed craters of Mercury, and in oceans deep inside the moons of Saturn and Jupiter, and maybe even beneath the icy surface of Pluto.

Testing the water

So while understanding living worlds remains a challenge, dead planets are slowly giving up their secrets. And it looks like their secrets could be very wet, indeed.

"There is evidence that water seems to be a general ingredient of planetary systems, even ones that have evolved to the very end of the lifetime of their host stars," Gänsicke says.

Fusillo agrees. "Water is not rare," he says. "Whenever a white dwarf is accreting rocks, it's also accreting water. It's a small amount, but very commonly present."

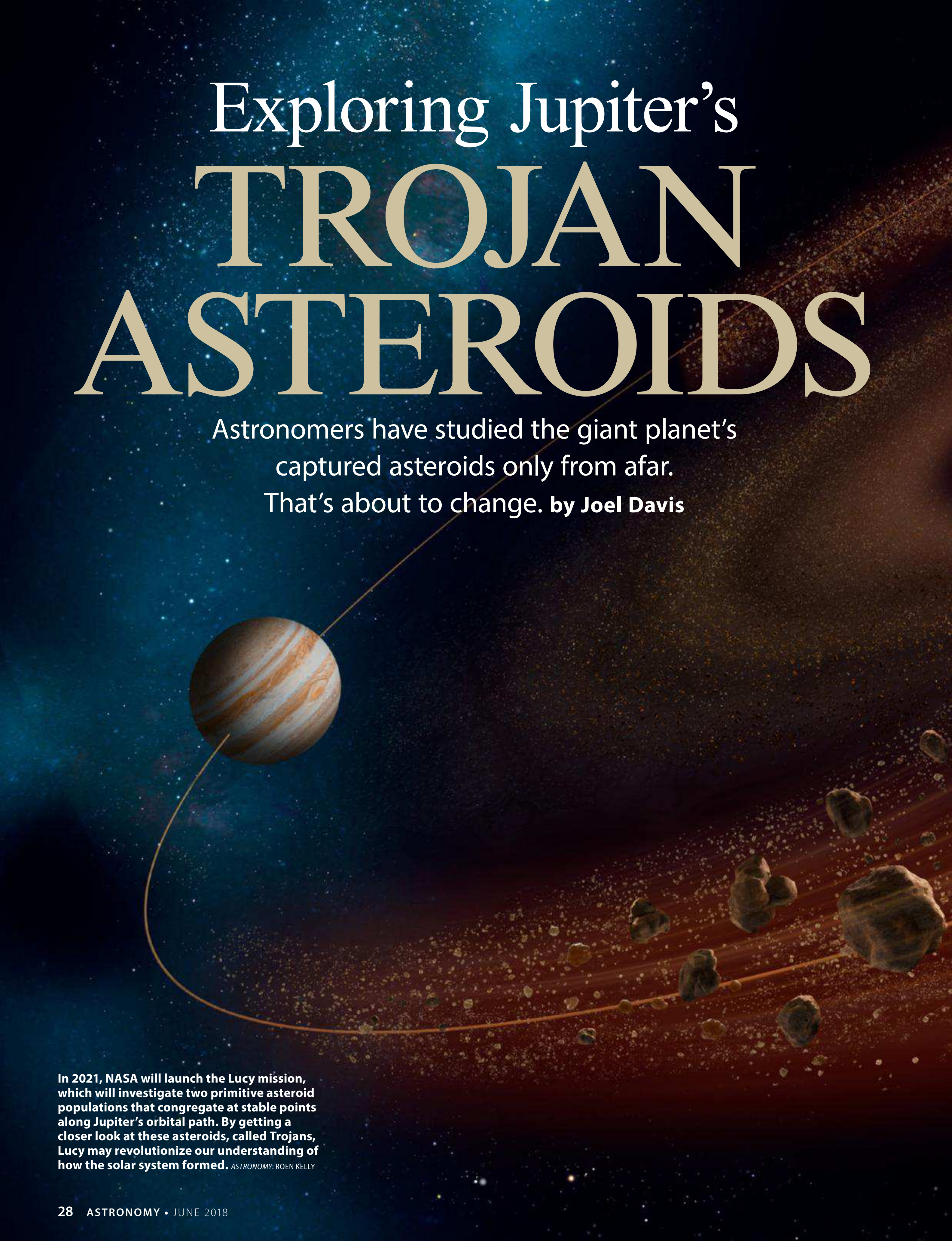
If water is abundant not only in dead planets but also in living ones, that could be good news for those hunting potentially habitable worlds. Planets around living stars may also have received water, either from asteroids or comets, and may hold onto that water until the end of their lifetimes.

"If rocky planets form in the habitable zone, there are a sufficient number of water-carrying bodies that deliver material and make them habitable, even if they were not habitable in the first place," Gänsicke says. "The kind of story that happened in the solar system is quite likely to happen in other planetary systems as well."

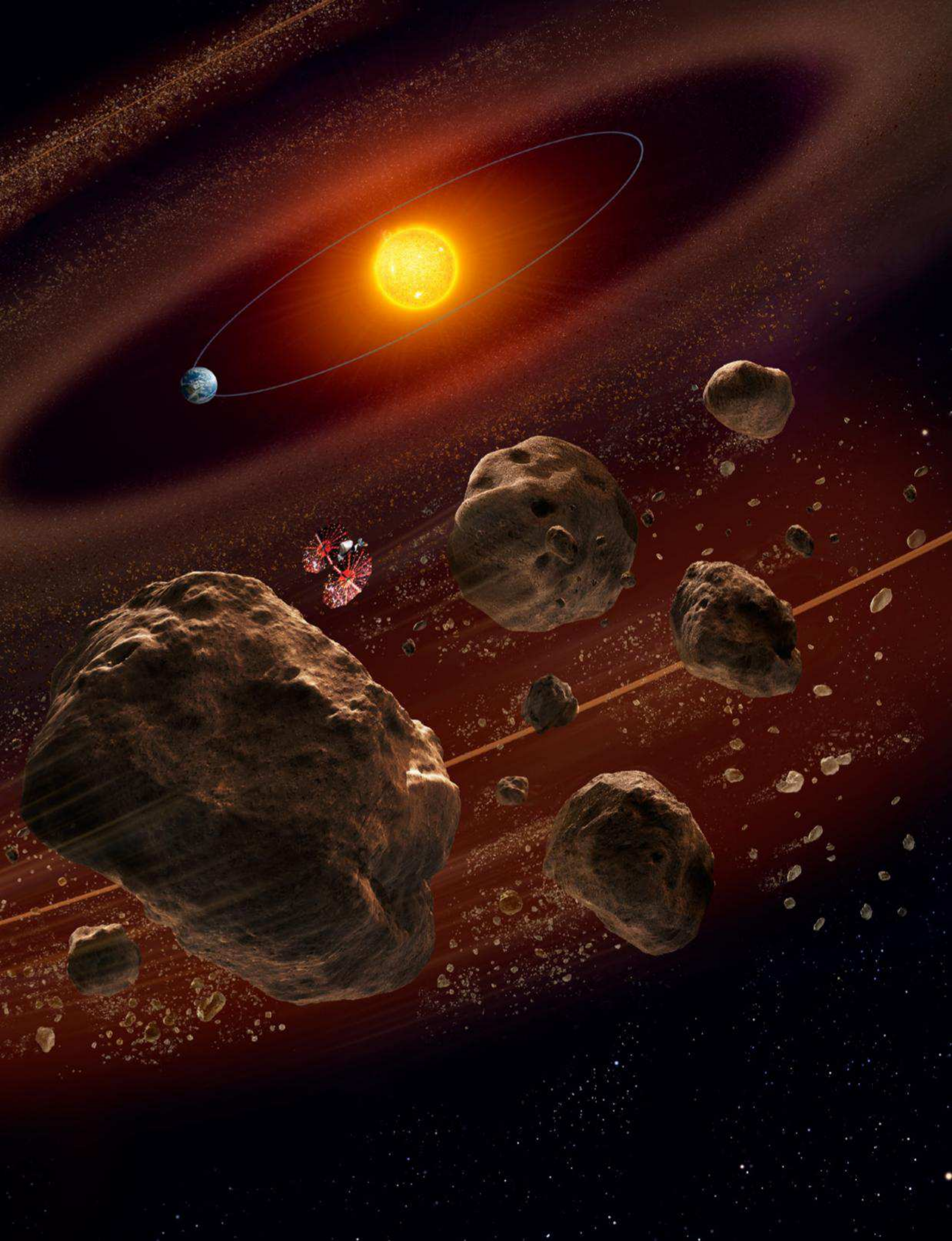
Nola Taylor Redd *is a freelance science writer who writes about space and astronomy while home-schooling her four kids.*

Exploring Jupiter's TROJAN ASTEROIDS

Astronomers have studied the giant planet's captured asteroids only from afar. That's about to change. **by Joel Davis**



In 2021, NASA will launch the Lucy mission, which will investigate two primitive asteroid populations that congregate at stable points along Jupiter's orbital path. By getting a closer look at these asteroids, called Trojans, Lucy may revolutionize our understanding of how the solar system formed. *ASTRONOMY:* ROEN KELLY



Jupiter is by far the largest and most massive planet in the solar system. And befitting a world named for the Roman king of the gods, Jupiter has an impressive entourage. It includes a set of faint and dusty rings, 67 known or suspected moons, and two swarms of asteroids that precede and follow the planet in its orbit. These last are the Trojan asteroids.

For all we've discovered about Jupiter, its moons, and even its gossamer rings, we know precious little about the Trojans. Pioneers 10 and 11, the two Voyagers, Galileo, and Juno have all returned a wealth of data about the jovian system. Until now, though, the only way to study the Trojans has been from afar, with ground-based and Earth-orbiting telescopes.

That's about to change. In 2017, NASA gave the go-ahead for a new Discovery-class robotic mission set for launch in 2021. The space probe will visit and explore six different Jupiter Trojans — and a main belt asteroid for good measure. So little is known about the Trojans that the data will certainly revolutionize our understanding of these ancient bodies. What the spacecraft uncovers could confirm some current theories of the solar system's early evolution — or turn it all upside down.

The sweet spots

Every planet has several gravitational "sweet spots" where a relatively tiny body, like an asteroid, can maintain a fairly stable position in relation to two larger bodies, such as the Sun and the planet, or the planet and its moon. The gravitational pull between the two large bodies provides enough centrifugal force to keep the smaller object orbiting with them. These sweet spots are called Lagrangian points, named for Joseph-Louis Lagrange, who identified two of them in 1772.

Five Lagrangian points exist for each such system. L1, L2, and L3 (discovered by mathematician Leonhard Euler a few years before Lagrange identified the other two) fall on a straight line drawn through the two large masses. L1 lies between the two bodies; L2 lies beyond the smaller of the two objects, but still on the line between them; and L3 lies behind the larger of the two objects, again still on the line between them. L1, L2, and L3 are unstable regions; almost any external force will knock objects at these points out of orbit. So it's extremely rare for natural objects such as moons or asteroids to occupy these locations. Spacecraft must periodically use some sort of station-keeping propulsion to stay at these Lagrangian points.

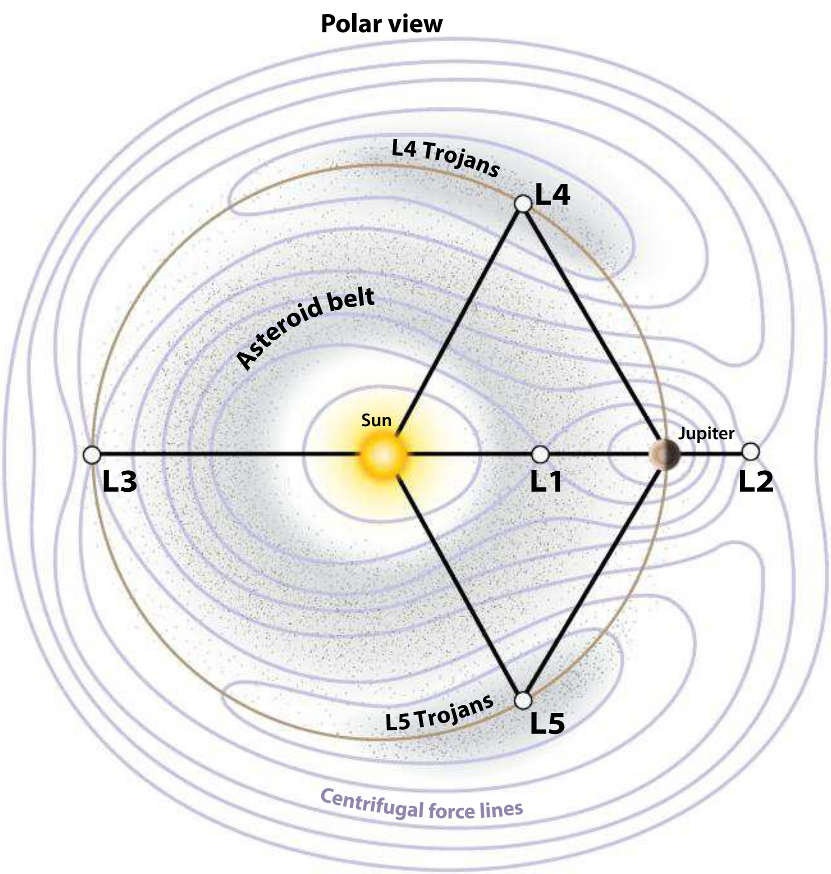
L4 and L5 are the third points of two equilateral triangles drawn in the plane of the two large objects, and both of these points are usually quite stable. The base of the triangle is the line between the large objects, say, the Sun and Jupiter. The other two sides of the triangles are the lines from each large body to points lying about 60° ahead (L4) and 60° behind (L5) in the orbit of the smaller of the two large objects (Jupiter, in this case).

Jupiter's Trojan asteroids

Jupiter's leading and trailing Lagrangian points are stable over the age of the solar system. Like the Sargasso Sea — the enormous circular gyre in the North Atlantic Ocean — they have accumulated eons' worth of objects. These bits of cosmic flotsam and jetsam are the Jupiter Trojan asteroids. They follow heliocentric orbits with nearly the same semi-major axis as Jupiter, about 5.2 astronomical units. (An AU is the average Earth-Sun distance of 483 million miles, or 778 million kilometers.) As they orbit the Sun, the Trojans tend to move closer to, or farther from, Jupiter. The planet's gravitational pull accelerates or decelerates the asteroids, causing them to librate — or oscillate — around the L4 and L5 points. This shepherds the Trojans into two elongated regions around those points. Each region stretches about 26° along Jupiter's orbit (a physical distance of about 2.5 AU), and is about 0.6 AU wide at the widest point.

Many Jupiter Trojans have orbital inclinations

Jupiter's Lagrangian points



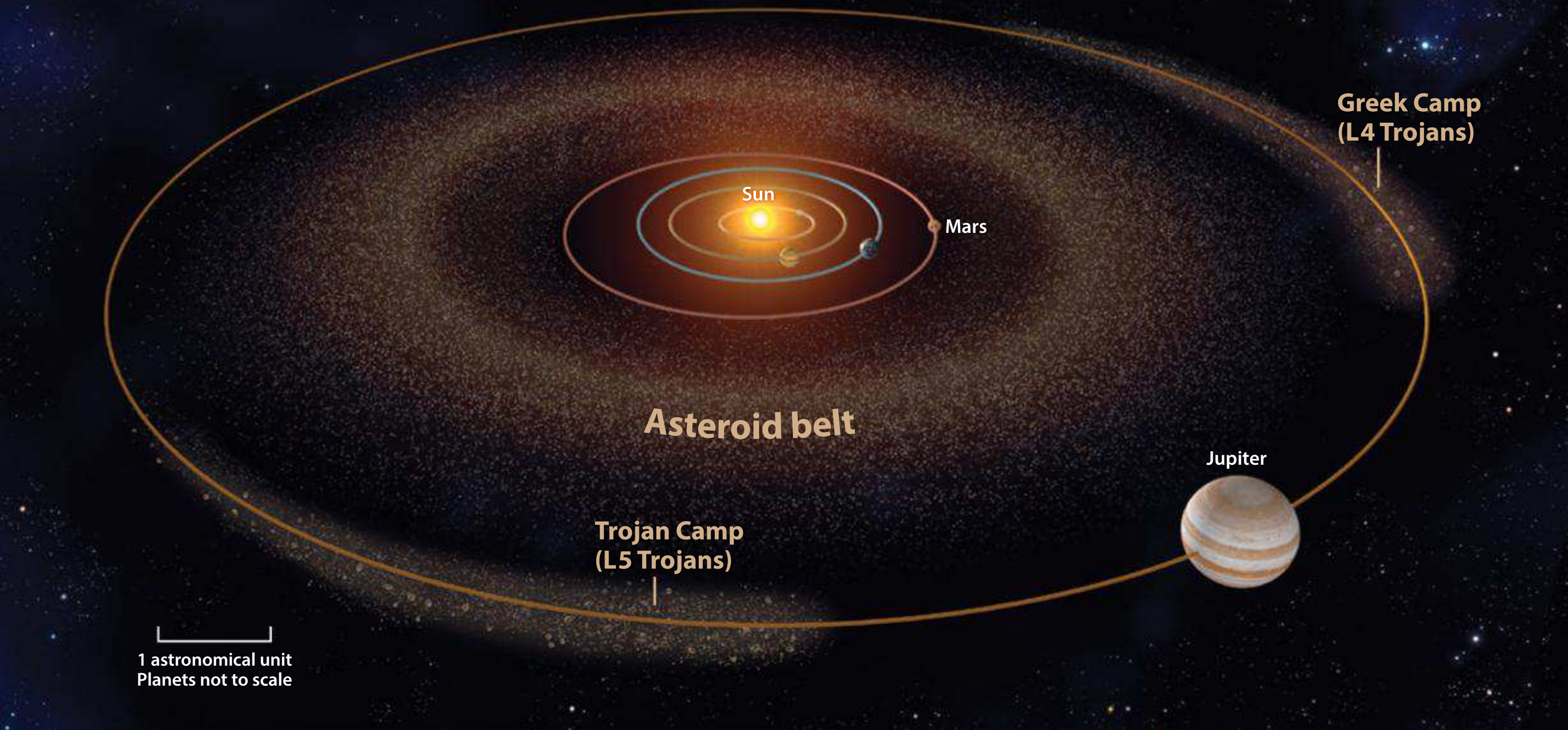
Every planet has a set of five Lagrangian points where much smaller objects, such as asteroids, can maintain somewhat stable positions relative to the Sun and the planet.

ASTRONOMY: ROEN KELLY AFTER NASA/WMAP SCIENCE TEAM; JUPITER ABOVE: NASA/ESA/A. SIMON (GSFC)

Camping with the Trojans

Jupiter's Trojan asteroids are divided into two main groups. Asteroids in the Greek Camp (leading Jupiter at L4) are named after Greek heroes, while those in the Trojan Camp (trailing Jupiter at L5) are named after Trojan heroes.

ASTRONOMY: ROEN KELLY



(or tilts in their orbital planes) larger than Jupiter, and some much larger. For example, the Trojans 2009 WN204 and 2010 BK101 have inclinations of 40.3° and 40.2°, respectively, while 2146 Stentor has an orbital inclination of 39.3°. Still, the gravitational dance between the planet and the Sun always brings them back to these two "sweet spots" along Jupiter's orbit.

The first official Trojan was discovered February 22, 1906, by German astronomer Max Wolf. Eight months later, August Kopff discovered a second asteroid near Jupiter's L5 point; the following February, Kopff found a third, this one near L4. Austrian astronomer Johann Palisa, a prolific discoverer of asteroids, followed up with multiple observations of all three, and he worked out their orbits. It was Palisa who suggested that asteroids in Jupiter's orbit be named for heroes of the Trojan War, and the first three Trojan asteroids were named Achilles, Patroclus and Hektor. As more of these bodies were discovered, a naming convention developed; asteroids near the L4 point were named for Greek heroes (the so-called "Greek Camp") and those near L5 for Trojan heroes (the "Trojan Camp"). However, 617 Patroclus (at L5) and 624 Hektor (at L4) were named before this convention took root. So each camp has a "spy" in its midst!

By 1961, more than half a century after Wolf identified the first Trojan, only 13 more had been discovered. With further improvements in instrumentation, the number increased, first slowly and then in a rush. By early 2017, more than 6,500 had been spotted: 4,184 at Jupiter's L4 point and 2,326 at L5. Scott Sheppard, an astronomer at the Carnegie Institution for Science and a decorated detector of small bodies within the solar system, has said that the number of Jupiter Trojans may well exceed the total number of objects in the main asteroid belt.

But despite the plethora of discovered Jupiter Trojans, we actually know relatively little about them. Most of our observations have been made with Earth-based telescopes. And although astronomers have discovered fewer Trojans in the L5 cloud than in the L4 cloud, this could be a result of observational biases in their coverage.

Lucy in the sky

About 3.2 million years ago, in what is today the Awash River valley in Ethiopia, a small apelike creature died. How it happened is unknown: Perhaps she fell from a tree, or perhaps she was on some journey and lost her way. But there she lay, parts of her skeleton lost to the wind and rain. Rocks, dirt, and volcanic dust covered her bones, layer after layer, as millennia passed.

Then in 1974, a team of paleoanthropologists

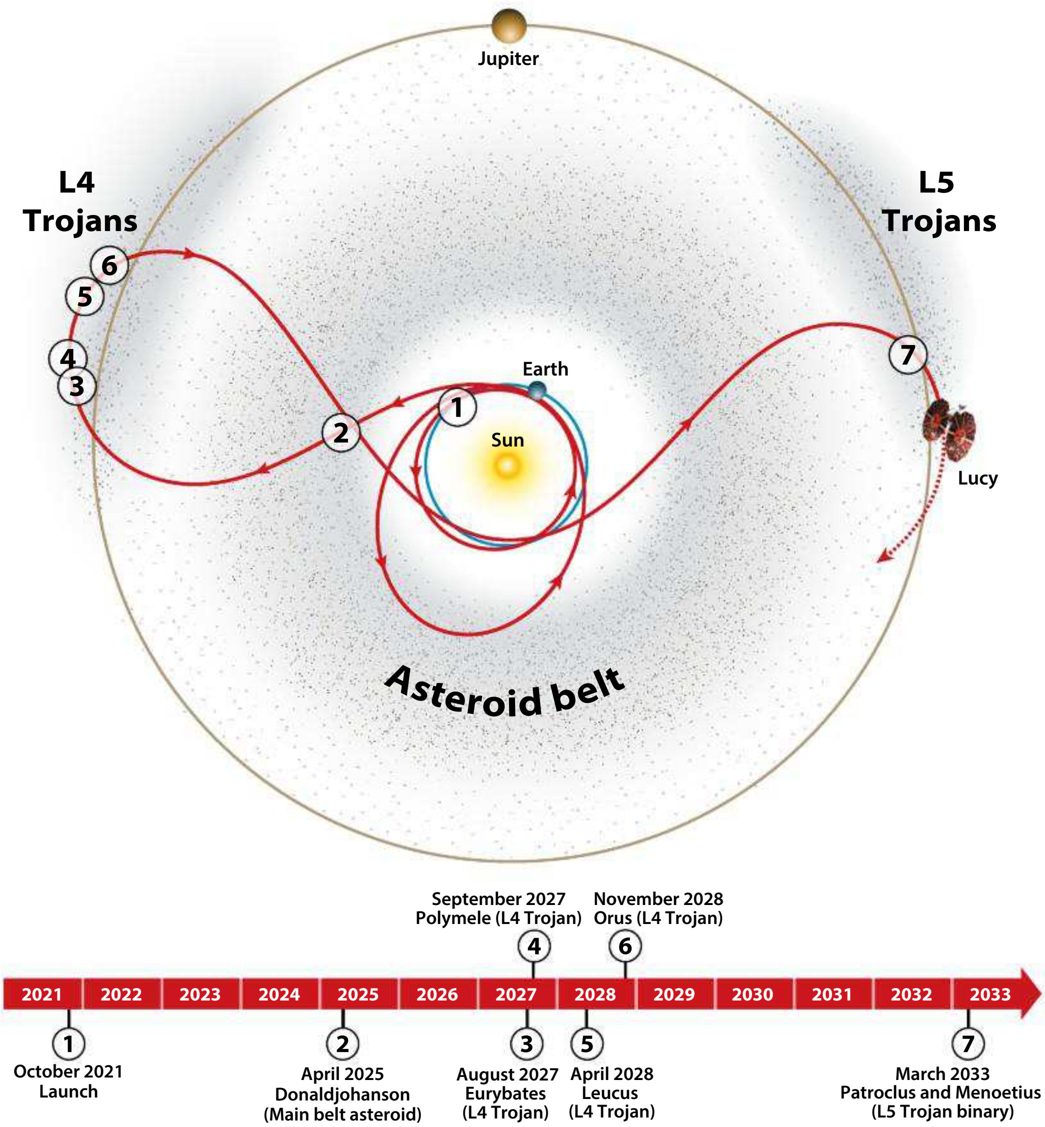
So little is known about the Trojans that the data will certainly revolutionize our understanding of these ancient bodies. What the spacecraft uncovers could confirm some current theories of the solar system's early evolution — or turn it all upside down.

