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OCTOBER 2018

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DARK MATTER MYSTERY

Clues from strange stars p. 18

Zooniverse
Citizen science for your computer p. 26

PLUS

EXPLORE galaxies in Pegasus p. 52

BOB BERMAN on the scary universe p. 14

HOW to take your hobby to the next level p. 56

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Vol. 46 • Issue 10


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CONTENTS

18

OCTOBER 2018

VOL. 46, NO. 10

TONY HALLAS

ON THE COVER

Astronomers know that dark matter is out there from its effects on galaxies. Will dark stars shed light on this great mystery?

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

Astronomy (ISSN 0091-6358, USPS 531-350) is published monthly by Kalmbach Media Co., 21027 Crossroads Circle, P. O. Box 1612, Waukesha, WI 53187–1612. Periodicals postage paid at Waukesha, WI, and additional offices. POSTMASTER: Send address changes to *Astronomy*, P.O. Box 62320, Tampa, Fla. 33662-2320. Canada Publication Mail Agreement #40010760.

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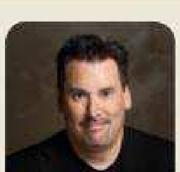

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FROM THE **EDITOR**

BY DAVID J. EICHER

Dark stars and dark matter

Eighty-five years after Fritz Zwicky raised the possibility of the existence of a type of unseen matter in the cosmos, we still don't know what it is.

Following the observational work of Vera Rubin and her colleagues in the 1970s, and the cosmological probes since the 1980s, we know dark matter is out there. The Planck spacecraft's most recent data suggest some 26 percent of the mass-energy of the cosmos exists in the form of dark matter. But we don't know what it's made of.

This month, science writer Mara Johnson-Groh gives us an overview of an intriguing line of research that's shining some light on dark matter. One possibility suggests it could exist in the form of WIMPs — weakly interacting massive particles. Mind you, these are hypothetical creatures. No such particle has yet been discovered. But the existence of such particles could explain dark matter. Their presence is also suggested by supersymmetry, a theory in particle physics that predicts how such particles would interact with each other.

The rise of dark matter extends back to the earliest days of the cosmos, nearly to the Big Bang, some 13.8 billion years ago. In the early days of the universe, scientists believe, a new infant type of star was born called a dark star. Erroneously named, dark stars are actually believed to be quite luminous, though no one has yet observed one. But they ought to exist, and their existence should provide substantial clues to the nature of dark matter.

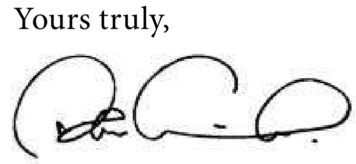
Dark stars may explain how supermassive black holes in the centers of galaxies got their starts.

If they exist, dark stars formed early on, a few hundred million years after the Big Bang, amid a universe awash in dark matter. These stars would be made almost entirely of hydrogen. A small percentage of these stars would consist of dark matter. Ultimately, they would collapse into black holes — in fact, they may explain how supermassive black holes in the centers of galaxies got their starts.

Astronomers are excited about the possibility of discovering dark stars, as the James Webb Space Telescope, set for launch in the next few years, would be the first instrument capable of seeing them in the early universe. Assuming that dark matter consists of WIMPs, dark stars should exist and be detectable. They might also be found via gravitational waves that would be produced from their mergers.

For now, dark stars lie on the frontier of the possible, even likely, but as yet unknown. But times are changing in astronomy. We may not be far away from finding such creatures, and finally beginning to solve the nearly century-old mystery of dark matter.

Yours truly,



David J. Eicher
Editor

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ASTRO**LETTERS**

Lessons from Andromeda →

The article "Sizing Up Andromeda" in the June 2018 Astro News section continues the tradition of astronomers, both professional and amateur, using the Andromeda Galaxy to study the formation and evolution of galaxies. We are fortunate to have a not-so-distant example to study, develop, and confirm theories.

In 2004, Rodrigo Ibata and others used the Keck telescope to map and measure the speeds of 2,800 red giant stars in the outskirts of Andromeda. Since these stars were not randomly moving but orbiting in the galaxy's plane, they argued that this movement makes the red giants part of the disk, and this tripled the size of the galaxy. This, of course, greatly affected the calculations of Andromeda's mass. New research uses the escape velocity of selected stars, along with dark matter estimations, to calculate galactic mass. The results more accurately predict mass and better simulate the projected collision of the Milky Way and Andromeda galaxies. With better telescopes and new techniques and ideas, astronomers will continue to improve our knowledge of the universe.
— Donald Craig, Indianapolis, IN

Chicago's hidden gem

Your "Backstage Pass Chicago" article arrived a month too late for my recent trip to the Windy City. I did, however, get to see a hidden gem not mentioned: the Dearborn Observatory at Northwestern University. I highly recommend heading to Evanston to check out their 18.5-inch refractor. While it's not the largest telescope in the city, its history is fascinating. The telescope dates back to the Civil War and survived the Chicago Fire. Free observing sessions are open to the public every Friday evening. The best part of my visit was the student hosts, who were knowledgeable, friendly, and excited to share their passion. Anyone visiting the Chicago area should add it to their to-do list. **— Samuel Raisanen,** Mount Pleasant, MI

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.*

NASA/JPL-CALTECH

Scientific speculation

I've been reading *Astronomy* since the late '70s. It has given me many hours of pleasure for many years now, even though I've come to not believe much of what is printed. That's not because you have neglected to print what you believe is true, but because scientists really don't know much to be true. Much of it is speculative and a lot of guesswork is involved. I just can't take what I see as fact. But keep on printing. I love a good a work of fiction. I love the articles and I believe that the authors believe what they write. Thanks for your work. **— Dennis Lucas,** Clinton, UT

UFO debunked

I read Stephen O'Meara's "Satellite 'fake-out'" article (June 2018 issue) with much interest. A couple of years ago, I was stargazing in my backyard when I saw a star continuously move from northeast to southwest. It wasn't flashing and was making sideway movements in a physically impossible fashion. I jokingly told my wife that I saw a UFO. Though I didn't really believe that, I had no other explanation. I think you have solved my UFO mystery.

Another puzzle needs an explanation, though. I saw what I believed was a satellite moving in a straight line when it suddenly became orange/red and much bigger. It then started to dim until it disappeared. Could this have been something re-entering our atmosphere and burning out? Thanks for the interesting article.
— Sam Nauman, Bayview, TX

Correction

The "Exploring Jupiter's Trojan Asteroids" article that begins on p. 28 of the June 2018 issue incorrectly states that an astronomical unit (AU) is 483 million miles, or 778 million kilometers. An AU is the average Earth-Sun distance of 93 million miles, or 150 million kilometers.

QG QUANTUM GRAVITY

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

HOT BYTES >>

TRENDING TO THE TOP

DIAMOND DUST
Tiny carbon crystals — nanodiamonds — in the gas and dust around newly born stars are responsible for a previously untraced source of microwaves.

MAKING HISTORY
On June 20, the American Physical Society designated the LIGO sites in Louisiana and Washington as Historic Physics Sites.

NEW APPLICATION
Researchers are using technology developed for mapping terrain on Mars from orbit to safely study unreachable areas of the Himalayas on Earth.

ESO; TOP FROM LEFT: S. DAGNELLO, NRAO/AUI/NSF; LIGO LAB/CALTECH/MIT; SHRIMPO1967 (FLICKR)

SNAPSHOT

A space spider

Stars abound in this cosmic insect's web.

Astronomers at Chile's Paranal Observatory used the VLT Survey Telescope to peer deep into the Large Magellanic Cloud, a nearby satellite galaxy of the Milky Way, and captured this new photograph of its most famous resident: the Tarantula Nebula. The colorful image was created by combining four separate shots from the telescope's wide-field, 256-megapixel camera, OmegaCAM.

Seen at the top of the image, the nebula sits about 160,000 light-years from Earth and is the most active star producer in the Local Group of galaxies. The Tarantula's core hosts NGC 2070, a massive star cluster that births some of the brightest and most massive stars ever discovered.

The image also captures NGC 2074, a smaller cluster rich in star formation, seen at bottom; and NGC 2100, a luminous open cluster to the left of the nebula that's densely packed with red and blue stars. — **Amber Jorgenson**

 AND THE AWARD GOES TO … The crew members of Apollo 7 received an Emmy from the National Academy of Television Arts and Sciences for their live broadcasts from orbit.

Apollo 7
50 YEARS AGO

On January 27, 1967, Apollo 1 crew members Roger Chaffee, Ed White, and Gus Grissom were killed in a fire during a test of the spacecraft while on the launchpad. Twenty-one months later, the three men who had originally served as their backup crew — Walter Schirra Jr., Donn Eisele, and Walter Cunningham — flew on Apollo 7, the first manned American spaceflight since the accident. Their mission was a resounding success, speeding the Apollo program ahead to reach the Moon by the end of the decade.

Apollo 7 launched from Cape Kennedy, Florida, October 11,

APOLLO 7'S RECORD FOR LONGEST MANNED AMERICAN SPACEFLIGHT WASN'T BROKEN UNTIL APOLLO 15 SURPASSED IT IN 1971.

1968. Onboard was a three-man crew of commander (Schirra), command module pilot (Eisele), and lunar module pilot (Cunningham). They remained in orbit for 10 days, 20 hours before splashing down October 22. The mission aimed to achieve several key objectives, including the demonstration of successful crew, mission support, and spacecraft capabilities in preparation for manned missions to the Moon.

"We were very pleased to be making the flight," Cunningham told *Astronomy* in an interview. "The general public at large was excited and kind of filled with tenseness over the fact that the last one had been a fatal accident. But we spent that 21 months getting about 1,060 changes in the spacecraft. Our crew was responsible for some of them, the engineers were responsible for most of them, and were all working together, looking forward to getting back on schedule and landing a man on the Moon before the decade was out, because that was the goal."

TESTING, TESTING

Schirra, Eisele, and Cunningham were the first to fly in the Apollo Command/Service Module (CSM), which provided housing and power for Moon-bound astronauts, as well as a re-entry and recovery vehicle. After launch on future Apollo missions, the CSM was manually docked with the Lunar Excursion Module (LEM), the lunar landing vehicle. Despite Cunningham's designation as lunar module pilot, Apollo 7 carried no lunar module. However, its mission goals included testing the CSM's rendezvous capability with a LEM, which on future excursions would sit inside the third stage of the Saturn rocket, the S-IVB, during launch.

Early in the mission, the Apollo 7 crew moved the CSM ahead of the rocket stage and turned it around to dock with a target mounted where the LEM was to reside. One of the four adapter panels connecting the base of the CSM to the Saturn rocket — which would be jettisoned on future missions but left attached to the rocket stage during Apollo 7 — had caught on a retention cable and

Apollo 7's Saturn IVB rocket stage over Sonora, Mexico, on the mission's second Earth orbit. The white disk is a mock target that allowed the crew to simulate docking the command module with a lunar lander. One of the four adapter panels can be seen temporarily stuck in a partially open position. ALL IMAGES: NASA

become stuck only partially open. After several orbits, the panel deployed completely, allowing the crew to successfully simulate the docking procedure used on subsequent Apollo missions to connect with and extract the LEM.

Other successful tests included checks of the radar that would be used to dock the CSM and LEM, tests and checks of the environmental control system, and eight successful firings of the service module's powerful rocket, which would put future Apollo missions on a trajectory to the Moon and return them to Earth. This rocket had no backup system: If it didn't fire properly, astronauts would not make it to the Moon, or might not be able to return home.

LIFE IN SPACE

Apollo 7 also performed the first live television transmissions from an American spacecraft. During the mission, the astronauts completed seven short TV sequences, showing

Walter Cunningham served as the lunar module pilot on Apollo 7.

Apollo 7 lifts off from the Kennedy Space Center's Launch Complex 34 just after 11:00 A.M. EDT October 11, 1968.

The crew of Apollo 7 (from left): Donn Eisele, Walter Schirra Jr., and Walter Cunningham.

The Apollo 7 astronauts practice exiting the command module after splashdown in the Gulf of Mexico. The three balloons are meant to right the capsule after re-entry if necessary; during the actual mission, the capsule landed upside down, and the balloons worked as intended within minutes.

Eisele (left) and Schirra show off a sign proclaiming, "Keep those cards and letters coming in folks" during the first of the mission's seven live television broadcasts.

the audience the spacecraft that housed them and other aspects of living in space, including demonstrations of weightlessness, food preparation, and the removal of condensation from the spacecraft's interior. "We were not looking forward to doing that," Cunningham recalls. "We knew it was in the plan because it was a deviation from the professional kind of technical things we were accomplishing. But we did, it turns out, enjoy it after we got started. … We actually saw it as kind of a break that we could enjoy while we were flying."

For the crew, "[broadcasting] was the least significant and important thing for the mission that we did in those whole 11 days; it was an outside entertainment," says Cunningham. "But I don't think the public saw it the same way as we did. They saw it as their chance to share in what was going on with the Apollo program."

One of the mission's few hiccups occurred shortly after liftoff, when Schirra developed symptoms of a cold. "Well, if you listen to the outsiders or even some of the ground controllers … today they probably still think that we all got sick. But that's not the case. Actually, Wally was the one that got sick," says Cunningham. "But Wally didn't want to have the world thinking that somehow or other he was weak and he got a cold and we didn't. So he insisted that we all take the cold pills."

As for the effect on the mission, "it kind of tied him up a little bit. He was not as efficient the first couple of days, but after that, he went back on," says Cunningham. "He was the most experienced one — the only experienced one — in the cockpit, and we did very well with accomplishing the mission objectives. But the fallout from that was that Wally irritated the ground controllers to some degree."

A SUCCESSFUL FIRST FLIGHT

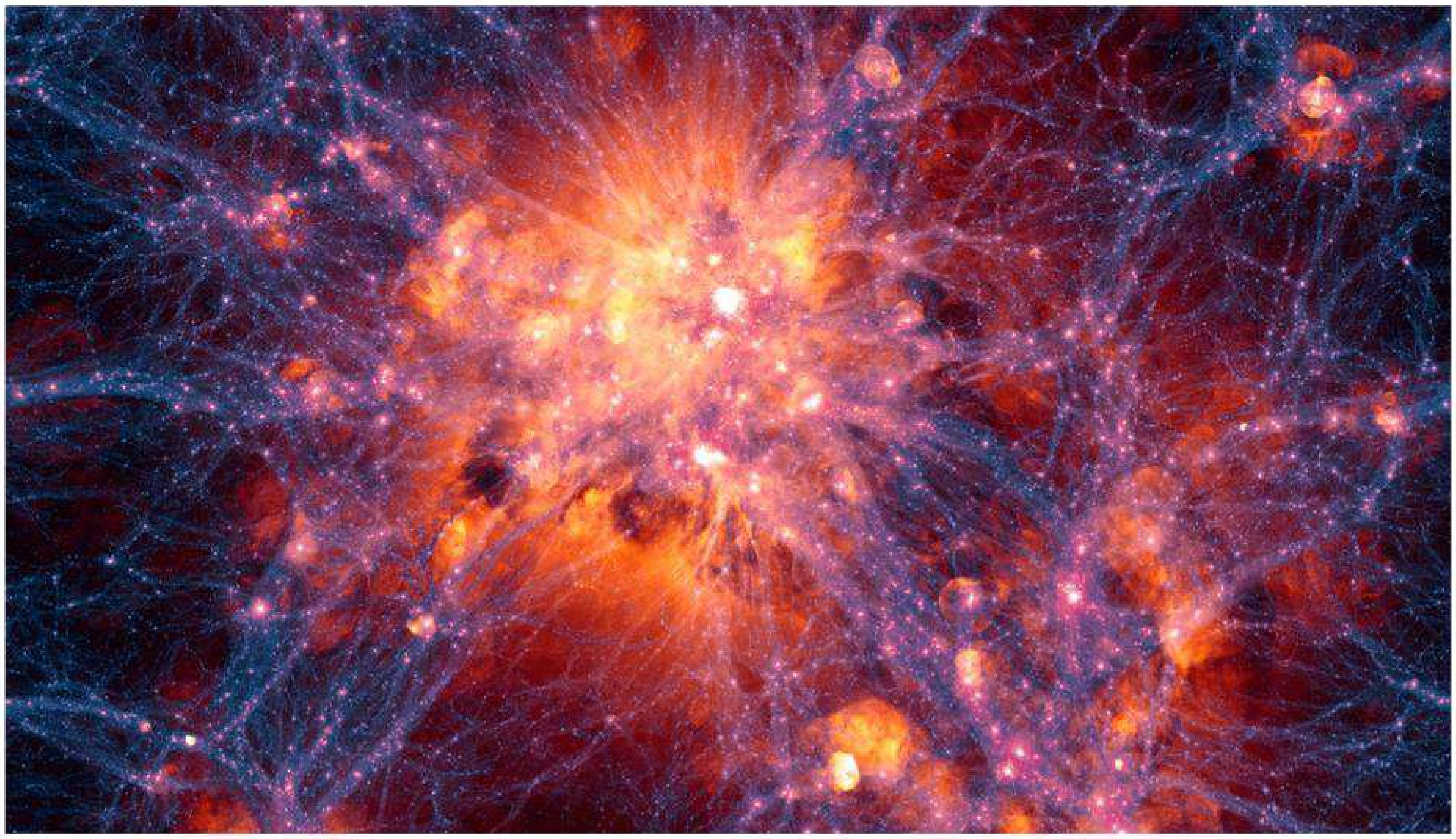
Ultimately, Apollo 7's crew spent more time in space than any previous mission. In fact, they spent more time in space than all the Soviet space missions combined up to that point, as well as more time than the initial Moon landings would ultimately require. They took with them a packed list of objectives to complete, and they were so successful that Mission Control added several more tasks to maximize the mission's benefits during the flight.

"In the end, it was declared 101 percent successful," says Cunningham. "And historically, if you look back at it, it is still today, 50 years later, the longest, the most ambitious, the most successful first test flight of any new flying machine ever."

— Alison Klesman

SKEWS YOUNG. New research that incorporates the effects of binary star systems on the light received from globular clusters shows these objects may be 4 billion years younger than previously thought.

ASTRONOMERS IDENTIFY UNIVERSE'S MISSING MATTER



STRUNG OUT. The filaments of the cosmic web (darker blue lines) fill the space between galaxies (bright yellow-orange spots) in this simulation. Astronomers have determined that the gas in the cosmic web, also called the warm-hot intergalactic medium, can account for the previously unidentified normal matter in the universe. ILLUSTRIS COLLABORATION

Our universe is made up of three major components: normal matter (5 percent), dark matter (26 percent), and dark energy (69 percent). Normal matter, also called baryonic matter or baryons, includes everything from stars and planets to black holes and interstellar gas. Even though 5 percent of the universe might seem comparatively tiny, astronomers have been able to identify only about two-thirds of the normal matter that exists.

Now, in a paper that appeared June 20 in *Nature*, an international team of researchers announced it had found the missing one-third, finally accounting for all the normal matter in our universe. The previously missing matter is found between galaxies, making up a "cosmic web" of gas filaments known as the warm-hot intergalactic medium (WHIM). The WHIM is made of ionized oxygen gas at temperatures of about 1.8 million degrees Fahrenheit (1 million degrees Celsius).

Astronomers found the missing matter by observing the quasar 1ES 1553, over 4 billion light-years away, with the XMM-Newton X-ray Space Telescope for a total of 18 days between 2015 and 2017. Quasars are the brightly shining disks of accreting matter around supermassive black holes; they are among the brightest objects in the universe and can be used as background light sources to find intervening material that may be difficult to see.

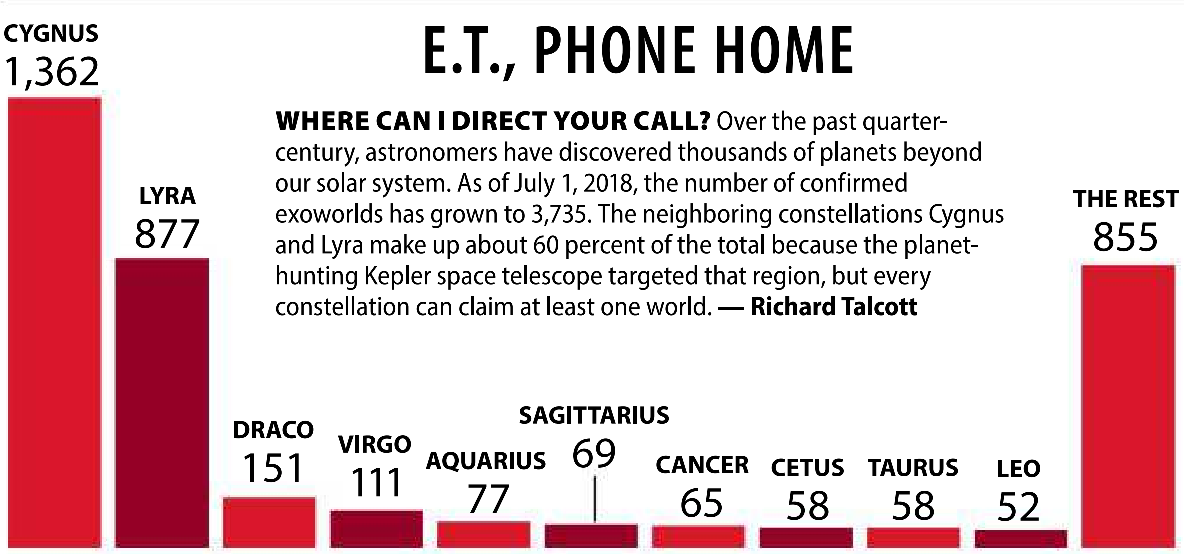
"After combing through the data, we succeeded at finding the signature of oxygen in the hot intergalactic gas between us and the distant quasar, at two different locations along the line of sight," said lead author Fabrizio Nicastro, of the Italian Istituto Nazionale di Astrofisica (INAF)-Osservatorio Astronomico di Roma and the Harvard-Smithsonian Center for Astrophysics, in a press release. Extrapolated across the universe, the oxygen signal is enough to account for all the missing matter. It fills the entire gap between the amount of previously identified normal matter and the total amount expected from observations of the cosmic background radiation left over from the Big Bang.

"We found the missing baryons," said Michael Shull of University of Colorado Boulder, a co-author on the paper. The team will now follow up its finding by observing more quasars to confirm that the WHIM does indeed account for all the missing matter.

In addition to lighting up the WHIM, quasars play another role in this study: The team believes the quasars are responsible for blowing out the hot gas that makes up the WHIM over the course of billions of years. However, the exact mechanisms aren't yet understood, so although the missing matter has now been found, its detailed history remains a mystery. — **A.K.**

E.T., PHONE HOME

WHERE CAN I DIRECT YOUR CALL? Over the past quarter-century, astronomers have discovered thousands of planets beyond our solar system. As of July 1, 2018, the number of confirmed exoworlds has grown to 3,735. The neighboring constellations Cygnus and Lyra make up about 60 percent of the total because the planet-hunting Kepler space telescope targeted that region, but every constellation can claim at least one world. — **Richard Talcott**



ASTRONOMY: ROEN KELLY

FAST FACT: Circinus sits at the bottom of the exoplanet totem pole, with only one known world calling this southern constellation home.

ASTRONEWS

LATE NOTICE. On June 2, hours after its initial detection, a 6-foot-wide asteroid entered Earth's atmosphere at 38,000 mph (61,000 km/h) before erupting as a bright fireball.

In memoriam: Alan Bean and Donald Peterson

TWO EXPLORERS. Alan Bean (left) was the fourth man to walk on the Moon and a talented artist. Donald Peterson (right) logged 4 hours, 15 minutes of extravehicular activity on the first flight of the space shuttle *Challenger*. NASA

Alan Bean, the fourth man to walk on the Moon and second commander of the Skylab space station, died May 26 at age 86. Bean served as the lunar module pilot of Apollo 12 in November 1969, and the commander of the second flight to Skylab in July 1973.

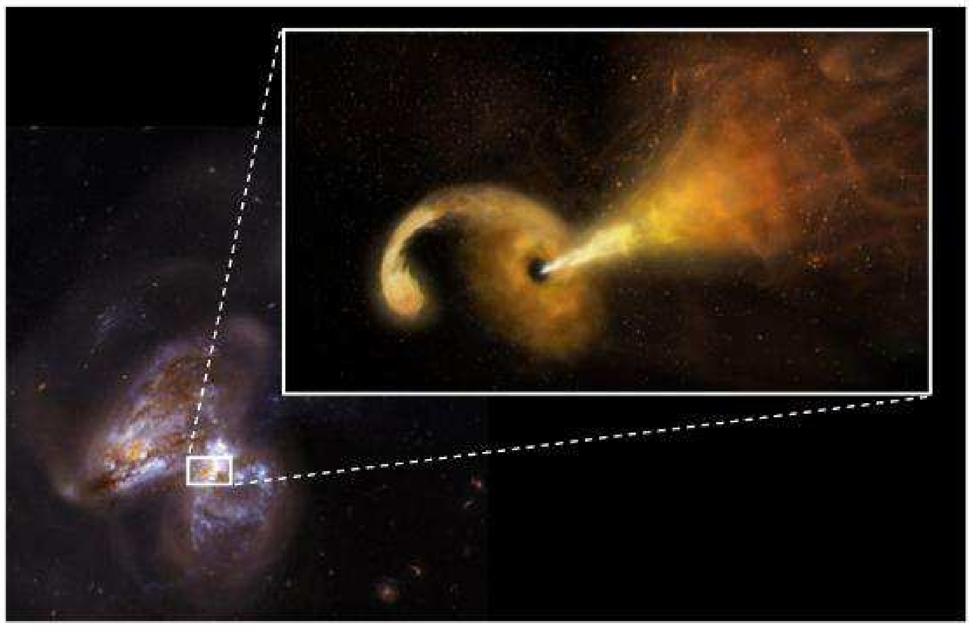
Bean retired from the Navy with the rank of captain in 1975, but he continued working in a civilian capacity for the Astronaut Candidate Operations and Training Group in NASA's Astronaut Office until 1981.