FAST FACTS: JUPITER'S TROJANS

- The largest known Jupiter Trojan, 624 Hektor, is just 140 miles (225 km) wide, smaller than the 15 largest main belt asteroids. At least 24 moons are larger than Hektor.
- The smallest known Trojan is 2002 CO208, discovered in February 2002 by the Lincoln Near-Earth Asteroid Research project (LINEAR) near Socorro, New Mexico. It's an estimated 4 miles (6.6 km) in diameter. Smaller objects surely exist in both camps, but no one knows the actual numbers or sizes. The size distribution of the discovered Trojans suggests that the smaller bodies are the remains left by collisions of larger Trojans.
- Hektor is the most elongated jovian Trojan at 125 by 230 miles (200 by 370 km). Observations made with the Keck II 10-meter telescope in 2006 showed that it has a distinctive dumbbell shape. So it's likely a contact binary — two asteroids "glued together" by their mutual gravitational attraction.
- Hektor is one of only two known Trojans with a companion. Skamandrios is about 7.5 miles (12 km) in diameter and orbits Hektor at a distance of 390 miles (630 km). The other is 617 Patroclus, a binary asteroid whose companion, Menoetius, has nearly the same diameter.
- 11351 Leucus, one of Lucy's targets, has a very slow rotation period — about 440 hours, or more than 18 Earth days. Most asteroids have rotation periods between 2 and 20 hours. Only 62 main belt asteroids are known to have rotation periods greater than Leucus. — **J.D.**

Twelve years, seven targets

This diagram illustrates the path Lucy will take during its 12-year journey, which will take it close by four L4 asteroids, two L5 asteroids, and one main-belt asteroid for good measure. *ASTRONOMY*: ROEN KELLY AFTER SOUTHWEST RESEARCH INSTITUTE



led by Donald Johanson found about 40 percent of her fossilized skeleton. She was a member of the hominin species *Australopithecus afarensis*, and she's probably the most famous pre-human fossil in history. Her scientific name is AL 288-1, but everyone knows her as Lucy. The name comes from the equally famous Beatles song, "Lucy in the Sky With Diamonds," which Johanson's team listened to at camp the night of their discovery.

Now, a spacecraft bearing her name will journey into the sky in search of scientific diamonds. It will take — to steal from another Beatles tune — a long and winding road to get there. But the results will be worth the wait.

For the Lucy mission, this is a second chance. The mission's principal investigator, Hal Levison of the Southwest Research Institute (SwRI) in Boulder, Colorado, notes that a mission named Lucy was proposed once before. "There was a call in 2010 for new Discovery missions," he says, "and one of the proposals then was for a mission also called Lucy." This first proposal was based on the New Horizons spacecraft and had different targets, only one of which was a Jupiter Trojan. It was not approved.

When the next call for Discovery missions was made in 2014, Levison decided to "reboot" it with the same name but with a new purpose. "The people involved in the first proposal were rather distracted by New Horizons, as you can imagine," he says. "I decided it would be a good thing to change the focus of the mission a little bit and really study the Trojan asteroids." SwRI and NASA's Goddard Space Flight Center in Greenbelt, Maryland, sought each other out to create the new Lucy proposal, with Lockheed Martin designing and building the spacecraft.

Lockheed Martin has a long and successful record building spacecraft for NASA, including the OSIRIS-REx asteroid sample-return mission, the 2001 Mars Odyssey orbiter, and the Mars InSight mission slated for launch in 2020. Tim Holbrook is the company's deputy program manager for Lucy. The science team, led by Levison and Catherine Olkin, is based at SwRI in Boulder. The Goddard Space Flight Center is the NASA facility managing the project, with Keith Noll serving as project scientist.

The new Lucy will not look like New Horizons. "When you look at Lucy, you see the size, the physical characteristics, and structure of the Mars Odyssey orbiter. It also incorporates all the latest-generation spacecraft systems — like the avionics package — from OSIRIS-REx," explains Holbrook. "We've also looked back at other spacecraft we have built in recent years, such as the planned InSight Mars lander. We [are] pulling together the best of the best."

The spacecraft will be 11.5 feet (3.5 meters) tall at launch, and 44 feet (13.5 m) across when it is fully deployed and its two circular solar arrays are unfurled. Lucy will have what Holbrook calls "a dual-mode propulsion system" that uses oxidizer and hydrazine for the mission's five major burns, and just hydrazine for smaller trajectory-adjusting maneuvers and station-keeping.

Lucy's Trojan targets are 3548 Eurybates, 15094 Polymele, 11351 Leucus, and 21900 Orus in the L4 Greek Camp, plus 617 Patroclus and its binary companion, Menoetius, in the L5 Trojan Camp. The spacecraft will gather data on the surface composition, surface geology, and the interior and bulk properties of the Trojan targets (plus one main belt asteroid named 52246 Donaldjohanson). And it will do it from close range. The Lucy team will also use the spacecraft's radio telecommunications hardware to measure Doppler shifts — or changes in a signal's frequency that are induced when an object is moving relative to an observer. As Lucy orbits a Trojan, minute variations in the asteroid's mass concentration will cause the craft to slightly speed up or slow down. These tiny changes in speed will shift Lucy's radio signal, allowing astronomers to deduce how much mass is required to account for the shift.

Two of Lucy's three scientific instruments are lifted directly from New Horizons, and the third from OSIRIS-REx. The L'Ralph telescope, built by the Goddard Space Flight Center, is a color optical CCD imager and infrared spectroscopic mapper. The original on New Horizons was named for Jackie Gleason's character in *The Honeymooners* television series. LORRI, a high-resolution visible light imager, is Lucy's version of the LOng-Range Reconnaissance Imager aboard New Horizons; it is from the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. The Thermal Emission Spectrometer (TES) is an upgraded version of the OSIRIS-REx instrument, built at Arizona State University in Tempe.

UP CLOSE AND PERSONAL WITH ASTEROIDS

Occasionally 2 Pallas is visible to the naked eye. But for 190 years, all the other asteroids have been little more than moving points of light seen through binoculars or telescopes. What we knew of them was limited to their size and to what we could glean from the light reflected off their surfaces.

That changed dramatically in 1991, when the Galileo spacecraft flew past 951 Gaspra on its way to Jupiter. On Valentine's Day in 2000, the NEAR-Shoemaker spacecraft went into orbit around the near-Earth asteroid Eros, and sent back a wealth of images and other information about that body. The probe eventually landed on the asteroid's surface, making it the first space probe to soft-land on an asteroid. In all, eight main belt asteroids and three near-Earth asteroids have been visited, orbited, or landed upon by space probes from China, the European Space Agency, Japan, and the United States. What we know about the Jupiter Trojans, though, is pretty much at the level of what we knew about main belt asteroids before 1991.

"Our understanding of the main belt population was revolutionized by those missions," notes Lucy principal investigator Hal Levison. "Lucy is going to go to almost as many objects as we have visited in the main belt throughout the history of space exploration. All in one fell swoop." — **J.D.**

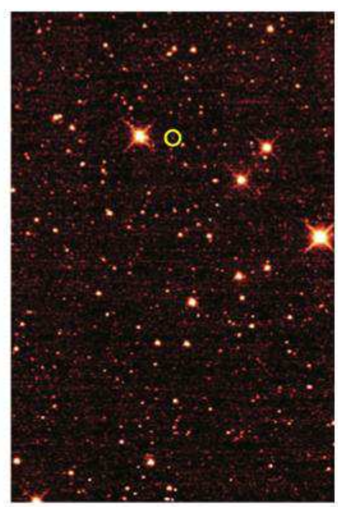
Date(s)	Asteroid	Spacecraft	Mission(s)
10/29/1991	951 Gaspra	Galileo	Flyby
8/28/1993	243 Ida/Dactyl	Galileo	Flyby
7/29/1999	9969 Braille	Deep Space 1	Flyby
1/23/2000	2685 Masursky	Cassini-Huygens	Flyby
2/14/2000-2/12/2001	433 Eros	NEAR-Shoemaker	Orbit, landing
11/2/2002	5535 AnneFrank	Stardust	Flyby
10/4-10/19/2005	25143 Itokawa	Hayabusa 1	Station-keeping, landing, sample retrieval, departure
12/5/2008	2867 Steins	Rosetta	Flyby
7/16/2011	4 Vesta	Dawn	Orbit
12/13/2012	4179 Toutatis	Chang'e 2	Flyby
3/6/2015	1 Ceres	Dawn	Orbit

The long and winding road

Lucy's journey to the Jupiter Trojans will be a long one, lasting nearly 12 years from start to finish. The current timeline calls for the spacecraft to launch in October 2021. Two flybys of Earth in October 2022 and December 2024 will slingshot the spacecraft through the asteroid belt toward the Greek Camp at Jupiter's L4 region. In April 2025, Lucy will make a close flyby of 52246 Donaldjohanson, a main belt asteroid 2.4 miles (4 km) wide and named for the discoverer of the original Lucy — an appropriate first encounter!

In August 2027, the spacecraft will reach its first Trojan target, Eurybates, about 39 miles (64 km) in diameter. The main belt includes many so-called asteroid "families" created by collisions, but only one such family is known in the Trojans. And Eurybates is its largest known member.

A month later, Lucy will fly by Polymele. This 13-mile-diameter (21 km) object is probably also a fragment from an ancient collision. Then in



NASA/JPL-CALTECH/UCLA

Astronomers discovered asteroid 2010 TK7 (circled in yellow), the first known Earth Trojan asteroid, by searching for asteroid candidates with NASA's Wide-field Infrared Survey Explorer (WISE). This image was taken in October 2010.

OTHER TROJAN ASTEROIDS

Every planet but Mercury and Saturn has at least one known Trojan asteroid, even a temporary one. Venus and Earth have one each; Mars has eight; Uranus has two; and Neptune has at least 18.

Astronomer Scott S. Sheppard of the Carnegie Institution for Science and the co-discoverer of four Neptune Trojans believes that Neptune actually has a Trojan swarm larger than Jupiter's. Two of Saturn's moons are also accompanied by Trojan asteroids. Several researchers have offered evidence that both the dwarf planet Ceres and the asteroid Vesta have at least one temporary Trojan each.

Despite extensive searching, no Trojan objects have been found at the Earth-Moon L4 and L5 Lagrangian points, nor at the Mercury or Saturn Lagrangian points. — **J.D.**

VENUS

Name	Location	Discoverer	Diameter (m)	Notes
2013 ND_{15}	L4	WISE	~40–100	Temporary; eccentric orbit crosses orbits of Mercury and Earth

EARTH

Name	Location	Discoverer	Diameter (m)	Notes
2010 TK_7	L4	WISE	~30	Temporary

MARS

Name	Location	Discoverer	Diameter	Notes
5261 Eureka	L5	D.H. Levy, H. Holt	~1.3 km	First known martian Trojan; discovered in 1990
1998 VF_{31}	L5	LINEAR	~800 m	
1999 UJ_7	L4	LINEAR	~1 km	Only known L4 martian Trojan
2001 DH_{47}	L5	Spacewatch	562 m	
2007 NS_2	L5	Observatorio Astronómico de La Sagra	800–1600 m	
2011 SC_{191}	L5	Mount Lemmon Survey	600 m	
2011 SL_{25}	L5	Alianza S4 Observatory	~550 m	
2011 UN_{63}	L5	Mount Lemmon Survey	560 m	

SATURN TROJAN MOONS

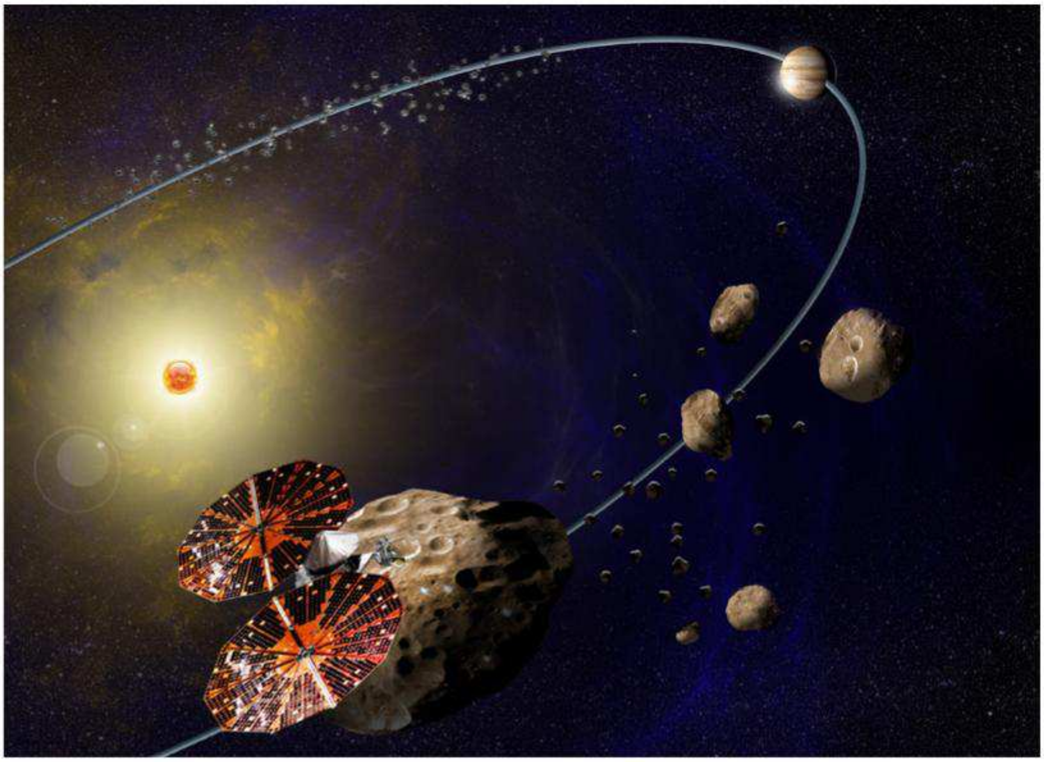
Name	Location	Discoverer	Diameter (km)	Notes
Telesto	Tethys, L4	B.A. Smith, H. Reitsema, S.M. Larson, J.W. Fountain	~24.8	Discovered in 1980; Trojan status determined in 1981
Calypso	Tethys, L5	D. Pascu, P.K. Seidelmann, W.A. Baum, D.G. Currie	~21.4	Discovered in 1980; Trojan status determined in 1981
Helene	Dione, L4	P. Laques, J. Lecacheux	~35.2	Discovered in 1980 during Earth ring-plane crossing
Polydeuces	Dione, L5	Cassini Imaging Science Team	~2.6	Discovered in 2004; first Trojan discovered by a space probe

URANUS

Name	Location	Discoverer	Diameter (km)	Notes
2011 QF_{99}	L4	M. Alexandersen, J. Kavelaars S.M. Larson, J.W. Fountain	~60	First discovered uranian Trojan; centaur in temporary Trojan orbit
2014 YX_{49}	L4	B. Gibson, T. Goggia, N. Primak, A. Schultz, M. Willman	40–120	Centaur in temporary Trojan orbit

NEPTUNE

Name	Location	Discoverer	Diameter (km)	Notes
2001 QR_{322}	L4	Deep Ecliptic Survey	~140	First Neptune Trojan discovered
2004 KV_{18}	L5		56	Temporary (~100,000 year)
2005 TN_{53}	L4	S.S. Sheppard, C. Trujillo	~80	First high-inclination Trojan discovered
2005 TO_{74}	L4	S.S. Sheppard, C. Trujillo	~100	Possibly unstable orbit
2006 RJ_{103}	L4	Sloan Digital Sky Survey	~180	
2007 VL_{305}	L4	Sloan Digital Sky Survey	~160	High (28.1°) inclination
2008 LC_{18}	L5	S.S. Sheppard, C. Trujillo	~100	First L5 Trojan discovered; high (27.5°) inclination
2010 EN_{65}	L4*	D. L. Rabinowitz, S.W. Tourtellotte	~200	*Jumping Trojan, moving from L4 to L5 via L3
2010 TS_{191}	L4	Hsing Wen Lin et al.	~120	Pan-STARRS 1 (PS1) survey
2010 TT_{191}	L4	Hsing Wen Lin et al.	~130	Pan-STARRS 1 (PS1) survey
2011 HM_{102}	L5	New Horizons KBO Search Survey	90–180	High (29.4°) inclination; second Trojan discovered by a spacecraft
2011 SO_{277}	L4	Hsing Wen Lin et al.	~140	Pan-STARRS 1 (PS1) survey
2011 WG_{157}	L4	Hsing Wen Lin et al.	~170	Pan-STARRS 1 (PS1) survey
2012 UV_{177}	L4		~80	
2013 KY_{18}	L5	Hsing Wen Lin et al.	~200	Pan-STARRS 1 (PS1) survey
2014 QO_{441}	L4	Dark Energy Survey Collaboration	~130	Most eccentric stable Neptune Trojan
2014 QP_{441}	L4	Dark Energy Survey Collaboration	~90	
385571 Otrera	L4	S.S. Sheppard, C. Trujillo	~100	First named Trojan



SOUTHWEST RESEARCH INSTITUTE

In this artist's concept (not to scale), the Lucy spacecraft flies by Eurybates, one of six notable Trojans that it will encounter between 2027 and 2033. Lucy will also fly by 52246 Donaldjohanson, a main belt asteroid named after the discoverer of a fossil hominin coincidentally nicknamed "Lucy."

April 2028, the spacecraft will visit Leucus, which is 21 miles (34 km) wide and very dark. The last L4 Trojan Lucy will visit is Orus in October 2028. Orus is about 32 miles (51.5 km) wide.

Lucy's orbit will bring it back to Earth for another gravity-assist flyby in December 2030. Then it will again coast out to Jupiter's realm and pass through the L5 swarm for a final Trojan encounter in March 2033. Patroclus, the second Trojan to be discovered, is a binary asteroid with a mean diameter of 70 miles (113 km), and its companion, Menoetius, is roughly 65 miles (104 km) wide. They orbit one another at a distance of 422.5 miles (680 km).

"That's going to be a great encounter, my favorite!" exclaims Levison. "It's at the end of the mission. We will have to wait, but it will be the highlight!"

The science team had two objects of particular interest for the Lucy mission, Levison says. Eurybates, the first Trojan Lucy will encounter, is the only one on the team's "must-visit" list. The other is Patroclus. "The fact that Patroclus is still a binary means that it is probably pretty pristine," says Levison. "If either of the objects in the binary had suffered a large collision, it would have completely disrupted the binary. That's why there are so few binaries in the inner part of the solar system.

"On the other hand, Eurybates is the largest member of a collisional family of objects," he says. "So we are visiting a binary that is probably pretty pristine, and a guy that we know got the crap kicked out of it. Comparing those will be interesting in and of itself."

The visit to Patroclus is a great example of the good fortune Levison's team has had. "This object has an orbital inclination of more than 20°, and it just so happens that it will be crossing the plane of the solar system just as Lucy goes by," he says. "It was pure luck. I've been studying celestial mechanics for 30 years, and the celestial mechanics gods are paying me back!"

With their low albedos and reddish spectra, most Jupiter Trojans appear similar to some outer main belt asteroids, centaurs, and Kuiper Belt objects. However, says Levison, many individual Trojans differ widely in spectral type, color, size, and collisional history. One possible explanation for this mystery is that these objects all originally formed in the outer reaches of the solar system and were later mixed together in the Trojan swarms. That could have occurred during planetary formation, or later as the giant planets migrated to their present-day orbits. But the only way to begin sorting it out is to study the diversity of the Trojans up close.

Fortunately, Levison and his team are confident that Lucy is the perfect mission to help shed new light on these dusky diamonds in the sky.

Joel Davis *has worked as a technical writer at Microsoft and WideOrbit. He blogs regularly at notjustminorplanets.blogspot.com.*

SPACECRAFT AT OTHER LAGRANGIAN POINTS

Lagrangian points provide unique vantage points for space research. The following operational spacecraft reside at or near two Sun-Earth Lagrangian locations:

Sun-Earth L1

- Solar and Heliospheric Observatory (SOHO), 1996–present
- Advance Composition Explorer (ACE), 1997–present
- GGS WIND, 2004–present
- Deep Space Climate Observatory (DSCOVR), 2015–present
- LISA Pathfinder, 2016–present

The International Sun–Earth Explorer 3 (ISEE-3) operated around the Sun-Earth L1 point for four years (1978–1982). After being moved to a heliocentric orbit and renamed the International Cometary Explorer (ICE) in 1985, it became the first spacecraft to visit a comet, 21P/Giacobini–Zinner.

Sun-Earth L2

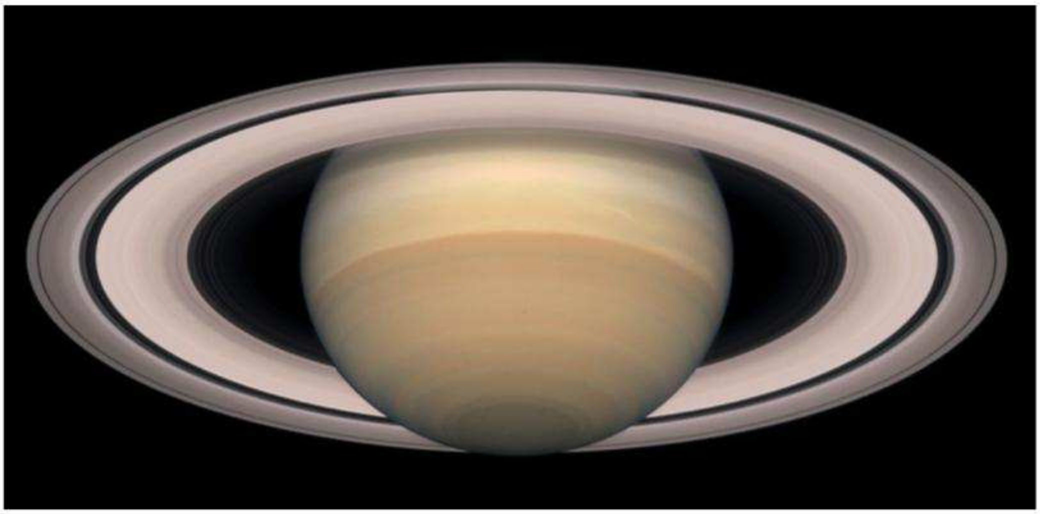
- Gaia Space Observatory, 2014–present

Gaia is currently the only operational spacecraft at the Sun-Earth L2 point. GGS Wind and Chang'e 2 spent time at L2 and then moved on to other locations in the solar system. They are still operational. Three others — the Wilkinson Microwave Anisotropy Probe, the Herschel Space Telescope, and the Planck Space Observatory — successfully completed operations at the L2 point and were then moved into heliocentric parking orbits. **— J.D.**

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

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

June 2018: Saturn takes center stage



With Saturn looming large and the rings wide open, this month promises exquisite views of the planet's ring structure, including the broad Cassini Division and thin Encke Gap. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

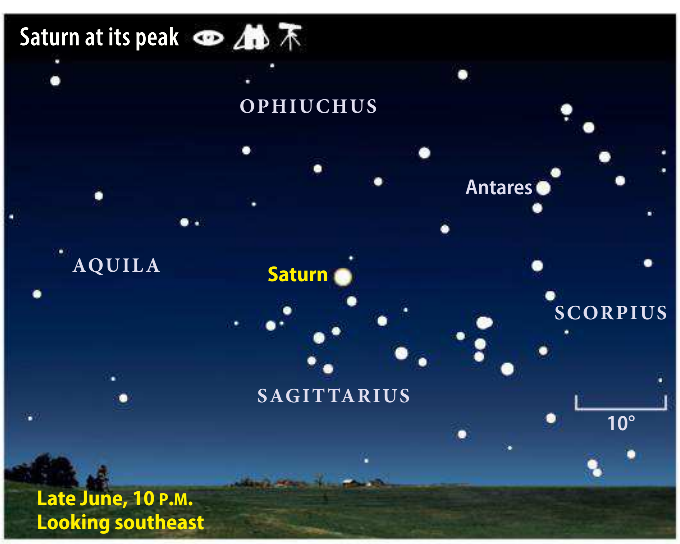
Our great run of spring and summer planets continues this month as Saturn comes to opposition and peak visibility. Meanwhile Jupiter, a month past its own opposition, lights up the sky from evening twilight until the wee hours. And Mars, which will reach opposition in July, stands out from late evening until dawn.

But the planetary delights begin with splendid appearances by the two inner planets shortly after sunset. We'll start our tour with innermost **Mercury** as it climbs into view after midmonth.

Your first good chance to spot this world comes June 19. Scan the area above your west-northwestern horizon starting 30 minutes after sunset. Mercury lies 7° high and should be fairly easy to spot in the twilight with your naked eyes, because it shines brightly at magnitude –0.8. That same evening, the planet forms a skinny triangle with Gemini's twins, Castor and Pollux. These bright stars stand side by side 10° above Mercury.

As the month progresses, Mercury's visibility improves as it climbs away from the Sun. Its ascent coincides with Gemini's descent, and on June 27, the planet sits in line with Castor and Pollux. Mercury (now at magnitude –0.3) appears on the left with Pollux 7° to its right and Castor 4.5° beyond it. The trio stands 10° high a half-hour after sundown.

Mercury typically appears as a blurry disk through a telescope because its light has to pass through a lot of Earth's turbulent atmosphere. On June 19, the planet spans 5.6" and shows an 81-percent-lit phase. By the 27th, it appears 6.3" across and 66 percent illuminated.



The ringed planet shines brightest in late June, when it remains visible all night against the backdrop of Sagittarius. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

As you gaze at Mercury, you no doubt will notice a much brighter object higher in the west. **Venus** brightens from magnitude –3.9 to –4.1 during June and is by far the brightest point of light in the sky. As the month opens, the dazzling object lies in central Gemini 9° below Pollux. By June 11, it stands 6° to the left of this 1st-magnitude star.

Although it appears near Gemini's brightest star on the 11th, it actually crosses into neighboring Cancer that same day. A waxing crescent Moon joins it June 15 and 16. On the 15th, Luna hangs 7° below the planet; on the 16th, our satellite climbs 8° to Venus' upper left. On this latter evening, the superb Beehive star cluster (M44) stands midway between the planet and the Moon. Once the sky grows dark, grab your binoculars for some amazing views of Venus, the cluster, and the Moon bathed in earthshine.

Venus skirts the northern edge of M44 on the 19th, passing just 44' from the cluster's center. This presents a golden photo opportunity. The stunning jewels of the Beehive are a favorite target for astroimagers, and Venus' brilliant light adds a nice touch.

The planet continues eastward through the rest of June, crossing into Leo on the 29th and ending the month 10° shy of the Lion's brightest star, 1st-magnitude Regulus. Surprisingly, Venus hangs a bit lower in the evening sky as June wraps up. It stood 16° high an hour after sunset in early June, but its altitude drops to 15° by month's end. And by the time it reaches

RISING**MOON**

Youthful impacts leave pristine scars

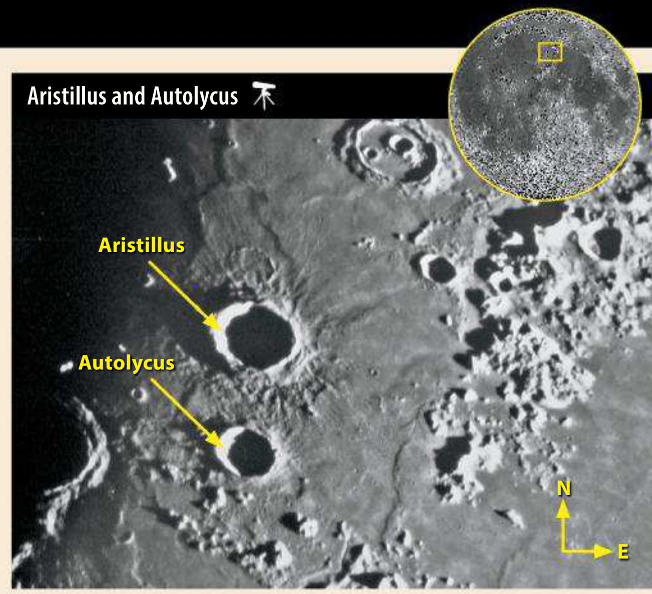
As the solstice approaches, the waxing crescent Moon appears higher each evening. Different wonders pop into view along the terminator that separates day from night as it advances westward across Luna's face.

By First Quarter Moon on June 20, our satellite rides halfway up the sky during twilight. Look for the rugged lunar Apennines thrusting diagonally into the sunlit domain north of the equator. In the plains along the terminator a bit north of these mountains lie two striking young craters: Autolycus and Aristillus. They formed a couple of billion years ago, after the Late Heavy Bombardment finished pummeling the solar system's inner worlds.

The low Sun angle at First Quarter highlights the debris aprons that splattered from these impact sites. The larger impactor that created Aristillus excavated a lot more material — notice the many streaks and ridges that radiate from this crater. Both craters' high walls prevent sunlight from reaching their central peaks and floors. If you return June 21, the higher Sun reveals Aristillus' multiple central peaks, but begins to conceal its apron's roughness.

Compare the characteristics of these "youthful" scars with the much larger and older impact craters Hipparchus and Albategnius along the terminator just south of the lunar equator. Their degraded features, the result of incessant pounding from smaller impacts over time, attest to their greater age. Their central peaks are lower, their walls are rounded and pockmarked with dozens of smaller craters, and their debris aprons are smoothed out.

Aristillus and Autolycus



These sharply defined craters stand out as the Sun rises over them at First Quarter Moon on June 20. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

greatest elongation from the Sun in mid-August, it will appear only half as high. Blame the ecliptic — the apparent path of the Sun and planets across the sky — which makes a steeper angle to the western horizon after sunset in spring.

Your best telescopic views of Venus come in twilight because the planet's glare is almost overwhelming in a dark sky. On June 1, it appears 13" across and 80 percent lit. By the 30th, the planet spans 16" and the Sun illuminates 70 percent of its disk.

Despite the inner planets' charms, June belongs to the solar system's outer worlds. **Jupiter** rides high in the south at dusk, a brilliant object set against the backdrop of Libra the Scales. It shines at magnitude –2.5 in early June and fades only to magnitude –2.3 by month's end.

The giant planet reached opposition and peak visibility

— *Continued on page 42*

METEORWATCH

On a quest for twilight clouds

June offers no major meteor showers, but keep watch for the few minor ones as well as the normal flow of sporadic meteors. Perhaps the best minor shower radiates from the constellation Ophiuchus and peaks the morning of June 20. The Ophiuchids could deliver up to 5 meteors per hour after the First Quarter Moon sets around 1 A.M. local daylight time.

Meteors arise when dust particles slam into Earth's atmosphere and burn up through friction. Similar dust helps create gorgeous noctilucent (night-glowing) clouds. These silver-blue clouds form when ice crystals freeze onto dust particles about 50 miles above Earth's surface, some five to 10 times higher than cirrus clouds. They occur most often in early summer from latitudes between 50° and 60°. Look for them during twilight an hour or two after the Sun sets (or before the Sun rises).

Beautiful noctilucent clouds

June's long twilight provides northern viewers with perfect conditions for seeing these highly reflective, high-altitude clouds. NEIL ENGLISH

OBSERVING HIGHLIGHT Saturn peaks June 27, shining at magnitude 0.0 and spanning 18.4" with rings extending 41.7" when seen through a telescope.

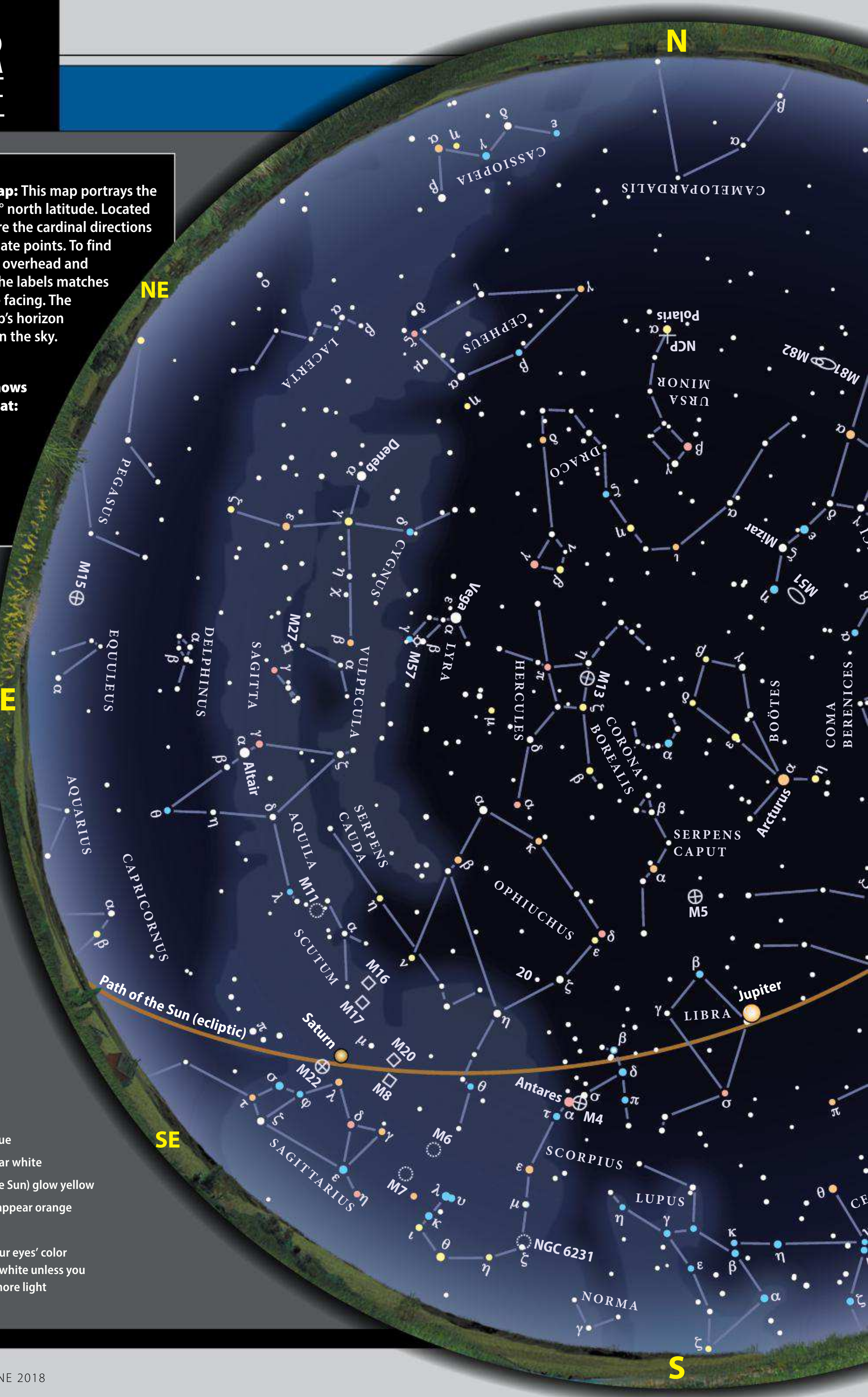
STAR DOME

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 June 1
11 P.M. June 15
10 P.M. June 30

Planets are shown at midmonth



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

MAP SYMBOLS

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

JUNE 2018

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

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

2 The Moon is at apogee (251,852 miles from Earth), 12:35 P.M. EDT

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

5 Mercury is in superior conjunction, 10 P.M. EDT

6 The Moon passes 2° south of Neptune, 2 P.M. EDT

Last Quarter Moon occurs at 2:32 P.M. EDT

8 Venus passes 5° south of Pollux, 9 P.M. EDT

9 The Moon passes 5° south of Uranus, 11 P.M. EDT

13 New Moon occurs at 3:43 P.M. EDT

14 The Moon is at perigee (223,385 miles from Earth), 7:53 P.M. EDT

15 Asteroid Amphitrite is at opposition, 9 A.M. EDT

16 The Moon passes 2° south of Venus, 9 A.M. EDT

Asteroid Metis is at opposition, 4 P.M. EDT

19 Neptune is stationary, 8 A.M. EDT

Asteroid Vesta is at opposition, 4 P.M. EDT

SPECIAL OBSERVING DATE

19 Venus passes 0.4° north of the Beehive star cluster this evening.

20 First Quarter Moon occurs at 6:51 A.M. EDT

21 Summer solstice occurs at 6:07 A.M. EDT

23 The Moon passes 4° north of Jupiter, 3 P.M. EDT

25 Mercury passes 5° south of Pollux, noon EDT

27 The Moon passes 0.3° north of asteroid Vesta, 5 A.M. EDT

Saturn is at opposition, 9 A.M. EDT

The Moon passes 1.8° north of Saturn, midnight EDT

28 Full Moon occurs at 12:53 A.M. EDT

Mars is stationary, 10 A.M. EDT

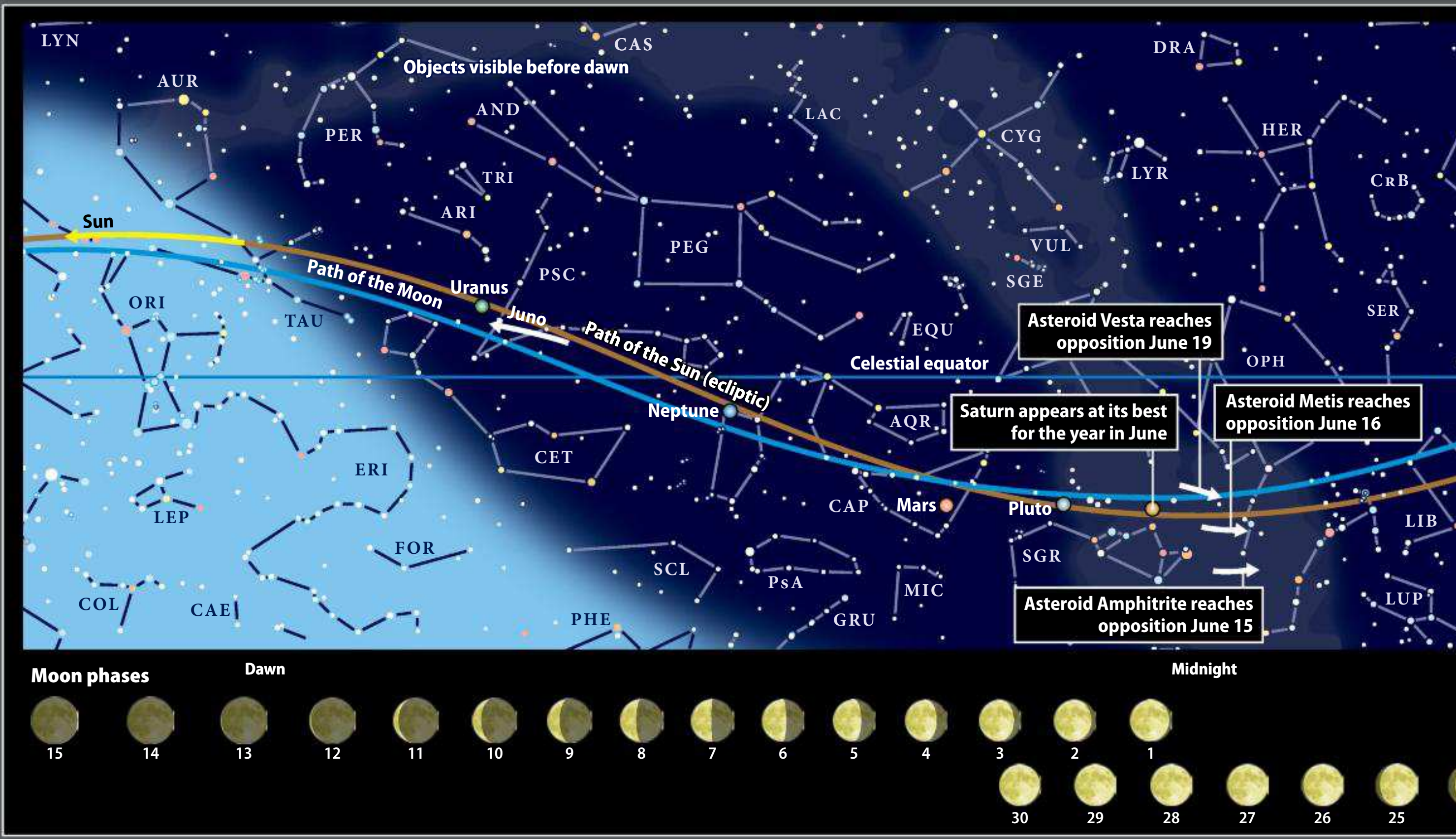
29 The Moon is at apogee (252,315 miles from Earth), 10:43 P.M. EDT

30 The Moon passes 5° north of Mars, 10 P.M. EDT

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

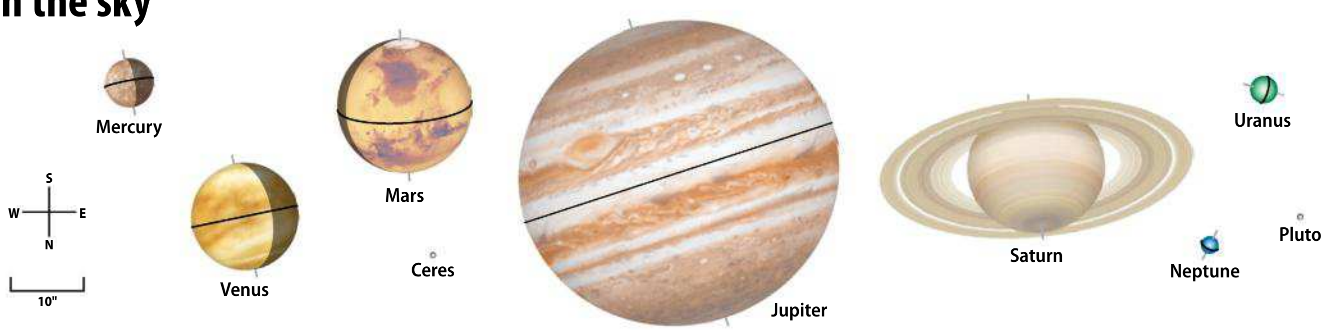
PATH OF THE PLANETS

The planets in June 2018



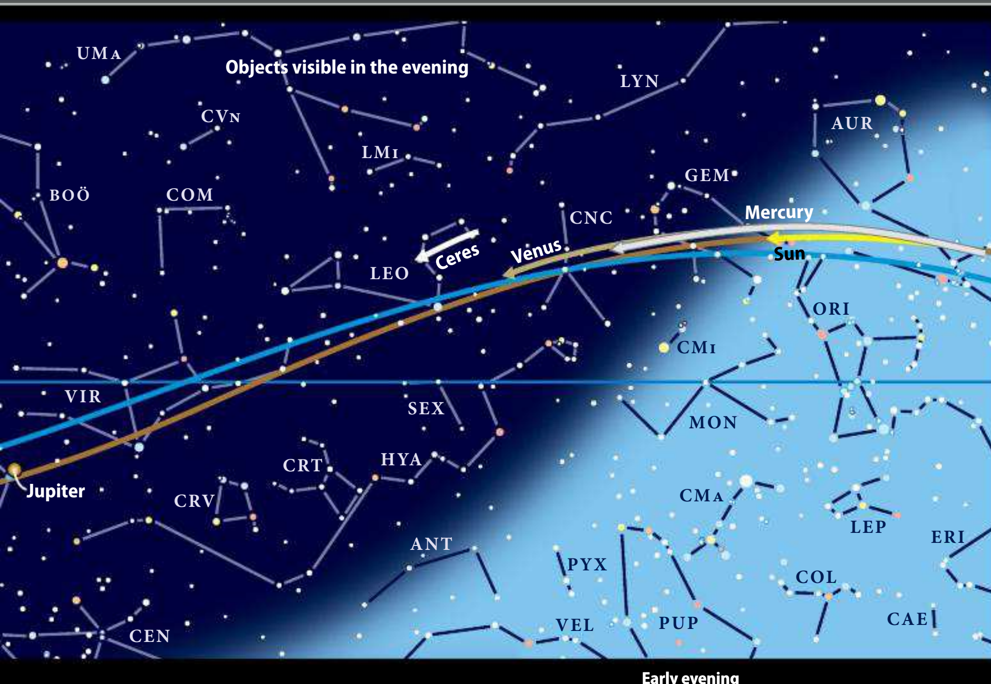
The planets in the sky

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



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	June 30	June 15	June 15	June 15	June 15	June 15	June 15	June 15	June 15
Magnitude	–0.2	–4.0	–1.6	8.7	–2.4	0.1	5.9	7.9	14.2
Angular size	6.5"	14.2"	17.8"	0.5"	43.0"	18.3"	3.4"	2.3"	0.1"
Illumination	63%	76%	93%	97%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.040	1.177	0.526	2.888	4.580	9.073	20.483	29.794	32.672
Distance (AU) from Sun	0.411	0.720	1.439	2.562	5.401	10.065	19.885	29.942	33.582
Right ascension (2000.0)	8h13.9m	8h14.9m	20h46.3m	10h01.0m	14h47.9m	18h28.2m	1h56.9m	23h10.8m	19h28.1m
Declination (2000.0)	21°23'	21°54'	–21°55'	22°07'	–14°57'	–22°25'	11°23'	–6°19'	–21°41'

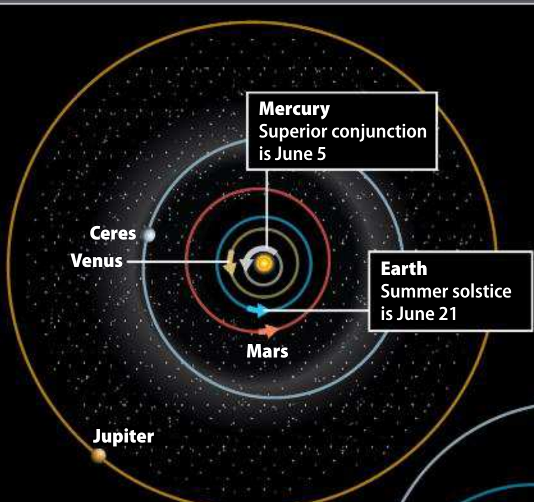
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

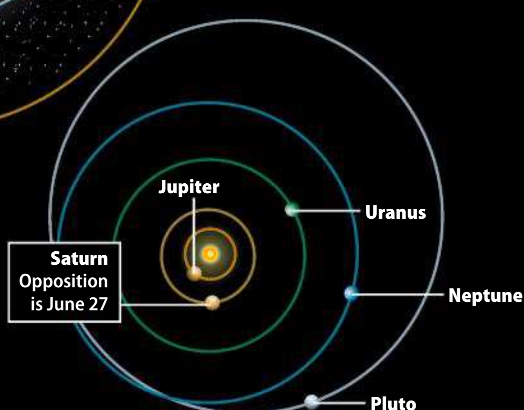


To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.