After retiring, Bean returned to his former passion — art — and created numerous paintings depicting the lunar landscape. Included in his paintings were scrapings of Moon dust from the patches worn on his Apollo spacesuit, as well as impressions of his boots and tools used on the lunar surface.

One day after Bean's death, space shuttle astronaut Donald Peterson, who flew aboard *Challenger*'s inaugural mission, died at age 84. After selection to become a NASA astronaut in September 1969, Peterson was part of the Apollo 16 support crew but did not reach space until April 4, 1983, aboard STS-6. During the five-day mission, he and fellow mission specialist Story Musgrave became the first spacewalkers of the Space Shuttle Program.

Peterson retired from the Air Force after more than 24 years with the rank of colonel, and resigned from the Astronaut Office in November 1984. He continued to work full time as a manned spaceflight consultant until 1993. **— A.K.**

Black hole is caught devouring a star



CRIME SCENE. This artist's concept shows a tidal disruption event (TDE), which occurs when a supermassive black hole tears apart a star and launches a relativistic jet. The background image was taken by the Hubble Space Telescope and shows Arp 299, the colliding pair of galaxies within which the TDE was found. SOPHIA DAGNELLO (NRAO/AUI/NSF); NASA; STScI

Astronomers Seppo Mattila and Miguel Pérez-Torres usually study the natural deaths of stars, but they couldn't pass up the chance to investigate a grisly stellar murder.

In a paper published June 14 in the journal *Science*, they describe capturing photographic evidence of a supermassive black hole as it tore up and consumed part of a star in a tidal disruption event (TDE), spewing out powerful jets of material in the process. Scientists have observed such cosmic crime scenes before, but this is the first time anyone has obtained such detailed images of the jets and their evolving structure.

In January 2005, Mattila, an astronomer at the University of Turku in Finland, found a bright flash of infrared light in Arp 299, a colliding pair of galaxies roughly 140 million light-years away. The source was near the center of one of the galaxies, which harbors a thick ring of dust surrounding its supermassive black hole. Later that year, Pérez-Torres, an astronomer at the Instituto de Astrofísica de Andalucía in Granada, Spain, found a bright source of radio light at the same location while conducting a separate study on supernovae. The two joined forces to ultimately lead a team of more than 30 scientists in investigating the bright emission.

Over the course of 10 years, the researchers saw that the source of the radio emission had started as a bright blob before extending into a jetlike structure moving at nearly the speed of light. These clues pointed not to a supernova, which would emit a spherical shell of light, but to a TDE, which can churn out jets of material at relativistic speeds.

This event could be the first TDE ever seen in a galaxy whose supermassive black hole is actively feeding from a disk of material. In the past, astronomers have only observed galaxies with relatively tame central black holes. These results show that such stellar murders can happen anywhere, bringing astronomers one step closer to understanding the violent behavior of black holes.
— Erika K. Carlson, Jake Parks

QUICK TAKES

KEEPING PACE
In a national survey of over 2,500 adult Americans, 72 percent stated they believe it is essential for the U.S. to remain a global leader in space exploration.

STRIKING DISTANCE
NASA's Dawn spacecraft has entered its lowest and final orbit around the dwarf planet Ceres. The probe now orbits within 22 miles (35 kilometers) of the icy world's surface.

NEW ORIGINS
A study investigating Pluto's chemical makeup suggests the icy dwarf planet was formed out of roughly a billion comets or other Kuiper Belt objects.

SKA BAND
Spain has joined the Square Kilometer Array, a massive interconnected web of radio telescopes, as the partnership's 11th member.

EMBRYONIC DUST
Researchers confirmed samples of interplanetary dust found in Earth's upper atmosphere contain particles from the solar system's formation.

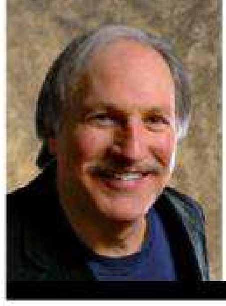
LIGHT BLOCKERS
Small clouds of obscuring dust may explain the complex and puzzling features observed in active galactic nuclei — the bright cores of large galaxies.

ENCORE
NASA's Juno spacecraft will continue studying Jupiter until July 2021 under a 41-month mission extension, providing time to meet all of its primary scientific goals.

TABBY'S PALLS
A team of teenage students showed that Tabby's star may dim erratically when multiple dust clouds pass in front of the star simultaneously.

SAFE ZONE
Recent simulations show that double- and triple-star systems have large stable regions where habitable exoplanets can exist.

MOON MATH
New geochemical-based calculations show that 1.4 billion years ago, Earth rotated once every 18 hours, 41 minutes. Thank the Moon for our current longer day. **— J.P.**



STRANGE**UNIVERSE**

BY BOB BERMAN

The fear effect

This Halloween, beware the scares from above.

Above: The Pleiades star cluster has long been associated with catastrophe. This infrared image, colored to show light at longer wavelengths as red, lends the familiar sight a more sinister look. NASA/JPL-CALTECH

Left: Mars is a scary place — if you read science fiction, that is. This crescent shot shows the Red Planet largely in shadow, but the nearby world will shine brightly this Halloween. KEVIN GILL

Politicians know it. So do pharmaceutical companies. What is "it"? We're talking about the power of fear to drive human behavior.

Some fears are common but elicit little sympathy, like coulrophobia (fear of clowns), which is exploited in horror movies. Others are rare, like turophobia (fear of cheese).

In many cases, being scared is simply an accepted part of life, like when kids terrorize their younger siblings. That's so traditional that each generation takes pride in dreaming up new ways to do it.

Most cultures have some holiday or tradition where scaring people — even total strangers — is sanctioned. Around here, that scary celebration is Halloween. In cities, where omnipresent streetlights eliminate the fear-of-darkness factor, the sky plays a negligible role. But in rural regions, yon inconstant Moon greatly changes the game from year to year.

Halloween is supposed to be scary. And 2018 is a *very* scary Halloween.

First of all, the Moon will be totally absent, so it'll be maximally dark. The Moon won't rise until after midnight, after most festivities are long over.

The Moon's absence is important because fear of darkness is a primal phobia, even if some surveys say it's topped nowadays by the fear of spiders. Moreover, darkness takes several forms. This time of year finds the sunset getting rapidly earlier. The loss of solar energy causes food production to shut down entirely, which has produced a sense of dread since time began. While this month of harvest, canning, and preserving still offered lots to eat, it's also when communities used to wonder what kind of winter lay ahead, and whether they'd survive the coming hardship.

Trees are suddenly barren. The greenery is gone. Birds have already headed south. Bears are eating everything in sight and will soon hibernate. The rats are deserting nature's sinking ship. It was in this disconcerting natural setting that Halloween was created, as pagan festivals merged with the Christian feast of Allhallowtide, in which the faithful were supposed to remember the dead.

Remember the dead? Just when nights are getting cold, frost is killing our final veggies, and flowers are vanishing along with pretty colors and nice fragrances? Depressing stuff. Couldn't they have diluted the morbid "remember the dead" theme and moved it to coincide with Fourth of July barbecues and beach picnics? Why hold it just when we're dealing with midterms and dead roses?

It's actually not all doom and gloom. A happier, light-based influence is the clock-changing ritual. Until 2007, clocks fell back to standard time in late October before Halloween, which made darkness descend before trick-or-treat festivities were complete. But the switch to the first weekend in November means it's still light until 6 or 6:30 P.M.

So much for Spook Night's more obvious aspects. Now for the stuff known mainly by astronomers, which the mass media may or may not latch onto and publicize.

We already cited the Moon's 2018 pre-midnight absence as Scare Factor One. Scare Factor Two is Mars. At 8 P.M., the typical peak of festivities, Mars is the brightest "star" in the whole sky. It's also then prominently due south on the meridian. Its distinct ruddy color has always conjured images of fire and blood, a happy item for no culture. Sitting in Capricornus places Mars only about one-third of the way up in the sky, which will make it eye-catching, since people tend not to crane their necks and notice overhead objects.

Mars has got a sinister rep, of course. Sci-fi books and films from H.G. Wells' *The War of the Worlds* onward have made the Red Planet the home of the Bad Guys, whether green-colored thugs in the John Carter books or obnoxious martian transplants in *Total Recall*. And the ominous world dominates the sky on Halloween.

Those with more classical sensibilities can look to the east at that same early hour of 8 P.M. and see the Pleiades rising. Though a gorgeous sight in binoculars, the blue star cluster had a sinister reputation for centuries — Scare Factor Three. Ceremonies that commemorated loss of life and catastrophe were focused on the Pleiades, along with the sad legend of "the lost Pleiad," which explains why only six of the seven stars are easily visible to the naked eye. Some historians speculate that the Pleiades might have been prominent when a volcano devastated the island of Thera (present-day Santorini) in the Aegean Sea in 1646 B.C., wiping out the advanced Minoan civilization on nearby Crete and perhaps giving rise to endless myths of Atlantis and lost civilizations.

And finally, if you then let each sporadic meteor remind you of the historic big ones that delivered mass extinctions, you'll find plenty in the sky to fear. That's Scare Factor Four.

Perfect. You'll be in sync with Halloween.

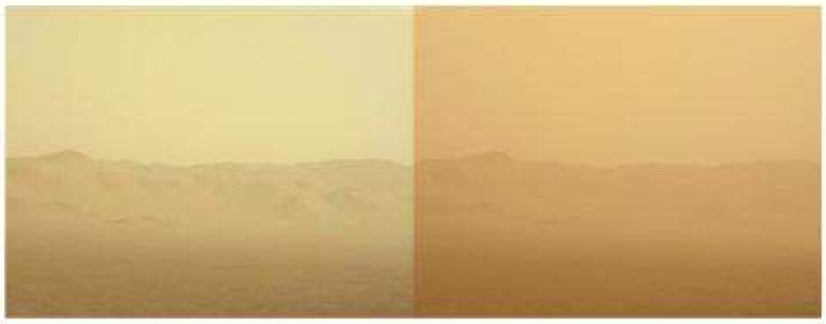
Join me and Pulse of the Planet*'s Jim Metzner in my new podcast,* Astounding Universe, *at* **http://astoundinguniverse.com.**

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

ASTRO**NEWS**

END OF AN ERA. Astronaut Peggy Whitson, NASA record-holder for most cumulative days in space, has retired after an illustrious career.

Dust storm engulfs Mars



NASA/JPL-CALTECH/MSSS

THE APPROACHING STORM. Curiosity snapped these images just three days apart. The shots show the increasing amount of dust in the martian air.

On June 10, less than two weeks after NASA's Mars Reconnaissance Orbiter first detected a building martian dust storm, the 14-year-old Opportunity rover transmitted data to Earth showing the opacity of Mars' atmosphere (a measure of dust) was twice as high as measured previously.

Opportunity then fell silent, conserving energy until the skies clear and its solar panels were again able to generate power for the rover's batteries. By June 20, NASA had upgraded the storm to a Planet-Encircling Dust Event that would cover an area roughly equal to North America and Russia combined.

Regional dust storms on Mars are common, but scientists aren't sure what causes them to grow to global scales. Storms are typically triggered by warming as the planet approaches its closest point to the Sun; temperature contrasts generate winds that pick up and spread fine surface dust grains. As the polar ice caps melt, additional carbon dioxide in the atmosphere increases surface pressure and suspends the particles in the air, sometimes in clouds reaching up to 40 miles (60 kilometers) high.

NASA's Curiosity rover relies on a nuclear-powered battery and continues to work, albeit under a haze of dust eight times thicker than previously seen above its position in Gale Crater. The rover's engineers estimate minimal impact to the rover's hardware from the storm, though they are pointing the rover's camera downward between uses to minimize the effects of blowing dust on the optics.

Though the storm diminished viewers' enjoyment of this year's Mars opposition, it will improve our understanding of how such storms arise, evolve, and impact the planet. With rovers on the surface and orbiters circling overhead, Mars is under constant surveillance, with instruments offering detailed, high-resolution views of this global event. **— A.K.**

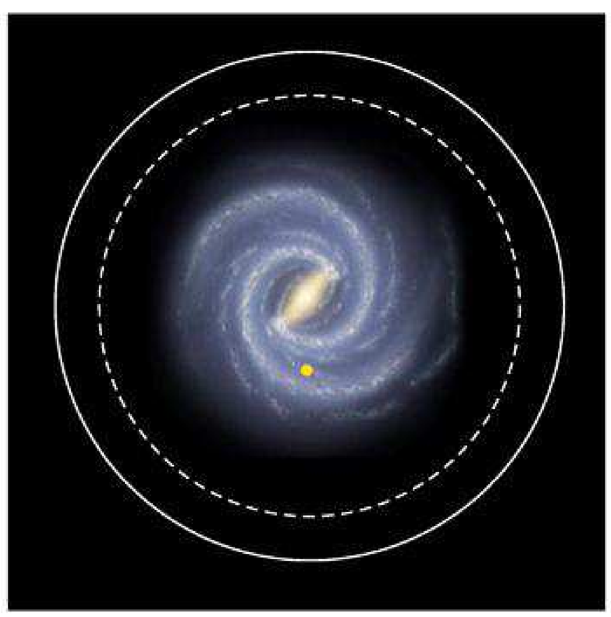
The Milky Way is larger than we thought

Measuring the size and mass of distant galaxies can be challenging. But, because we are trapped inside it, astronomers struggle most to develop an overarching picture of the Milky Way's structure, size, and mass. Two recent studies, however, have now improved that picture.

The first study, led by Martín López-Corredoira of the Instituto de Astrofísica de Canarias (IAC) in the Canary Islands and published May 7 in *Astronomy & Astrophysics*, found that the diameter of the Milky Way's spiral disk is about 200,000 light-years. This doubles the oft-stated estimate of 100,000 light-years.

The team arrived at this measurement by tracking stars that appear in the APOGEE and LAMOST catalogs, which provide information about stars' motions and chemical composition, also known as metallicity. "Using the metallicities of the stars in the catalogs from the high-quality spectral atlases of APOGEE and LAMOST, and with the distances at which the objects are situated, we have shown that there is an appreciable fraction of stars with higher metallicity, characteristic of disk stars, further out than the previously assumed limit on the radius of the galaxy disk," said co-author Carlos Allende, also of IAC.

The second study, led by Ekta Patel at the University of Arizona and published April 17 in *The Astrophysical Journal*, tracked the three-dimensional motions of nine of the Milky Way's satellite galaxies to measure our galaxy's mass. The Milky Way's mass affects the way the satellites move by influencing the speed and direction of their orbits. Previous estimates of the galaxy's mass have ranged from 700 billion to 2 trillion solar masses. This new result pins the number at 0.96 trillion solar masses. The authors say their measurement will only improve in accuracy as more data on the motion of the Milky Way's satellites become available from large-scale surveys conducted by the Gaia satellite and the upcoming Large Synoptic Survey Telescope. **— A.K.**



A BIGGER HOME. This artist's rendering shows the Milky Way as it was previously pictured at 100,000 light-years across (colored regions). A new study estimates a 99.7 percent and 95.4 percent probability that disk stars lie outside the dashed and solid lines, respectively, increasing the estimated diameter of our galaxy to 200,000 light-years. A yellow dot shows the Sun's position. R. HURT, SSC-CALTECH, NASA/JPL-CALTECH

ASTRONEWS

COSMIC CRUCIBLES. Supermassive stars roughly 10,000 times the mass of the Sun may be responsible for the unique chemical makeup of ancient globular clusters, new research suggests.

Mars rover detects seasonal surge in methane, finds hidden organics

In June, NASA announced the Mars Curiosity rover had uncovered new evidence of methane — a potential indicator of life — as well as signs of organic compounds buried in ancient martian mudstone. Though the finds are far from evidence of alien life, the results are still tantalizing.

This announcement was tied to two papers published June 8 in the journal *Science*. One study focused on the methane and the other looked at the organics.

In the first paper, a team analyzed three Mars years' (55 Earth months) worth of atmospheric data from Curiosity. During that time, the rover caught methane levels spiking as the seasons changed, growing several times stronger at the height of summer in the northern hemisphere.

The scientists believe that heating causes the release of methane trapped in permafrost beneath the planet's surface. They suspect large amounts of the gas may be frozen in such underground reservoirs, but its exact origin remains a mystery.

The second study examined drill samples of 3 billion-year-old mudstones that Curiosity collected from two different sites in Gale Crater, which was formed by an asteroid impact that exposed multibillion-year-old sedimentary rocks. When analyzed in the rover's onboard lab, the rocks released organic molecules much like those found in organic-rich rocks on Earth.

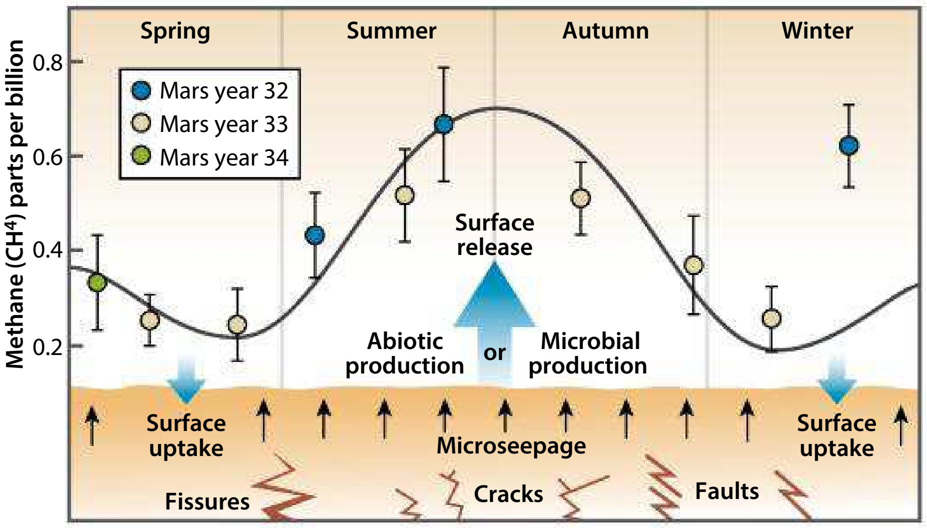
This is not the first time Mars researchers have claimed to find methane on Mars; in the past half-century, many teams have found potential evidence of methane in the martian atmosphere, yet further proof has been scarce. However, this time, the researchers were able to watch the signal come and go. What's far less certain is exactly what it means.

Methane, a hydrocarbon, is a common molecule composed of four hydrogen atoms and one carbon atom. It's also fragile, meaning its chemical bonds are easily broken. On Earth, atmospheric methane doesn't last long — only about nine years, on average. This suggests the martian methane formed relatively recently.

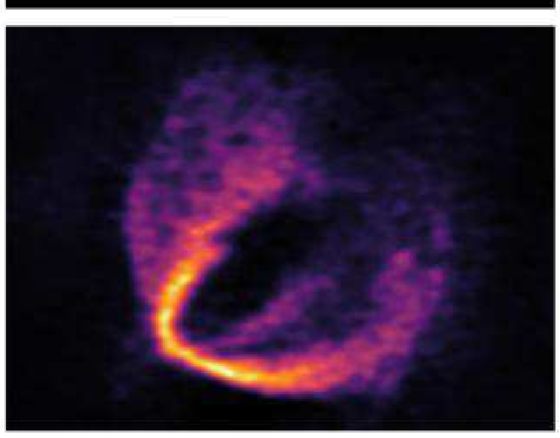
On Earth, living things churn out methane: Cows and other livestock produce enormous amounts of this greenhouse gas. Life-forms known as methanogens also produce methane. And when living things die, their hydrocarbons are eventually incorporated into stores deep underground or in permafrost. On Earth, methane is a sign of life, and that has given astronomers good reason to see methane as a potential signal of microbes on Mars.

Yet life isn't the only process that makes methane. So to truly find out what's causing these seasonal surges of methane, we'll need new Mars missions capable of better searching for definitive signs of life. NASA's Mars 2020 rover, launching in a few years, is custom-built for this purpose. And the European Space Agency's ExoMars rover should soon follow with similar aims.

Whatever the final cause, we're now closer to finding the source of Mars' methane than ever before. **— Eric Betz, J.P.**



METHANE MADNESS. Researchers used the Curiosity rover to track the amount of methane present in the martian atmosphere over the course of three years, while also tallying possible sources and sinks of methane. Their results show that methane levels spike during the peak of summer in the northern hemisphere, then wane during other parts of the year. *ASTRONOMY*: ROEN KELLY AFTER NASA/JPL-CALTECH



ESO, ALMA (ESO/NAOJ/NRAO); PINTE ET AL.

ALMA spots three newborn planets

BABY PICTURE. Using ESO's Atacama Large Millimeter/submillimeter Array (ALMA), two teams of astronomers have demonstrated a new way of detecting planets in the dust- and gas-filled disks that surround infant stars and birth their planets. The teams studied the motions of carbon monoxide (CO) gas within the disk of HD 163296, a 4 million-year-old star just 330 light-years away. ALMA, which can detect CO molecules at millimeter wavelengths, tracked subtle changes in wavelength due to the Doppler effect to reveal the motion of the gas. The data show three distinct areas with small-scale motion differing from their surroundings by just a few percent. Such motion suggests interactions with massive objects within the disk, believed to be infant planets. This novel, precise method could be an exoplanet-hunting game changer. **— A.J.**

RELATIVE SPEEDS OF THE PLANETS

ROUND THE BASES. It's World Series time. To picture how fast each planet travels relative to its neighbors, imagine a baseball diamond. For this comparison, a home run represents one orbit of Earth. **— Michael E. Bakich**

Mercury: Four times around, plus 54.2 feet (16.5 meters) toward first base

Venus: Once around, plus 45.2 feet (13.78 m) past second base

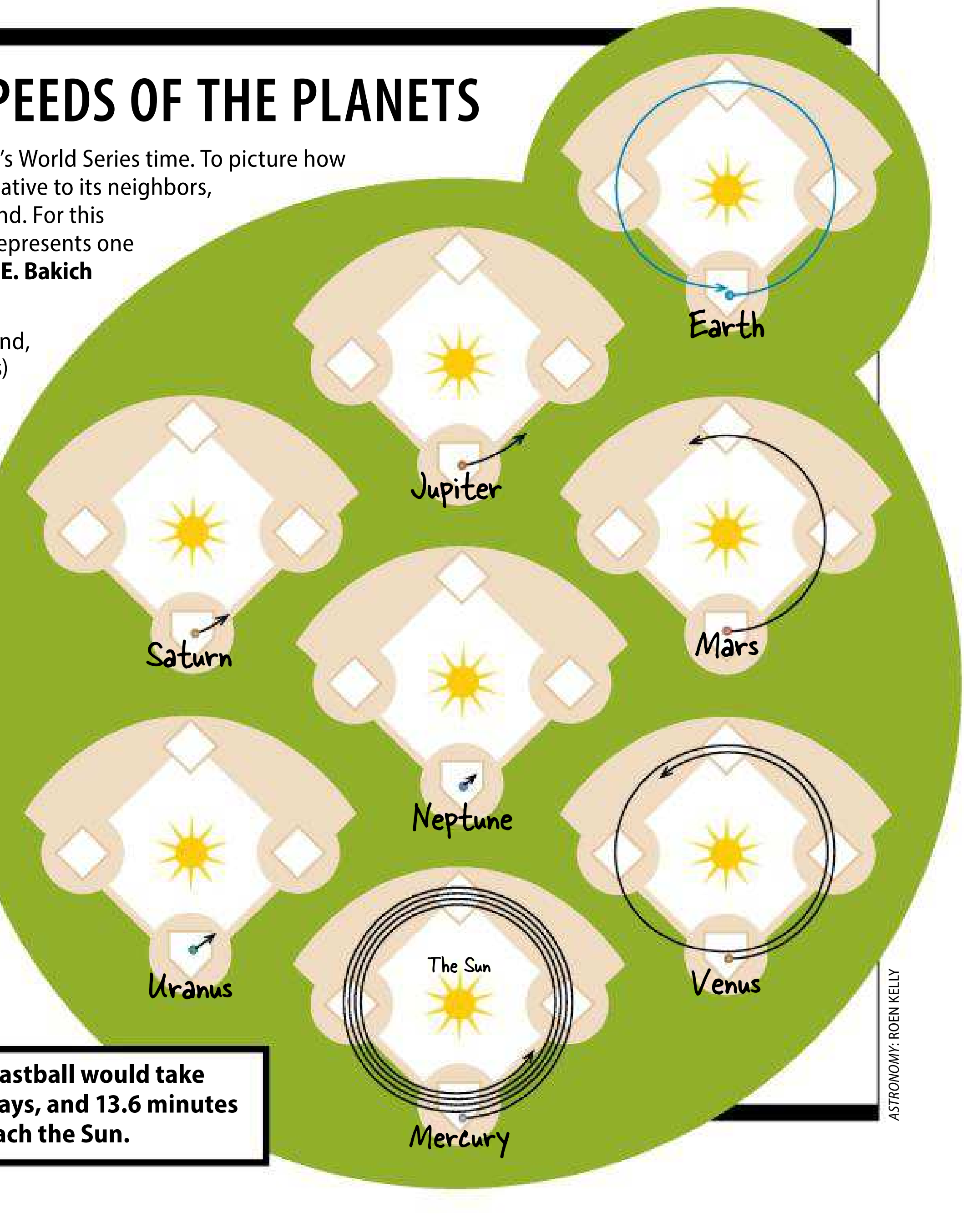
Mars: 11.4 feet (3.47 m) past second base