The planets in their orbits

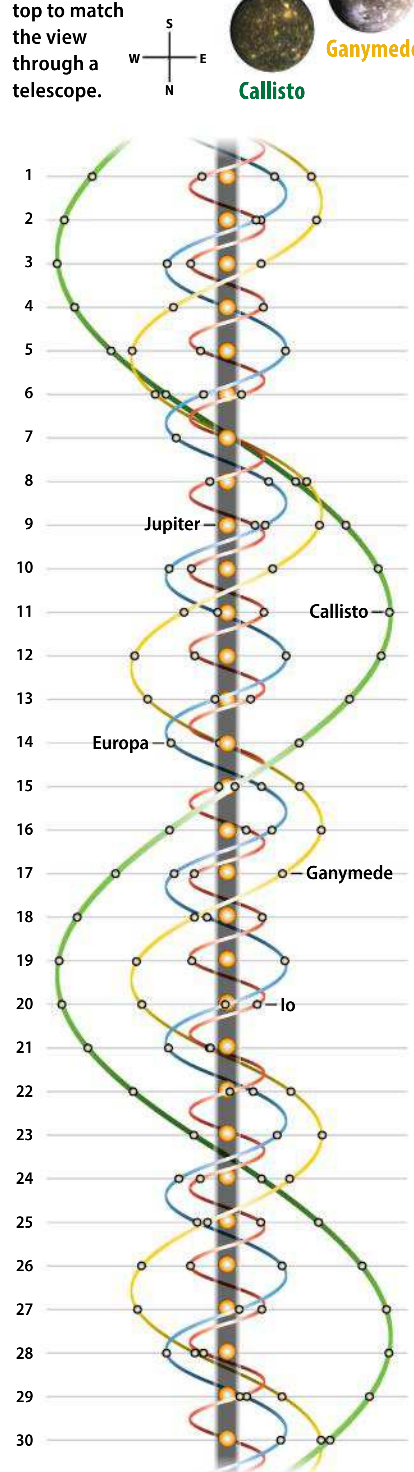
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.





Jupiter's moons

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



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (northwest)	Mars (southeast)	Mars (south)
Venus (west)	Jupiter (southwest)	Saturn (southwest)
Jupiter (south)	Saturn (southeast)	Uranus (east)
Saturn (southeast)		Neptune (southeast)

in early May, and it spends June moving slowly westward relative to the background stars. It begins the month 0.9° north-northeast of Zubenelgenubi (Alpha [α] Librae) and ends the month 2° northwest of this 3rd-magnitude star.

Although Jupiter's diameter shrinks from 44" to 41" during June, that's big enough to show nice detail through any telescope. Begin observing in early evening when the gas giant stands high in the south and its light passes through less of Earth's atmosphere.

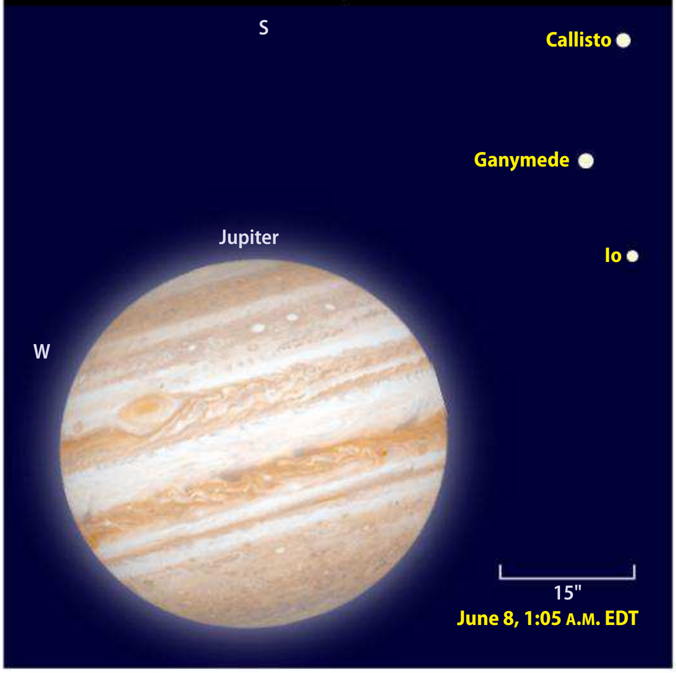
The first features to appear are two dark belts that sandwich a brighter zone coinciding with the gas giant's equator. Details along the belts' turbulent northern and southern boundaries pop into view during moments of good seeing.

The planet's four Galilean moons also show up clearly through small scopes. Be ready to observe an intriguing event the night of June 7/8. Ganymede lies in Jupiter's shadow in early evening but gradually returns to view between Io and Callisto. At 12:40 A.M. EDT, Io and Callisto appear 25" apart southeast of the planet. If you watch the space between these moons, you'll see Ganymede emerge into sunlight starting at 12:43 A.M. It returns to full visibility by 1:02 A.M.

Saturn rises shortly after 10 P.M. local daylight time in early June, but your best views will come around the time it reaches opposition June 27. It then lies opposite the Sun in our sky and remains visible all night. It also shines brightest at opposition, cresting at magnitude 0.0.

Saturn lies among the background stars of Sagittarius. Binoculars reveal several outstanding deep-sky objects in its vicinity. On June 1, the planet stands 1.9° northwest of the 5th-magnitude globular star cluster M22 and 3.2° south of the similarly bright open cluster M25. The Lagoon and Trifid nebulae (M8 and M20, respectively) lie 7° west of Saturn. By month's end, Saturn's westward motion brings it about halfway between M25 and M8. Unfortunately, a Full

Ganymede emerges into sunlight



The solar system's largest moon materializes out of the darkness between Io and Callisto when it exits Jupiter's shadow the night of June 7/8.

COMETSEARCH

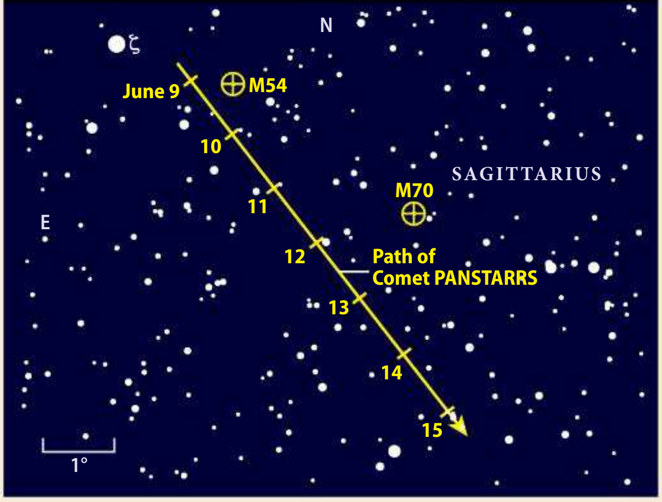
Masquerading among the globulars

Several periodic comets are slated to cross our summer and fall skies. The best of the lot should be Comet 46P/Wirtanen, which may be visible to the naked eye in late fall and early winter.

But plan to set your sights on Comet PANSTARRS (C/2016 M1) this month. The 10th-magnitude object passes through the bottom of Sagittarius' Teapot asterism in June's second week. On the 9th and 10th, it slides about 40' from the 8th-magnitude globular star cluster M54. A few nights later, it passes twice as far from the similarly bright globular M70. The waning crescent Moon doesn't rise until 3 A.M. local daylight time on the 9th and about a half-hour later each succeeding night, so it won't hinder your quest.

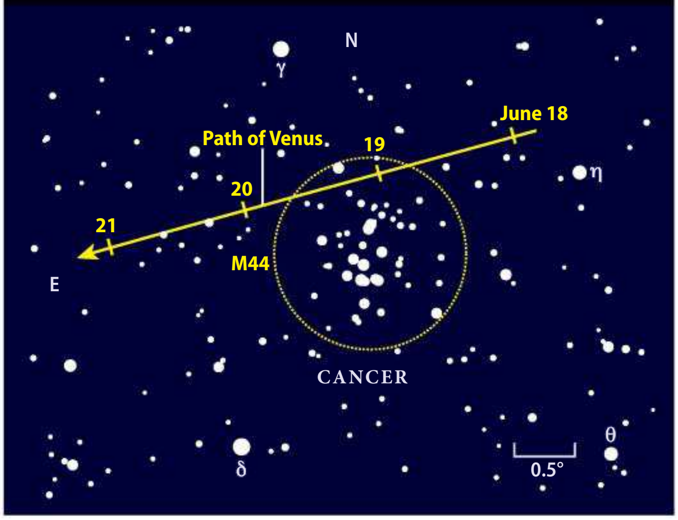
You'll want to observe between 2 and 3 A.M., when Sagittarius climbs highest in the south. And you'll probably need a 6-inch or larger telescope and a dark observing site to see it. The light from PANSTARRS likely will spread out enough to render it invisible at low power. Crank the magnification up to 100x or so to pull it out of the background. And if conditions allow, don't hesitate to add more power.

Comet PANSTARRS (C/2016 M1)



Sagittarius' Teapot hosts two 8th-magnitude globular clusters, M54 and M70, that provide an enticing backdrop for this Oort Cloud visitor.

Venus buzzes the Beehive



The brilliant planet slides through the northern outskirts of the stunning Beehive star cluster (M44) just after the middle of June.

Moon lies within 2° of Saturn on opposition night and ruins the binocular view.

Of course, nothing really detracts from the view of Saturn through a telescope. At opposition, the planet's equatorial diameter extends 18.4" while the rings span 41.7" and tilt 26° to our line of sight. Saturn is only 1 percent smaller in early June, so its appearance hardly changes this month. Look for the Cassini Division that separates the outer A ring from the brighter B ring. An 8-inch scope shows the narrow Encke Gap near the A ring's outer edge.

Saturn's brightest moon, 8th-magnitude Titan, shows up through any telescope. A 4-inch instrument also reveals Tethys, Dione, and Rhea closer to the planet.

Mars follows about two hours after Saturn. It rises shortly after midnight local daylight time in early June and 90 minutes earlier by month's end. The planet spends the month in Capricornus, moving slowly eastward until it reaches its stationary point June 28.

If you observe Mars all month, you can't help but notice rapid changes in its appearance as it approaches a spectacular late July opposition. Mars more than doubles in brightness during June, climbing from magnitude –1.2 to –2.1. And the improvement visible through a telescope is no less striking — the planet's diameter grows 35 percent, from 15.3" to 20.7". At its peak in late July, Mars will gleam at magnitude –2.8 and will swell to 24.3" across.

From its position in southern Capricornus, Mars remains low in the sky for Northern Hemisphere observers. The best telescopic views come when it climbs highest in the hours before dawn. The ruddy world rotates on its axis once every 24.6 hours, so the hemisphere we see changes slowly from night to night. Oddly enough, the planet's darkest feature, Syrtis Major, lies near the same longitude as its most prominent bright feature, Hellas. From North America, both lie near the center of Mars' disk on mornings from about June 6–10.

The two outermost planets appear best before dawn. **Neptune** rises around 2 A.M. local daylight time in early June and two hours earlier by month's end. Look for it in the southeast among the background stars of eastern Aquarius just before twilight starts to paint the sky. It glows at magnitude 7.9 and shows up through binoculars just 1° west-southwest of magnitude 4.2 Phi (ϕ) Aquarii. A telescope reveals its 2.3"-diameter disk and subtle blue-gray color.

You'll want to wait until late June to view **Uranus**. It then stands 20° high in the east as twilight begins. The ice giant resides in the southwestern corner of Aries, 12° south of the Ram's brightest star, magnitude 2.0 Hamal (Alpha Arietis). Uranus shines at magnitude 5.9 and is an easy binocular object, though a handful of similarly bright stars may confuse you. To identify the planet, point a telescope at your suspected target. Only Uranus will show a blue-green color on a disk that measures 3.4" across.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

LOCATING**ASTEROIDS**

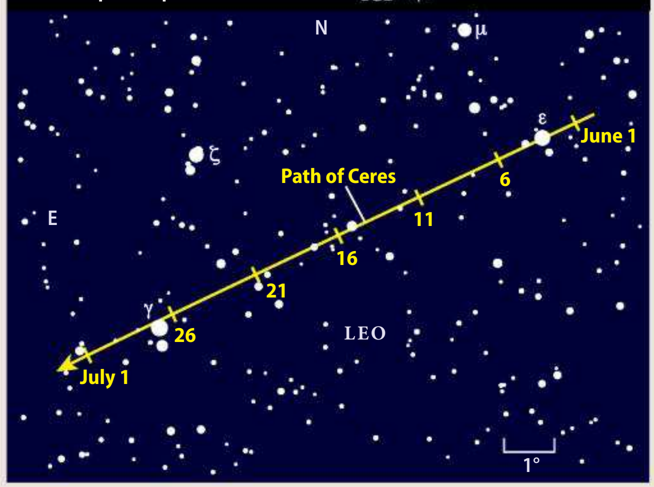
Slicing through Leo's Sickle

If you look to the west as darkness falls this month, you can't help but see brilliant Venus. Above it lurks the familiar shape of Leo the Lion, current home to a much fainter solar system relative, the dwarf planet Ceres.

To find Ceres, first locate Leo's Sickle asterism. (Many people see this shape as a backward question mark.) First-magnitude Regulus marks the bottom of this asterism, but your guide stars to Ceres lie a short distance north in the curved section. Pinpoint 2nd-magnitude Gamma (γ) Leonis, a lovely double star, and 3rd-magnitude Epsilon (ε) Leo, the Sickle's end point, and you're but a short hop from identifying the dwarf planet.

The map below points the way on any night this month, but June 3, 15, and 27 stand out because 9th-magnitude Ceres then passes within 0.1° of prominent background stars. It's near Epsilon on the 3rd, a 6th-magnitude sun on the 15th, and Gamma on the 27th. On each of those evenings, the dwarf planet's motion should be obvious within an hour.

A dwarf planet prowls with the Lion



The largest object between Mars and Jupiter should be easy to find in June as it tracks near several bright stars in the head of Leo the Lion.

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

Astronomy BACKSTAGE PASS CHICAGO

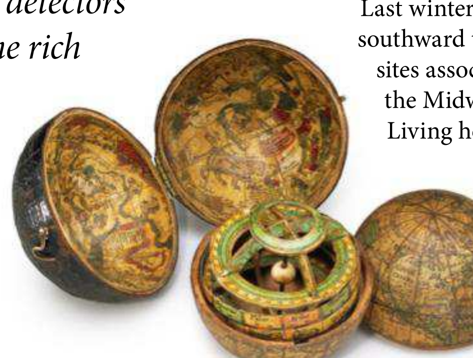
Adler Planetarium sits on the shore of Lake Michigan in Chicago. Some 500,000 people visit it each year.
COURTESY OF ADLER PLANETARIUM

This behind-the-scenes tour of cool astro stuff in the Windy City includes Adler Planetarium's priceless artifacts, incredible meteorites in the Field Museum, neutrino detectors at Fermilab, and the rich history of Yerkes Observatory.

by David J. Eicher

Chicago is a fantastic place on this planet. I live a whisper beyond 100 miles (160 kilometers) from this great city, which sprang up on the American Midwestern plain in the 1830s as a portage between the Great Lakes and the Mississippi River. Now hosting 2.7 million people, it is the third-largest city in the United States, and Chicagoland is home to some 10 million people.

Last winter, *Astronomy* Senior Editor Michael E. Bakich and I traveled southward to Chicago and the surrounding region to explore some famous sites associated with the world of astronomy. Now anyone who lives in the Midwest realizes it's not a great place for astronomical observing. Living here as an observer has taxed my patience for 35 years. But that's not to say that astronomical treasures don't exist in the Windy City.



My comrade Mr. Bakich and I are going to share with you some of the stunning sights we saw at four great institutions: Adler Planetarium, the Field Museum, Fermilab, and Yerkes Observatory.

CHICAGO

ADLER PLANETARIUM

The indoor sky

ADLER PLANETARIUM IS the oldest such institution in the United States, founded by Chicago businessman Max Adler in 1930. Built in the same year Pluto was discovered, Adler is celebrated for its inclusion in the Century of Progress Exposition in Chicago in 1933.

Each year, Adler draws more than half a million visitors who flock to see exhilarating sky shows and enormous numbers of displays and artifacts relating to the history of astronomy, the exploration of the solar system, and the universe at large. Our hosts at Adler were the wonderful Jennifer Howell, Michelle Nichols, Pedro Raposo, and Mike Smail.

We experienced live demonstrations of the sky theaters, including the Grainger Sky Theater, which is the main domed theater; the Definiti Theater, which uses an all-digital system; and the Samuel C. Johnson Family Star Theater, which can be used for 3-D presentations, talks, or seminars. We also explored the famous Atwood Sphere, Chicago's first planetarium, dating from 1913.

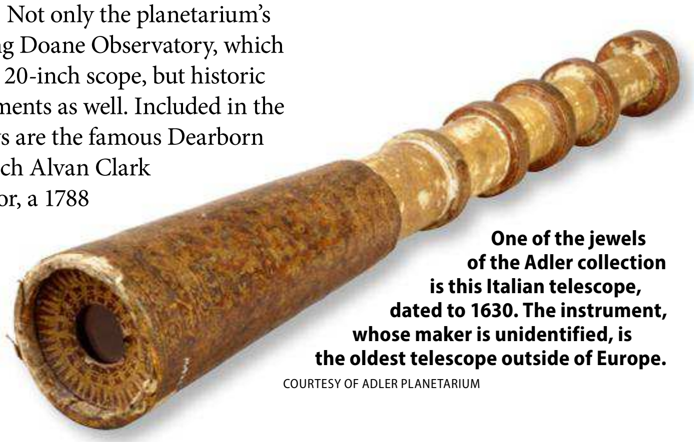
The major artifacts on display at Adler generated some of the greatest excitement for us. We walked through a grand spaceflight gallery centered on Apollo, called Mission Moon, which was made possible by the generous support of Apollo astronaut Jim Lovell. Among the many artifacts was the Gemini 12 capsule used by Lovell and Buzz Aldrin on their historic 1966 flight.

And telescopes — we saw telescopes. Not only the planetarium's working Doane Observatory, which hosts a 20-inch scope, but historic instruments as well. Included in the displays are the famous Dearborn 18.5-inch Alvan Clark refractor, a 1788 telescope made by William Herschel, and many others.

The choicest moments at Adler came when we visited the Collections Department, where we got a true behind-the-scenes tour. Adler's collection of antique instruments and books relating to astronomy is one of the greatest in the world, we knew that. Still, what we saw stunned us.

The treasures included a celestial globe made by Gerardus Mercator, a 1,000-year-old astrolabe from present-day Iran, a German pocket globe from the late 17th century, and a refracting telescope from Italy, made around 1630. Pedro told us the mind-blower on the last one: It is believed to be the oldest existing telescope outside of Europe.

The amazing treats continued when he showed us a collection of rare astronomical books. We saw a beautifully colored edition of Johannes Bayer's 17th-century star atlas, *Uranometria*; Johannes Hevelius' 1679 *Machinae coelestis*; and Peter Apian's 1540 work, *Astronomicum Caesareum*. Then came the two jaw-droppers. The first was a copy of Johannes Kepler's famous *Tabulae Rudolphinae*, in which he laid out the planetary orbits accurately; it was inscribed by Kepler to a fellow mathematician, Benjamin Ursinus! The second amazing treasure was a copy of Johann Bode's 1801 work *Uranographia*. This copy was owned and inscribed by the Herschel family — William, Caroline, and John!



One of the jewels of the Adler collection is this Italian telescope, dated to 1630. The instrument, whose maker is unidentified, is the oldest telescope outside of Europe. COURTESY OF ADLER PLANETARIUM

Three state-of-the-art theaters educate and entertain school groups and the general public throughout the year. COURTESY OF ADLER PLANETARIUM

An exhibition at Adler, called Our Solar System, contains displays of all the planets. Demonstrations and hands-on activities allow visitors to interact with science. COURTESY OF ADLER PLANETARIUM

Adler's Doane Observatory houses a 20-inch reflector that ranks as the largest telescope in Chicago. In addition to offering nighttime viewing, Doane is open between 10 A.M. and 1 P.M. for solar observing, weather permitting. COURTESY OF ADLER PLANETARIUM

The Murchison Meteorite is one of the favorites of the staff at the Field Museum. More than 200 pounds of it fell to Earth on September 28, 1969, in Australia. It's part of a group known as carbonaceous chondrites. Murchison is among the most primitive of meteorites, and it contains complex organic compounds, such as amino acids. DAVID J. EICHER

Jim Holstein is the Field Museum's collections manager of physical geology, and the person in charge of the meteorite collection. Here, he holds a large piece of the Allende Meteorite. Like Murchison, it fell in 1969 (on February 8, in the Mexican state of Chihuahua). Allende is the largest carbonaceous chondrite ever found. DAVID J. EICHER

This cut and polished iron is the first meteorite cataloged in the Field Museum's collection. Designated ME–1, it is also the facility's oldest meteorite. It fell in Elbogen (now known as Loket) in the Czech Republic around 1400. The museum acquired this and 300 other specimens after the World's Columbian Exposition, which took place in Chicago in 1893. DAVID J. EICHER

CHICAGO
THE FIELD MUSEUM

Cool meteorite science

Top: We were backstage at the Field Museum specifically for meteorites. Philipp Heck gave us a great tour of some special meteorites and the equipment he uses to analyze them. In this photo, he demonstrates the museum's Raman Spectroscopy System. MICHAEL E. BAKICH

Left: The Field Museum of Natural History in Chicago is one of the largest such facilities in the world. It opened at its present location on May 2, 1921. COURTESY OF THE FIELD MUSEUM

When you visit the Field Museum, don't leave without spending time in the Grainger Hall of Gems. In this exhibition, you'll see exquisite, rare jewels and gold objects from around the world, as well as never-before-seen creations from top designers. DAVID J. EICHER

WE WERE, OF COURSE, blown away by Adler's incredible historical artifacts. When Michael and I finished, we crossed a short distance to another great institution, the Field Museum.

There we were met by Angelica Lasala and Brianna Peoples, and joined by Philipp Heck, the curator of the museum's meteorites. In the hidden hallways of the Field Museum, up in the research labs and libraries of the second floor, we were treated to a long discussion with Philipp about the meteorite collection — one of the finest around — and the ongoing research happening there. Ever since its commencement in 1893, the collection has grown every year and still receives annual donations from well-placed scientists and collectors.

Philipp showed us a large specimen of the Murchison Meteorite, famous for containing amino acids, some of the compounds necessary for life. He showed us a jar filled with submillimetric diamonds — stardust — extracted from primitive meteorites. He also showed us a beautiful slice of Allende, a wonderful primitive meteorite that fell to Earth in 1969 with large chondrules and calcium-aluminum inclusions. These blobs of material that cooled and solidified in meteorites are older than Earth. Philipp then showed us one of his primary tools used for analyzing meteorites, his Raman spectroscopy setup.

Philipp's colleague Jim Holstein, curator of the meteorite "vault," then took us into the secret depths of the collection. From numerous drawers (the collection holds more than 12,000 pieces), he picked out an impressive array of famous and rare stones from space for us to examine. There were drawers full of Allende! We saw the very first meteorite in the Field collection, a cut (and engraved!) piece of Elbogen, which fell in 1400 in what is now the Czech Republic. We saw an enormous chunk of the Santa Rosa de Viterbo meteorite found in Colombia in 1810. Jim then showed us huge lunar meteorites found in Northwest Africa. What a treat!

We then walked through one of the Field Museum's highlights, the Grainger Hall of Gems. Minerals are the center of planetary geology — they're the way the universe assembles atoms into rocky bodies like Earth. The gallery showed an incredible array of minerals, and we can imagine that many other planets would also have similar mineral specimens. We saw great examples of diamonds, gold, topaz, the tourmaline group, varieties of quartz, rubies, emeralds, and more.

Neutrino physics

THE NEXT DAY, Michael and I made our way to Fermilab in Batavia, Illinois, a suburb west of Chicago. For many years, this U.S. National Accelerator Laboratory has been just that — a series of underground accelerators. But now the huge, sprawling facility, which is like a small city in itself, is transforming into a neutrino detector among its primary functions. The quest for cosmological answers is daily business at Fermilab. Among them: finding out exactly what constitutes dark matter.

Our host, Andre Selles, introduced us to Marcela Carena, head of the Theoretical Physics Group. Marcela, who leads a dynamic group of researchers, generously told us about all the research activities going on at this amazing place. She gave us an overview of particle physics, of the role of Fermilab's discovery of quarks, and of the discovery of the Higgs Boson at CERN. She described in detail the current major role of neutrino detection.

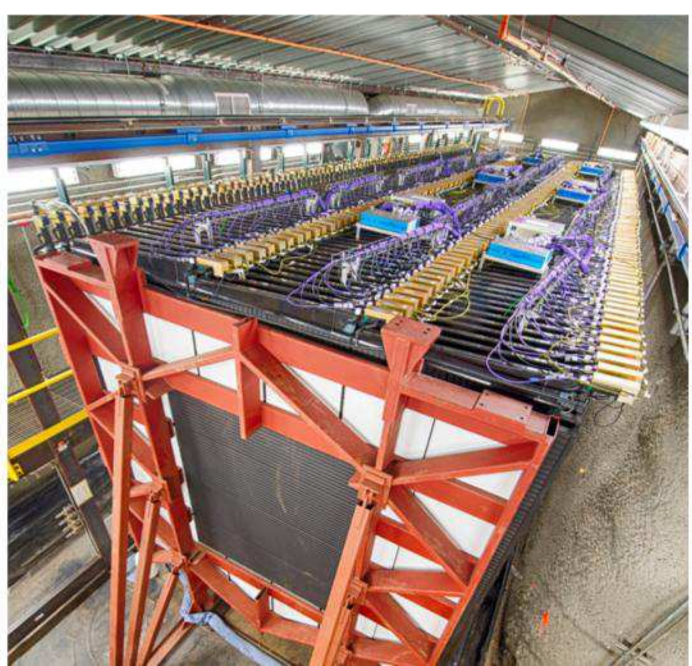
Senior Operator Beau Harrison then gave us an insider's tour of the heart of Fermilab operations, the master control room. Our Fermilab visit was crowned by a great discussion with Dan Hooper, a well-known expert on dark matter who gave us a solid overview of the challenges that researchers face in identifying what dark matter consists of, and how his research is tackling the issue.

Fermilab's main particle accelerator, known as the Tevatron, is the large ring in the background. In front of it are the main injector rings. In 1995, researchers using the Tevatron discovered the top quark. The accelerator has been inactive since 2011. COURTESY OF FERMILAB

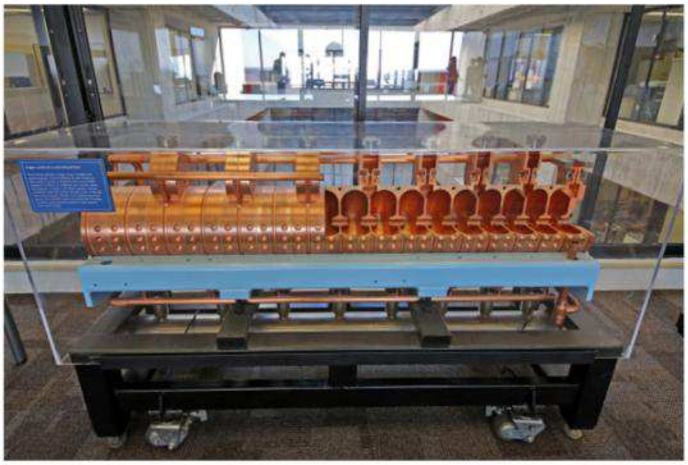
Left: Marcela Carena, head of the Theoretical Physics Group and a professor at the University of Chicago, was one of our hosts at Fermilab. She gave us a tour of the facility and told us about the exciting physics happening there. MICHAEL E. BAKICH

Below: This is the 300-ton (near) particle detector for NOvA, the experiment in which Fermilab sends neutrinos to a 14,000-ton detector in northern Minnesota. The near detector sits 350 feet underground and measures the composition of the neutrino beam as it leaves Fermilab. COURTESY OF FERMILAB

Employees gather around readouts in 2015 on the day the MicroBooNE Experiment — a 170-ton liquid-argon time projection chamber — recorded its first particle tracks. "BooNE" is an acronym for Booster Neutrino Experiment. COURTESY OF FERMILAB



Robert Rathbun Wilson Hall is the main building of the Fermi National Accelerator Laboratory, founded in 1967. COURTESY OF FERMILAB



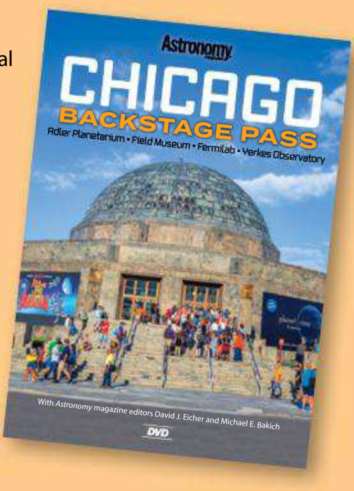
This copper cavity accelerates particles to high energy. A beam of particles enters and travels in sync with an 805-megahertz wave, gaining speed and energy. Fermilab has 30 strings of such cavities that can accelerate protons to three-quarters the speed of light. MICHAEL E. BAKICH

YOUR OWN PRIVATE TOUR

Obviously, we cannot hope to cover institutions like Adler Planetarium, the Field Museum, Fermilab, and Yerkes Observatory in depth by dedicating a scant two pages to each site. However, we do have a way for you to experience them at length — and in the comfort of your own home.

Astronomy Backstage Pass: Chicago is a three-hour informal account of our visit to these wonderful astronomy facilities in the Chicago area. Along the way, you'll meet scientists, lecturers, and curators; you'll see equipment, books, and artifacts that are not on public display; and not only will you learn about the past of these historic institutions, but what their futures hold as well.

To purchase a copy, visit **www.myscienceshop.com.**



The world's largest glass

AFTER A FULL MORNING experiencing Fermilab, we headed north, back into Wisconsin, winding our way through country highways. A 90-minute drive brought us to the town of Williams Bay on picturesque Lake Geneva, home of one of the great historic astronomy research centers in the United States: Yerkes Observatory.

There, we met with Dan Koehler, the observatory's director of tours and special programs. He gave us an incredible behind-the-scenes tour. We started with the famous 40-inch Alvan Clark refractor, the largest refracting telescope ever built, and we discussed at length the role of Yerkes, which commenced in 1897.

The observatory's founder, George Ellery Hale, went on to California to create Mount Wilson Observatory, and he became the driving force behind the Palomar 200-inch scope. So in a sense, much of the era of American astrophysics originated at Yerkes. It was certainly a thrill to stand on the floor of the big dome, right where Albert Einstein famously posed with the Yerkes staff back in 1921. We also got a great insider look at the observatory's 24-inch reflector.

Treasures awaited us inside the observatory's hallowed hallways, too. Dan showed us the office used by the legendary Subrahmanyan Chandrasekhar, the Nobel Prize-winning physicist who spent much of his career at the University of Chicago and at Yerkes. Additionally, Wayne "Ozzie" Osborn gave us an extensive tour of Yerkes' glass photographic plates.

From the collection of 180,000 plates, Ozzie showed us images from the 40-inch refractor, cometary plates, tiny spectra used to measure stellar motions, an eclipse photograph that proved Einstein's general theory of relativity, and records of photographs taken and kept by Edward Emerson Barnard and many others. Ozzie also showed us amazing artifacts. We saw the lunar sphere used by Gerard Kuiper to project craters so that astronauts could train for lunar landings. We saw a rare blink comparator from 1905, like the one used to discover Pluto and Barnard's Star. And we saw the spectrograph used on the 40-inch scope by William W. Morgan to classify stars, as well as the filar micrometer used in the early history of Yerkes to make precise double star measurements.

Share our experience

Our trip to Chicago was unlike any we had taken before. Visiting some of the region's brilliant astronomers and seeing hidden artifacts and some of the great instruments and displays of astronomy in the Midwest, we were spellbound.

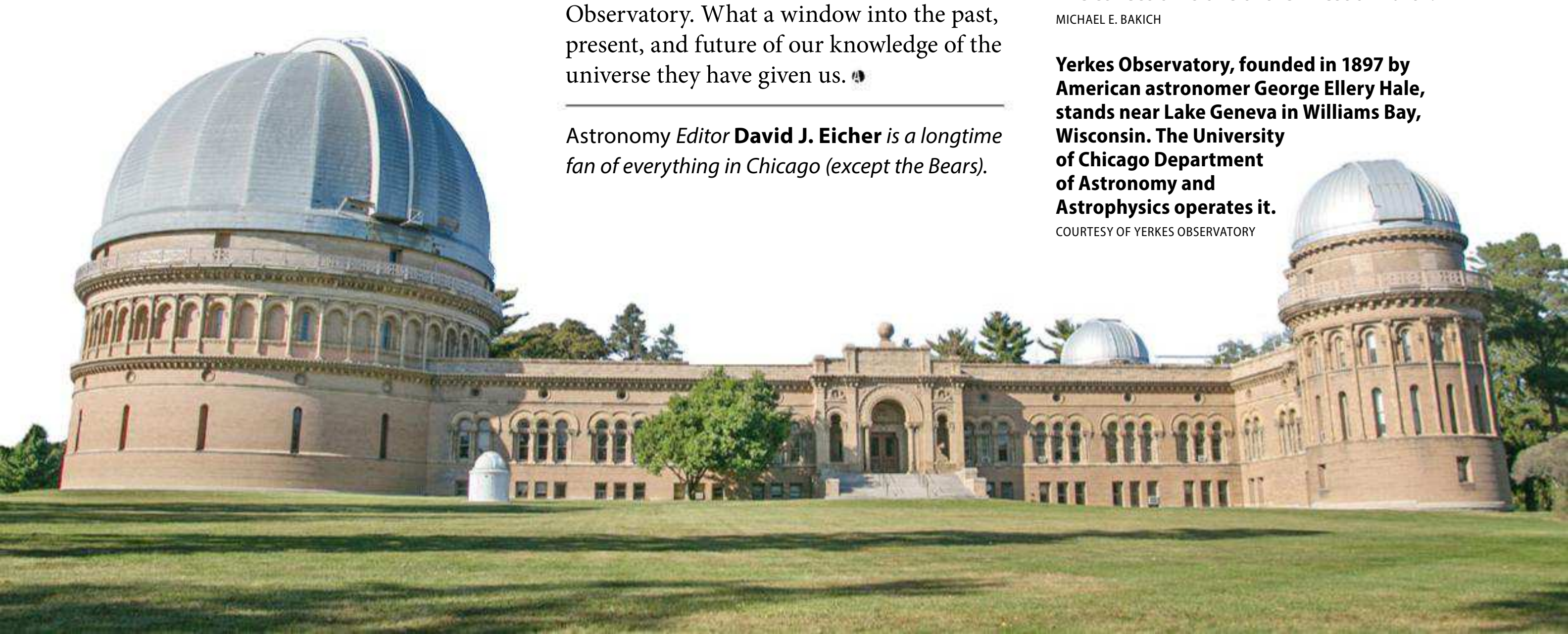
Michael and I took turns filming this whole experience, and we captured three hours of amazing footage that provide a "backstage pass" to astronomy and space science in and around Chicago. In fact, we have created a DVD that contains the entire experience, showing all that I have described in this story and much more. (See "Your own private tour" on p. 49 for information on how to get your own copy.)

Our hats are off to the accommodating staffs of Adler Planetarium, the Field Museum, Fermilab, and Yerkes Observatory. What a window into the past, present, and future of our knowledge of the universe they have given us.

Astronomy *Editor* **David J. Eicher** *is a longtime fan of everything in Chicago (except the Bears).*

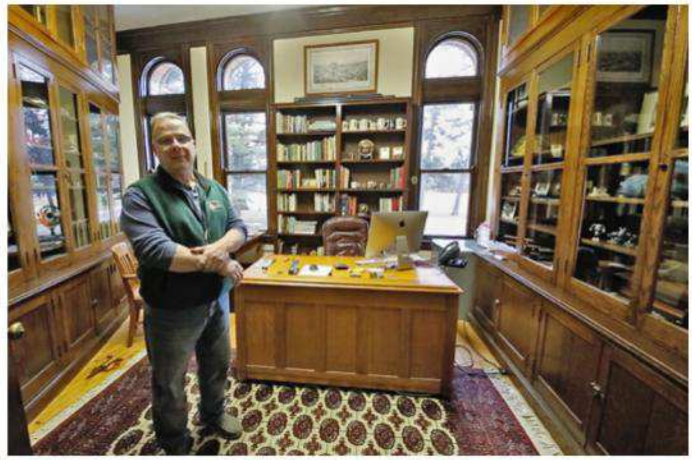
***Astronomy* Senior Editor Michael E. Bakich stands near the 40-inch refractor at Yerkes Observatory. As this image was being shot, he was riding the motorized floor in the observatory. The floor weighs 38 tons and is rated for 26 passengers.** DAVID J. EICHER

The plate vault at Yerkes contains the photographs taken on glass plates since the 40-inch telescope began operating in 1897. The collection is one of the finest on Earth. MICHAEL E. BAKICH



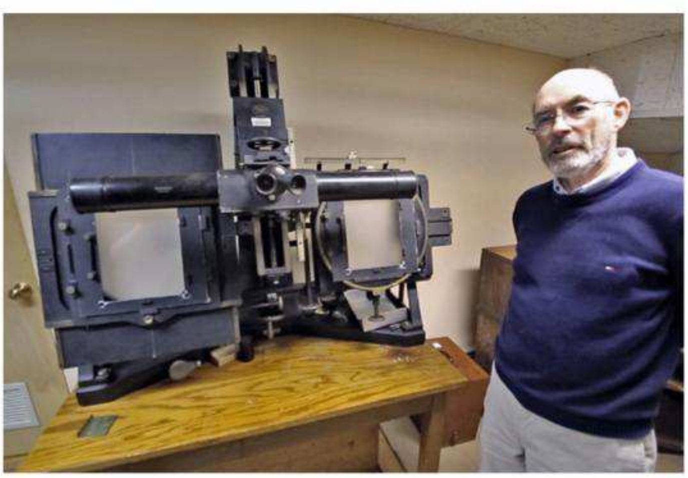
Yerkes Observatory, founded in 1897 by American astronomer George Ellery Hale, stands near Lake Geneva in Williams Bay, Wisconsin. The University of Chicago Department of Astronomy and Astrophysics operates it. COURTESY OF YERKES OBSERVATORY

Dan Koehler (left), director of tours and special programs at Yerkes, chats with the author about the history of the facility. In the background looms the famous 40-inch refractor — the world's largest lens-type telescope. The telescope weighs 82 tons with a tube 64 feet long (19.5 meters). The entire assembly rises above the basement level by 65 feet (19.8 m). MICHAEL E. BAKICH



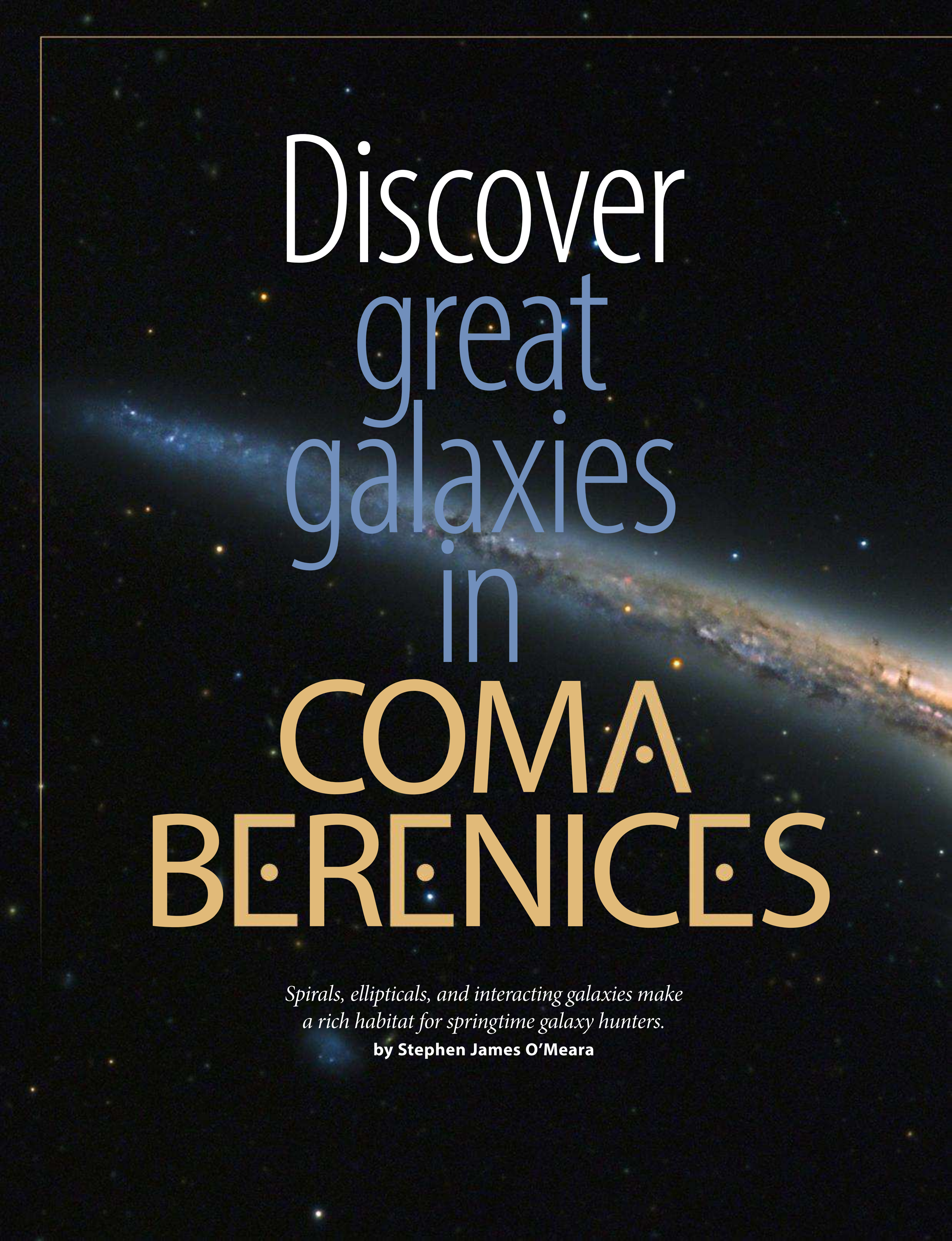
Among the many historical settings at Yerkes is the office of Subrahmanyan Chandrasekhar, who began working at the University of Chicago in 1937. It is currently occupied by Jim Gee, the observatory's director of operations. DAVID J. EICHER

Astronomer Wayne Osborn explains some of the records of observations made by American astronomer Edward Emerson Barnard during the time he spent at Yerkes Observatory. MICHAEL E. BAKICH



This blink comparator dates to 1905. Astronomers at Yerkes used it to discover high proper motion stars, variable stars, and other changing celestial phenomena. DAVID J. EICHER

Another of the telescopes at Yerkes with a high usage curve is the 24-inch reflector. Groups use it, as well as the 40-inch refractor, most clear nights of the year. COURTESY OF YERKES OBSERVATORY



Discover great galaxies in COMA BERENICES

Spirals, ellipticals, and interacting galaxies make a rich habitat for springtime galaxy hunters.

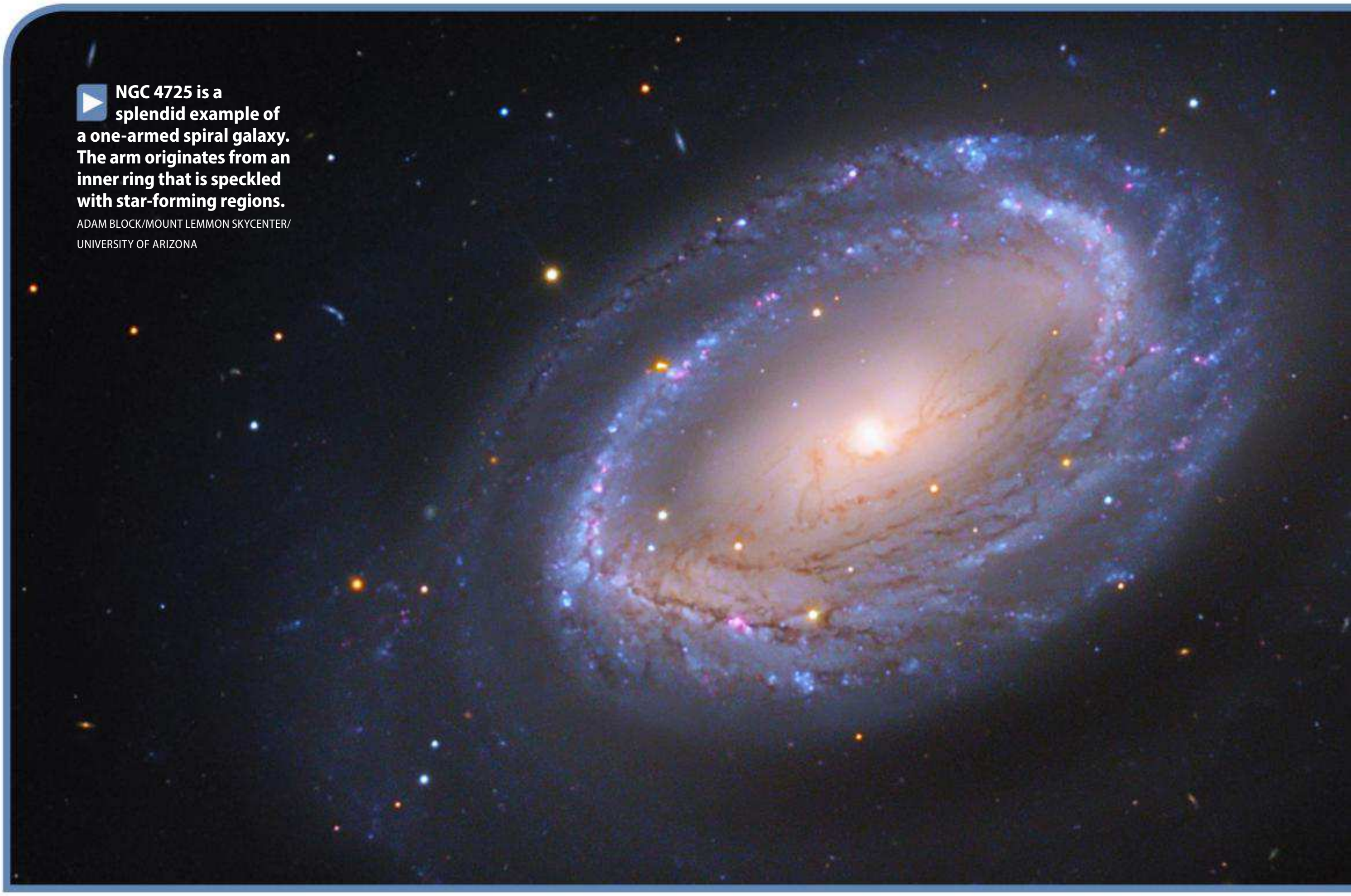
by Stephen James O'Meara

Coma Berenices (Berenice's Hair), that delicate web of starlight tickling Leo the Lion's tail, harbors a fleet of galaxies strewn with deep-sky objects. There are too many to detail here, but I've combed through the celestial hair and picked out a choice selection of intriguing objects that can please observers using everything from the unaided eye to monster Dobsonians. And for diversity, I will focus our attention on some deep-sky objects off the well-trodden path of backyard searches, steering away from the brighter Messier objects (M53, M64, M85, and M100), as well as the wild scattering of galaxies that Coma contributes to the extension of Markarian's Chain in the Virgo Cluster of galaxies.

Let's start our tour with one of the most overlooked deep-sky objects in the heavens: open cluster **Melotte 111**. At a distance of 288 light-years, it ranks as the third-closest star cluster to the Sun — only the Ursa Major moving group and the Hyades are closer — as well as one of the largest. Its 270 members form a loose aggregation that stretches nearly 5° across the sky. You'll find the brightest members huddled around a wishbone-shaped star pattern in the Hair's crown formed by Gamma (γ, a foreground star), and cluster members 12, 13, 14, 16, and 17 Com. Sweeping this region with binoculars fractures Melotte 111 into tiny patterns that seem to float in the darkness like letters in alphabet soup.

We can now use the stars of the wishbone as stepping-stones to other celestial wonders. Start by centering Gamma Com in your telescope. This orange giant star, 170 light-years distant, shares the field with 11th-magnitude **NGC 4448**, about 30' to the northeast. Look for a dim, 3'-long spindle of light (oriented east to west) with a noticeable core. A 1½° slide west of Gamma takes you to the 6.5-magnitude stars 9 and 10 Com; center 9 Com in your

NGC 4565 is one of the best edge-on galaxies in the sky, easily visible through moderate-sized telescopes. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



NGC 4725 is a splendid example of a one-armed spiral galaxy. The arm originates from an inner ring that is speckled with star-forming regions. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The faint globular cluster NGC 5053 (lower left) lies near the far brighter M53, making the challenging cluster relatively easy to find under dark skies. BERNHARD HUBL

telescope and look about 20' west for 11th-magnitude **NGC 4251** — a 3'-long barred lenticular galaxy with a conspicuous bulge and tapered disk. With sufficient imagination, it looks like a tiny UFO.