Jupiter: 30.4 feet (9.27 m) toward first base

Saturn: 12.2 feet (3.72 m) toward first base

Uranus: 4.3 feet (1.3 m) toward first base

Neptune: 2.2 feet (0.67 m) toward first base



ASTRONOMY: ROEN KELLY

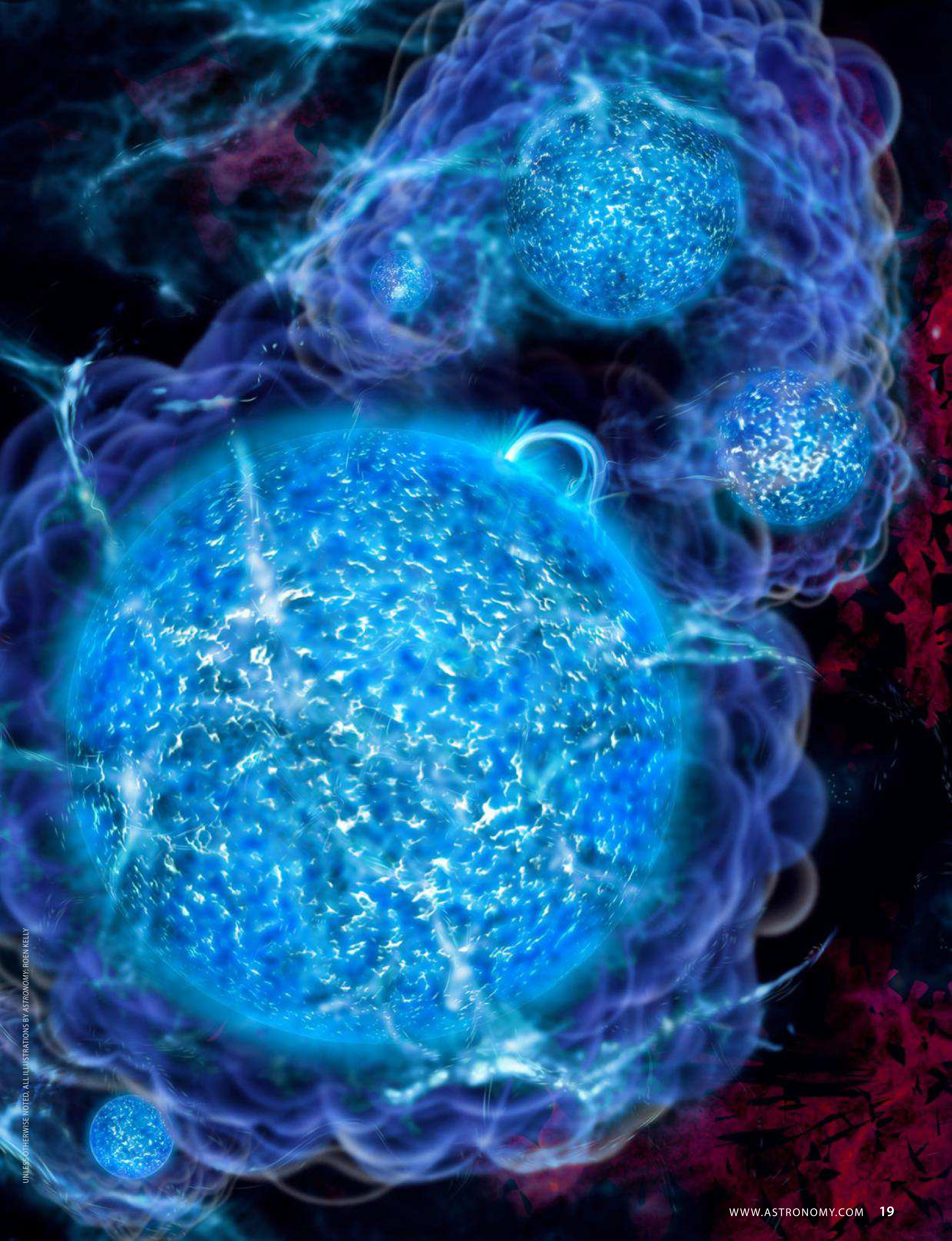
FAST FACT

A 100 mph fastball would take 106 years, 16 days, and 13.6 minutes to reach the Sun.

Dark stars
COME INTO THE LIGHT

With help from dark matter annihilation, some of the universe's earliest stars were able to grow much larger than they would otherwise.

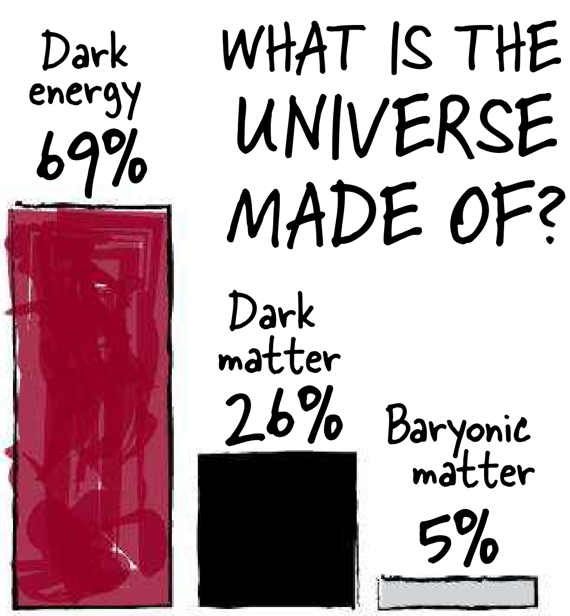
by Mara Johnson-Groh


UNLESS OTHERWISE NOTED, ALL ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

LONG, LONG AGO,

the universe looked very different than it does today. When the Big Bang was a recent memory and the first stars were forming and beginning to shine, the universe was much smaller. In this dense environment, a mysterious substance known as dark matter ran amok in infant galaxies. Scientists think that out of this rich environment, a new breed of star was born: dark stars.

Dark stars are somewhat of a misnomer — they're not actually dark. In fact, they're likely some of the biggest and brightest stars in our universe. Yet no one has ever seen one. These giants, powered differently than the stars we see in the night sky, may reveal a lot about the true nature of our universe — that is, if scientists can ever actually find a dark star.

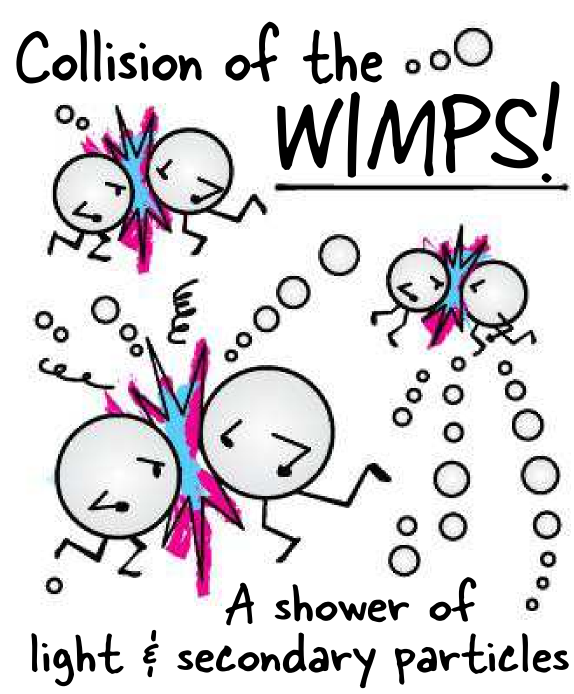


Back to the beginning

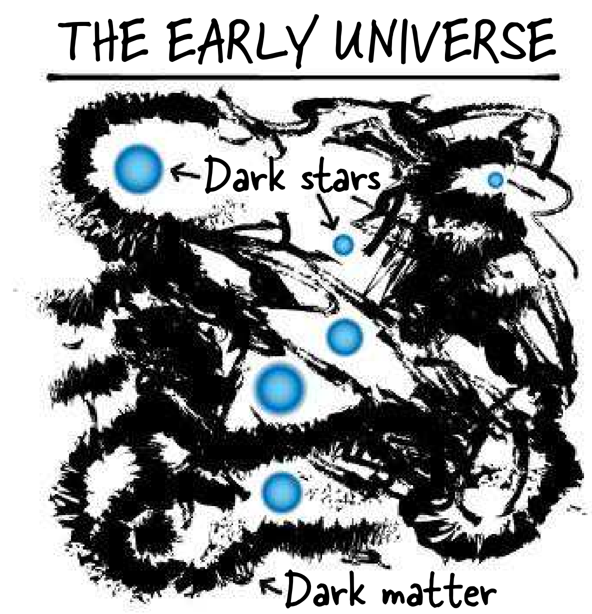
Everything we see in the universe today makes up only 5 percent of what is known to be out there. The majority, about 69 percent, is dark energy — the unknown driver that scientists believe is causing the accelerating expansion of the universe. Dark energy doesn't seem to interact with the normal type of matter our world is composed of, called baryonic matter — even gravitationally.

The remaining 26 percent of the universe is dark matter. According to some predictions, hundreds of these dark matter particles zip through your body every second. Fortunately for us, this type of matter, though it follows the laws of gravity, does not interact with the baryons our bodies are composed of. Unfortunately for researchers, this makes it extremely difficult to study. Dark matter emits no light, so it can only be probed indirectly through its gravitational fingerprints, such as the way it bends light around massive galaxies. For the most part, researchers must rely heavily on models to make informed predictions about the nature of this elusive material.

A leading theory on dark matter predicts the substance is in the form of weakly interacting massive particles — WIMPS for short. This class of particles is a natural consequence of the idea of supersymmetry, which is a part of the accepted standard model of particle physics, explaining how particles interact with each other and the fundamental forces of the universe.



Supersymmetry theory proposes that each type of particle has an identical, oppositely charged partner called an antiparticle. (Since WIMPS have no charge, they act as their own antiparticles.) When these partners — the particle and antiparticle — meet, they collide with a bang, utterly



destroying one another in a shower of light, energy, and, in some cases, newly conceived lighter particles.

The universe's first stars didn't form overnight. It took around 200 million years after the Big Bang for star formation conditions to ripen — a process in which dark matter played a key role. Dark matter, ruled by gravity and unabated by interactions with light or baryonic matter, was the first material to start clustering in patches. Baryonic matter quickly followed and soon formed clumps a million times more massive than the Sun. These minihalos, as they are termed, became the nurseries for the first generation of stars, and they would eventually evolve into galaxies.

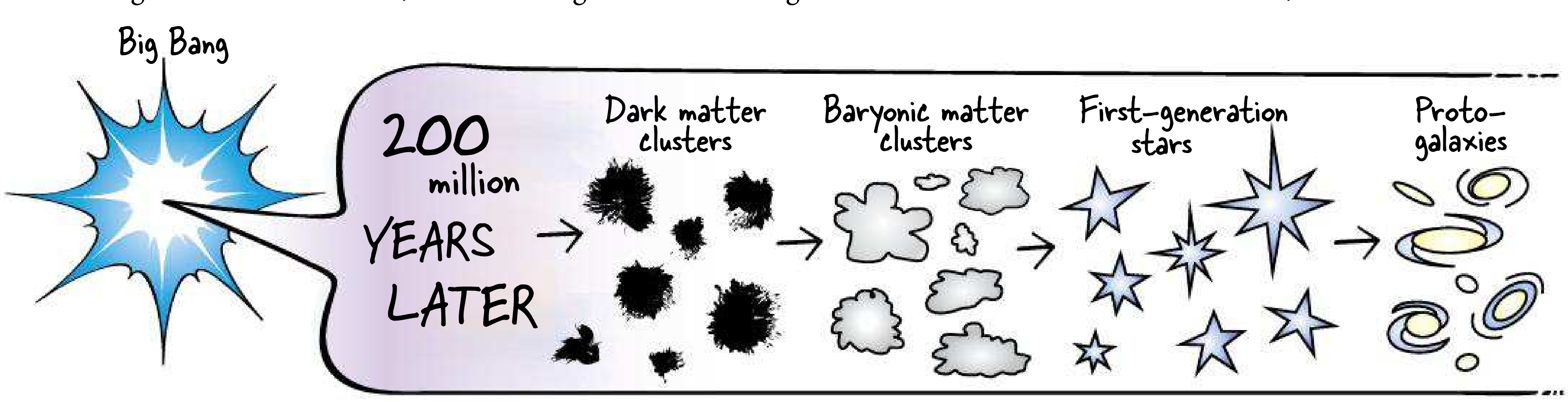
Back then, the universe was a denser and more compact place, and the WIMP partners tangoed with tenacity, continually annihilating each other in energetic blasts. During this time, WIMPs may have been swept up in the gravitational clutches of giant gas clouds. And as these clouds condensed to form early stars, they would have taken the WIMPs along for the ride.

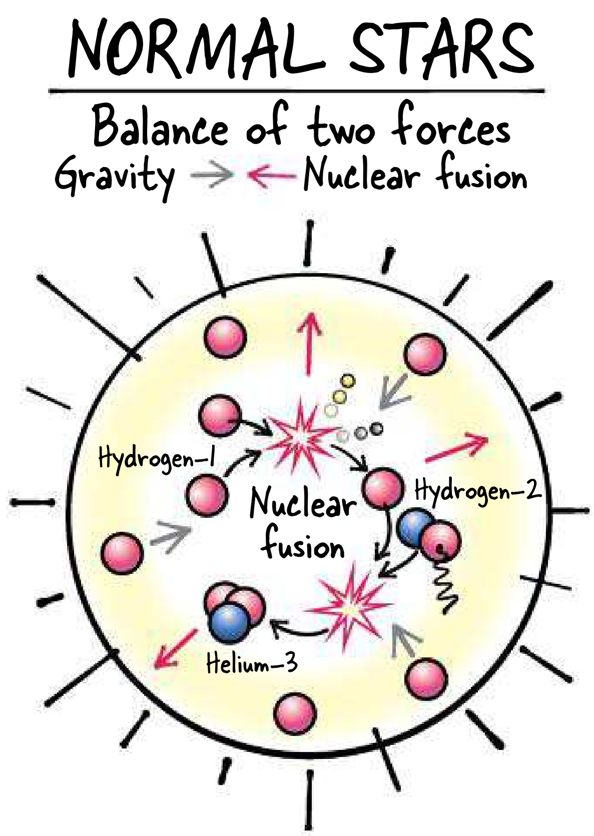
Dark stars may help solve a long-standing mystery concerning how supermassive black holes — like the one believed to reside at the center of the Milky Way, shown here — formed in the early universe. Current theories indicate that black holes cannot accumulate material fast enough to reach supermassive status within a billion years of the Big Bang, but some astronomers believe massive dark stars may have helped kick-start the formation of these giant black holes. JON LOMBERG

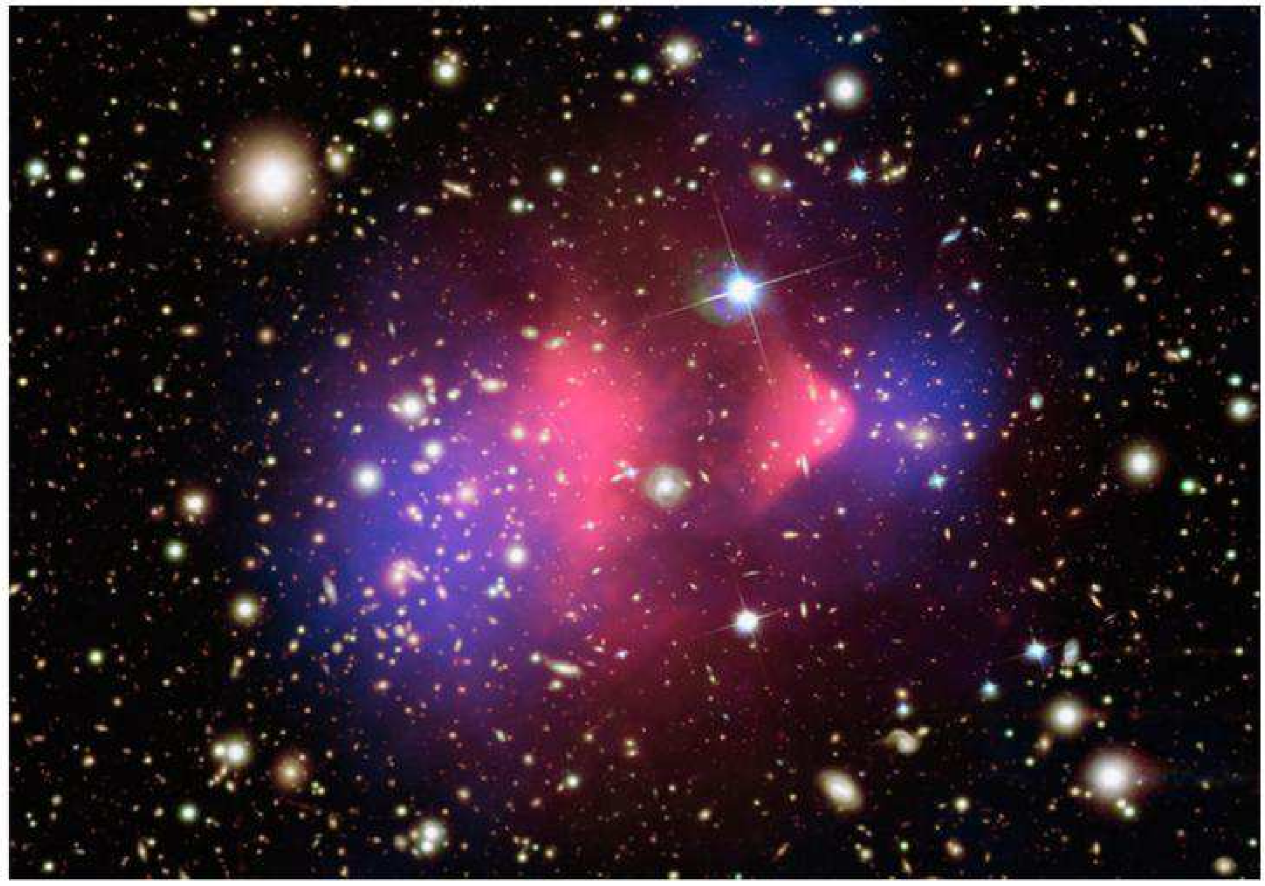
Stars are normally supported by a delicate balance of forces: Gravity pulls the stellar atoms toward the center, while the forging of hydrogen into helium — the way a star powers and lights itself — creates an outward pressure. Annihilating dark matter throws a wrench into this system, with the energy from annihilation adding a powerful outward force. During star formation, the particles' annihilations would have at some point prevented the star from contracting further. At this time, the star would not have reached the density required to begin nuclear fusion, so the outward force generated by annihilating dark matter would solely balance the inward force of gravity.

Born in the dense early universe, these stars may have started out the size of our own Sun, but could have quickly grown a million times larger as they collected more material from their surroundings. But because they were heated in a different way, they were able to grow to much larger sizes than normal stars. (Dark stars would have been puffy giants. If one replaced the Sun, its extent would reach out past the orbit of Saturn.) Yet despite their immense size, it wouldn't have taken much dark matter to fuel them.

"[Dark stars] are almost entirely made of hydrogen. Only one part in a thousand is dark matter," says Katherine Freese, theoretical







The Bullet Cluster is a colliding pair of galaxy clusters some 3.7 billion light-years from Earth. Gravitational lensing studies of the Bullet Cluster have shown there is an offset between the overall mass and the baryonic mass of the galaxies, providing some of the strongest evidence yet for the existence of dark matter, which appears in blue in this image. NASA/ESA/STScI

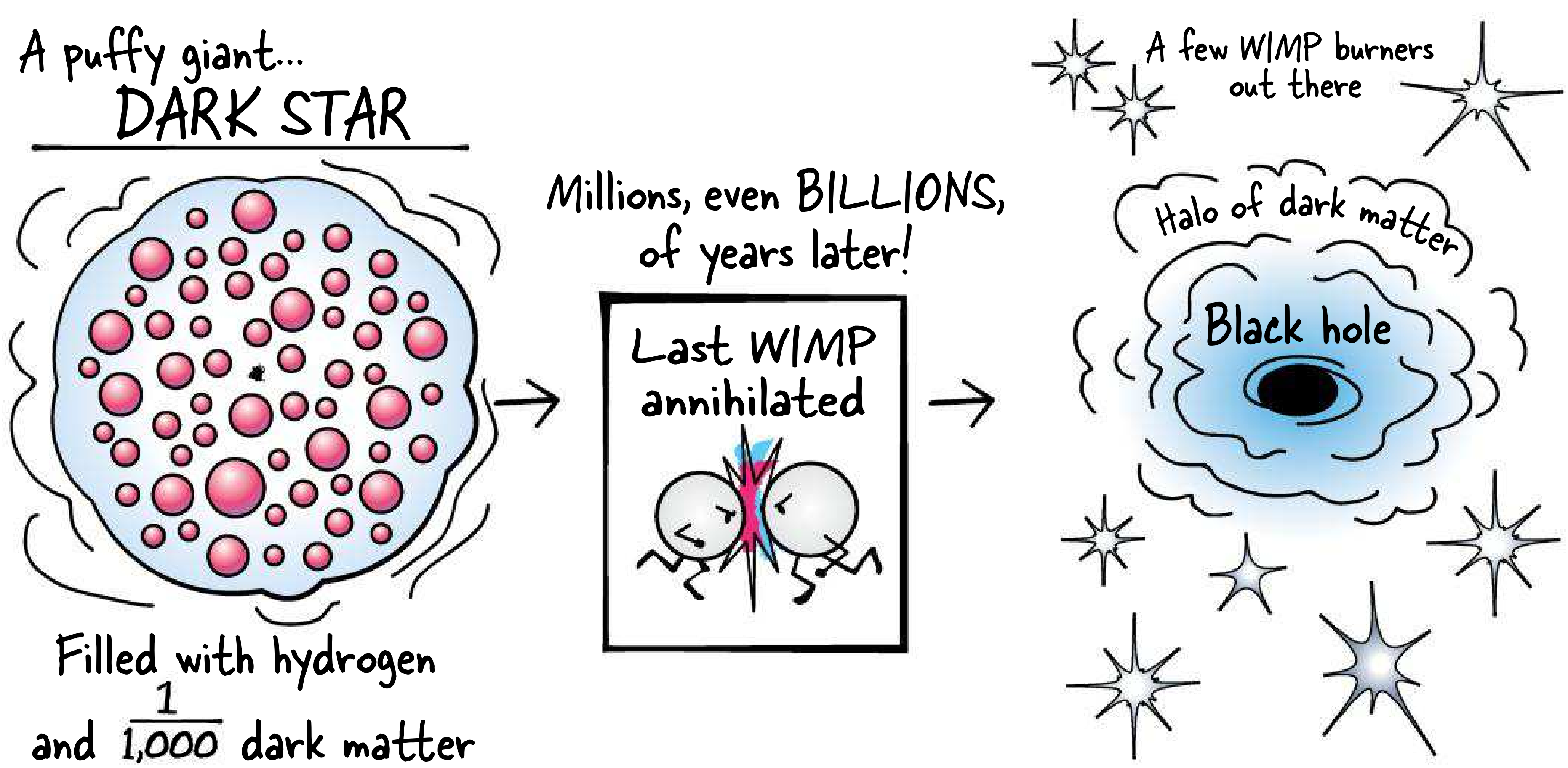
astrophysicist at the University of Michigan. Freese has pioneered the study of dark stars, which she conceived with colleagues a decade ago.

Even at such a small amount, the dark matter fuel in a dark star is likely to power that star for millions or even billions of years. But as the last WIMPS annihilate, the star would have nothing remaining to counteract the force of gravity, and so it would begin to contract again. The smaller dark stars — a relative term meaning those only 100 times the mass of the Sun — would start nuclear fusion, giving them the power to sustain life as an active star a bit longer.

In today's expanded universe, the density of dark matter is much too low for it to power stars in the way it may have near the beginning.

"There is some dark matter going through the Earth and Sun," says Freese. "As the dark matter passes through, it collapses to the center where it annihilates. But it's not providing a heat source because there is not enough of it around."

Only at the centers of galaxies, where the dark matter density is highest, could dark stars potentially reside. Some scientists have predicted that there may be a few "WIMP burners" — white dwarf and neutron stars at the centers of galaxies — that have captured enough dark matter to at least partially fuel them. This extra power source likely would change the evolution and appearance of the star, acting like a stellar youth serum. Typically, these stars fade and cool at the ends of their lives, but the additional source of dark matter fuel would keep them abnormally hot,



making them look much younger than they actually are. Theoretically, these stars should be observable, though none have been found to date.

Cosmic clues

Eventually all dark stars collapse into black holes. Indeed, these unique stellar objects might help solve a long-standing mystery of the early universe: the origin of supermassive black holes. Observations have found numerous giant black holes — a million to a billion times the mass of the Sun — in the early universe, but theorists are uncertain how such massive black holes could have formed in so little time.