Swing over to 10 Com and move 1¾° north, where you'll find a pretty pair of elliptical galaxies: 10th-magnitude **NGC 4278** and 12th-magnitude **NGC 4283** less than 5' to its northeast. Both objects are compact targets (3.5' and 1' long, respectively) for small apertures. Adding to this scene is a 1°-long pompadour of three additional galaxies immediately to the north: **NGC 4314**, **NGC 4274**, and **NGC 4245** (from northeast to southwest, respectively).

NGC 4274 is a delightful magnitude 10.4 ringed spiral resembling the uniform head of a distant comet (nearly 7' wide) with a bright nucleus. NGC 4245 rivals it in brightness, but appears half its size. This marvelous barred spiral has a faint circular halo and a bright inner ring. NGC 4314 is a magnitude 11.5 barred spiral and one of the closest examples (40 million light-years away) of a galaxy with a star-forming ring of infant stars close to the galaxy's core.

We'll leave the crown after looking for **NGC 4203**. This beautiful 11th-magnitude lenticular galaxy lies only 20' northwest of a magnitude 5.5 star, which hugs the constellation's far northern boundary about 3½° north of NGC 4274. Although small (3.5' long), NGC 4203 is round and uniform, and its soft light and bright core is reminiscent of a young planetary nebula just beginning to shine.

Combing the eastern locks

Center Gamma once again in your telescope. Now make a generous 2° sweep east-southeast to find **NGC 4559**. This easily overlooked 10th-magnitude object, which is brighter than some Messier galaxies,

▲ The bright spiral galaxy NGC 4559 appears like a spinning saw blade hovering in the sky. JEFF HAPEMAN/ADAM BLOCK/NOAO/AURA/NSF

◀ The bright double star 24 Comae Berenices consists of an incredible color contrast: The golden primary star shines beside a slightly fainter sea-green companion. The artist sketched this pair with a 6-inch f/8 reflector at 240x. JEREMY PEREZ

is a remarkable example of a spiral system. In images, it looks like a spinning saw blade whisking toward the observer at a skewed angle. From Hawaii, I have spied it with 7x50 binoculars. The 10'-long oval glow displays a fuzzy core (with a starlike nucleus), from which feathery extensions give way to a strong spiral arm to the northwest and a weaker one to the southeast. Larger scopes may be able to make out its prominent star-forming regions and dust lanes.

Return to the wishbone and seek out the magnitude 6.5 star **17 Comae Berenices**, a strikingly wide double star marking the wishbone's southeastern tip. Only ½° to its southeast you'll find another remarkable 10th-magnitude galaxy: **NGC 4494**, a highly condensed elliptical system appearing as a 2'-wide cometlike glow with a diffuse core and bright central condensation. We are now within striking distance of the gem in Berenice's Hair.

NGC 4565 — the most popular edge-on spiral galaxy in the night sky — lies but 1° east-northeast of NGC 4494. While the galaxy shines conspicuously at magnitude 9.5, it is wafer thin, spanning 16' in length, but only 2.5' in width. Years ago, I watched in awe as the galaxy drifted from tip to tip through a 16-inch Boller & Chivens Cassegrain telescope at Oak Ridge Station in Harvard, Massachusetts. Of that experience, I wrote: "Suddenly the sharp tip of a blade of light entered the field from the upper left. Deeper and deeper it cut into the field of view, until the galaxy's robust hub and girdle of darkness all but shattered the visual serenity that had preceded its appearance. I continued to slew the telescope, but the galaxy did not end — not until its leading edge began to exit the opposite edge of the field of view."

While some observers tend to stop at NGC 4565 and go no further, do push on, because 3° to the east-southeast you'll find one of the constellation's hidden treasures: magnitude 9.5 **NGC 4725**. This supergiant spiral has only one arm, which originates from a youthful inner ring rife with young blue stars and red star-forming regions; that ring is, in fact, the most complete spiral ring of any galaxy known. The single

The most popular edge-on galaxy in the sky, NGC 4565 is wafer thin, spanning 16' in length, but only 2.5' in width.

arm is also warped from a tidal interaction with 12th-magnitude **NGC 4747**, roughly 30' to its northeast. In images, NGC 4747 displays three tidal tails, all of which have resulted from the gravitational encounter with its superior neighbor.

Let's now run our visual comb 4° south-southeast to **35 Comae Berenices** — an understated triple star whose primary components are a great resolution test for a 4-inch telescope. The closest pairing consists of a 5th-magnitude pale yellow primary and a colorless magnitude 7.5 secondary 1" to its southeast. The third component is a 9th-magnitude blue gem 29" farther to the southeast. (A 1° swing will bring you to the famous Black Eye Galaxy, M64. Can you see the pale blue hue of the galaxy's disk appearing like milk residue on a glass?)

The Umbrella Galaxy displays a crescent-shaped structure extending laterally from an enormous jet that seems to emanate from the galaxy's heart.

Hair extensions

If we extend the eastern tress 5° farther to the southeast from 35 Com, we arrive at the constellation's Alpha [α] star, Diadem, and the magnificent globular star cluster **M53** just 1° to its east-northeast. This glorious cluster belongs to the Sagittarius tidal stream — the tidal tail of the Sagittarius dwarf spheroidal galaxy, of which globular star cluster M54 in Sagittarius is the nucleus. But the elusive object in this region is the 10th-magnitude ghost globular **NGC 5053**, which looms like an ashen spirit about 1° southeast of M53. It's a challenging object for city observers and small telescopes, because the dim light is almost uniformly spread across nearly 11' of sky with little central concentration. Even its brightest stars evade the casual gaze, as they shine around 14th magnitude. Nevertheless, this phantom wears several superlatives, including being the most metal-poor and least concentrated globular cluster known.

Let's move over now to the constellation's middle tress. A lovely sight in itself, the gentle southward flow of stars follows Gamma, 14, 16, 17, 21, 23, and 26 Com before a kink extends it southwestward to **24 Comae Berenices**. Stop here, because 24 Com is the binary gem of the constellation. Any size telescope at any power will show the amazing color contrast. I see a golden 5th-magnitude primary with a sea green magnitude 6.5 companion 20" to the west; others see the pair as yellow and blue. The stars are strikingly reminiscent of Albireo in Cygnus the Swan. What usually goes unnoticed in this scene is the challenging 3'-long spindle of the near edge-on 12th-magnitude barred spiral galaxy **NGC 4539**, which lies only 15' southwest of 24 Com.

Another kink carries the tress 3° southeast of 24 Com to 5th-magnitude 27 Com. Center that star and look about 45' to the west-southwest for the 11th-magnitude NGC 4651, the amazing

The Umbrella Galaxy (NGC 4651) is visible through small telescopes. Medium-sized instruments show the galaxy's faint tidal tail, which is the result of an encounter with a small interloping galaxy. R. JAY GABANY

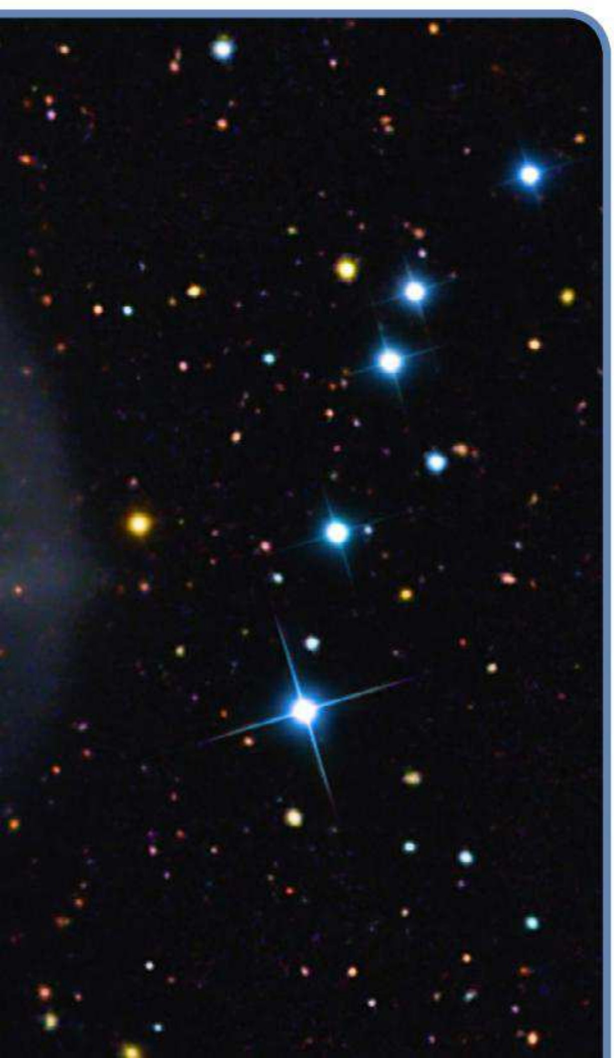
Umbrella Galaxy. While visible in even a 4-inch telescope, this object should excite CCD imagers because it displays a crescent-shaped structure extending laterally from an enormous jet that seems to emanate from the galaxy's heart; we now know it to be a tidal tail that formed when NGC 4651 ripped apart a smaller companion during a series of repeated encounters.

Let's now follow the western lock of Berenice's Hair southwest — from 12 to 7 Com, and then about 3¾° farther to the southwest. Here we arrive at a splendid (though often overlooked) double star, **2 Comae Berenices**. The 6th-magnitude primary has a magnitude 7.5 secondary 3.6" to the southwest. In the 19th century, Admiral William Henry Smyth called it a "beautiful object … two jewels fixed in the field," with a "pearly white" primary and a "lilac" secondary; the lilac being a common color contrast phenomenon.

The Coma Cluster of Galaxies (Abell 1656) lies some 300 million light-years away and contains more than 650 galaxies. The cluster's center is dominated by two bright ellipticals, NGC 4889 and NGC 4874, visible as the oval smudges in the middle of this image. BERNHARD HUBL

Extragalactic pandemonium

We end our journey by returning to the wishbone and looking about 10° east for a bright pairing of stars: 4th-magnitude Beta (β) and 5th-magnitude 41 Com, which itself is a naked-eye double. Center 41 Com in your telescope, move about 1½° west-northwest, and let your gaze relax — you have arrived at the heart of the **Coma Cluster of Galaxies** (Abell 1656). As it is close to the north pole of the Milky Way, its members are not dimmed by intervening dust.



A veritable blizzard, the cluster contains more than 650 galaxies, making it one of the densest collections in the universe. The members spread across 1½° of sky. In the grander scheme, the Coma Cluster is a vast jungle of galaxies, with some 30,000 of them down to magnitude 19 lying within 6° of the cluster's core. Despite its great distance (300 million light-years), about a dozen of its members are within reach of a 4-inch telescope.

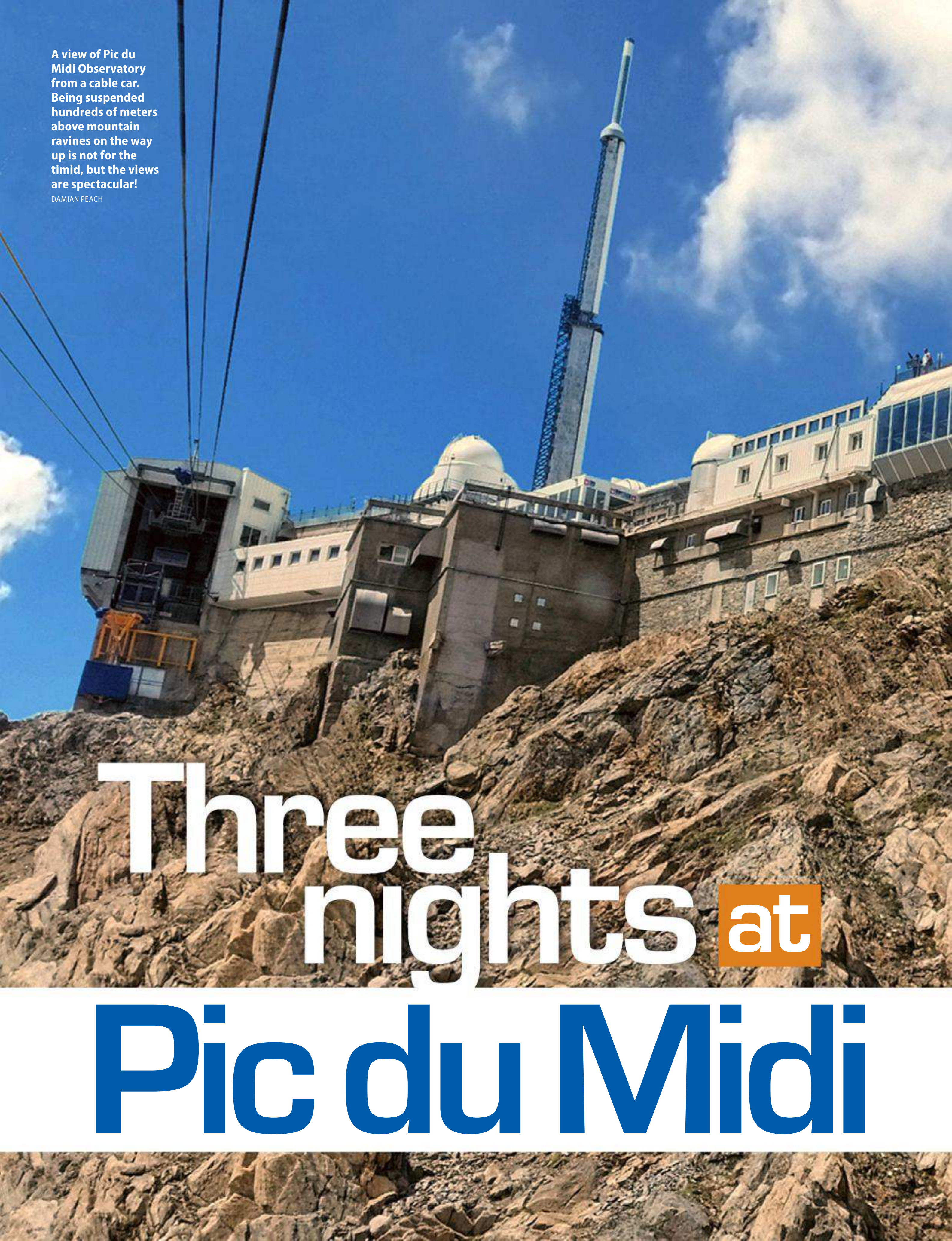
The two brightest — **NGC 4889** and **NGC 4874** — are both 11th-magnitude giant ellipticals. NGC 4889 appears as a small, faint, slightly out-of-round glow with a smooth outer halo that gradually brightens to a sharp core. NGC 4874 is merely a swollen spot of haze. Once, without knowing it, I sketched two 13th-magnitude companion galaxies to NGC 4889 — **NGC 4886** and **NGC 4898** — believing at first that they were details belonging to NGC 4889. Unlike the Virgo Cluster, which is rich in spirals, the Coma Cluster is rich in ellipticals.

As you survey the region for fainter members, also keep in mind that astronomers have recently discovered within this cluster more than 800 galaxies that could contain as much as 100 times more dark matter than visible matter. These are "failed" galaxies, which stopped producing stars between 7 billion and 10 billion years ago.

When probing this extragalactic graveyard, you can also use your imagination to sense the 47 ghost galaxies discovered in 2015 by Dragonfly — an array in New Mexico composed of eight Canon telephoto lenses. These "ultra-diffuse" galaxies are as large as our Milky Way but contain only about one-thousandth as many stars, making them appear as large spheroidal phantoms.

In the Coma Cluster, astronomers have recently discovered more than 800 galaxies that could contain as much as 100 times more dark matter than visible matter.

Stephen James O'Meara *is a contributing editor of* Astronomy *and author of numerous popular books on astronomical observing.*



A view of Pic du Midi Observatory from a cable car. Being suspended hundreds of meters above mountain ravines on the way up is not for the timid, but the views are spectacular! DAMIAN PEACH

Three nights at Pic du Midi

Perched more than 9,400 feet above sea level, this French observatory offers some of the finest viewing on Earth. **by Damian Peach**

THE OPPORTUNITY to use a large professional telescope at a historic and renowned observatory is the dream of most amateur astronomers, beginner or advanced. Most of the time, we have to battle against weather and the limits of our equipment to obtain good results. But we wonder what a larger telescope would reveal. This well-known affliction, called aperture fever, runs rampant within the astronomical community.

The observing team stands alongside the dome of the 1.06-meter telescope. From left are Ricardo Hueso, Damian Peach, Marc Delcroix, Gérard Therin, Constantin Sprianu, Emil Kraaikamp, and François Colas. DAMIAN PEACH

The telescope is operated from the laboratory directly below the dome, but the initial setup of locating the target object and installing the camera has to be done in the dome itself.

Such an opportunity arose in the summer of 2017, when I joined a small group of advanced planetary observers at Pic du Midi Observatory. The memorable few days we spent there led to some remarkable images.

The group was made up of two professional astronomers: François Colas, who works at Pic du Midi and has, for more than 25 years, imaged with the telescope we would be using; and Ricardo Hueso, a planetary scientist with the Escuela de Ingeniería de Bilbao. Besides me, the amateur astronomers in our group were Marc Delcroix, an advanced planetary observer with the French Astronomical Society; Emil Kraaikamp, the creator of the Autostakkert software used for planetary image processing; Gérard Therin, a pioneer in amateur high-resolution astrophotography; and Constantin Sprianu, a planetary observer from Romania.

A rich history

There's no doubt you've heard of Pic du Midi Observatory, perched 9,440 feet (2,877 meters) above sea level atop Pic du Midi de Bigorre in the French Pyrenees. The observatory, about 90 miles (150 kilometers) southwest of Toulouse, has been a world-renowned site for astronomical observations for more than a century.

Construction of the observatory began in 1878, and telescopes rapidly appeared on the mountaintop thereafter. The remains of these original buildings are still on-site. One can only wonder how difficult it must have been to build an observatory where heavy snowfall and freezing temperatures can occur at almost any time of the year.

Pic du Midi is especially well known for its history of planetary observations. In the early 20th century, observations of Mars made there helped discredit the infamous theory of martian canals. Many famous astronomers have observed at Pic du Midi, including Bernard Lyot of France. In fact, the largest telescope at the observatory, a 2-meter reflector, is named in his honor.

Perhaps the most famous telescope at Pic du Midi is the one we used for our observations: the 1.06m f/17 Cassegrain reflector in the Gentilli dome. This telescope was built in the pre-Apollo era (1963) and funded by NASA primarily to capture detailed images of the lunar surface for mission planning. After the telescope saw first light, astronomers found the optics to be of only average quality, so French master optician Jean Texereau, a well-known figure to amateur telescope-makers, refigured them.

From the 1960s through the 1990s, the telescope was mainly used for planetary photography. Many of the finest photographic film images of the planets were taken with it. Recently, researchers have used the telescope only sporadically for planetary observations, and this fact led to the realization of this observing mission.

The team arrives

In 2016, Colas, the lead astronomer of the 1.06m telescope, spoke with a few French amateurs who had regularly visited the observatory over the past several years. He

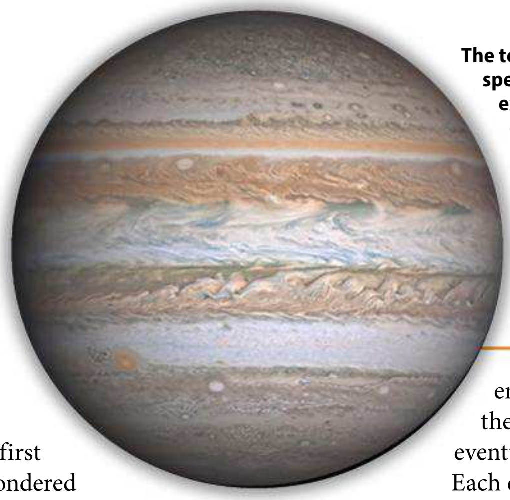
decided to form a small, dedicated team of experienced planetary observers — of whom I was one — who would use the telescope more regularly for planetary studies.

Thanks to funding from Europlanet, the team decided suitable dates for the prototype mission. We chose June 2017 because Saturn would be close to opposition, Jupiter would be well placed in the early evening, and Uranus, Neptune, and Venus would also be visible toward dawn.

The group met at Toulouse Airport. We then packed into two cars for a three-hour drive to the small town of La Mongie. The journey through this region was spectacular, passing through mountainous scenery and small country villages. As we reached La Mongie, we broke through a sheet of low clouds into blazing sunlight. From here, we transported several boxes of food and drink for the stay.

The cable car journey from La Mongie to Pic du Midi is not for those with a fear of heights! On the slow ascent up the mountain face, we were often suspended high above mountainous ravines. The view was spectacular, though, with low clouds below and jagged mountain peaks as far as the eye can see.

Eventually we reached the first cable car station, where we disembarked and moved to a second cable car for the final ascent to the summit. At this point, we could clearly see the observatory perched atop the mountain. When it first came into view, I wondered how an observatory could be built at such a site.



The team obtained this spectacular 13-minute exposure of Jupiter on June 11, 2017, at 21h57m24s UT. The planet reveals a wealth of fine detail within its atmosphere. D. PEACH/E. KRAAIKAMP/F. COLAS/M. DELCROIX/R. HUESO/C. SPRIANU/G. THERIN

Upon arriving, we took all of our equipment and supplies to the laboratory. Our team stayed at the astronomers' lodgings, which consist of several small rooms with beds and wash facilities in a quiet area several meters below the telescope domes. We took some time to prepare for the first night's observations, which would begin at sunset.

The 1.06m telescope, or T1M as it's known, isn't at all like your typical large amateur scope. Because it was built in the '60s, many of its control systems take time to learn. So we spent some of that first evening prior to sunset learning how to operate the telescope, which was a key part of our mission. The telescope is operated from the laboratory directly below the dome, but the initial setup of locating the target object and installing the camera has to be done in the dome itself. Locating the target proved quite challenging, mainly because it involved climbing a tall ladder to reach the finder scope's eyepiece. Colas' many years of using the telescope were invaluable here.

Jupiter imaging

After a delicious evening meal prepared by Colas, we walked across to the western side of the observatory to watch the sunset, always a spectacular sight at this amazing location. Then we quickly walked back to T1M, where we would spend the next three nights.

From the wide range of cameras and filters to choose from, we ended up using a ZWO ASI174MM monochrome CMOS camera for most captures, but we also used the ASI224MC (color) and ASI290MM (monochrome) cameras. We made sure to bring large amounts of memory storage for what we hoped would be a productive few days. As it turned out, we had just enough space for all the data we would eventually capture.

Each evening began with Jupiter. Although well past opposition, the planet was situated high in the southwest, and we spent the first couple of hours imaging it. The first night, we dealt with quite a few thick, high cirrus clouds, but we were able to obtain good images. The second and third evenings, however, produced far better conditions that resulted in some extremely detailed images.

Although we obtained images through various filters on all the cameras, the best results were in the near-infrared wavelengths, where the resolution was remarkable. During the three nights, we covered most longitudes of the planet and obtained high-resolution images that would later allow us to measure wind speeds in Jupiter's atmosphere.

Through the night

Once we finished with Jupiter, we moved on to Saturn. This meant heading back up to the dome to move the telescope, recalibrate the dispersion corrector, and take a few peeks through the eyepiece.

Saturn was only a few days from opposition during our mission. The ring system

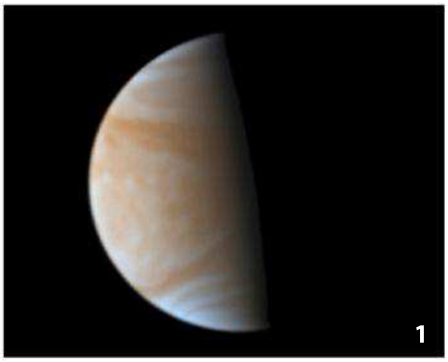
Ganymede, Jupiter's largest moon, was in the team's crosshairs on the second evening. Even though the satellite's diameter spanned a scant 1.42", this image shows many clearly identifiable features. The team shot through infrared and RGB filters June 10, 2017, at 21h42m UT. E. KRAAIKAMP/D. PEACH/M. DELCROIX/G. THERIN/C. SPRIANU/R. HUESO/F. COLAS

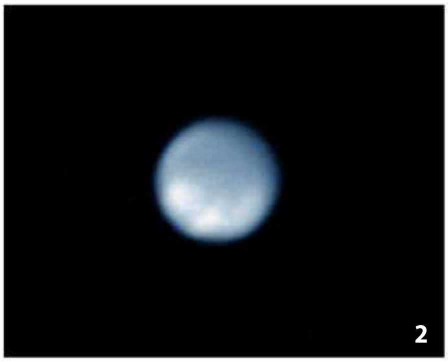
The author stands with the 1.06m f/17 Cassegrain telescope used for the team's planetary observations.
DAMIAN PEACH

1. The team imaged Venus through infrared and ultraviolet filters June 11, 2017. They captured the exposures to create this image between 4h36m and 4h51m UT. D. PEACH/E. KRAAIKAMP/F. COLAS/M. DELCROIX/R. HUESO/C. SPRIANU

2. Neptune appeared full of features on the second and third mornings. Note the bright storms visible on the planet, the first discovered for this apparition. The team captured this image June 12, 2017, at 2h39m36s UT. D. PEACH/E. KRAAIKAMP/F. COLAS/M. DELCROIX/R. HUESO/C. SPRIANU/G. THERIN

3. This image of Saturn was captured June 11, 2017, at 1h22m54s UT, under excellent seeing conditions. Many rarely seen details, such as the fine ringlets within the planet's C ring, are visible. D. PEACH/E. KRAAIKAMP/F. COLAS/M. DELCROIX/R. HUESO/C. SPRIANU/G. THERIN





was also close to its maximum possible tilt toward Earth. We feared the planet's low altitude in the sky might limit our results. In the end, the sessions imaging Saturn into the early morning hours were perhaps the highlight of our nights' work.

While Saturn never rose above 25°, the exceptional conditions that can prevail at Pic du Midi were in full effect. The second night produced seeing conditions of exceptional quality. Never have I observed a planet so still at such low altitude. Even when Saturn dropped to just 18°, the image remained razor sharp and still — a remarkable thing to witness, especially when you consider we were using 42 inches of aperture.

Even when Saturn had dropped to just 18°, the image remained razor sharp and still — a remarkable thing to witness, especially when you consider we were using 42 inches of aperture.

While imaging the ringed planet, we could see minor details such as the Encke Division, a 200-mile-wide gap within Saturn's A ring. But after we processed our images, we realized we had gotten some really exceptional data, perhaps resulting in the sharpest ground-based image of the planet ever taken.

Dawn approaches

Once our Saturn observations were complete in early morning, just before twilight began, we shifted our attention to Neptune. One of the mission's objectives was to capture images of the planet early in its apparition, as it was still quite low in the dawn sky. It marked a great opportunity to be the first to detect recent activity on the planet (since it emerged from the Sun's glare), and we got lucky on both mornings.

We swapped cameras to use the highly infrared-sensitive ASI290MM camera, which works great for imaging the distant ice giants. We took several runs in near-infrared wavelengths, and on both mornings, we saw strikingly bright storms on the planet. This made our team the first to detect new features during the first part of the planet's apparition. We also obtained one early image of Uranus, but we could not detect anything on the planet aside from the familiar bright polar region.

As the sky brightened with the approaching dawn, we moved on to Venus, blazing away brilliantly in the east. By this time, those of us remaining were feeling pretty tired, but it was worth the effort. We took some fine images of the planet, especially through ultraviolet filters, clearly revealing its familiar cloud patterns. Observations continued beyond sunrise, until we finally closed up and powered down about an hour later.

Mission accomplished

Having completed the processing for all the data, our team views the mission as a resounding success. We were indeed fortunate with the weather conditions, but the commitment of each member to maximize every available moment really helped to deliver the results you see here.

On a personal note, Pic du Midi Observatory is a remarkable place to observe from, not only for the superb astronomical conditions, but also the spectacular natural scenery visible in every direction. We never got tired of the breathtaking views, especially during dawn and dusk when the lighting and colors were spectacular.

The continuation of a long tradition of planetary imaging from this historic observatory looks assured. As I thought back to the results of astronomers such as Lyot, Audouin Dollfus, and Henri Camichel, I certainly felt a connection with those famous observers who also spent many memorable nights here pondering the details they saw through the telescopes.

Modern technology, such as high-speed cameras coupled with sophisticated image-processing software, has given this observatory a whole new lease on life to continue to produce astounding planetary images. I can only see a bright future both for the observatory and the historic T1M telescope, and I look forward to returning. As the saying goes: Vive le Pic!

Damian Peach, *a longtime contributor to* Astronomy, *is one of the world's finest imagers of planets and comets.*

Astronomy tests

QHYCCD's NEW ASTROCAMERA

QHYCCD's 128C contains a full-format (36 mm by 24 mm) cooled CMOS chip. The "purple" filter is the ultraviolet/infrared-blocking filter necessary for the camera to produce clean RGB images.

The 128C offers full-color imaging, low noise, and ease of use.

text and images by Tony Hallas

There's a new kid in town, and his name is COLDMOS. At the 2017 Advanced Imaging Conference in San Jose, California, I couldn't help noticing some shiny new cameras without filter wheels. I went in for a closer look.

The cameras had various CMOS color chips in them just like many DSLR cameras, but they were cooled like the chip in a CCD camera. They also allowed you to download a RAW file as a FITS file, a big advantage for advanced imagers. In some of these cameras, the amplifier noise was less than expected.

Would I be interested in trying one out? I was curious, so I said yes.

What's in a name?

The QHY 128C uses Sony's IMX128 chip that Nikon uses in its D750 SLR. This is a full-frame 35-millimeter chip with 6-micron pixels that can record a 24-megapixel image in 14 bits. The QHY camera features a 128-megabyte image buffer and USB 3.0 connectivity for fast and smooth downloads.

QHYCCD, the camera's manufacturer, named the camera COLDMOS because the CMOS chip is cooled during use, and to differentiate it from other types of cameras that use CMOS chips. Over the last several years, Sony has been moving the CMOS chip design forward. These new devices feature a lot of advanced technology found in CCD chips, like double-correlated sampling and even back illumination. The result is a new level of performance for imaging.

Enter the matrix

Let's take a quick look at how CMOS works. Behind all digital recording devices is a photosensitive chip. All of these chips are monochrome in the sense that they do not differentiate colors. To get color, manufacturers add a microscopic grid of red, green, and blue filters on top of the chip. This is called the Bayer matrix, and typically it's composed of one red, one blue, and two green squares for each unit of color.

Looking at a raw result from an exposure, you would only see various shades of gray and lots of little squares. The magic comes via software that combines each color unit into a single point of true RGB color. In a DSLR, this happens internally, and you see the color image immediately. With a COLDMOS camera, you need to perform the combination yourself.

The 128C differs from CCD cameras in another huge way: You can adjust the gain (or ISO) of the chip. If you increase the gain, you can take many short exposures and combine them. Although the noise does not increase significantly, you lose deep-well capacity. This means that anything bright will wash out, and there will be no data there. The core of the Orion Nebula (M42), for example, would be a pure white blob showing no detail.

Experiments that I've done with a DSLR indicate that the CMOS chip performs best when I capture longer exposures at lower ISO settings. I have applied the same concept to my COLDMOS exposures with good results. Typically, I'll set it for no more than one-half the maximum gain and

Above: This image of the Orion Nebula (M42) took only one hour of exposures to create. The author described a time that short to produce a shot of this quality as "crazy!"

Top right: To create this wide-field image of the region around M78 in Orion, the author connected the 128C to a Stellarvue SVQ-100 refractor. He set the gain at 2,000 and combined eight 15-minute exposures.

Right: The author used this setup for all his shots, including both of the pictures he shot for this story.

PRODUCT INFORMATION

QHYCCD 128C
Sensor: Sony IMX128 color CMOS
Sensor size: 36 mm by 24 mm, 24 megapixels
Pixel size: 5.97 microns square
Exposure times: 60 microseconds to 1 hour
Power consumption: 30 watts
Weight: 27.8 ounces (788 grams)
Price: $3,499
Contact: Michael Barber
QHYCCD
805.308.6976
sbscientific1@gmail.com

exposures between 10 and 20 minutes, depending on the brightness of the target and focal ratio of the imaging device.

Let's compare

Now it's time to answer the question that everyone asks: Is this as good as a CCD camera? No, but it is close. The main reason is the CMOS system: Incoming light has to be split among four separate receptors for every point of RGB. Furthermore, you're limited to the specific colors that the filters of the Bayer matrix give you.

In a CCD system, you image through filters made specifically for astrophotography, so each color fully covers the chip. There's no splitting up the light. Using individual filters in front of a monochromatic chip is laborious and time consuming by comparison, but the end result benefits from each color getting full coverage. Additionally, you can expose the luminance separately from the color data, greatly enhancing the depth of detail.

This brings up another important difference. With the COLDMOS camera, the acquisition of a color image is instantaneous; with a CCD, it is sequential. If you are trying to take a color photograph of something moving fast, like meteors or satellites, the COLDMOS camera works great. The CCD does not. You also can raise the gain of the COLDMOS to record faint objects.

Although it is possible to add narrowband filters in front of a COLDMOS camera, remember that there is only one receptor out of the four that will record, for example, Hydrogen-alpha (Hα) light. The matrix's red filter allows the Hα to go through, but the green and blue filters will block it. So, you are getting only one-quarter the resolution and sensitivity that you would get with a CCD camera where 100 percent of the Hα light is recorded. In other words, don't do that.

We have a verdict

The 128C camera is easy to use. There's no filter wheel, no complicated registration, and no combining of colors. It's all done for you via the Bayer matrix. And dare I say it? This camera was also fun to use. (But you do need to know how to stretch and enhance raw data to get the results you see in this article.) The camera has limitations, of course, but if all you want to do is take some good color images of the night sky, you can do a lot with it.

In line with this, the COLDMOS camera works well with a large variety of optical devices, from camera lenses and refractors to long-focal-length telescopes. The gain of the camera can be adjusted to the f-ratio of your imaging device and the nature of your target.

Furthermore, the camera is well suited to situations where you have only one night available for imaging. For example, each photo in this article was made with two or fewer hours of total exposure time.

QHYCCD's 128C COLDMOS camera brings a new perspective to astrophotography. CMOS technology continues to evolve, and this camera uses it in a new way to image the night sky.

Tony Hallas *is a contributing editor of* Astronomy, *one of the world's top astroimagers, and someone who loves new tech.*

NEW PRODUCTS

Attention, manufacturers: To submit a product for this page, email **mbakich@astronomy.com**.

Solar scope
Meade Instruments
Irvine, California

The Solarmax III 70mm Solar Telescope with Richview System and 10mm Blocking Filter is an achromatic f/5.7 Hydrogen-alpha telescope with a 400mm focal length. The filter's band-pass is less than 0.7 angstrom. Meade provides a Sol Ranger viewfinder and a hard carry case, and fully multicoats all optics.

$2,399
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www.meade.com

2.6-inch telescope
Orion Telescopes & Binoculars
Watsonville, California

Orion's ED 66 CF Carbon Fiber Refractor Telescope has a 400mm focal length and a focal ratio of f/6.1. The objective is an air-spaced, fully multicoated doublet made of extra-low-dispersion glass. The optical tube weighs 3.8 pounds (1.72 kilograms) and is 12 inches (30.5 centimeters) long. Orion includes a 14mm Plössl eyepiece and a hard carry case.

$699.99
800.447.1001
www.telescope.com

Giant binoculars
Orion Telescopes & Binoculars
Watsonville, California

Orion's GiantView BT-100 Binocular Telescope features a pair of 4-inch objective lenses. The company includes two 18mm eyepieces for a magnification of 31x and a true field of view of 2.1°. Eye relief is 17mm, and all optics are fully multicoated. The binoculars weigh 14.5 pounds (6.6 kilograms).

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www.telescope.com

DSLR
JK Imaging
Gardena, California

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www.kodakpixpro.com

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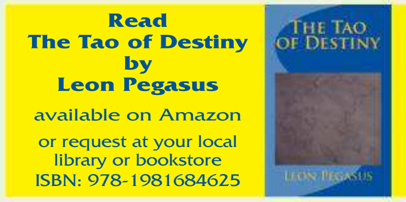
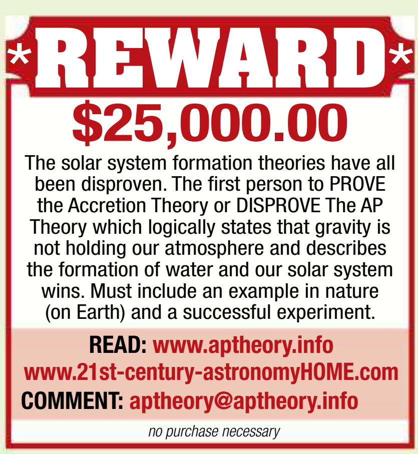




BINOCULARUNIVERSE

BY PHIL HARRINGTON

Check out the Big Dipper!

The closest moving group of associated stars offers plenty for binocular gazers.

The Big Dipper is perhaps the most easily recognizable star group in the sky. It also constitutes a moving group of stars, with most of them physically linked in space. JEFF DAI

The most famous pattern of stars north of the celestial equator, the Big Dipper dominates this month's late-spring sky. Its high position as the late-evening sunset fades makes it a prime hunting ground for our binoculars.

Let's begin with the closest open cluster visible from Earth, cataloged as **Collinder 285**. Nearly every resident of the Northern Hemisphere has seen it at least once, yet few know it exists. If this sounds like a riddle to you, in a way I suppose it is. The five brightest stars in Collinder 285 belong to a much more famous asterism — the Big Dipper itself.

If we could compare the positions of the Dipper's seven stars 100,000 years from now to how they appear today, we would be hard-pressed to identify the familiar figure. But even though the familiar bowl-and-handle pattern will be lost over that stretch of time, five of the stars will still move with a common proper motion.

Their shared movement through space was first suspected by Richard Proctor in 1869, and was confirmed three years later by William Huggins. Studies conclude that at least 16 stars belong to this weak open cluster. The group is about 75 light-years away, and it is spread across an area spanning 18 by 30 light-years. That translates to an apparent diameter of over 23°. The more prominent members include the Dipper stars Merak (Beta [β] Ursae Majoris), Megrez (Delta [δ] Ursae Majoris), Alioth (Epsilon [ε] Ursae Majoris), Phecda (Gamma [γ] Ursae Majoris), Mizar (Zeta [ζ] Ursae Majoris), and Alcor (80 Ursae Majoris). Other cluster members that have struck their own path but continue to show similar proper motions include Alpha (α) Coronae Borealis, Beta (β) Aurigae, and brilliant Sirius (Alpha [α] Canis Majoris).

Let's examine one of the prominent core members of the group, 2nd-magnitude **Mizar**, marking the central crook in the Big Dipper's handle. If you have good eyesight and reasonably dark skies, you should be able to detect without any optical aid that Mizar is accompanied by a fainter companion to the east. That's 4th-magnitude **Alcor**, another core member.

Alcor and Mizar make up one of the most beautiful multiple star systems, as seen in this telescopic exposure. Alcor is the fainter star between and just below the brighter twin suns of Mizar A and B. GREGG RUPPEL

Both have been well known for millennia. Arabic cultures, for instance, imagined them as the "Horse and Rider" galloping across the sky.

Swing even the smallest pocket binocular their way, and both easily resolve into white beacons. You might also see an 8th-magnitude field star through binoculars that joins Alcor and Mizar to form a flattened triangular pattern.

Given monstrous binoculars, like my 25x100s, Mizar resolves into two tightly packed points separated by 14". The brighter star is known as Mizar A, while the dimmer is Mizar B. Mizar's duality was first recorded in 1617 by Italian astronomer Benedetto Castelli, a friend of Galileo. Galileo went on to confirm his discovery.

Then 240 years later, on April 27, 1857, Mizar became the first binary ever photographed through a telescope. That night, using the 15-inch refractor at Harvard College Observatory, photographer John Whipple and observatory director George Bond captured Mizar A and B on a glass photographic plate.

Nearly half a century later, studies showed that both Mizar A and Mizar B are themselves spectroscopic binaries, making this a quadruple star system.

Until recently, astronomers believed that while the stars shared a common proper motion, Alcor and Mizar were too far apart to be true physical companions. That changed in 2009, when two research teams independently discovered that Alcor is orbited by a dim red dwarf companion. Examining revised parallax data for Alcor and Mizar, both studies concluded that the red dwarf, and Alcor itself, are in fact gravitationally linked to Mizar. The discovery turns Alcor and Mizar into a sextuple star system.

Oh, and that 8th-magnitude field star visible in your binocular field that I mentioned earlier? It holds its own interesting footnote in astronomical history. In 1722, German mathematician Johann Liebknecht thought he saw the star shift against the background from one night to the next. He concluded that it was not a star at all, but rather a new planet orbiting the Sun. In his excitement, he christened it **Sidus Ludoviciana** ("Ludwig's Star") after Ludwig V, then the king of Germany. It eventually became apparent that Liebknecht was mistaken, but the star is still called Sidus Ludoviciana nearly three centuries later.

Have a favorite binocular target that you'd like to share with the rest of us? I'd love to feature it in a future column. Drop me a line through my website, philharrington.net.

Until next time, don't forget: Two eyes are better than one!

Phil Harrington is a longtime contributor to Astronomy *and the author of many books.*

THE TIDES ON TITAN

Q: DOES TITAN EXPERIENCE ANY TIDES IN ITS OCEANS, OR IS IT TIDALLY LOCKED WITH NO TIDES?

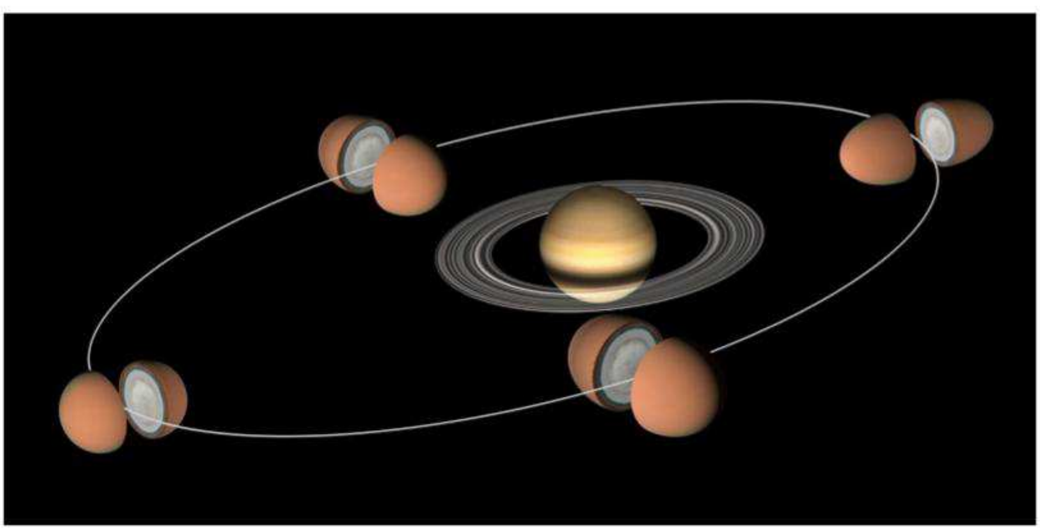
***Richard Robinson,** Clay, New York*

A: In 2012, Cassini revealed that, based on data taken between 2006 and 2011, Saturn's largest moon, Titan, changes shape due to tides raised on the satellite as it circles the planet. Over the course of its nearly 16-day orbit, Titan's surface deforms by more than 33 feet (10 meters).

This amount of tidal deformation is associated with a malleable, likely liquid ocean layer inside the moon. Current estimates place Titan's ocean at more than 62 miles (100 km) thick. If Titan were solid all the way through, the expected deformation of the surface throughout its orbit would total only about 3 feet (1 m).

However, like most of the solar system's larger satellites, Titan *is* tidally locked to Saturn. A tidally locked satellite simply rotates once per every orbit around its parent body, always showing the same face to the planet. Such satellites can still experience tides. Because Titan's orbit is elliptical, the gravitational influence of Saturn from the near to far side of the moon varies throughout its orbit, which causes the deformations recorded by Cassini.

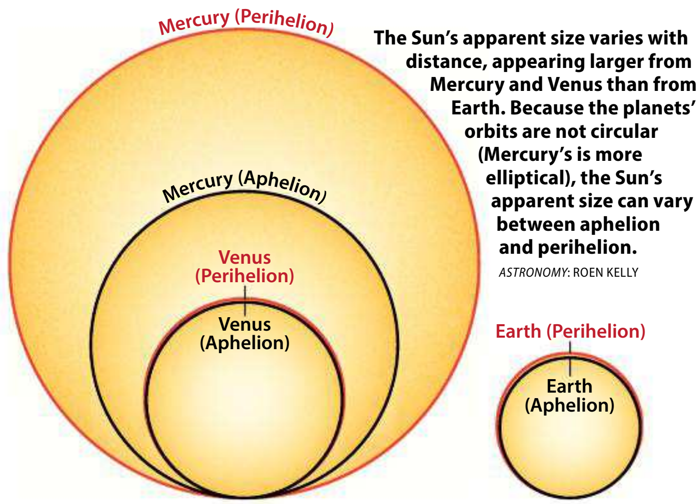
Alison Klesman
Associate Editor



Titan's orbit is slightly elliptical, bringing it closer to Saturn during some points and taking it farther during others. The moon is most spherical at the farthest point from the planet, and most football-shaped when it passes closest to Saturn; the amount of deformation Titan experiences requires a liquid ocean beneath its surface. NASA/JPL

Q: HOW LARGE DOES THE SUN APPEAR FROM MERCURY AND VENUS, AS COMPARED TO HOW WE SEE IT FROM EARTH?

Robert Harrison
Los Ranchos, New Mexico



The Sun's apparent size varies with distance, appearing larger from Mercury and Venus than from Earth. Because the planets' orbits are not circular (Mercury's is more elliptical), the Sun's apparent size can vary between aphelion and perihelion. *ASTRONOMY:* ROEN KELLY

A: The apparent size of the Sun (with a physical diameter of about 865,000 miles [1.4 million kilometers]) varies with its distance from the observer. On Earth, where we average a distance of 93 million miles (150 million km) from our star, the angular diameter of the Sun is about half a degree (0.5°).

Mercury orbits the Sun at an average distance of about 36 million miles (58 million km). As a result, the angular diameter of the Sun from Mercury is much larger: about 1.4°. Venus' average distance from the Sun is about 67 million miles (108 million km), and the Sun's angular diameter from this planet is about 0.7°.

It is worth noting that the planets' orbits are not quite circular. Between perihelion and aphelion, the angular diameter of the Sun as seen from Earth changes by about 3 percent. On Mercury, that change is nearly 53 percent, while on Venus, it's a little over 1 percent.

Alison Klesman
Associate Editor

Q: I'VE READ THAT THE PLANNED CREWED MARS MISSIONS WILL TAKE SIX MONTHS OR TWO YEARS TO ARRIVE. WHICH IS IT? COULD A LONGER TRIP BE DUE TO THE HEAVY PAYLOAD? OUR ROVERS TOOK ONLY EIGHT TO NINE MONTHS TO ARRIVE.