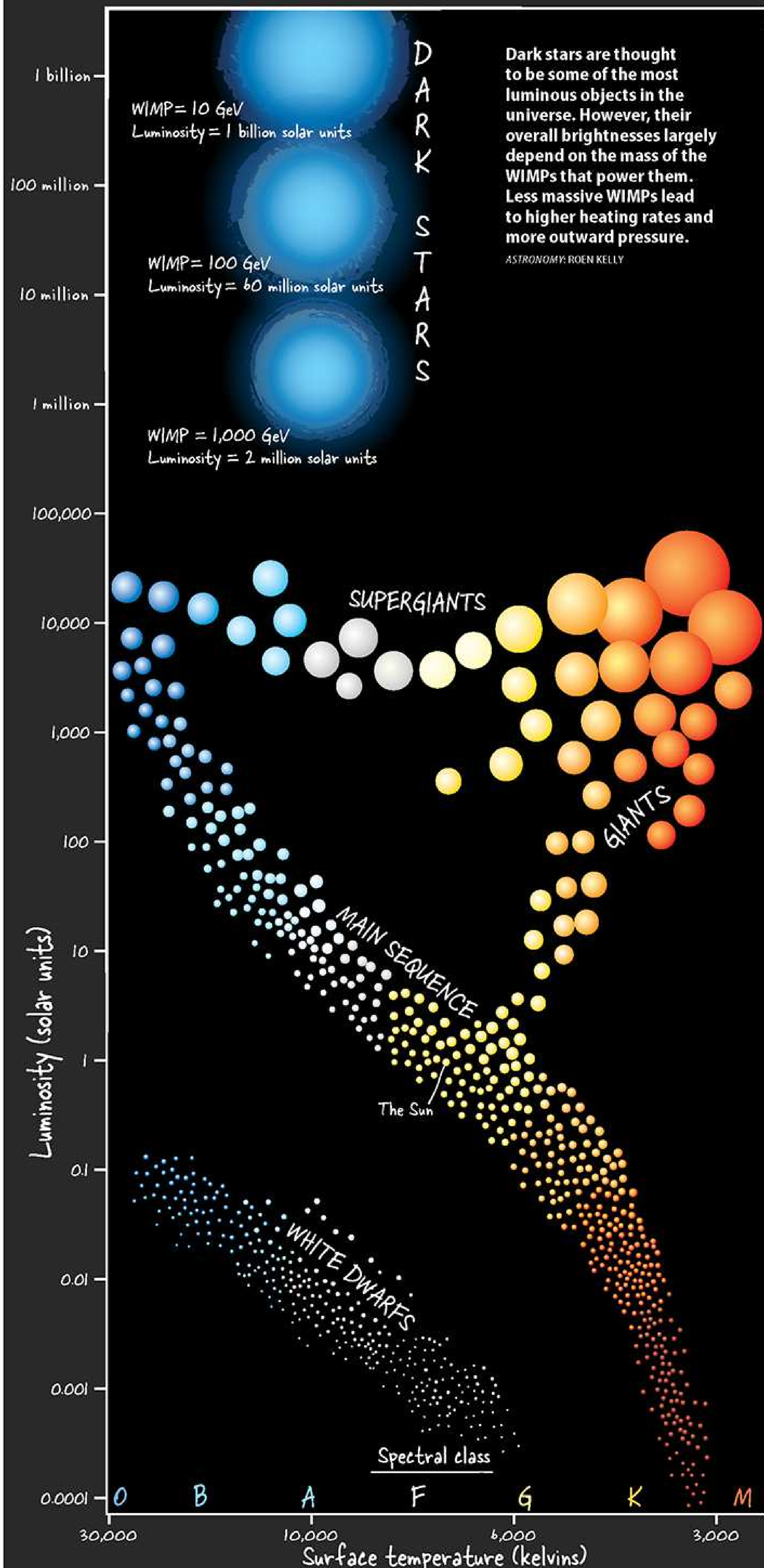
Standing theories for black hole formation have limitations on the speed at which a black hole can accumulate mass. These speeds are far below that necessary for a supermassive black hole to form within the first billion years of the universe, where many have been found. Dark stars, which can grow much larger than typical stars and thus create much larger black holes, could represent one seed from which supermassive black holes may have grown in the early universe. "Currently there really is no good answer, and this could provide a solution," says Freese of supermassive black hole formation.

Dark stars, if discovered, could also help scientists better understand dark matter. "The physics of the dark stars, and the way we observe them, potentially will then tell us about the dark matter particle that underlies it," says Tanja Rindler-Daller, an astrophysicist at the University of Vienna. "Some of these stellar properties depend on the mass of the dark matter particle."

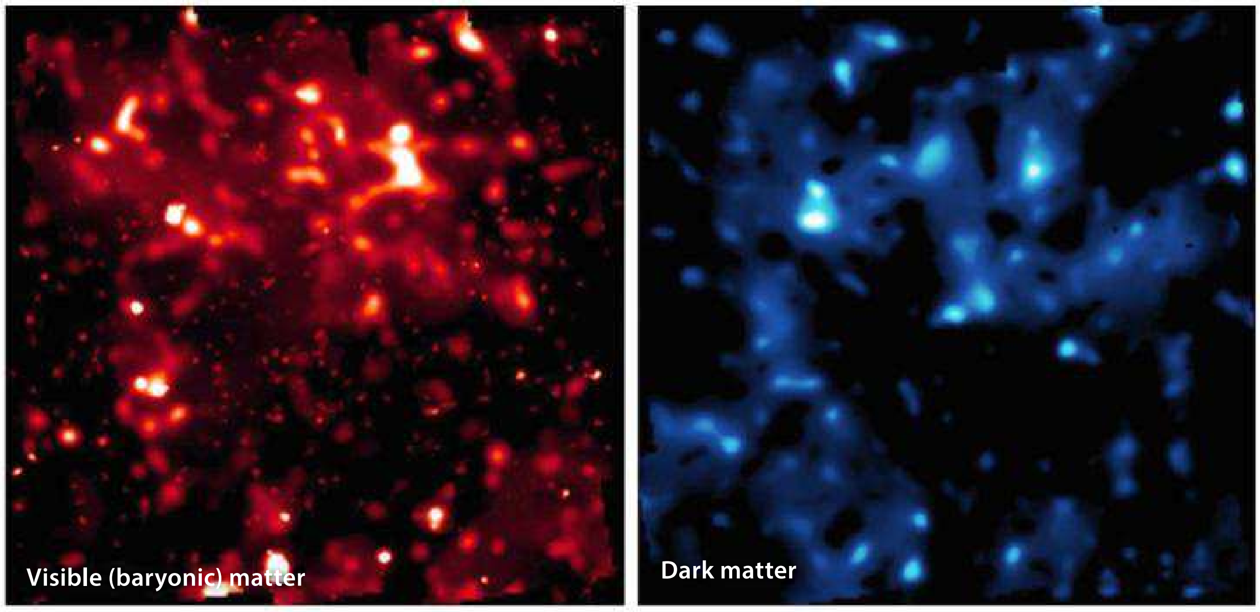
Rindler-Daller studies dark stars with computer models, specifically looking at ways the stars might pulsate. Many stars periodically expand and contract, causing their light to pulse, and dark stars might show this behavior as well. Comparing different models, Rindler-Daller discovered that different masses of WIMPs would lead to different periods of variability in the dark stars. If observed, these pulsations could be one way to measure the mass of WIMPs.

The pulsations could also eventually be used as a measuring stick in the early universe. Cepheid variable stars, whose pulsations and physics are known in

Dark stars burn brightly



Dark stars are thought to be some of the most luminous objects in the universe. However, their overall brightnesses largely depend on the mass of the WIMPs that power them. Less massive WIMPs lead to higher heating rates and more outward pressure. *ASTRONOMY*: ROEN KELLY



These false-color images captured by the Hubble Space Telescope compare the distribution of normal matter (red) to dark matter (blue) in the universe. The map covers an area of the sky nine times larger than the Full Moon, making it one of the best maps of dark matter ever obtained. NASA/ESA/R. MASSEY

great detail, have been used extensively to measure the distances between galaxies. However, Cepheids are not bright enough to be seen in the early universe — at what astronomers refer to as high redshift.

"Dark stars are harder to use because we would need to study them in detail once we found them," says Rindler-Daller. "Only once we understood them, we could then also use this as an indicator to measure the distance to galaxies at high redshift."

While it's theoretically possible to use dark stars to measure the universe, it would require finding many of these objects. And for now, scientists are simply hoping to find one.

Seeing in the dark

No current telescope is powerful enough to see a dark star in the early universe. But this will soon change. The James Webb Space Telescope, the successor to the Hubble Space Telescope, is set to launch in 2021. With a 6.5-meter primary mirror and special instruments built for capturing infrared light, the James Webb should be able to see protogalaxies and dark stars, should they exist, in the early universe.

"There's not a whole lot around in the early universe, so there's not much competing stuff. The standard first stars without dark matter are too small and too faint to be seen by James Webb," says Freese. If something extremely luminous is found in the early universe, dark stars will be a leading candidate. However, dark stars will still need to be big enough and bright enough in order to be seen.

"If dark matter is made of WIMPS, I really believe dark stars exist. Now if they start out at one solar mass and start accreting, the question is how big can they get before the accretion stops?" says Freese. "If they stop at a thousand solar masses, then James Webb can't see them. So they might exist, but in my lifetime I'll never see them."

Dark stars could further be distinguished from other cosmic bodies in the early universe by the type of light they give off. Dark stars are relatively cool — only around 10,000 kelvins (17,500 degrees Fahrenheit, 9,700 Celsius) — and would radiate at longer wavelengths than warmer objects.

Pulsations such as those Rindler-Daller suspects would also be a dead giveaway, as no star is known to vary in that manner. Though dark stars should pulsate over periods of weeks, by the time the star's light reaches us, the expansion of the universe will have stretched out the light so much that the pulsations we observe will last over a period of a hundred days or more. Observing a dark star over such a lengthy period would be financially and logistically challenging, but it would provide the best proof for the stars' existence.

Even if the James Webb Space Telescope detects no dark stars, there might be other ways to find them. Gravitational wave detectors like LIGO have been pushing the boundaries of astronomy, finding signatures of colliding black holes and neutron stars. A collision between two dark stars could create gravitational waves that are detectable by these instruments, and would also yield signatures that may distinguish them from merging black holes.

Additionally, the next generation of ground-based telescopes, with mirrors 30 meters across, is at the drawing board. Infrared detectors on these telescopes could easily peer into the dusty interior of our galaxy. Astronomers may

When the James Webb Space Telescope launches in 2021, its unprecedented resolution will allow astronomers to observe some of the most distant objects in the universe, including dark stars — if they exist. In this image, six of Webb's 18 mirrors are being subjected to temperatures as low as 24 kelvins (–416 F, –249 C) to measure how the shape of each mirror changes. NASA/MSFC/DAVID HIGGINBOTHAM/EMMETT GIVEN

be able to find hidden near the center of the Milky Way old white dwarfs and neutron star WIMP burners whose lives have been extended, thanks to dark matter accretion.

It also may be possible to see the byproducts of WIMP annihilations. The black holes created by dark stars will likely have halos of dark matter that never made it into the star. The annihilation of this dark matter could produce enough gamma rays to be seen by NASA's Fermi Gamma-ray Telescope, which has been scoping out high-energy light from across the cosmos since its launch in 2008.

A shadowy future

While dark stars remain in the theoretical realm for now, their existence is inferred based on real science, and it may not be long until the first are found.

"The dark matter particle which underlies this dark star idea is really a very prominent one. It's the WIMP dark matter, which is still the most prominent and plausible candidate for dark matter," says Rindler-Daller. "These dark stars don't require some exotic dark matter no one has heard of — it's really the standard dark matter particles which would be able to have this effect on the first stars."

Though only a handful of scientists are currently dedicated to studying these objects, Freese expects the field to grow in the future. "We've made a prediction, so if you see something that looks like that, then the motivation for studying dark stars will go through the roof," she says.

In the meantime, scientists will continue searching for these peculiar objects, hoping to reveal more clues about how and where they might someday be found.

Mara Johnson-Groh *is a science writer and photographer who writes about everything under the Sun, and even things beyond it.*

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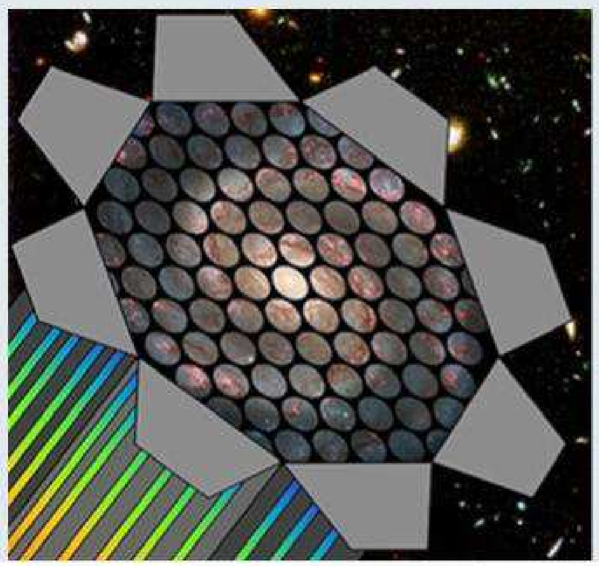
A citizen science success story

Zooniverse allows you to take part in cutting-edge research with nothing more than an internet connection. **by Alison Klesman**

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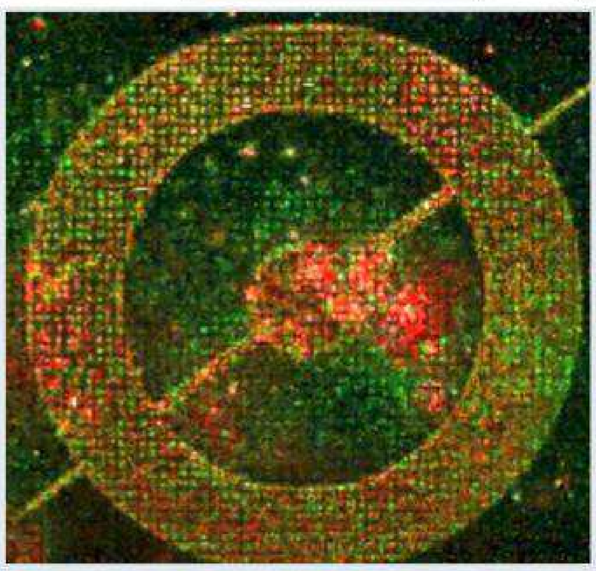
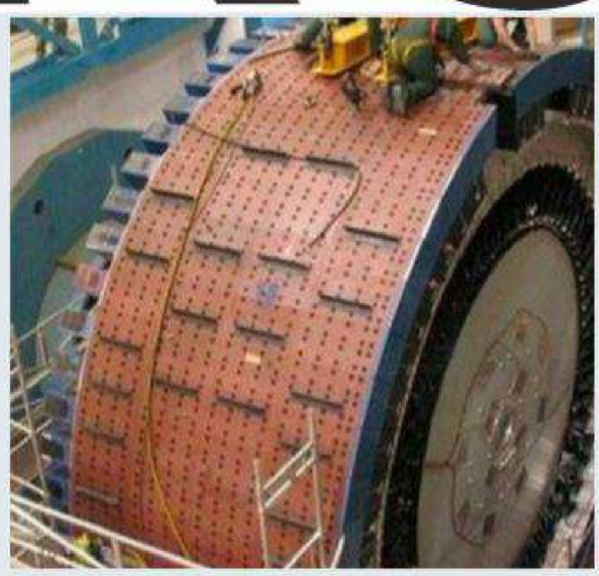
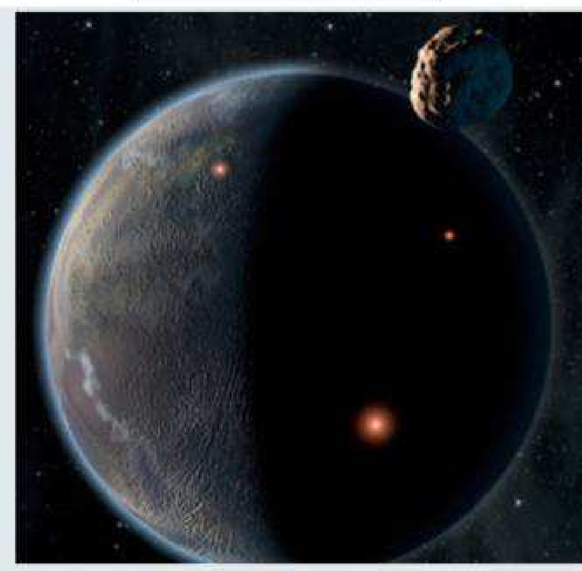




Astronomy is entering a new regime of "big data." The volumes of information being collected are staggering, and future projects promise data sets of ever-increasing size. The total data volume of the Sloan Digital Sky Survey's Data Release 14 tops out at over 156 terabytes (TB). By 2018, the Dark Energy Survey, which takes up to 2.5 TB of data per night, will have mapped 5,000 degrees of the Southern Hemisphere sky, including 300 million galaxies, to ultimately produce about one petabyte (1,000 TB) of data. When the Large Synoptic Survey Telescope begins full science operations in 2022, its 3,200-megapixel camera will be able to collect 15 to 30 TB of data every night.

With such huge volumes of data comes the need for an increased ability to handle them. That's where citizen science comes in, filling a unique role to propel science forward.

Zooniverse is a self-proclaimed platform for people-powered research. This unique website connects citizen scientists — you — with professional researchers, to promote collaboration and discovery using vast catalogs of data.

It's not just astronomy and physics that have benefited from this amazing platform. Zooniverse's diverse project categories include biology, history, climate science, the arts,

ACCESS THE ZOONIVERSE

Zooniverse.org is the main gateway to the Zooniverse. The homepage provides extensive background about the platform and a full listing of all active and past projects. Through the website, you can contribute to any project — anytime and from anywhere with an internet connection. User registration on the site is free.

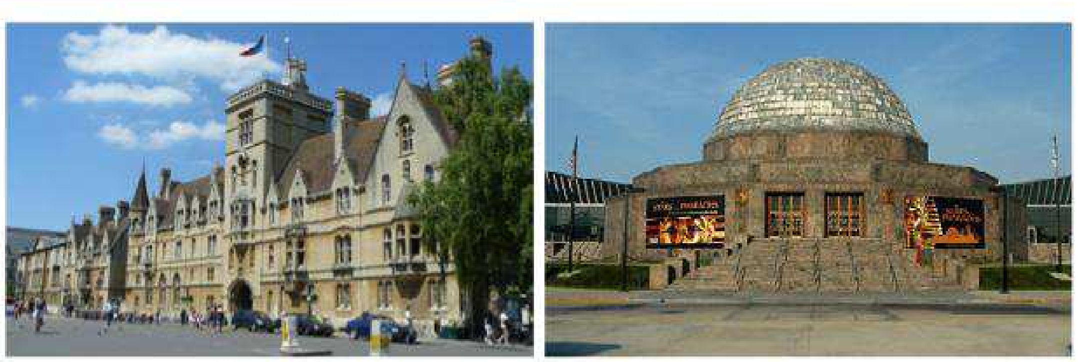
The site also contains resources that include news, blogs, frequently asked questions, and resources available for use if you're interested in writing or talking about the Zooniverse platform or any of its projects.

But you don't need a web browser to take part in citizen science. The Zooniverse app, available for both iOS and Android devices, lets you take many of the platform's projects with you on the go. The app allows you to participate in projects just as if you were on a computer. You can also opt to enable push notifications and receive updates about the subjects that interest you most, or scroll through a list of publications based on Zooniverse results to dig deeper into your favorite projects and the impact of your contributions on cutting-edge science.

medicine, ecology, and the social sciences. If you grow tired of studying transit data from the Kepler space telescope (Exoplanet Explorers: exoplanetexplorers.org) or characterizing glitches in the LIGO instruments to improve gravitational wave detection (Gravity Spy: gravityspy.org), you can easily switch to counting Weddell seals in Antarctica's Ross Sea (Weddell Seal Count: www.zooniverse.org/projects/slg0808/weddell-seal-count). Or perhaps sorting through fragments of Middle Eastern and Mediterranean texts dating from the 10th to 13th centuries is more your style (Scribes of the Cairo Geniza: www.zooniverse.org/projects/judaicadh/scribes-of-the-cairo-geniza).

Regardless of the projects you choose to explore, you'll be taking part in scientific research alongside some 1.6 million volunteers around the world. "Zooniverse is inclusive. It's about discoveries we can make together," says Chris Lintott, Zooniverse's founder and principal investigator, and professor of astrophysics at the University of Oxford.

Founded in 2007, Zooniverse is a collaboration between the Adler Planetarium, the University of Oxford, and the broader Citizen Science Alliance. Over the past 10 years, the platform has grown from a single project to over 125 current and completed "zoos" that connect professional researchers with citizen volunteers to produce otherwise unattainable results.

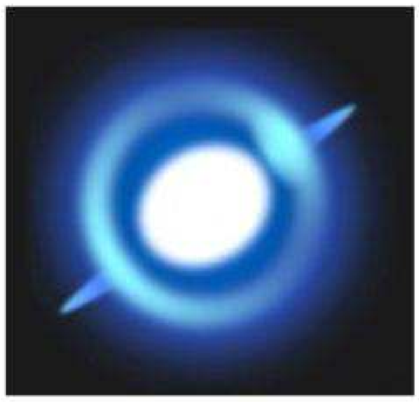


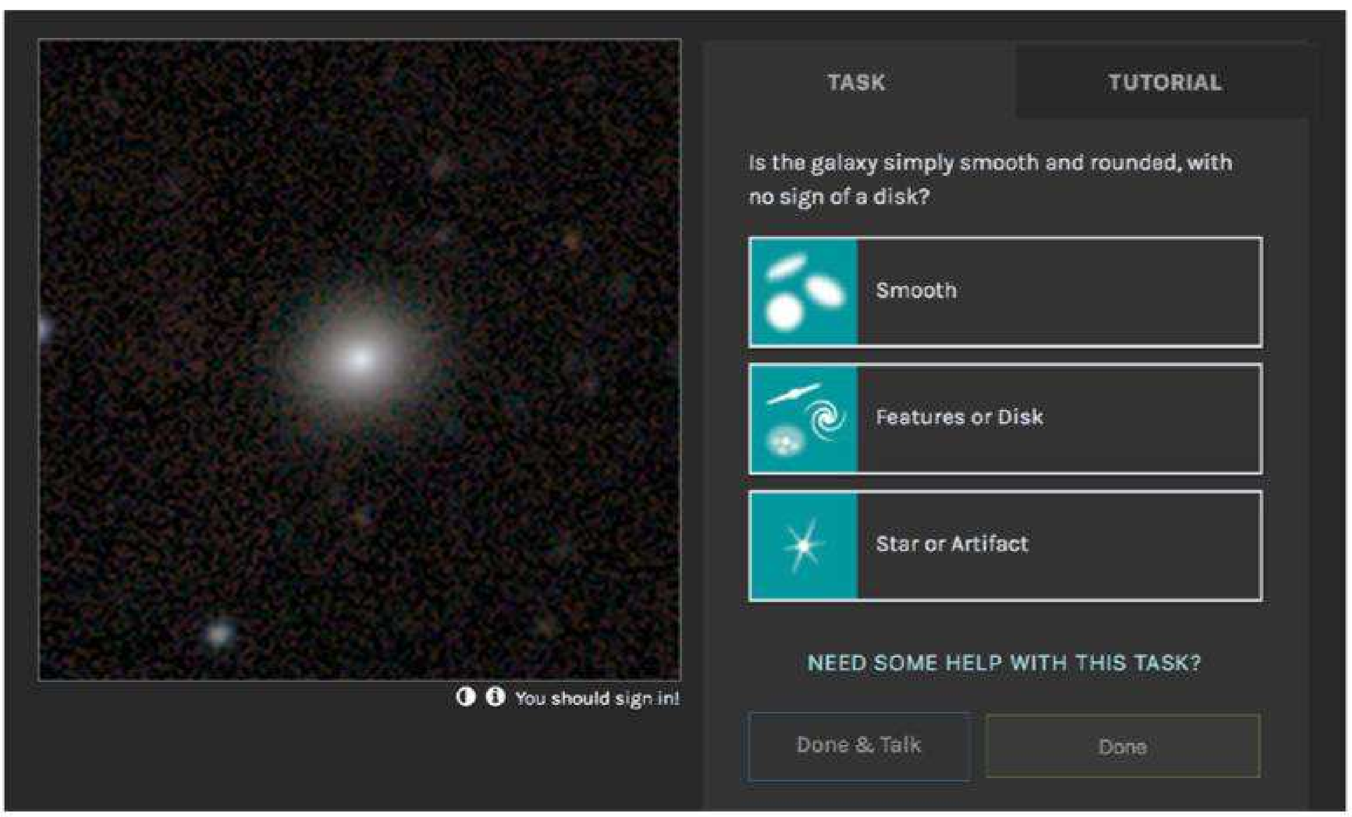
Zooniverse was founded in 2007 by the University of Oxford and the Adler Planetarium. These institutions still serve as the headquarters for most of the Zooniverse team.
UNIVERSITY OF OXFORD: PETER TRIMMING; ADLER PLANETARIUM: GOCHICAGOCARD BLOG

A galaxy zoo

Just like its name, Zooniverse began with a zoo. In 2007, Lintott developed Galaxy Zoo, calling upon volunteers to look at digital images of galaxies from the Sloan Digital Sky Survey and classify them as spirals, ellipticals, or mergers. There are a lot of galaxies in the universe, posing a challenge for astronomers who need to classify data sets rich with millions of them. When he was a graduate student at Oxford, Kevin Schawinski, an original team member, spent a month doing nothing but classifying galaxies for roughly 12 hours a day, topping out at about 50,000.