Ronald Greene
Kingman, Arizona

A: When it comes to a trip to the Red Planet, your mileage may vary — literally. Earth and Mars are constantly moving, but they don't stay a constant distance apart. Furthermore, spacecraft from Earth don't travel in a straight line to the Red Planet. Instead, astronauts leaving Earth would follow a path known as the Hohmann transfer orbit, an ellipse from where Earth is now to where

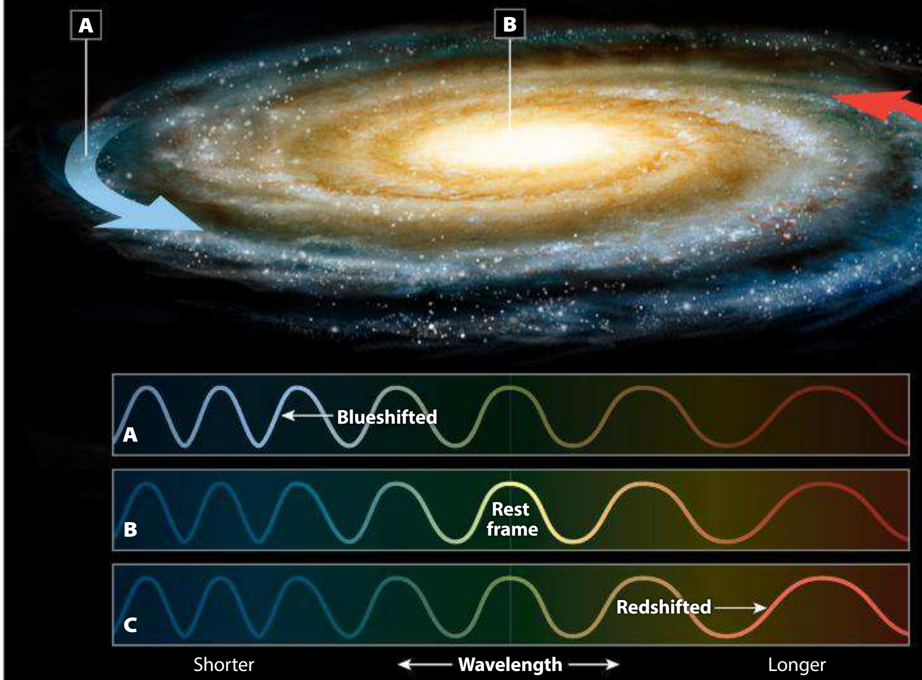
Mars will be in the future. This orbit requires the least energy (and thus the least fuel) and allows the spacecraft to arrive within seven to nine months.

But you can't just decide to pick up and go. Mars and Earth are in their best position for interplanetary travel only every 26 months. A launch outside that window can dramatically increase how long the spaceship — and any astronauts — spend in space.

NASA's Orion spacecraft will carry crew members to Mars on top of the Space Launch System (SLS) rocket, which will be more powerful than the Saturn V rocket that carried astronauts to the Moon. The agency plans to test the pair with Exploration Mission-1 (EM-1), an uncrewed journey around the Moon and back to Earth, in 2019.

Nola Taylor Redd
Freelance science journalist and Astronomy *contributor*

Measuring a galaxy's rotation



As a galaxy rotates, the material moving away from us shows a redshift in the wavelength of any emitted light (red arrow). Material moving toward us shows a blueshift (blue arrow). By measuring these shifts across a galaxy, astronomers can determine its rotation. *ASTRONOMY*: ROEN KELLY

Q: HOW DO YOU MEASURE THE ROTATIONAL SPEED OF A GALAXY, TAKING INTO CONSIDERATION THE MOTION OF OUR GALAXY, SOLAR SYSTEM, PLANET, ETC.?

Chris Mathews
Plano, Texas

A: Almost all measurements of motion in astronomy make use of a law of physics called the Doppler effect. This change in the wavelength (or frequency, color, or pitch) of a wave emitted by a moving source was first described by physicist Christian Doppler in 1842. It is familiar to most of us: I'm sure you've noticed that the siren of an ambulance changes pitch as it passes you, going from higher (as it moves toward you) to lower (as it passes and moves away). This same effect happens to the light emitted by stars and gas in galaxies. With light waves, even large motions create only a tiny shift in color, but we can still measure it using an instrument called a spectrograph, which divides light into its component wavelengths, allowing astronomers to pick out specific features caused by atoms in stars or gas.

One of the most famous — and prevalent — of these features is Hydrogen-alpha (or Hα), which lies at precisely 656.28 nanometers (for a non-moving source). To measure the rotational speed of a galaxy, we map out a line like Hα across the galaxy and compare it to the value from a source at rest. If we can see that on one side of the galaxy the line is blueshifted (moving toward us), and on the other redshifted (moving away) relative to the central redshift of the galaxy, we know the galaxy is rotating, and the amount of shift of either line tells us how much. It is common to do this using a long-slit spectroscope, which measures the shifts in a single spectral line across the galaxy. Alternatively, resolved spectroscopy of entire galaxies has become possible in more recent years, so now we often get full spectral maps.

Another technique uses a radio telescope to measure the 21-centimeter emission line of hydrogen, which also reveals galaxy rotation. The 21 cm line shows us where the hydrogen in a galaxy lies, and as that hydrogen either rotates toward or away from us relative to the central redshift of the galaxy, the resulting Doppler shift broadens the single emission line into a line with two peaks, each associated with motion in one direction or the other.

As you note, we must indeed take into consideration the average shift of light from the motion of our galaxy. This will almost always result in a net redshift, as it includes the expansion of the universe, and also our solar system's motion toward or away from the galaxy we are observing (the rotation of our planet, our orbit around the Sun, the Sun's motion around the galaxy, and the galaxy moving through the universe). These are known quantities, and any extragalactic measurements are done relative to them.

Karen Masters
Associate Professor, Department of Physics and Astronomy, Haverford College, Pennsylvania

Send us your questions

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

READER GALLERY

1. BLUE STREAK
Comet PanSTARRS (C/2016 R2) displays a complex tail as it passes through the constellation Taurus the Bull on January 7, 2018. The bluish hue comes from sunlight causing ionized carbon monoxide molecules to fluoresce.
• Damian Peach/José J. Chambó

2. ONCE IN A BLUE MOON
The eclipsed Moon makes ready to set behind a group of saguaro cacti growing on a mountainside west of Tucson, Arizona. This total lunar eclipse occurred January 31, 2018. This date also marked a blue Moon, the second Full Moon of the month.
• John Vermette

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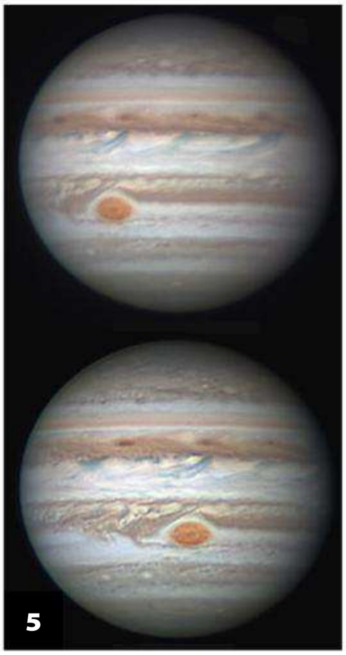

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3. GREAT BALL OF FIRE
The Flaming Star Nebula (IC 405) occupies the upper right part of this wide-field image. IC 410 is the smaller emission nebula at bottom left. Both lie in the constellation Auriga. IC 405 glows red because of AE Aurigae, the brightest star in the nebula. Note the two bright gaseous "tadpoles" within IC 410. Ultraviolet radiation from the young star cluster NGC 1893 carved their shapes. • ***Jon Talbot***

4. POINTS OF VIEW
Face-on spiral M77 floats through space with edge-on spiral NGC 1055 some 60 million light-years away in the constellation Cetus the Whale. The galaxies are quite similar except for the way they align to our view. As a bonus, one shot of the 44¾ hours of exposures needed to create this image shows a Geminid meteor's trail quite close to NGC 1055. • ***Mark Hanson***

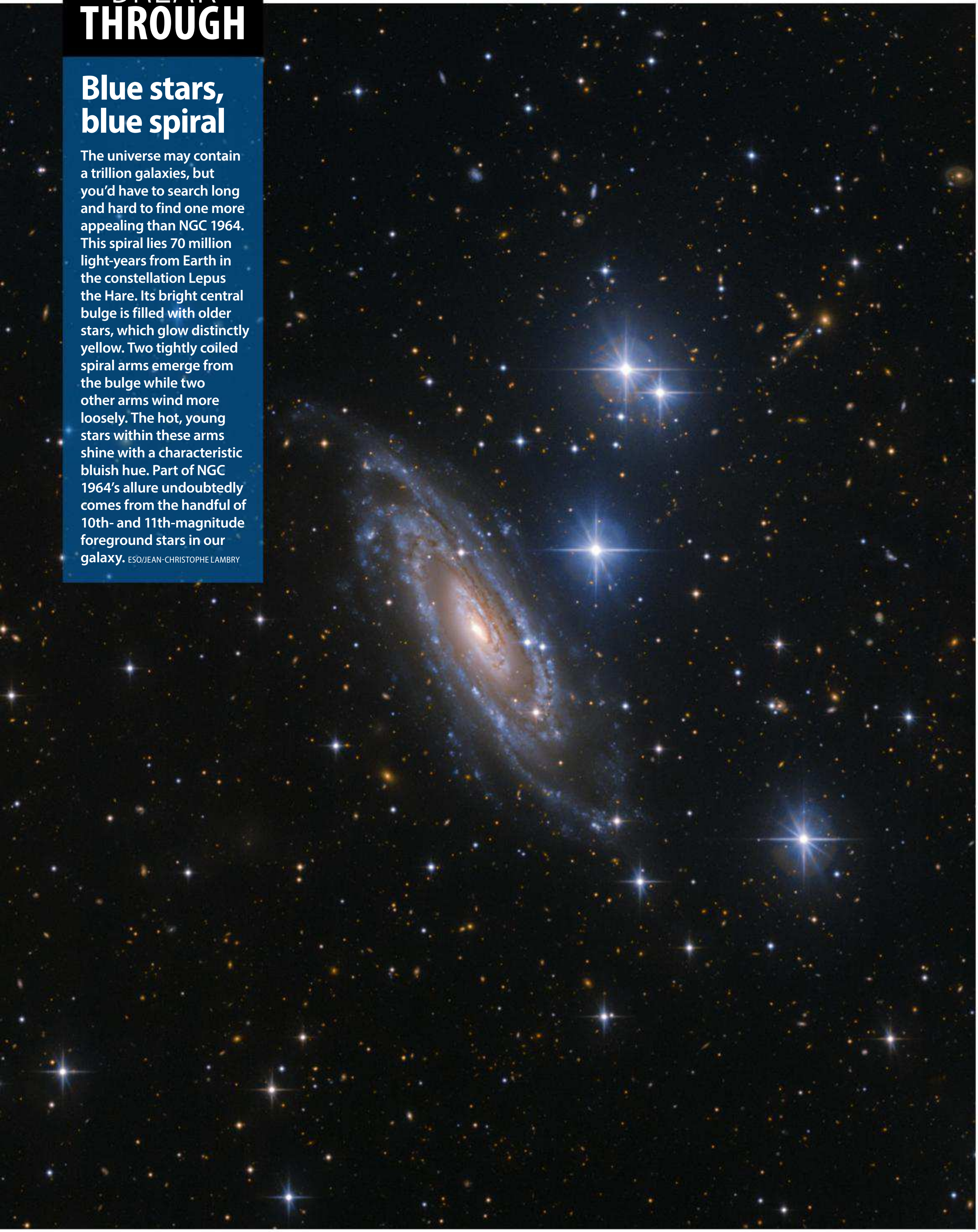
5. THE GIANT MOVES
These two images of Jupiter, taken from Cebu, Philippines, show the planet's rotation from 20h40m UT (top) to 21h30m UT. The Great Red Spot is easy to see, as are many bright belts and dark bands. • ***Christopher Go***

6. LUCKY STREAKS
The Geminid meteors are captured in this composite image taken December 13 and 14, 2017. The photographer then combined those exposures with a nighttime shot of Truckee, California, near where the meteor exposures were taken. • ***Daphne Hallas***

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.

BREAK
THROUGH

Blue stars, blue spiral



The universe may contain a trillion galaxies, but you'd have to search long and hard to find one more appealing than NGC 1964. This spiral lies 70 million light-years from Earth in the constellation Lepus the Hare. Its bright central bulge is filled with older stars, which glow distinctly yellow. Two tightly coiled spiral arms emerge from the bulge while two other arms wind more loosely. The hot, young stars within these arms shine with a characteristic bluish hue. Part of NGC 1964's allure undoubtedly comes from the handful of 10th- and 11th-magnitude foreground stars in our galaxy. ESO/JEAN-CHRISTOPHE LAMBRY

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

August 2018: An evening extravaganza

Four bright planets stretch across August's evening sky. **Venus** lies farthest west, shining brilliantly against the background stars of Virgo. On the 1st, it appears 30° below 1st-magnitude Spica, the Virgin's luminary. The magnitude –4.3 planet outshines the star by some 100 times.

Venus moves eastward against the starry backdrop during August. It reaches greatest solar elongation on the 17th, when it appears 46° east of our star and stands more than 30° high an hour after sundown. The planet remains the sky's brightest point of light until it sets shortly after 9 P.M. local time. By month's end, Venus pulls within 1.5° of Spica.

The planet's appearance through a telescope changes noticeably throughout August. On the 1st, it shows a slightly gibbous phase on a disk that spans 20". At midmonth, the Sun illuminates precisely half of Venus' 24"-diameter disk. And by the time August closes, the planet swells to 29" across while its phase dwindles to a crescent.

Next in line is **Jupiter**. The giant planet stands high in the northwest as darkness falls, residing among the relatively dim stars of the constellation Libra. Jupiter shines at magnitude –2.0, barely one-tenth as bright as Venus but still noticeably brighter than any star.

The gas giant's atmosphere provides a visual treat through any telescope. Look for two parallel dark belts, one on either side of a much brighter zone coinciding with the planet's 36"-diameter equator. Smaller features along the edges of these belts show up during moments of good seeing. You can also track the movements of Jupiter's four largest moons over the course of a few hours.

If you trace a line from Venus to Jupiter and extend it a bit farther than the distance between those two, your eyes will fall on magnitude 0.3 **Saturn**. The ringed planet resides in Sagittarius and appears high in the sky throughout the evening hours. (From a wide swath of the Southern Hemisphere, it passes nearly overhead at its peak.) Saturn moves slowly westward, or retrograde, relative to the background stars as Earth continues to outpace it in the months following opposition.

Although Saturn is the dimmest of the four evening planets, it is also the most beautiful through a telescope. And its great altitude on August evenings provides nearly perfect viewing conditions. At midmonth, the planet's disk measures 18" across while the rings span 40" and tilt 27° to our line of sight. Any scope should reveal the broad Cassini Division that separates the outer A Ring from the brighter B ring. The narrow Encke Gap near the A ring's outer edge shows up under excellent conditions with a 20-centimeter or larger instrument.

Head one constellation farther east and you can't miss **Mars**. Only the Moon and Venus outshine Mars this month, and neither has the Red Planet's distinctive color. Mars spends most of August in southwestern Capricornus, but its retrograde motion carries it into far eastern Sagittarius in the month's final week.

The ruddy world reached opposition and peak visibility in late July, and it remains a stunning sight throughout August. Although it dims from magnitude –2.8 to –2.1 and its apparent diameter shrinks from 24" to 21", these values still exceed a typical martian opposition. And its high evening altitude promises good seeing conditions for viewing fine detail through a telescope.

Mercury proves to be a difficult target during August. The innermost planet passes between the Sun and Earth on August 9 and then slowly climbs into view low in the east-northeast before dawn. Still, even at greatest western elongation on the 26th, it appears only 4° high a half-hour before sunrise.

The starry sky

The southern sky contains enough telescopic delights to keep an observer busy for a lifetime. Even something as small as a 20-cm instrument will let you observe a huge number of these deep-sky wonders.

In winter and early spring, we reap the benefits of living in the Southern Hemisphere. In early evening, the spectacular southern Milky Way stretches across the sky while the center of our galaxy passes nearly overhead.

One of winter's most familiar star patterns is Scorpius the Scorpion. The constellation does resemble a scorpion, though some see a reversed question mark in its form. Its most distinctive features are 1st-magnitude Antares, the star that marks the Scorpion's heart, and the arachnid's curved tail. The arc of the tail encloses a fascinating deep-sky object.

The Bug Nebula (NGC 6302) lies near the center of the tail, 4° due west of magnitude 1.6 Shaula (Lambda [λ] Scorpii), the bright star marking the Scorpion's Stinger. The Bug is a planetary nebula, but the word "planetary" is a misnomer — such nebulae have nothing to do with planets. They are the glowing embers of material ejected by aging Sun-like stars. They got their name because early observers saw a superficial resemblance to the blue-green glow of the planet Uranus.

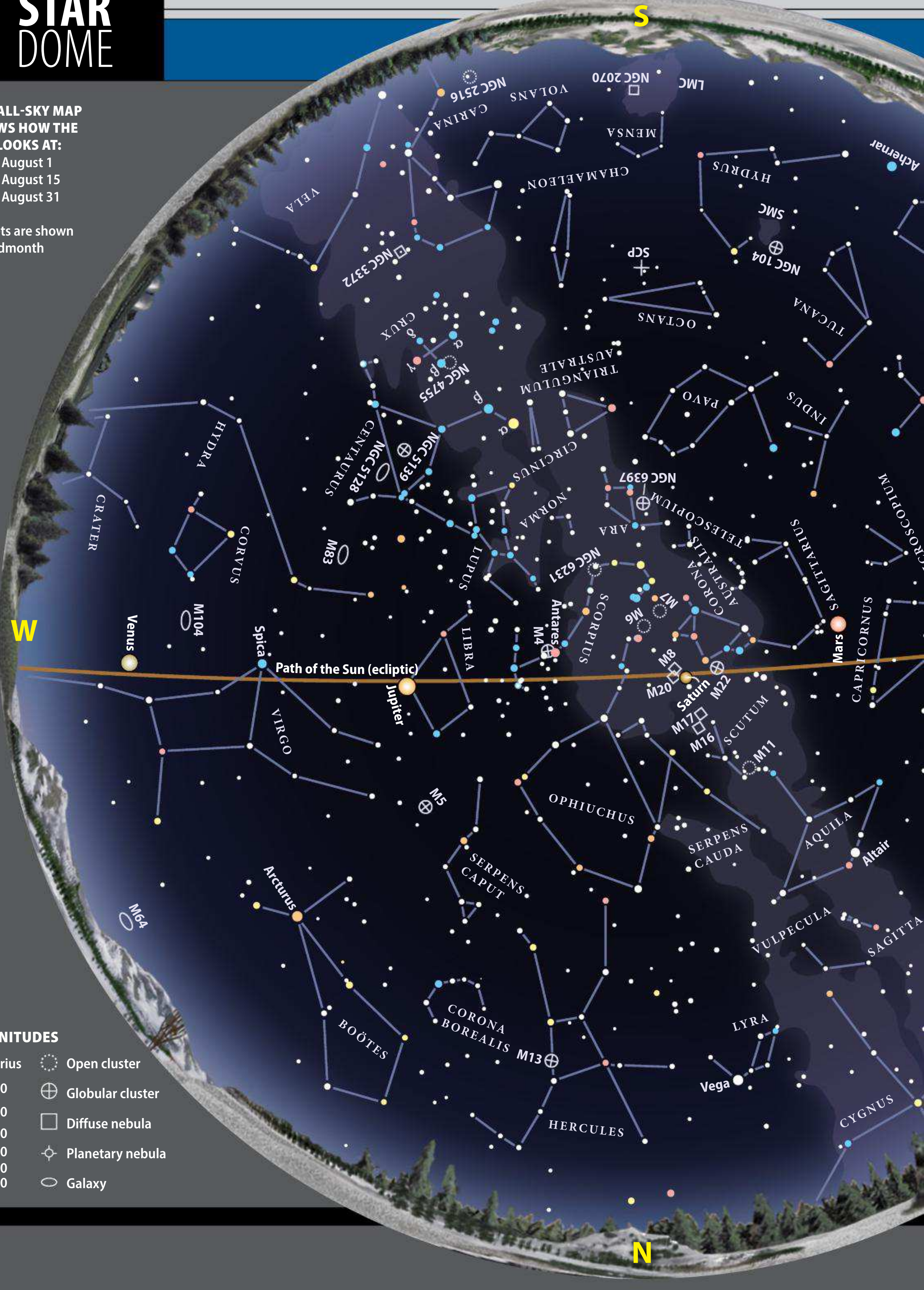
The Bug Nebula looks spectacular through a 20-cm telescope, though smaller apertures do show it. It is rather small, spanning 50", but has a high surface brightness and thus shows up quite easily. The nebula appears elongated and has a bright center. You won't see the central star that puffed off these wispy tendrils, however. Astronomers finally detected this ultrahot star, which has a surface temperature of about 200,000 K, with the Hubble Space Telescope in 2009.

Although photographs show the Bug's complexity, its overall appearance is reminiscent of a flying insect with a large wingspan. Every time I gaze at this object, however, it reminds me more of an unfortunate bug that met an untimely end on the windscreen of my car.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. August 1
8 P.M. August 15
7 P.M. August 31

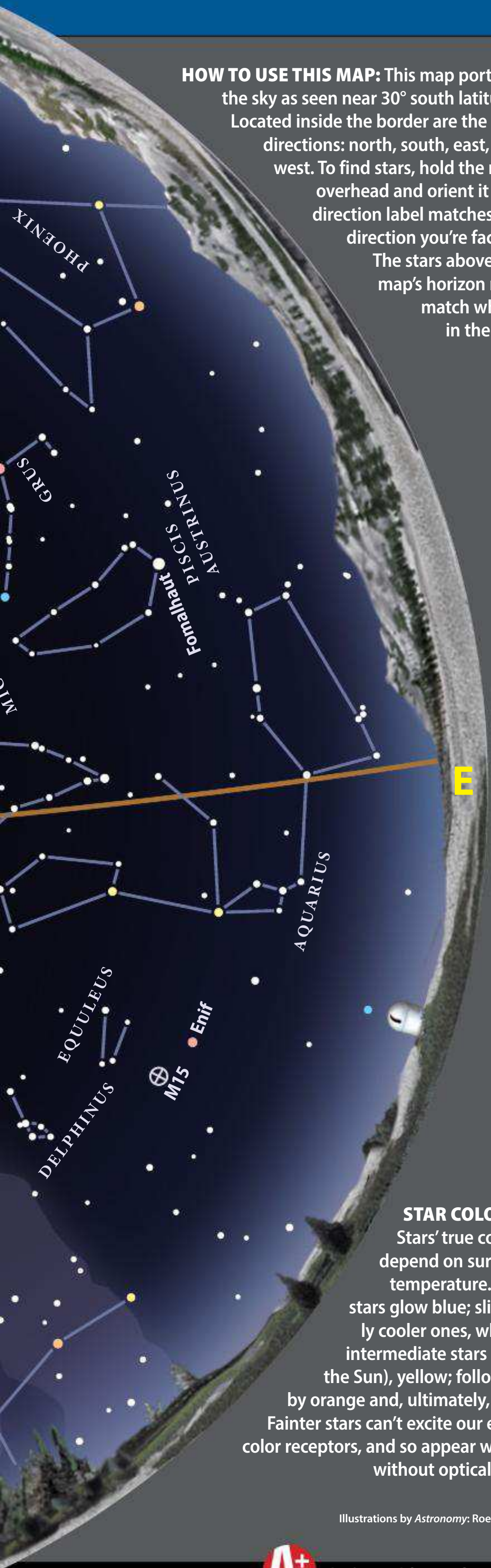
Planets are shown at midmonth



MAGNITUDES

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

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



HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

AUGUST 2018

Calendar of events

1 Asteroid Vesta is stationary, 23h UT

3 The Moon passes 5° south of Uranus, 21h UT

4 Last Quarter Moon occurs at 18h18m UT

The Moon passes 1.2° north of asteroid Juno, 23h UT

6 The Moon passes 1.1° north of Aldebaran, 19h UT

7 Asteroid Pallas is in conjunction with the Sun, 13h UT

Uranus is stationary, 21h UT

9 Mercury is in inferior conjunction, 2h UT

10 The Moon is at perigee (358,078 kilometers from Earth), 18h07m UT

11 New Moon occurs at 9h58m UT

14 The Moon passes 6° north of Venus, 14h UT

17 The Moon passes 5° north of Jupiter, 11h UT

Venus is at greatest eastern elongation (46°), 17h UT

18 First Quarter Moon occurs at 7h49m UT

Mercury is stationary, 12h UT

21 The Moon passes 2° north of Saturn, 10h UT

23 The Moon is at apogee (405,746 kilometers from Earth), 11h23m UT

The Moon passes 7° north of Mars, 17h UT

26 Full Moon occurs at 11h56m UT

Mercury is at greatest western elongation (18°), 21h UT

27 The Moon passes 2° south of Neptune, 10h UT

28 Mars is stationary, 10h UT

31 The Moon passes 5° south of Uranus, 3h UT

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