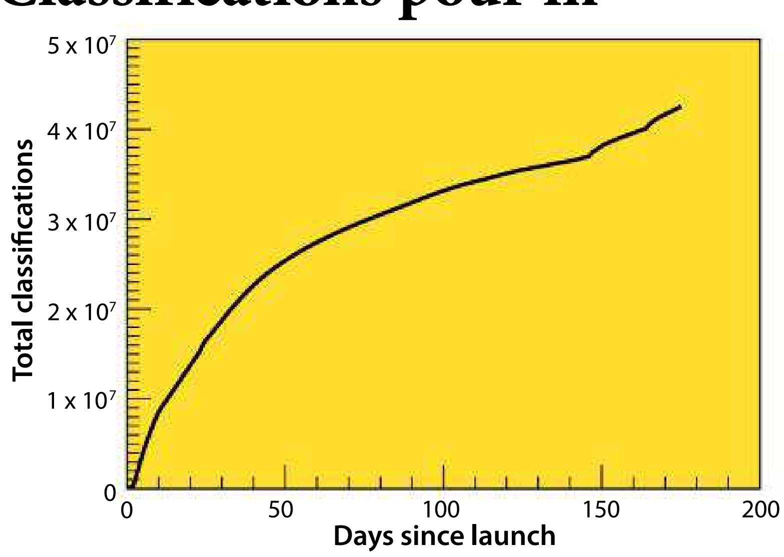


Galaxy Zoo is the project that started it all. Users are asked to view digital survey images and classify galaxies based on their shape and other characteristics. ZOONIVERSE (GALAXY ZOO: GALAXYZOO.ORG)

That's impressive, but it's not a realistic pace to maintain. So instead of subjecting one person to such a huge task and risking that objects might be missed or misclassified — or that the researcher may lose their mind — what if the task could be distributed to volunteers? Despite what you may think, it doesn't take years of studying astrophysics to recognize a galaxy's type by its shape and structure. It only takes a little bit of practice, and anyone — from schoolchildren to retirees — can do it.

In fact, human volunteers can do it better than computers,

Classifications pour in



When Galaxy Zoo launched, the team was overwhelmed by the public's response. This graph shows the number of cumulative classifications in the project's first 200 days, including notable jumps at 145 and 160 days, which are associated with email newsletters. *ASTRONOMY*: ROEN KELLY, AFTER LINTOTT ET AL., 2008

JUMP RIGHT IN!

Are you ready to get started? Here are a few of the currently active Zooniverse astronomy projects that need volunteers like you to classify real data and contribute to new scientific discoveries.

SPACE WARPS
This project searches for gravitational lenses in data from the Hyper Suprime-Cam Survey, which is ideal for identifying previously unknown lenses that offer a peek into the distant universe. The project's science team estimates there may be hundreds of previously unknown lenses in images from this survey, just waiting for volunteers like you to find them. (spacewarps.org)

GALAXY ZOO
In the latest version of the project that started it all, Galaxy Zoo lets volunteers loose on images from the Dark Energy Camera Legacy Survey. This data set is 10 times more sensitive than the Sloan Digital Sky Survey used in the initial Galaxy Zoo project. You'll be asked to note each galaxy's shape, as well as any strange features such as tidal tails, dust lanes, gravitational lensing, or overlapping objects. (galaxyzoo.org)

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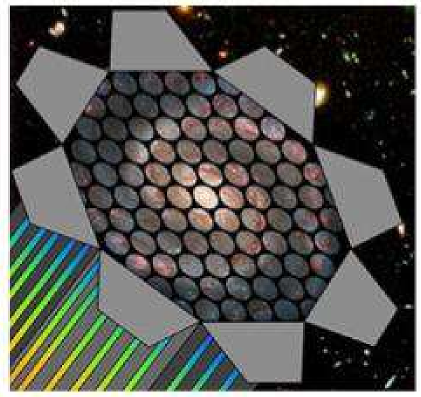
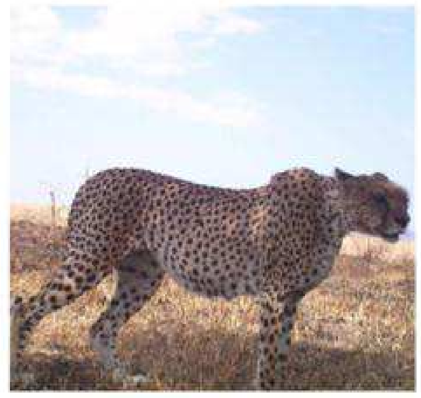




PUBLISHING THE RESULTS

The efforts of volunteers don't simply disappear after they've closed the browser or app. Zooniverse classifications have resulted in more than 130 scientific posters and publications, including peer-reviewed articles in journals such as *Icarus*, *Monthly Notices of the Royal Astronomical Society*, and *The Astrophysical Journal*. Many of these articles list Zooniverse volunteers as co-authors. The Zooniverse projects with the most associated publications to date are Galaxy Zoo (57 publications), Planet Hunters (13 publications), and Supernova Hunters and Solar Stormwatch (seven publications each).

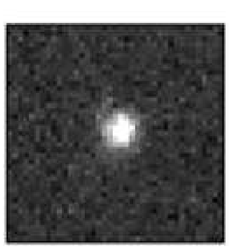
In addition to research performed with Zooniverse results, the platform has also spawned more than 30 meta studies on the Zooniverse itself, exploring topics that range from how museums and other public institutions can better engage with the public to the tools that researchers can use to assess the quality of crowdsourced data. These studies date back to 2010, when researchers published a paper in the journal *Astronomy Education Review* looking into the motivations of the citizen science volunteers who had made the original Galaxy Zoo project such a resounding success.

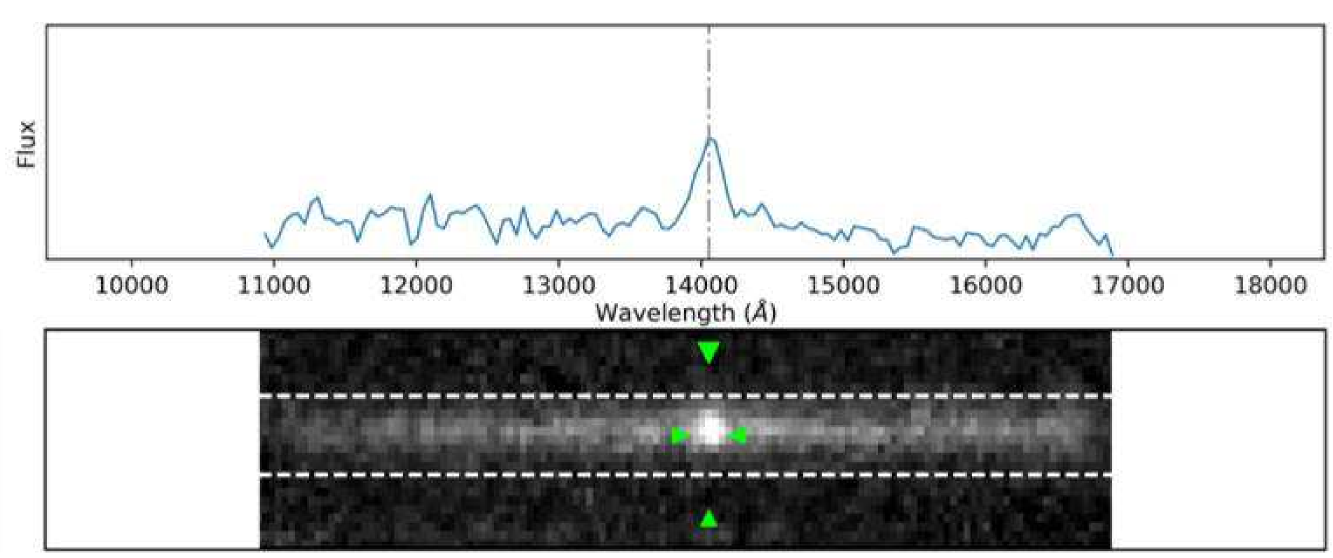
which can easily get confused or even miss galaxies altogether in images. The human brain is far better at picking out patterns than any computer algorithm yet devised.

That's the true power behind Zooniverse. "The things that we ask of our volunteers are things that computers are not really good at," emphasizes Zach Wolfenbarger, a Zooniverse web developer at the Adler Planetarium.

The more volunteers who look at a single galaxy or image, the more likely the resulting classification is to be correct. So if you're worried about influencing a project's results because you might misclassify an object, don't be: Each image you'll work with is viewed and classified by many people, and as the number of classifications increases, the most common answer grows in statistical significance.

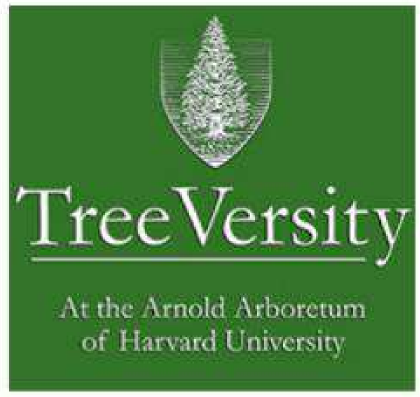
When Galaxy Zoo launched, the response was overwhelming, says Lintott. Within a day, the site was receiving nearly 70,000 classifications per hour. Within a year, more than 50 million classifications had been submitted by over 150,000 participants. And 10 years later, Galaxy Zoo is still running (galaxyzoo.org), albeit with a few changes, including a vastly expanded data set. The tasks volunteers are asked to complete have grown as well, from initially putting galaxies in one of just a few groups to now estimating the roundness or flatness of elliptical galaxies or the number of arms in a spiral galaxy and the size and shape of its bulge.

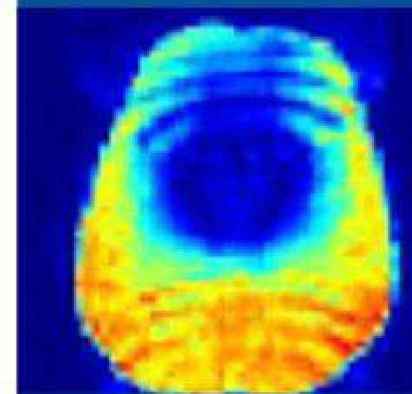


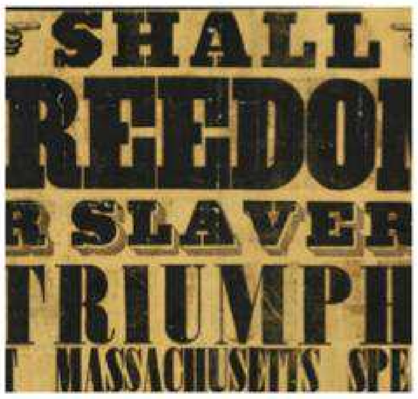


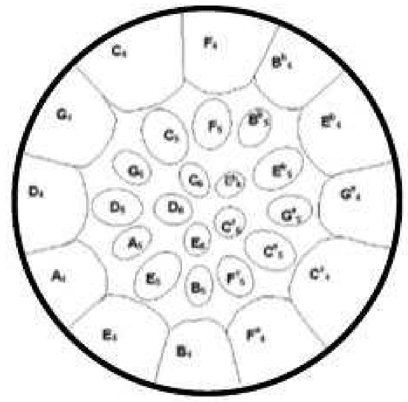
Galaxy Nurseries was Zooniverse's 100th project. Now complete, it asked users to identify emission lines in galaxies spotted with the Hubble Space Telescope to derive their distances. The project singled out young "baby" galaxies forming stars in the early universe to study how they age over time to become the local galaxies we see today.

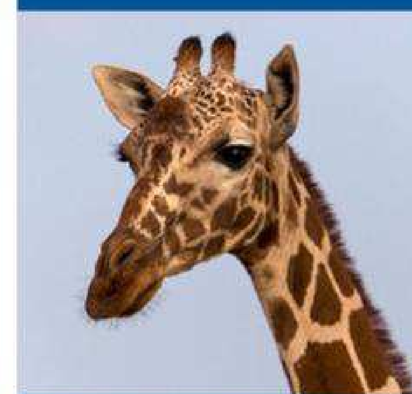
ZOONIVERSE (GALAXY NURSERIES: WWW.ZOONIVERSE.ORG/PROJECTS/HUGHDICKINSON/GALAXY-NURSERIES)







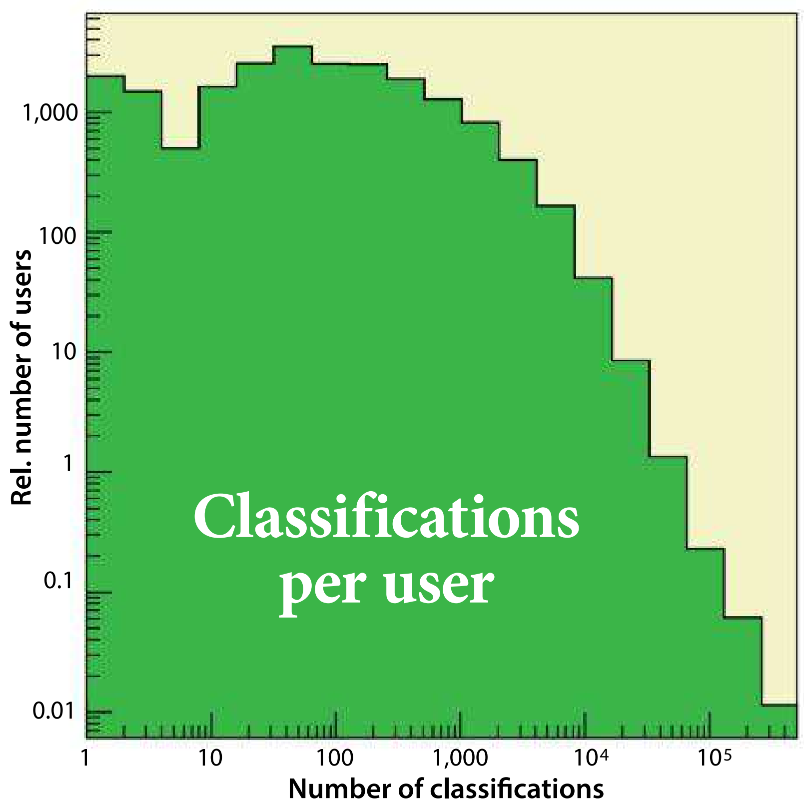




Making discoveries together

So far, this sounds like a pretty sweet deal for researchers. After all, why spend hours scouring data yourself when you can get volunteers to do it in their spare time — for free?

But the benefits of the Zooniverse go both ways. Researchers find the help they need to manage large data sets and make new discoveries, and volunteers become part of a community that facilitates exploration, communication, and scientific advancement. Volunteers' names are listed alongside project leaders' on discovery papers, and dozens of volunteers are co-authors on articles in which they have participated in the data analysis and discussion. They help moderate online discussion forums for each project and sometimes participate in secondary, more in-depth scientific tasks. Their feedback on new projects under development guides researcher and developer efforts to improve Zooniverse.



The Zooniverse team has charted the number of classifications in Galaxy Zoo per user. Most single users provide about 30 classifications, with fewer people providing progressively more. A small group of individuals has completed more than 100,000 classifications each. *ASTRONOMY:* ROEN KELLY, AFTER LINTOTT ET AL., 2008

By providing the public with a role in the scientific process, Zooniverse puts the power of science in your hands. The platform also gives volunteers a firsthand look at how science progresses from raw data to real results. "We're very much focused on engaging people in the process of scientific discovery," says Michelle Larson, president and CEO of the Adler Planetarium. "We learn about science in a formal setting in so much of our lives, and don't have a full appreciation of the mystery and discovery. Zooniverse is very well aligned with that focus. We want you doing the discovery," she stresses.

Each Zooniverse project provides a primer that explains the project's goal and task. The development team is constantly improving the site to provide volunteers with the information they need in a simple, fun, and straightforward way. "We strive to never waste the volunteers' time," says Laura Trouille, Zooniverse co-investigator and director of citizen science at the Adler Planetarium.

This sentiment is echoed by the entire web development team, which seeks feedback through Zooniverse's Talk feature (a project-specific online discussion board) and is constantly working to adapt the specific needs of each new project into code and tools for use throughout the platform.

— Continued from page 29

GRAVITY SPY

Want to join the hunt for gravitational waves? Gravity Spy needs volunteers to characterize glitches and false signals in the extremely sensitive instruments used to detect gravitational wave events. These glitches then can be used to teach algorithms how to filter out false signals — and identify real ones. (gravityspy.org)

BACKYARD WORLDS

What lurks in our own backyard? The outer solar system still hides many objects, and Backyard Worlds aims to uncover them in data from NASA's Wide-field Infrared Survey Explorer mission. From the theorized Planet Nine to brown dwarfs and other low-mass stars, you could discover a celestial neighbor we never knew we had. (backyardworlds.org)

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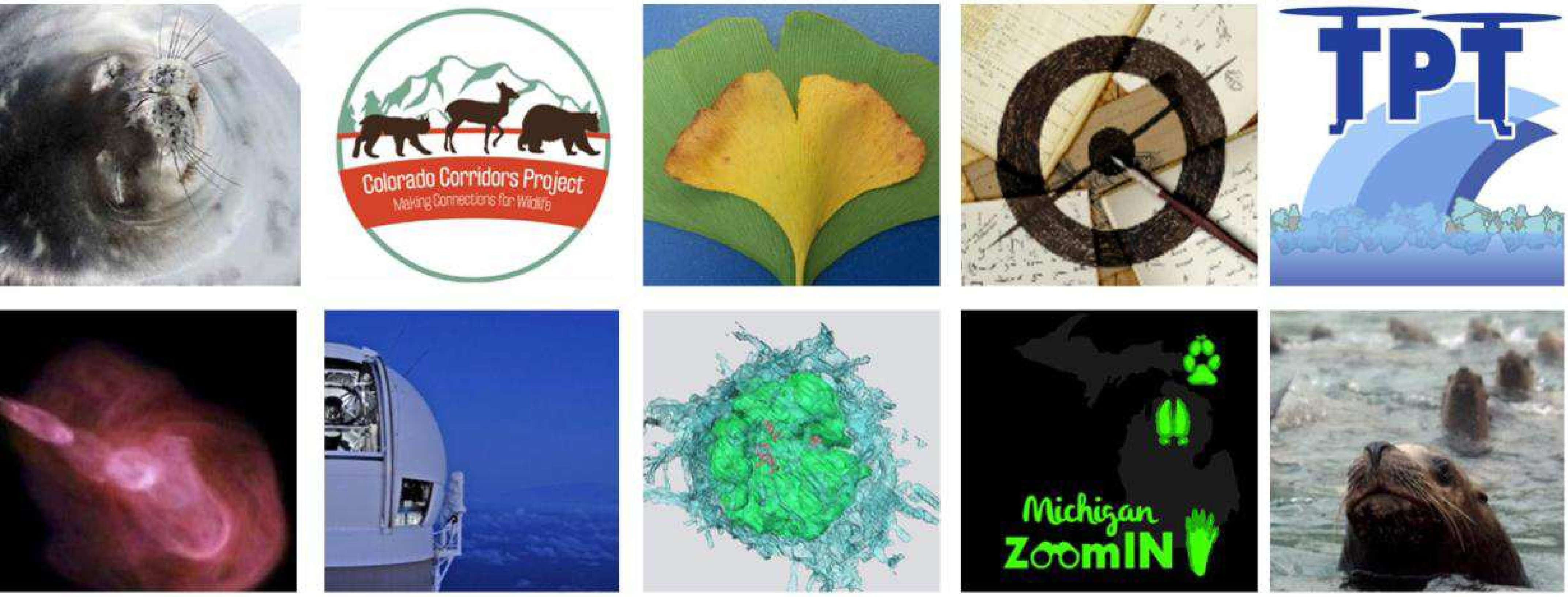


SPACE WARPS' SUCCESS

Space Warps is a search for gravitational lenses — galaxies whose gravity bends the light from distant objects, magnifying it and allowing astronomers to study objects otherwise too distant and too dim to see.

The human brain is much better at identifying the strange shapes created by gravitational lenses than any existing computer program, so Space Warps volunteers hunt through images to find gravitational lenses that computer algorithms may have missed.

On April 27, Zooniverse and Science Friday (www.sciencefriday.com) announced the weeklong Space Warps 1 Million Classification Challenge. Between April 27 and May 4, the site challenged volunteers to provide 1 million classifications on over 70,000 images obtained with the Hyper Suprime-Cam instrument on the 8.2-meter Subaru Telescope in Hawaii.

Within minutes of the initial announcement, the project had gained about 1,000 volunteers providing hundreds of classifications a minute. At the end of the one-week challenge, more than 3,500 people from around the globe had provided over 1.2 million classifications. They made more than 3,000 comments on the project's discussion forum and connected with volunteer moderators and the research team.

The challenge resulted in the discovery of 40 new candidate gravitational lenses for scientific follow-up in just one week. Since then, volunteers have contributed an additional 1 million classifications to the project.

ZOONIVERSE (SPACE WARPS - HSC: SPACEWARPS.ORG)

That feedback comes not only from the volunteers, but also the research teams running the projects. Facilitating an open line of communication between the two has allowed Zooniverse to grow and evolve into a worthwhile, engaging, and versatile citizen science tool.

The online discussion boards keep the volunteers around, Trouille believes. Every project has one, she says, and about 40 percent of volunteers go there to interact with each other and the researchers running the project. This extra layer of engagement allows for greater collaboration and, ultimately, discovery, Trouille explains.

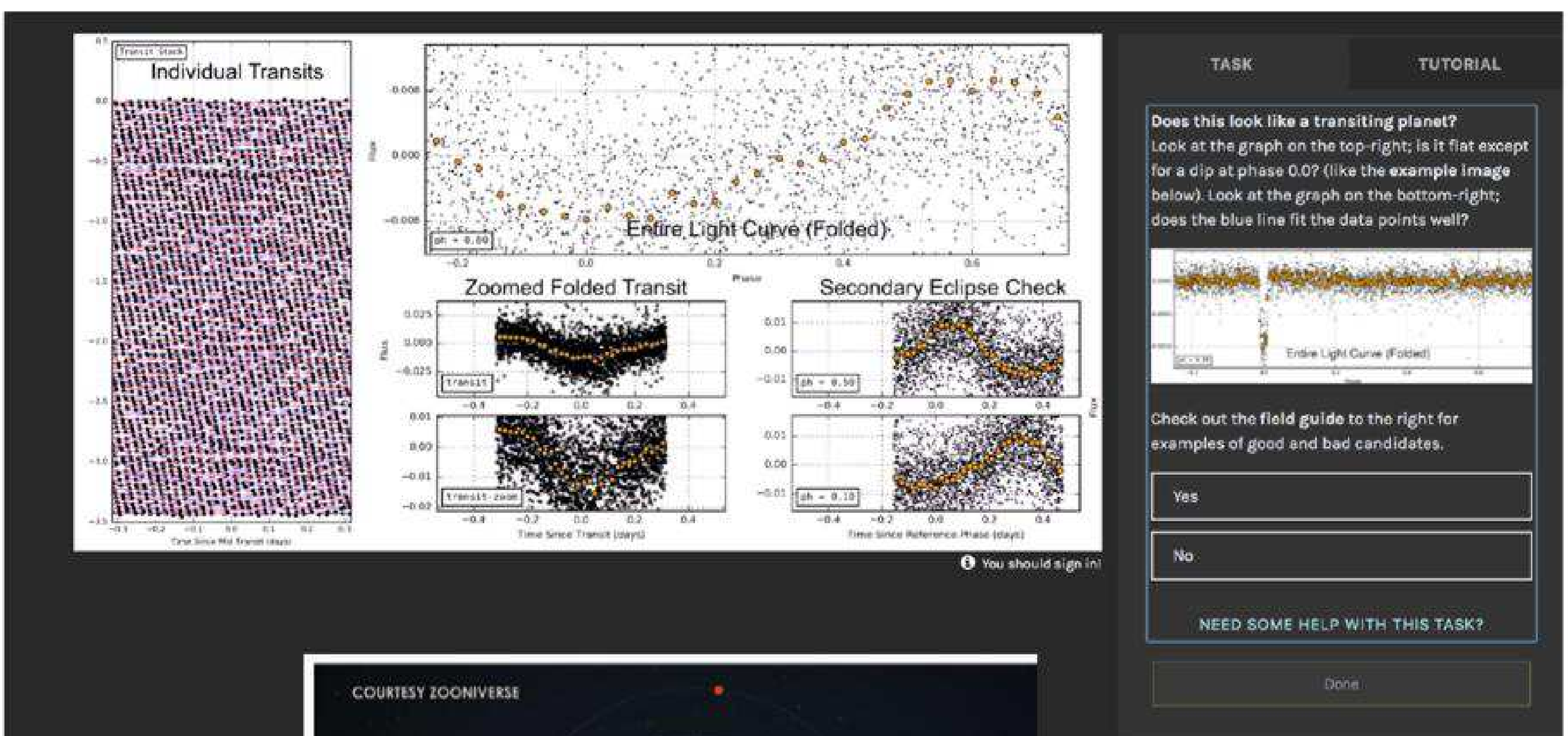
"When a researcher says, 'I want to do a Zooniverse project,' they commit to being active on the discussion board," she says. "They commit to providing blog posts, giving updates on their research, about who they are, what the broader research context is. The key to an engaged volunteer community and enabling the scientific discoveries is really the interaction on the discussion boards."

The boards provide a place to spotlight strange finds such as Hanny's Voorwerp, a "blue cloud" near the galaxy IC 2497 flagged by Dutch schoolteacher Hanny van Arkel in 2007. The ability to immediately get the attention of her peers and the research team resulted in a real scientific find that most likely would have been thrown away as noise by a computer algorithm.

"We have this amazing opportunity, with 1.6 million people around the world who've registered to participate in Zooniverse, to help in the process of learning about science, learning about the nature of science, learning how science works," says Trouille. The ability to contact a researcher directly is "sort of lifting the veil on who researchers are, that they're just people."

And Zooniverse is designed so researchers can "grow in their communication skills through engaging with volunteers" as well, Trouille says. It provides professional researchers the opportunity to create citizen science projects within their comfort zone, allowing them to promote their research via targeted communication and receive feedback directly from volunteers during the development and testing stage.

"I think we can get a bit lost in the idea of academia being for academics," says Samantha Blickhan, a postdoctoral fellow at



Exoplanet Explorers provides light curves (measurements of brightness over time) so volunteers can look for dips in starlight associated with transiting planets.
ZOONIVERSE (EXOPLANET EXPLORERS: EXOPLANETEXPLORERS.ORG)

the Adler Planetarium. "Zooniverse does a really great job of showing the academic community that you can involve the public in your work."

Building a zoo

The diversity of Zooniverse is, in part, a reflection of the diversity of the web development team working behind the scenes. "There's such an interesting mix of people who get attracted to work in Zooniverse," says Trouille. "They're all really drawn to the mission. They have these interesting backgrounds, and what they bring to the user experience is really reflective of their personalities."

From the design of the Zooniverse.org homepage to the instructional pop-ups that appear as users progress, those developers are constantly working to facilitate better research and an improved user experience on both ends. They keep track of which interactive feedback is best and what keeps volunteers willing to stay and contribute. For example, "We have a lot of camera traps throughout the Serengeti, and we found that if we removed all the images where the wind moved a branch or something, with no animals in sight, users actually classified fewer images," says Amy Boyer, another member of Adler's team of Zooniverse web developers.

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SUPERNOVA HUNTERS

Identifying supernovae — bright stellar explosions — helps astronomers better understand the life cycles of stars, as well as map out the universe around us. Supernova Hunters invites volunteers to examine data from the Pan-STARRS1 Telescope to catch these bright but transient (and thus easily missed) events. (www.zooniverse.org/projects/dwright04/supernova-hunters)

GALAXY BUILDER

Have you ever wanted to build a galaxy? If the answer is yes, then you should check out Galaxy Builder, a project that lets you assemble galaxies piece by piece to help astronomers better model these immense systems and determine how their past shapes their present. (www.zooniverse.org/projects/tingard/galaxy-builder)

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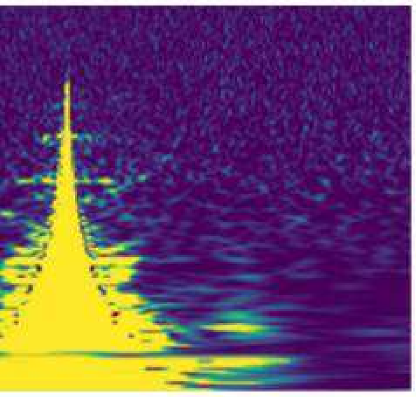
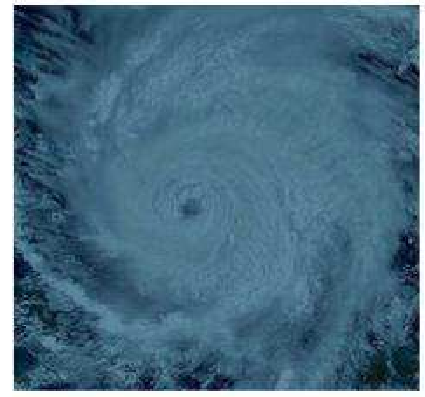
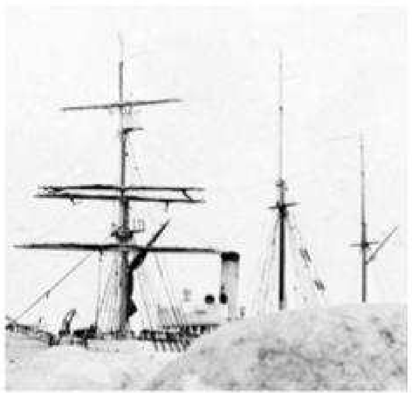







It's the thrill of discovery that keeps volunteers engaged, and that thrill is what the developers seek to maintain from project to project, all while keeping the value of volunteers' time and effort in mind.

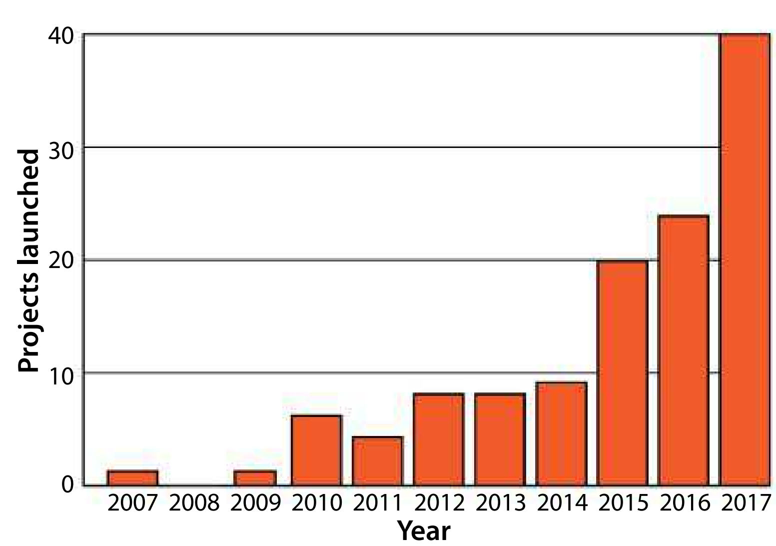
One of the biggest steps forward for the Zooniverse in recent years was the release of its free project builder tool, which was funded by a Google Global Impact Award and a Sloan Foundation grant. Launched in July 2015, this tool puts the power to create effective crowd-sourced research directly in researchers' hands. Before its release, it would take the web development team a year to build about five projects, Trouille says. That number jumped to 26 in 2016 and 40 in 2017.

New projects that want promotion via Zooniverse still undergo a rigorous beta testing phase, but the tool is available to anyone regardless of whether they want an association with Zooniverse or not. And all of Zooniverse's code is open source, available for researchers and volunteers alike to view and, if so inclined, improve.

100 projects and beyond

In 2017, Zooniverse celebrated its 10th anniversary with the launch of its 100th project: Galaxy Nurseries. By identifying emission lines associated with particular

Zooniverse projects per year



In Zooniverse's first years, the web development team produced each new project, resulting in about five to 10 each year. In mid-2015, the release of Zooniverse's free project builder tool increased the number of projects created each year to over 20 in 2016. ZOONIVERSE TEAM

STRANGE FINDS

While hunting for signals or classifying objects, Zooniverse volunteers often come across strange, unexpected finds that yield surprising new scientific results. Here are just a few.

TABBY'S STAR

KIC 8462852, also known as Tabby's star, is one of the most famous — and most intriguing — stars in our galaxy. The star's strange behavior was first discovered by volunteers classifying data for the Zooniverse Planet Hunters project. When they couldn't determine the cause of the star's sudden and random dips in brightness, they contacted the project's science team (including Tabetha Boyajian at Louisiana State University, for whom the star is named), and the object has been the subject of scientific speculation ever since.

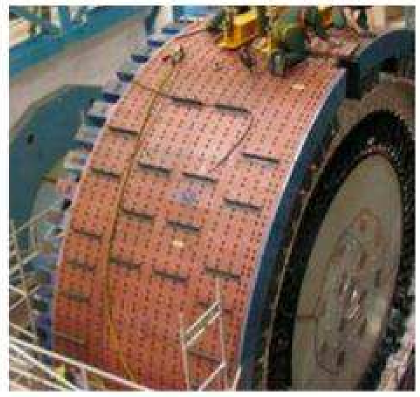
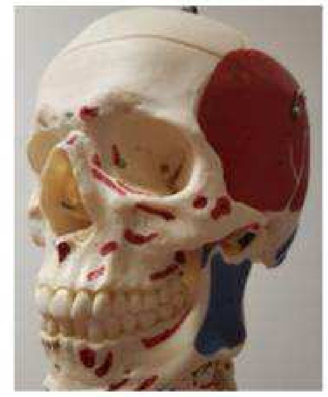
GREEN PEAS

"Green pea" galaxies are so named for their compact appearance and greenish color, which arises from ionized oxygen emission. These galaxies were largely discovered by Galaxy Zoo volunteers, who had noted several of these strange-looking objects in the project's discussion forum and wondered what they were. Thanks to the volunteers' hard work identifying and collecting "peas," researchers were able to follow up on the findings, and the first volunteer-inspired Galaxy Zoo paper was submitted for publication in the *Monthly Notices of the Royal Astronomical Society* in 2009.

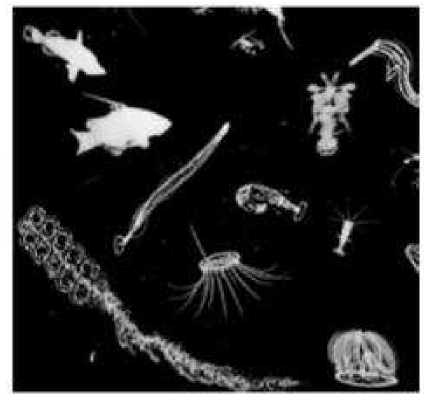
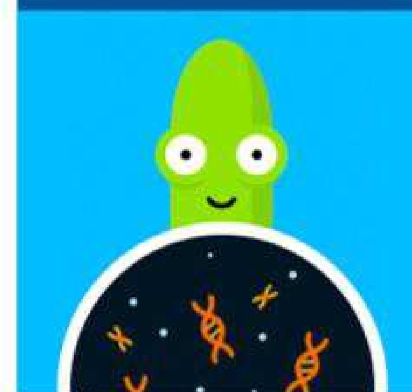
PLANET HUNTERS 1

Planet Hunters tasks volunteers with sifting through data from the Kepler space telescope, hunting for dips in starlight associated with transiting planets. The project's first discovery was a doozy: Dubbed Planet Hunters 1 (PH1), the first confirmed planet discovered by the project was also the first planet ever discovered in a four-star system. This circumbinary planet orbits a double star system, but that double star is in turn orbited by a second pair of binary stars 90 billion miles (145 billion kilometers) away. Not only is PH1 a fascinating world, but it is also helping astronomers better understand how and where planets form.





elements in a given galaxy, one can estimate its distance based on the amount its light is shifted due to the expansion of the universe. With accurate distances, astronomers can single out faraway "baby galaxies" to study the universe when it was much younger.

Galaxy Nurseries has now reached its goal, ending with more than 400,000 classifications and over 27,000 subjects. It is the latest in a long line of engaging projects made possible by the Zooniverse platform and its project builder tool.

The platform is now being embraced by more researchers in more disciplines than ever before. The review process for the first Galaxy Zoo paper, Trouille says, was "horrendous because [crowdsourced science] was totally new." That's no longer the case, and now there are more than 120 peer-reviewed publications associated with Zooniverse discoveries. The AnnoTate zoo has proven that volunteers can transcribe handwritten materials with a 95 percent accuracy rate compared with experienced specialists. "[Specialist skills are] absolutely necessary, but we're showing how researchers and volunteers are supplementing one another. They're working together,

The assembled Zooniverse team, including founder and principal investigator Chris Lintott (back row, center), poses for a group photo. ZOONIVERSE TEAM

strengthening the community," Blickhan stresses.

Furthermore, "we have some pretty exciting results that suggest that humans and computers working together can actually produce better results than either one alone," says Boyer. In addition to the scientific papers that come out of projects, she says, several "meta research" papers examine the process of citizen science itself.

"Zooniverse continues to push itself as well," says Larson. "The Gravity Spy project has a machine learning component to it. Humans are doing the work that computers can't … and then feeding their knowledge back to the computer, which moves the programming forward, and the process begins again. That's the magic of Zooniverse, that it's about scientific progress."

That magic has seen the platform through a decade of success. "Galaxy Zoo was not supposed to still be running 10 years later," says Lintott. Yet it is, and it has successfully spawned a wealth of private and public projects that have carried science into a new era of big data and bigger discoveries.

It wouldn't be possible without the millions of registered Zooniverse users donating time and sharing excitement as part of the modern scientific process. Are you one of them?

Alison Klesman, *an associate editor of* Astronomy*, has enjoyed leading students in galaxy classification using Galaxy Zoo in the past.*

— Continued from page 33

DISK DETECTIVE

The Disk Detective project puts you at the forefront of planet formation studies by asking volunteers to identify young stars surrounded by the dusty, gas-filled debris disks that birth planets, comets, and asteroids. You'll click through images taken by NASA's Wide-Field Infrared Survey Explorer, which has mapped the entire sky at infrared wavelengths — the perfect regime in which to search for young, forming planetary systems. (diskdetective.org)

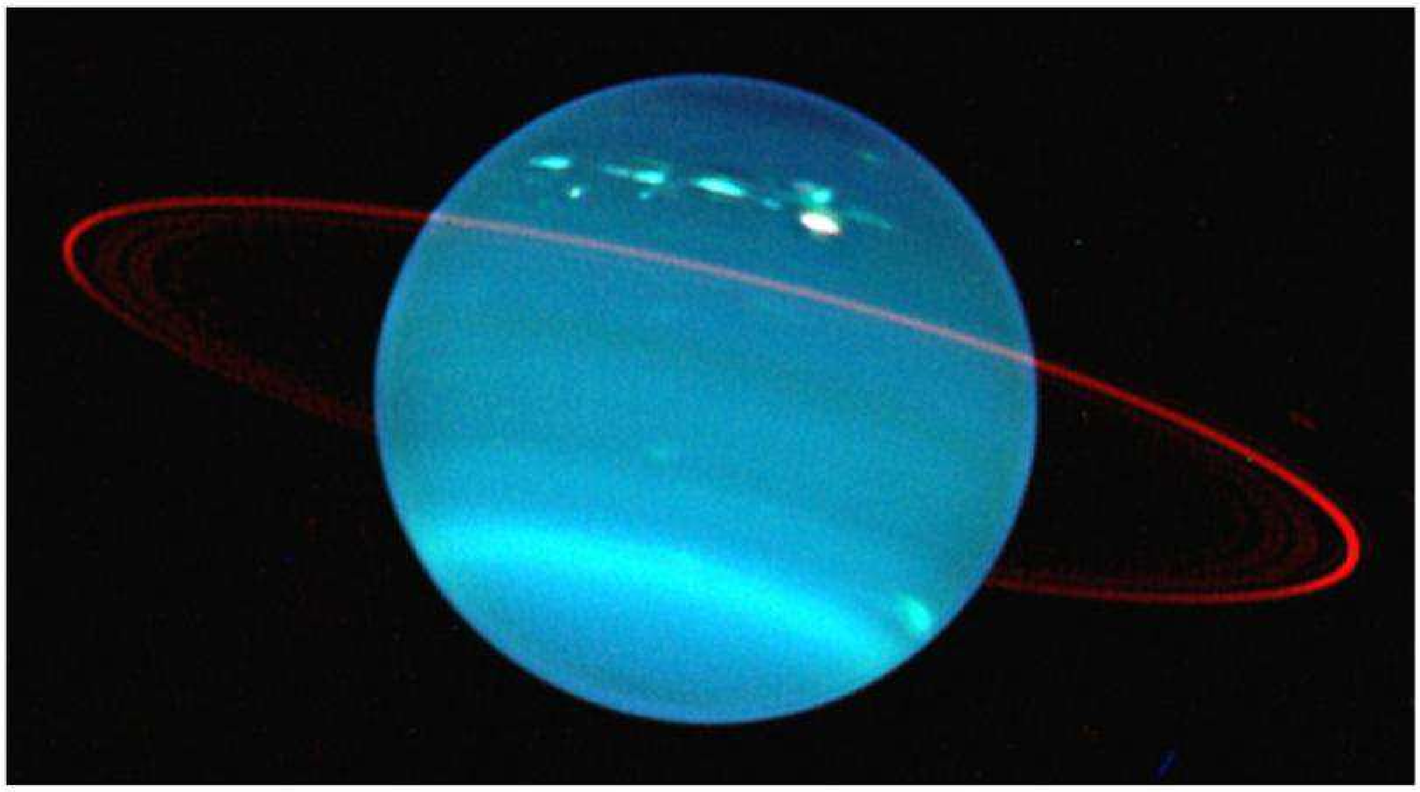
PLANET FOUR: TERRAINS

Closer to home, Planet Four: Terrains focuses on the Red Planet with images taken with the Context Camera on the Mars Reconnaissance Orbiter. You'll be asked to identify terrain types in Mars' south polar regions such as "spiders," "channel networks," and "swiss cheese" to help researchers discern impact craters from natural terrain. (www.zooniverse.org/projects/mschwamb/planet-four-terrains)

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

October 2018: Uranus reaches its peak



Amateur telescopes show Uranus' tiny disk and distinct blue-green color. This view through the Keck II Telescope also reveals delicate cloud structures and the planet's dark rings. LAWRENCE SROMOVSKY (UW-MADISON)/W.M. KECK OBSERVATORY

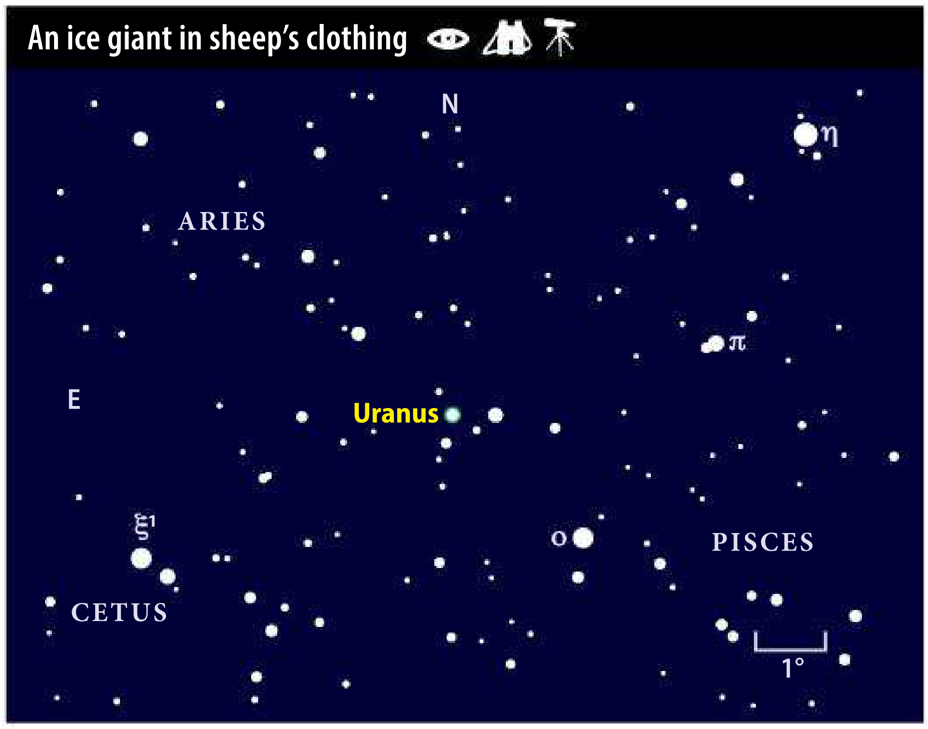
The planetary bonanza we enjoyed this summer has started to slip away. The Sun's relentless march to the east gradually overtakes each of the planets. Venus succumbs first, disappearing into evening twilight after October's first week. And though Jupiter manages to hang on all month, it dips lower with each passing day.

Still, Saturn and Mars remain standouts. The ringed planet lies high in the south as darkness falls, offering superb views to anyone with a telescope. And the Red Planet remains a beacon. Although it has lost some of its summer luster, Mars shines brightly and looms large through telescopes.

The Sun's advance brings the two outer planets to center stage. Neptune stands high in the late evening sky and shows up nicely with optical aid. Meanwhile, Uranus reaches opposition and peak visibility in late October, giving us our best views of this ice giant in more than a half-century.

But we'll start our tour of the night sky in evening twilight with the most difficult target of all. **Mercury** hangs just above the southwestern horizon after sunset during October's final week. Perhaps your best chance to spot it comes on the 27th, when it lies directly below brilliant Jupiter. Use binoculars to locate the giant planet, which lies 6° high a half-hour after sunset, and you should see Mercury 3.4° (about half a field of view) beneath it. The inner planet shines at magnitude –0.2, one-quarter as bright as Jupiter.

An ice giant in sheep's clothing



At opposition October 23, magnitude 5.7 Uranus resides in Aries the Ram, 2.8° from 4th-magnitude Omicron (ο) Piscium. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

Mercury's poor visibility arises in part from solar system geometry. On October evenings, the ecliptic — the apparent path of the Sun across our sky that the planets follow closely — makes a shallow angle to the western horizon from mid-northern latitudes. So Mercury's elongation from the Sun translates mostly into distance along the horizon and not into altitude.

The same geometry affects **Venus**, with the planet's location south of the ecliptic further compromising our view. From 40° north latitude on the 1st, Venus stands 2° high 30 minutes after sunset. It gleams at magnitude –4.7, however, so you should see it if you have an unobstructed horizon. A telescope shows the planet's 47"-diameter disk and slender crescent phase.

Venus disappears from view within a week. It passes between the Sun and Earth on October 26, and will emerge into the morning sky early next month. Fortunately, the ecliptic makes a steep angle to the eastern horizon before dawn at this time of year, and Venus will gain altitude quickly.

Jupiter proves to be an easier target. The outer world lies 14° to Venus' upper left October 1, and it stands 10° high in the southwest an hour after sundown. Shining at magnitude –1.8, it shows up well against the darkening sky.

The giant planet loses about 3° of altitude each week. This leaves only a narrow window for observing it through a telescope, with the best conditions coming early in the month when it lies

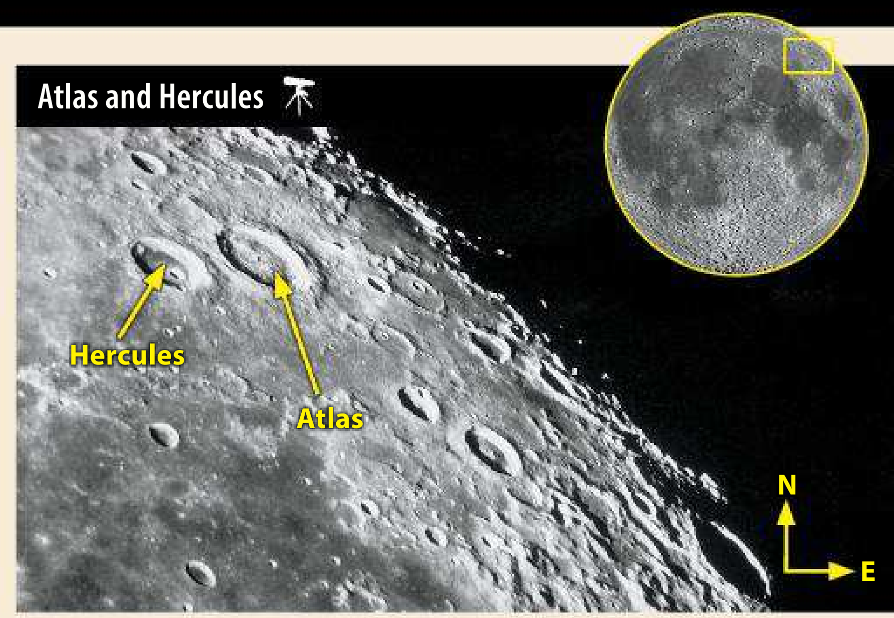
RISING**MOON**

The Sun sets on two mythical strongmen

The Hunter's Moon effect allows early evening observers a chance to see our satellite under reverse illumination. In the nights after Luna reaches its Full phase October 24, the waning gibbous Moon rises only about 30 minutes later each evening, compared with a more typical delay of 50 minutes.

This gives viewers a nice chance to see sunset illumination on the Moon without staying up late. And just as the play of light and shadows looks different at sunrise and sunset in your own neighborhood, the Moon appears different under reversed lighting.

Target the Moon's northeastern quadrant through your telescope as night falls October 26. You'll quickly see a pair of nice craters named after brawny legends from Greek mythology: Atlas and Hercules. Hercules spans 43 miles and shows a dark, lava-flooded floor punctuated by a sharp-edged crater. Atlas measures 54 miles across and lies closer to the Moon's limb. This older crater has a wrinkled floor and a jumble of central peaks. As the Sun sets over this area on the 27th, the mountain peaks disappear into darkness shortly before Hercules' inner crater succumbs to the shadows.



This pair of large craters stands out under the low Sun angle of the October 26 waning gibbous Moon. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

Under "normal" lighting on a waxing crescent Moon, the two craters emerge into sunlight with all the shadows reversed. Sunlight illuminates their outer rims on the east and their inner crater walls on the west. The small crater inside Hercules is lost in shadow October 13, but shows up easily on the 14th.

relatively high. The gas giant's disk spans 33" on the 1st and shows a pair of dark atmospheric belts.

Early evening views of **Saturn** should be spectacular. The magnitude 0.5 planet stands about 25° high in the south as darkness starts to fall in early October, and it doesn't set until 11 P.M. local daylight time. The ringed world shifts into the southwestern sky after sunset as the month progresses, but it doesn't lose much altitude.

Although a naked-eye view of Saturn is impressive, any optical aid will blow you away. Binocular views from under a dark sky reveal the planet set against the rich backdrop of the Milky Way in Sagittarius.

But Saturn always looks best through a telescope. Even the smallest scope shows the planet's stunning ring system encircling a yellowish globe. In mid-October, the gas giant's disk measures 16" across while the rings span 37" and tip 27° to our line of sight. This large tilt gives us a dramatic view of the ring system's structure. The most obvious feature is the Cassini Division, a dark gap that separates the outer A ring from the brighter, broader B ring.

Small telescopes also reveal several moons. Titan glows at 8th magnitude and shows up through any instrument. It orbits the planet once every 15.9 days, passing south of the

— *Continued on page 42*

METEORWATCH

Will the Hunter slay the Dragon?

The Orionids are usually October's top meteor shower. And that may well be the case in 2018. Although the shower peaks under a waxing gibbous Moon on October 21, our satellite sets around 4 A.M. local daylight time. That leaves two hours of darkness until twilight begins. Observers could see up to 20 meteors per hour radiating from Orion the Hunter.

But the Draconids could give the Orionids a run for their money. This typically minor shower might erupt the night of October 8/9 because its parent comet — 21P/Giacobini-Zinner — passed closest to the Sun last month. (See "Catch a comet crossing the Milky Way" on p. 42.) Previous outbursts have followed the comet's return. Viewers could see 10 or more meteors per hour coming from Draco the Dragon in the hours before midnight.

Observers have nearly two hours to enjoy this month's premier shower once the Moon sets the morning of October 21. LARRY KUHN

Orionid meteors

Active dates: Oct. 2–Nov. 7
Peak: October 21
Moon at peak: Waxing gibbous
Maximum rate at peak: 20 meteors/hour

OBSERVING HIGHLIGHT Uranus reaches its 2018 peak October 23, when the ice giant glows at magnitude 5.7 and spans 3.7" 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:

10 P.M. October 1
9 P.M. October 15
8 P.M. October 31

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

OCTOBER 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	31			

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

2 Last Quarter Moon occurs at 5:45 A.M. EDT

4 Venus is stationary, midnight EDT

5 Mercury passes 2° north of Spica, 2 P.M. EDT

The Moon is at perigee (227,666 miles from Earth), 6:27 P.M. EDT

7 Dwarf planet Ceres is in conjunction with the Sun, 6 A.M. EDT

8 New Moon occurs at 11:47 P.M. EDT

10 The Moon passes 13° north of Venus, 11 A.M. EDT

11 The Moon passes 4° north of Jupiter, 5 P.M. EDT

14 Mercury passes 7° north of Venus, 11 A.M. EDT

The Moon passes 1.8° north of Saturn, 11 P.M. EDT

16 Asteroid Juno is stationary, 2 P.M. EDT

First Quarter Moon occurs at 2:02 P.M. EDT

17 The Moon is at apogee (251,175 miles from Earth), 3:16 P.M. EDT

18 The Moon passes 1.9° north of Mars, 9 A.M. EDT

20 The Moon passes 3° south of Neptune, 6 P.M. EDT

SPECIAL OBSERVING DATE

21 The annual Orionid meteor shower peaks under a waxing gibbous Moon, providing nearly two hours of dark skies before dawn.

23 Uranus is at opposition, 9 P.M. EDT

24 The Moon passes 5° south of Uranus, 9 A.M. EDT

Full Moon occurs at 12:45 P.M. EDT

26 Venus is in inferior conjunction, 10 A.M. EDT

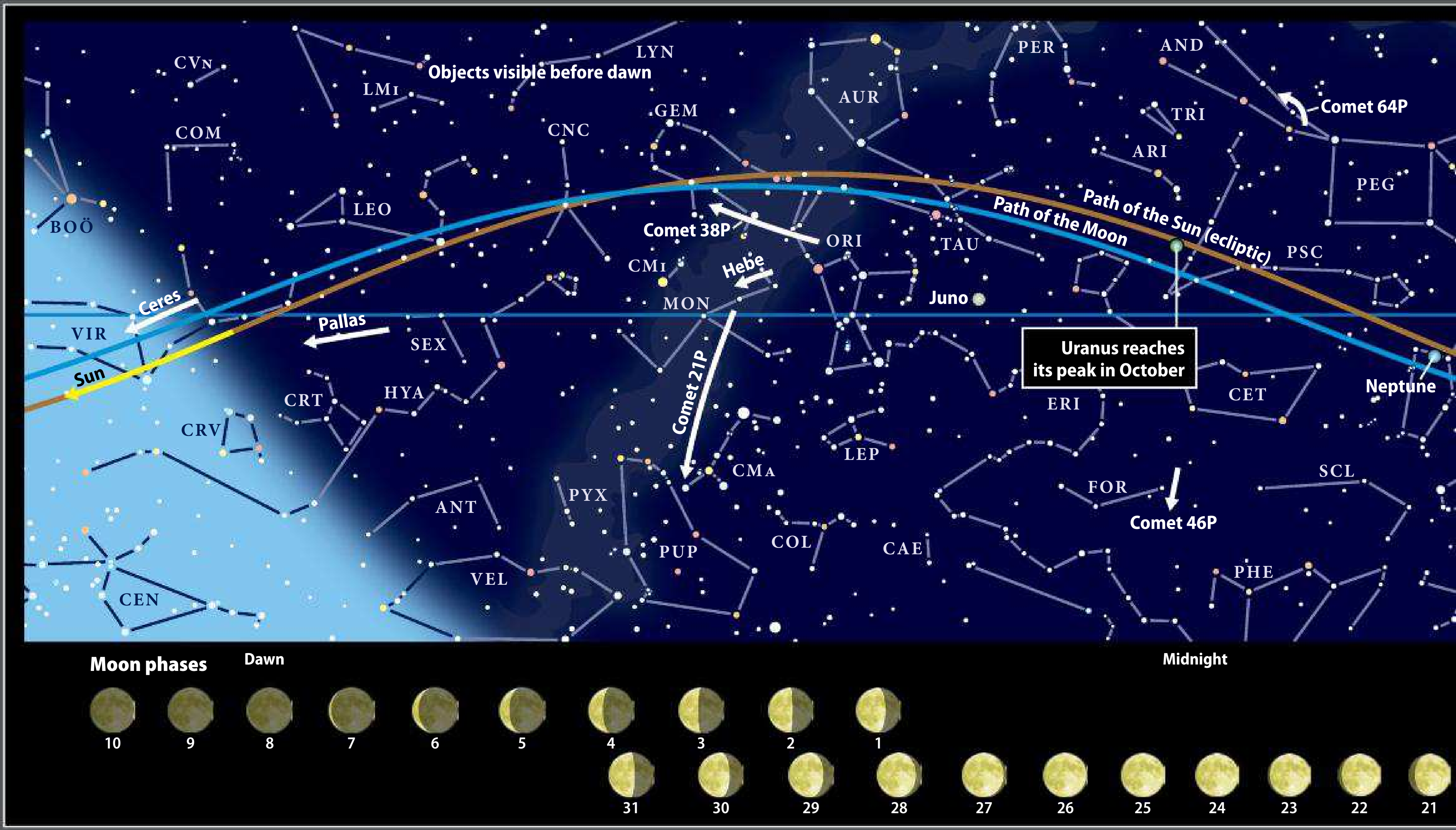
29 Mercury passes 3° south of Jupiter, midnight EDT

31 Last Quarter Moon occurs at 12:40 P.M. EDT

The Moon is at perigee (230,034 miles from Earth), 4:23 P.M. EDT

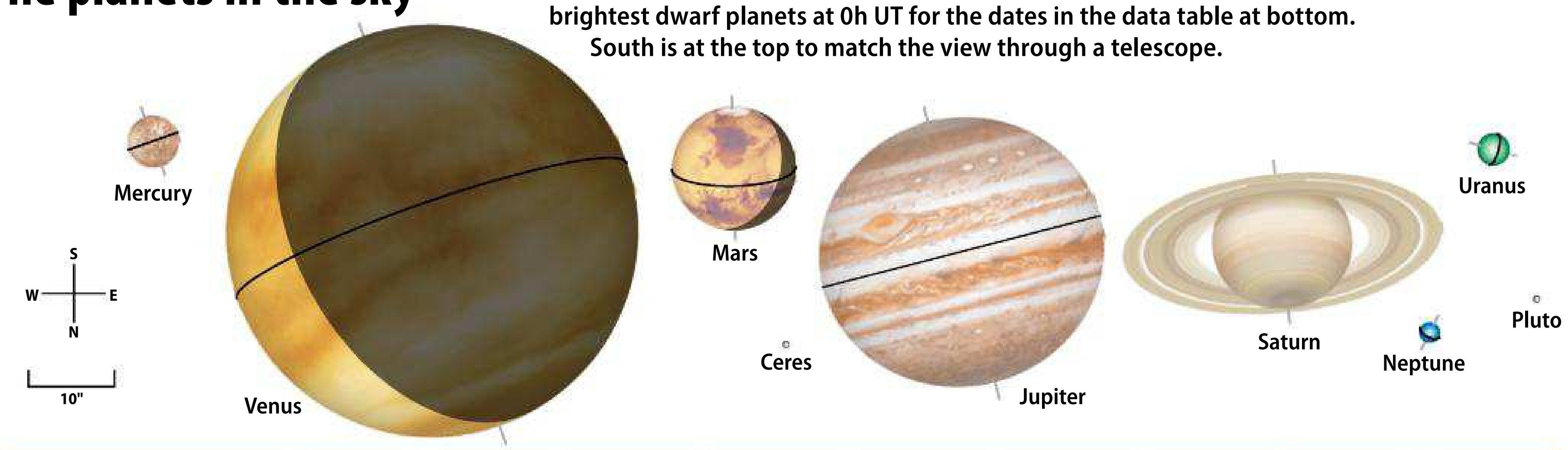
BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

The planets in October 2018



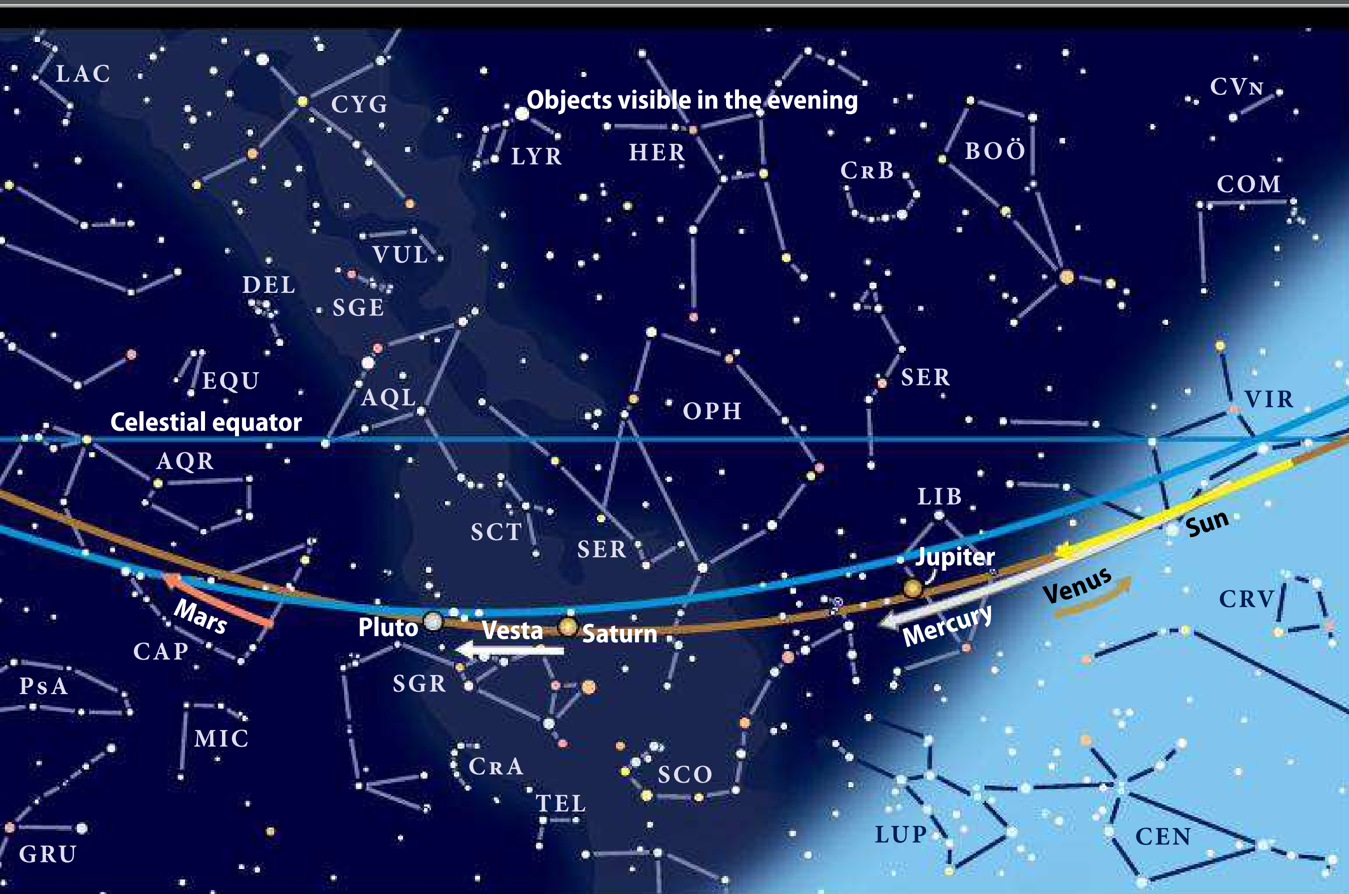
The planets in the sky

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.



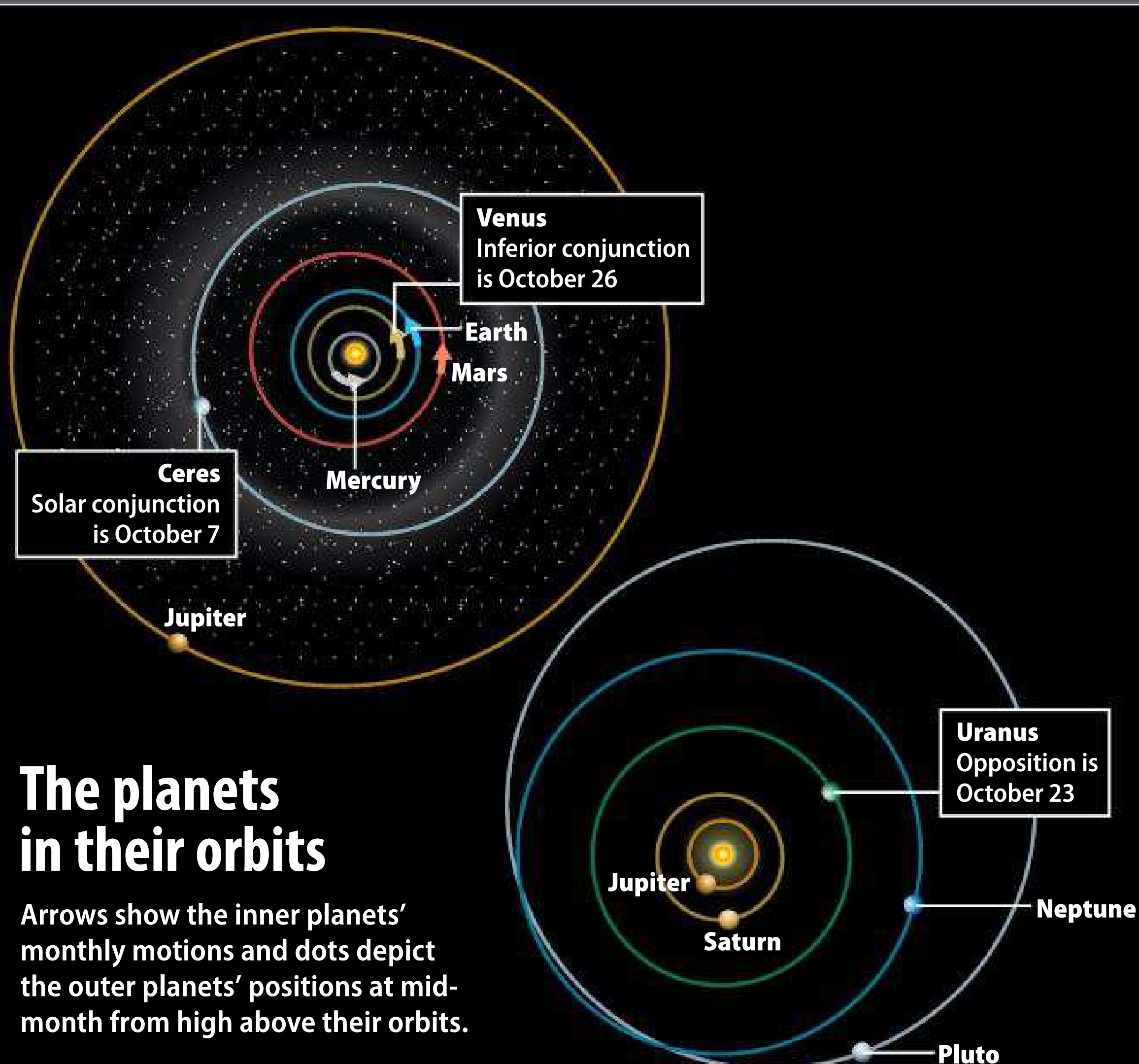
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Oct. 31	Oct. 1	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
Magnitude	–0.2	–4.8	–1.0	8.5	–1.8	0.5	5.7	7.8	14.3
Angular size	5.9"	46.2"	13.9"	0.4"	31.9"	16.1"	3.7"	2.3"	0.1"
Illumination	75%	17%	87%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.138	0.361	0.676	3.588	6.178	10.324	18.886	29.142	33.695
Distance (AU) from Sun	0.438	0.727	1.387	2.605	5.372	10.063	19.871	29.940	33.661
Right ascension (2000.0)	15h46.9m	14h21.8m	21h01.1m	13h14.3m	15h29.5m	18h15.1m	1h55.0m	23h02.1m	19h20.3m
Declination (2000.0)	–22°32'	–21°19'	–20°13'	–0°21'	–18°12'	–22°47'	11°11'	–7°16'	–22°08'

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.



Early evening

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.

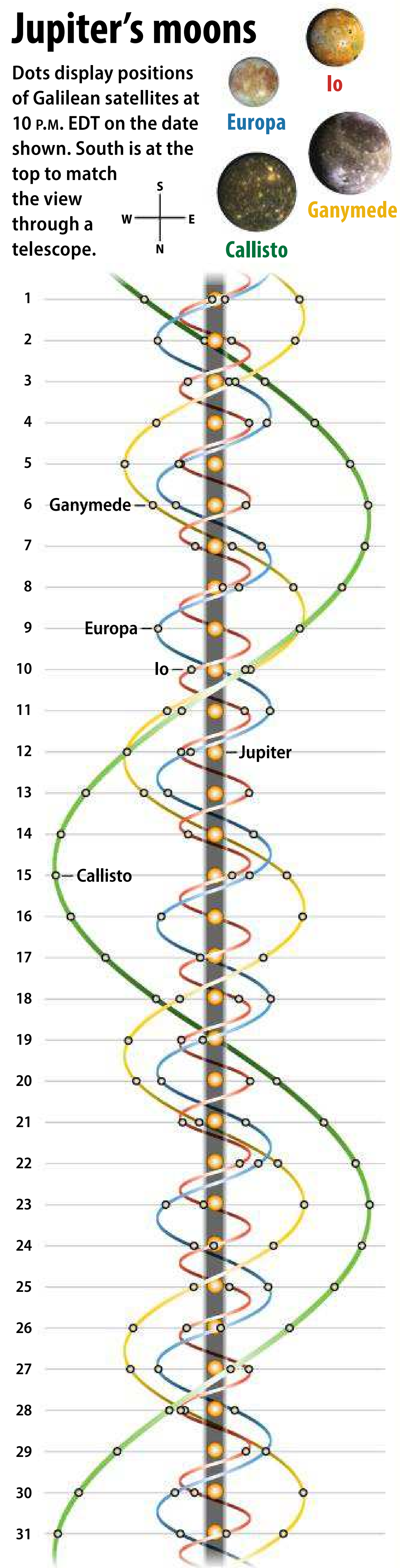


The planets in their orbits

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 10 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



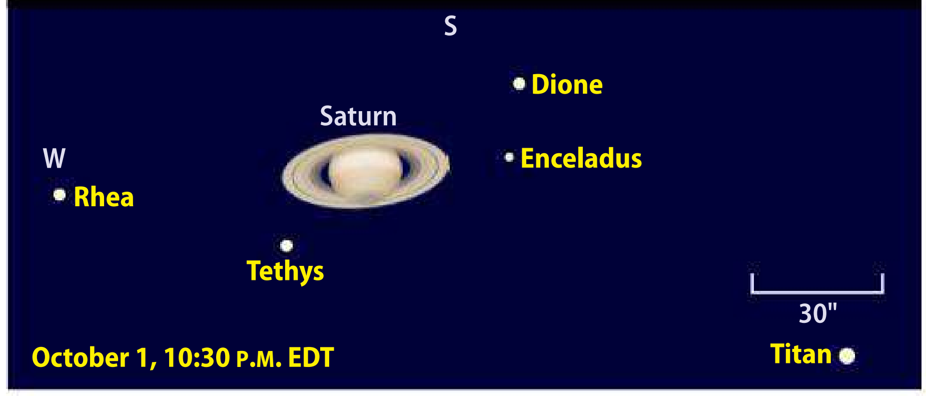
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

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

Enceladus peeks out from the rings' glare



The evening of October 1 offers viewers a great opportunity to spy this 12th-magnitude moon as it reaches greatest eastern elongation.

planet October 7 and 23 and north of it October 15 and 31.

A 4-inch scope brings in three 10th-magnitude moons. Tethys, Dione, and Rhea circle Saturn inside Titan's orbit, and they change positions noticeably from day to day.

Fainter still is Enceladus. You'll likely need an 8-inch instrument to see this 12th-magnitude moon, which revolves around Saturn once every 1.4 days. The rings' glare masks this inner satellite unless it lies near greatest eastern or western elongation. North American observers should hunt for Enceladus on October 1, when it lies farthest east of Saturn (14" from the rings' edge) and 17" north of Dione.

Look to the south after darkness falls, and **Mars** meets your gaze. Although the Red Planet reached opposition in late July, it remains dazzling against the background stars of Capricornus. Mars shines at magnitude –1.3 as October opens and loses about half its luster by month's end, when it glows at magnitude –0.6. Still, this is brighter than any star visible on October evenings.

Mars crosses the breadth of Capricornus during October. It starts the month in the constellation's southwestern corner, and appears nearly 30° high at its peak around 9 P.M. local daylight time. By late October, the planet lies in northeastern Capricornus and stands 5° higher when it peaks around 8 P.M.

With Mars placed high in the south in early evening, observers with telescopes should be in for a treat. Although the planet's apparent diameter shrinks from 16" to 12" during October, that's still big enough to show some surface features. And that might be an improvement over the opposition view. A dust storm that began in late May blew up in June, filling the planet's atmosphere with dust and obscuring the surface. As of mid-July, it looked like the global storm would continue through opposition.

Assuming clear martian skies, North American observers will see the following features near the center of the planet's gibbous disk on October evenings. Mare Cimmerium should be the

COMETSEARCH

Catch a comet crossing the Milky Way

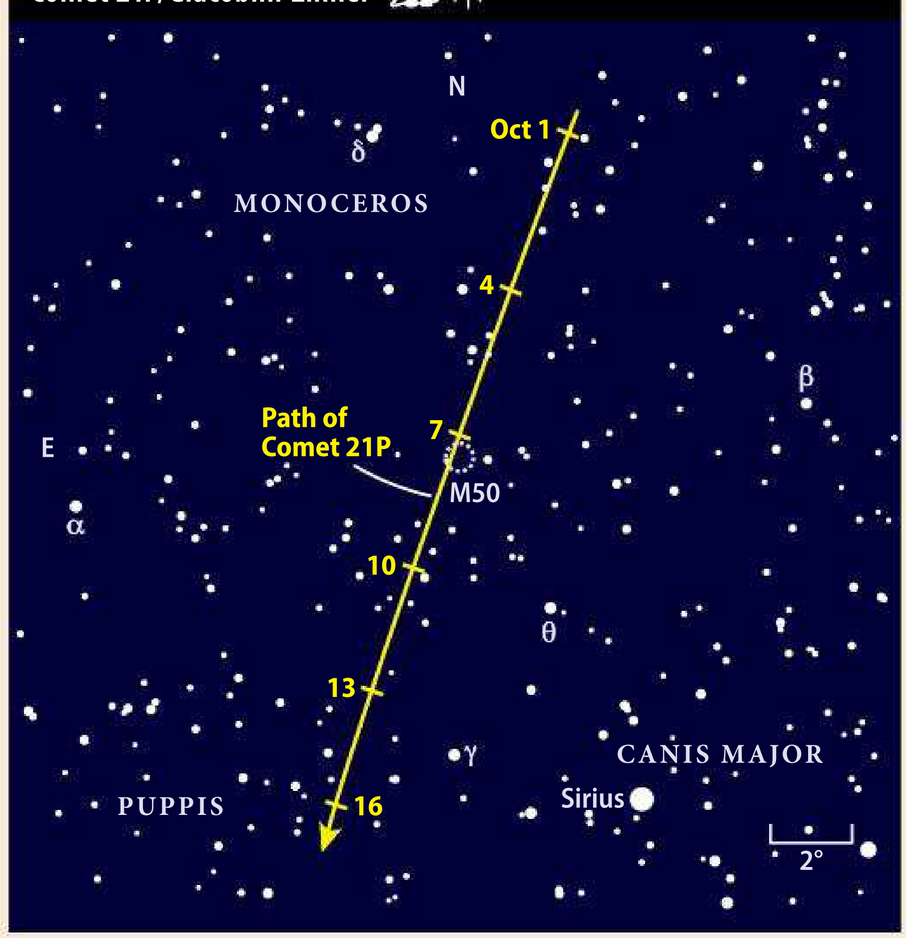
Observers don't often get a chance to see a reasonably bright comet and a meteor shower at the same time, but it's truly rare to set eyes on the very body producing those streaks of light. Such an opportunity presents itself during October's first half, when Comet 21P/Giacobini-Zinner graces the morning sky while the Draconid meteor shower reaches its peak. (See "Will the Hunter slay the Dragon?" on p. 37 for details on the Draconids.)

Comet Giacobini-Zinner should glow at 8th magnitude in early October. Observers can then find it plunging southward through the winter Milky Way, passing from Monoceros into Canis Major. Because this is only a few weeks after the comet made its closest approach to both the Sun and Earth, astronomers expect it to sport a nice gas tail about 1° long.

The Draconid meteor shower peaks the night of October 8/9, coinciding with Earth's passage through the comet's orbital plane. It's worth following Giacobini-Zinner in the days before, during, and after this crossing. Thanks to our changing perspective, the gas tail initially looks like a blue ribbon. It then turns edge-on as we pass through the orbital plane, and then flattens out again when we view it from the other side.

Astroimagers will have many chances this month to capture 21P floating in front of the pretty fields and star clusters of the winter Milky Way. The finest pairing occurs the morning of October 7, when the comet lies just north of open cluster M50.

Comet 21P/Giacobini-Zinner



Glowing at 8th magnitude during October's first half, this dirty snowball traverses the rich background of Monoceros and Canis Major.

Shine on, Hunter's Moon

Late October's nearly Full Moon hangs low in evening twilight for several days. This extra light once helped hunters catch their prey. CHIRAG UPRETI

most prominent feature at the beginning of the month, with Mare Sirenum taking over at the end of the first week. Solis Lacus appears front and center in mid-October, while Sinus Meridiani and Sinus Sabaeus take center stage during the month's third week. The planet's two most prominent features — the bright Hellas Basin and the dark Syrtis Major — appear best on October's final few evenings.

While Mars shines brightly enough to see from the city, you'll need a dark sky and optical aid to see **Neptune**. The outer planet glows at magnitude 7.8 among the background stars of Aquarius, a region that appears due south and nearly halfway to the zenith in late evening.

Neptune lies between the 4th-magnitude stars Lambda (λ) and Phi (ϕ) Aquarii. In early October, it's midway between these two. The planet's westward motion during the month carries it closer to Lambda, and on the 31st it stands 2.1° east of this star. A telescope reveals Neptune's 2.3"-diameter disk and subtle blue-gray color.

Uranus reaches opposition October 23. It then lies opposite the Sun in our sky, so it rises at sunset and remains visible all night. It also comes closest to Earth at opposition and thus glows brightest. But an outer planet's appearance changes slowly, and Uranus sustains its magnitude 5.7 peak all month.

The ice giant glows brightly enough to spot with the naked eye, but binoculars make the task much easier. (That's particularly true the night of opposition, when the Full Moon lies nearby.) Look for Uranus in southwestern Aries, just over the border from Pisces. In the nights around opposition, you can find it 2.8° northeast of 4th-magnitude Omicron (o) Piscium.

The view of Uranus through a telescope should be superb because it lies so high in our sky. From 40° north latitude on the night of opposition, the planet climbs 61° above the southern horizon at its peak around 1 A.M. local daylight time. This is the highest it has appeared at opposition since February 1962. Even small scopes show a distinctive blue-green disk that spans 3.7".

Full Moon arrives October 24, a day after Uranus reaches opposition. But don't be surprised to see a nearly Full Moon hanging low in the east after sunset for a few days around this date. The so-called Hunter's Moon rises only about 30 minutes later each night compared with an average of 50 minutes. This shorter-than-normal delay arises because the ecliptic makes a shallow angle to the eastern horizon around sunset on autumn evenings.

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**

Vesta pops the Teapot's lid

The brightest minor planet couldn't be much easier to find early this month. If you can tear yourself away from Saturn, just drop 4° southeast to magnitude 2.8 Lambda (λ) Sagittarii, the star that marks the lid of the Teapot asterism in Sagittarius the Archer.

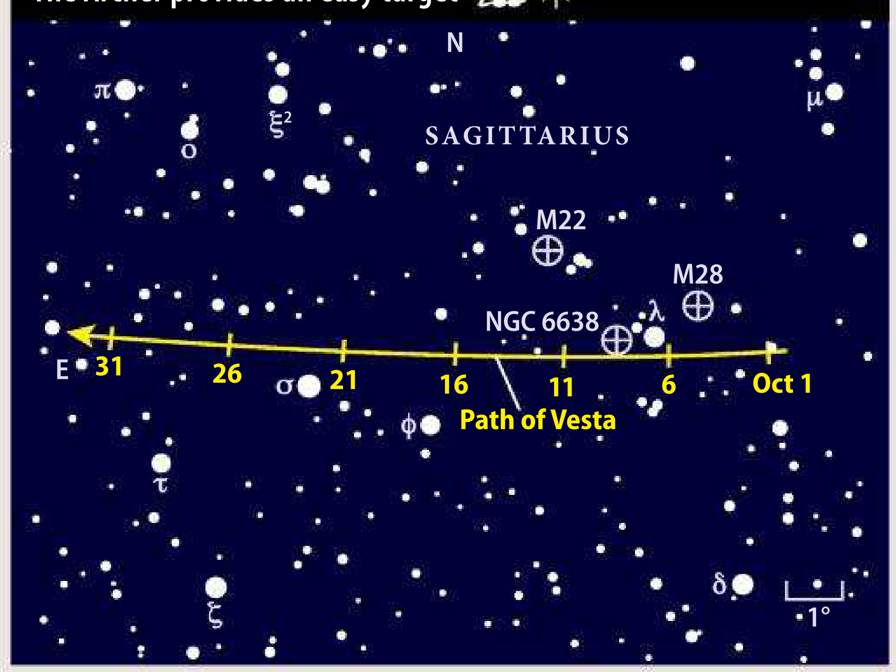
On October 1, Vesta lies 2.1° due west of Lambda and just 4' south of a magnitude 6.5 field star. The asteroid glows a magnitude fainter. Identifying Vesta becomes easier as it heads eastward during the next week. From the 5th to the 9th, the space rock lies within 1° of Lambda, passing 20' south of the orange giant star the evening of the 7th.

Continuing eastward, Vesta slides within 1° of magnitude 2.1 Sigma (σ) Sgr in the Teapot's handle from October 21–24. During these four evenings, the asteroid is the brightest object to the north of this bluish star. Closest approach occurs on the 23rd, when 40' separate the two.

Throughout October, Vesta travels at a pace of nearly 1' per hour. This is fast enough that you can notice its movement in one observing session, particularly when it passes near one of the field stars mentioned earlier.

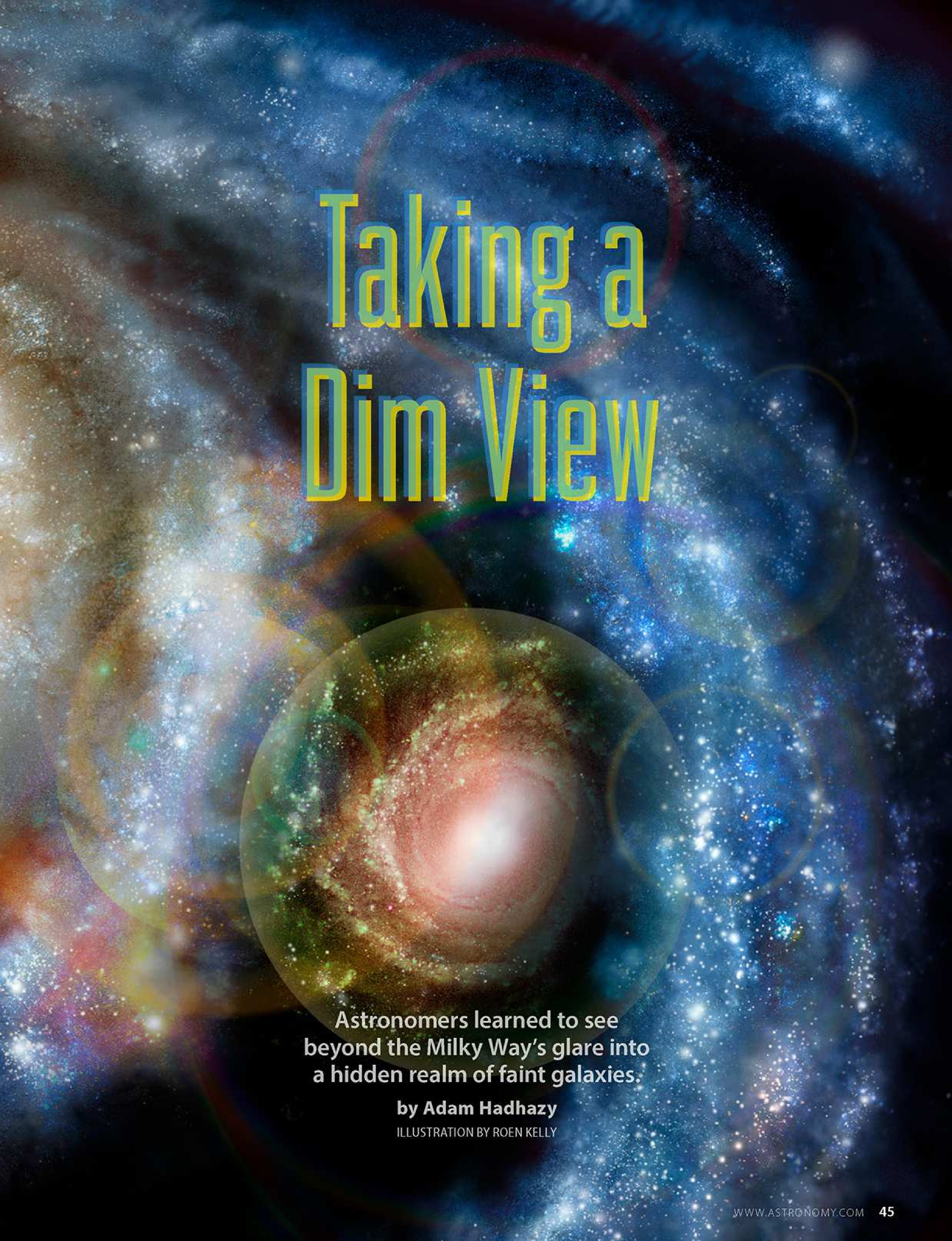
The Teapot also boasts a few bright globular star clusters near Vesta's path that are worth exploring. Both 7th-magnitude M28 and 9th-magnitude NGC 6638 lie within 1° of Vesta during October's first 10 days, and 5th-magnitude M22 lies 2° north of the asteroid during the month's second week.

The Archer provides an easy target



Eighth-magnitude Vesta should be easy to find this month as it passes near several bright stars and globular clusters in Sagittarius the Archer.

From *Discover* Magazine



Taking a Dim View

Astronomers learned to see beyond the Milky Way's glare into a hidden realm of faint galaxies.

by Adam Hadhazy

ILLUSTRATION BY ROEN KELLY

One winter night in 1969, at an observatory atop Kitt Peak in Arizona, Michael Disney had a funny thought. As he peered into a huge, superluminous galaxy, he wondered: What if an alien astronomer there were staring right back? At the eyepiece of its own telescope, the intelligent extraterrestrial might likewise be ogling Disney's smaller, fainter home galaxy, the Milky Way.

Then another thought cut through the whimsy. The young Welsh astronomer realized the alien had no chance of seeing the Milky Way, let alone the universe's oodles of dimmer galaxies. Overwhelmed by the glare of all the stars stuffed into its resident galaxy, the alien would unknowingly be blinded to most of the cosmos.

Disney wondered if we might be similarly deceived, awash in the inescapable glow of our own surroundings. "It occurred to me there could be a whole universe up there of hidden galaxies, just a little dimmer than those we can detect from Earth," says Disney, an emeritus professor at Cardiff University in Wales.

"We truly are imprisoned in our lighted cell," says Michael Disney. "It's like you're in the middle of a lighted room at night and you look out the window." Your room's light drowns out anything less bright.

Since that revelation in the desert nearly a half-century ago, Disney, now 80, has searched for a shadowy galactic realm. His hunch gained momentum in the 1980s and 1990s, but at the turn of the century, the trail ran cold. Disheartened and defeated, Disney relinquished the hunt.

But recently, serendipitous sightings and new technology have reinvigorated the concept of a hidden cosmos. "Most of the universe is likely undiscovered," says Greg Bothun, an astrophysicist at the University of Oregon who has long studied faint galaxies. The emerging population of dim galaxies likely outnumbers, and is strikingly different from, the typical bright galaxies we know and love, challenging our conventional theories of galaxy formation and evolution. Dim galaxies also may solve an old mystery about missing matter in the universe.

By these reckonings, hidden galaxies are the cosmic norm, not our garish Milky Way and its ilk. Long overlooked, the dominion of dim galaxies may finally be getting its due.

BLINDED BY THE LIGHT

Our universe is suffused with luminous galaxies. We can see the nearest few of these great collections of stars, gas (mostly hydrogen), and dust with our eyes from Earth. Telescope surveys suggest as many as 2 trillion are out there, albeit mostly of a small, faint, "dwarf" variety. Tidily, these galactic hordes come in stereotypical shapes and sizes, such as large spirals like the Milky Way, even bigger football-shaped ellipticals and those dime-a-dozen dwarf galaxies. They follow typical life cycles, making abundant stars in their youths and slowing down as they age.

For all we've learned about galaxies and the wider cosmos, though, astronomers have struggled with human limitations as heavenly observers. Our instruments can only readily perceive objects whose brightness contrasts enough with the glow of the night sky. For sure, night *looks* dark — around 50 million times darker than day — but that's still just *relatively* dark. "We live right next to this bloody luminous star called the Sun," says Disney. "That's always going to make it difficult for us to find this hidden universe."

The Sun's brilliance affects astronomical viewing in two roughly equal ways. At night, an "airglow" lingers in our atmosphere as molecules radiate away the heat they soaked up during the day. To avoid airglow, we can send instruments into orbit, like the Hubble Space Telescope (for which Disney designed instruments). But these spacecraft still must squint through the second of the Sun's impacts, its bright illumination of icy and dusty particles around it, known as the zodiacal light. Add this to the copious light generated by all the other stars in our galaxy, and you get quite a glare. This natural "light pollution" extends to the entire electromagnetic spectrum, well beyond visible light.

"We truly are imprisoned in our lighted cell," says Disney. "It's like you're in the middle of a lighted room at night and you look out the window." Your room's light drowns out anything less bright. In 1976, seven years after his experience in Arizona, Disney wrote in a paper in *Nature* that our catalogs of galaxies are probably an unrepresentative subset of the true galactic population. A great number of dimmer and potentially sizable galaxies likely awaited discovery,

The spiral galaxy M101 in the constellation Ursa Major takes center stage in this photo from the Dragonfly telescope, but astronomers are also interested in the fainter galaxies lurking in the background. ROBERTO ABRAHAM

he proposed. Yet with little in the way of supporting data, the prophecy gained little traction.

That changed a decade later, when astronomers stumbled upon a galaxy unlike anything they'd ever seen.

A GIANT GALACTIC GHOST

Intrigued by faint blurs on old photographic plates of the Virgo galaxy cluster, a nearby region teeming with galaxies, Bothun and colleagues wondered if the apparitions might be smallish galaxies with "low surface brightness" — astronomer-speak for emitting less light per unit area than typical galaxies.

Using Puerto Rico's Arecibo radio telescope in 1986 to detect galactic hydrogen clouds, Bothun and colleagues uncovered a vast game changer of a galaxy a billion light-years away. Dubbed Malin 1, it's been heavily studied ever since, and it remains the largest

Despite being the largest known spiral galaxy, Malin 1 is so dim and its arms so faint that it remained undetected until the 1980s. BOISSIER/A&A/ESO/CFHT

known spiral galaxy, seven times wider than the Milky Way with 50 times its mass. Yet, bizarrely, the galactic titan is rendered profoundly dim by its wispy spiral arms, spaced 10 times farther apart than in conventional spiral galaxies.

"It's impossible to understand how that object exists," says Bothun. "All our models do not produce objects anywhere near Malin 1." The dim giant proved there might be more to the universe's galaxies than anyone suspected.

FOUND AND LOST

Galvanized by the discovery of Malin 1, astronomers pored over the previous decades' photographic plates for hints of unnoticed, low-surface-brightness galaxies. (In fact, they still do — there are a lot of plates.) Although less grand than Malin 1, thousands more materialized throughout the 1990s.

Further aiding in the search were charge-coupled devices (CCDs), a far more light-sensitive imaging technology that took off in the 1980s and dominates astronomy today. "Discovering low-surface-brightness galaxies was a thrilling thing to do," says Karen O'Neil, then a student of Bothun's and now the director of Green Bank Observatory in West Virginia. "It's always fun to go out and look for the unknown."

Though intriguing, next to the billions of known luminous galaxies, these hundreds of dim ones still didn't amount to a hill of beans, cosmically speaking. The phantom universe, so far, was just a phantom niche.

But ironically, it was work by Disney himself that ended up slamming the door shut on the field. He helped install a powerful receiver at the Parkes Observatory radio dish in Australia in 1997, hoping to wrangle many Malin 1-esque galaxies and finally blow the lid off the dim universe. In data collected over several years, more than 4,000 concentrations of hydrogen gas turned up — promising candidates as low-surface-brightness galaxies.

By 2005, however, optical telescope follow-ups on these sources suggested they were almost all just hydrogen clouds in normal galaxies. "Not one looked to be a hidden galaxy," says Disney. The discovery was a crushing result, seeming to prove beyond doubt that Malin 1 and its ilk were just bizarre freaks, not part of a larger phantom universe.

"That killed the subject off," says Disney. "Even I gave up."

... AND FOUND AGAIN?

But the subject did not give up on him, for other sky-gazers thought Disney was on to something.

At a 2009 conference in the Caucasus region, Disney met Ukrainian astronomer Valentina Karachentseva, who suggested some of those thousands of hydrogen clouds in the Parkes survey were indeed galaxies. Over her career, through keen eyesight alone, Karachentseva has identified numerous dim galaxies on photographic plates. She told Disney she'd spotted standalone galaxy-like objects right where the Parkes survey had found gas clouds identified as merely extended parts of nearby bright galaxies.

Thunderstruck, Disney returned to Wales and tried something new. He went over calculations affirming just how clustered the universe's galaxies are. They're fundamentally social creatures, piling up practically on top of each other, leaving immense, desolate voids between clusters. Could his unseen galaxies be hidden among these huddled galactic herds, with their separate gas clouds mistaken as belonging to the closest, resplendent galactic neighbor?

Disney came to realize that the Parkes observations lacked the resolution, the fineness of detail, to make out dim galaxies tightly bunched with luminous galaxies. He tried to convince study colleagues and an astronomical journal of the possible error, but none was receptive. "I was a bit of a figure crying in the darkness," says Disney, "literally."

He eventually found a way to settle the matter. In early 2015 Disney was awarded time on the upgraded, exquisitely sensitive Karl G. Jansky Very Large Array (VLA) of radio dishes in New Mexico. He rescanned a sample of 19 hydrogen clouds from the 4,000 candidates in the Parkes survey. Fourteen of the clouds, it turned out, had no visible counterpart galaxy in the new data.

"Bingo," says Disney. Straightaway, it was clear that the gas cloud radio wave sources shouldn't have been lumped together with nearby, optically bright galaxies. He was onto something.

HIDING IN PLAIN SIGHT

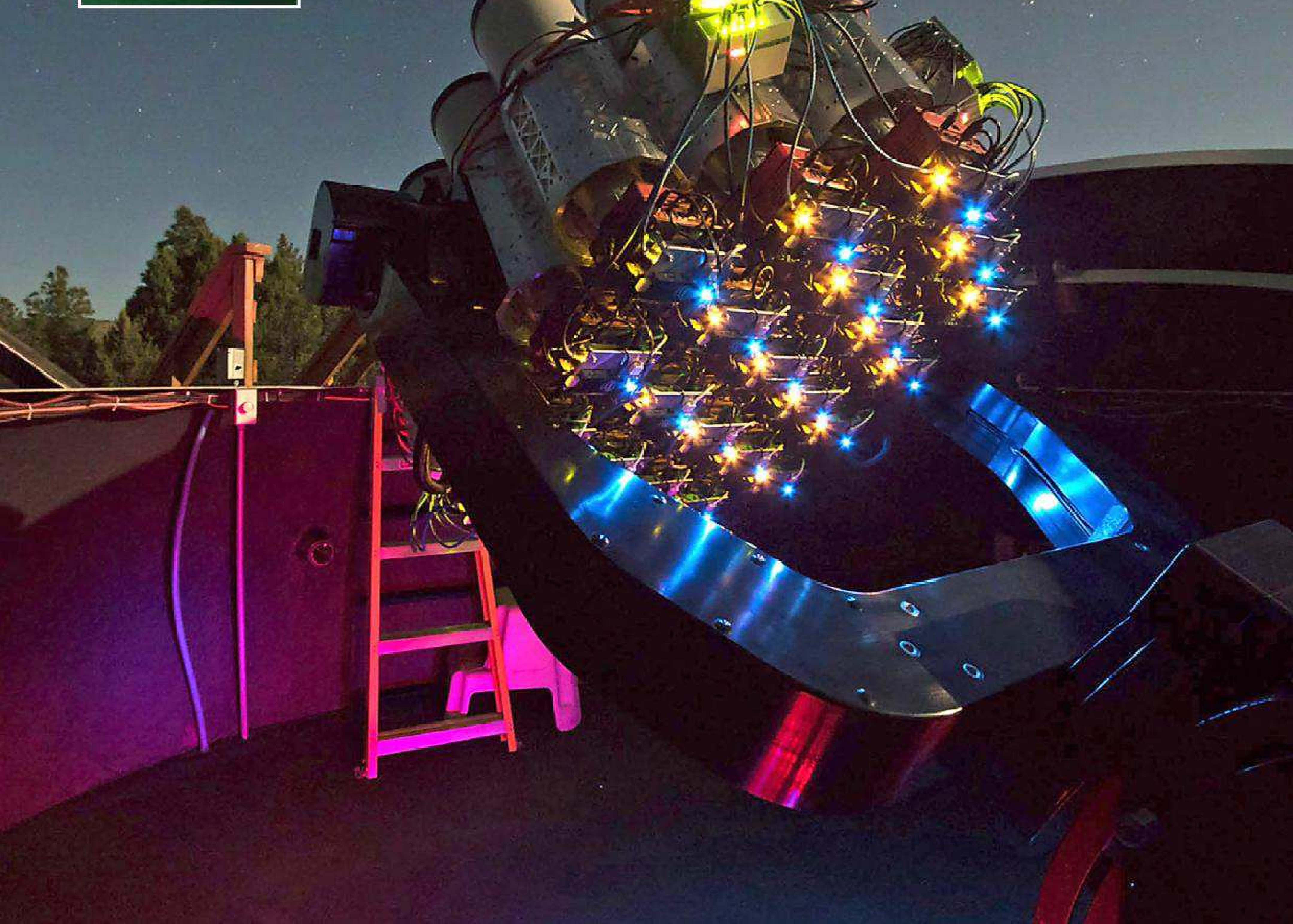
Disney didn't know what these clandestine objects might be like, and he immediately wanted to follow up with new observations, which are now taking place. In late 2016, using the William Herschel Telescope in the Canary Islands, he spied hints of a dozen newfound, unmistakable dim galaxies.

These objects will increasingly have ample new company, it seems. In a 2015 study, Pieter van Dokkum of Yale University and colleagues announced they had unearthed 47 never-before-seen, Milky Way-sized yet extremely diffuse (spread out, so relatively dim) galaxies in the Coma Cluster of galaxies, among the most studied in astronomy. "This was a complete surprise," says van Dokkum.

It was not some mammoth new telescope that sussed out these faint objects. The ever-larger telescopes the astronomical community usually clamors for are actually bad at revealing low-surface-brightness objects. These telescopes typically use mirrors, which capture more random, unwanted light, burying any faintly emitting objects. Instead, van Dokkum found his galaxies by grouping eight 400-millimeter lenses into a contraption resembling

P. VAN DOKKUM/YALE UNIVERSITY (2)

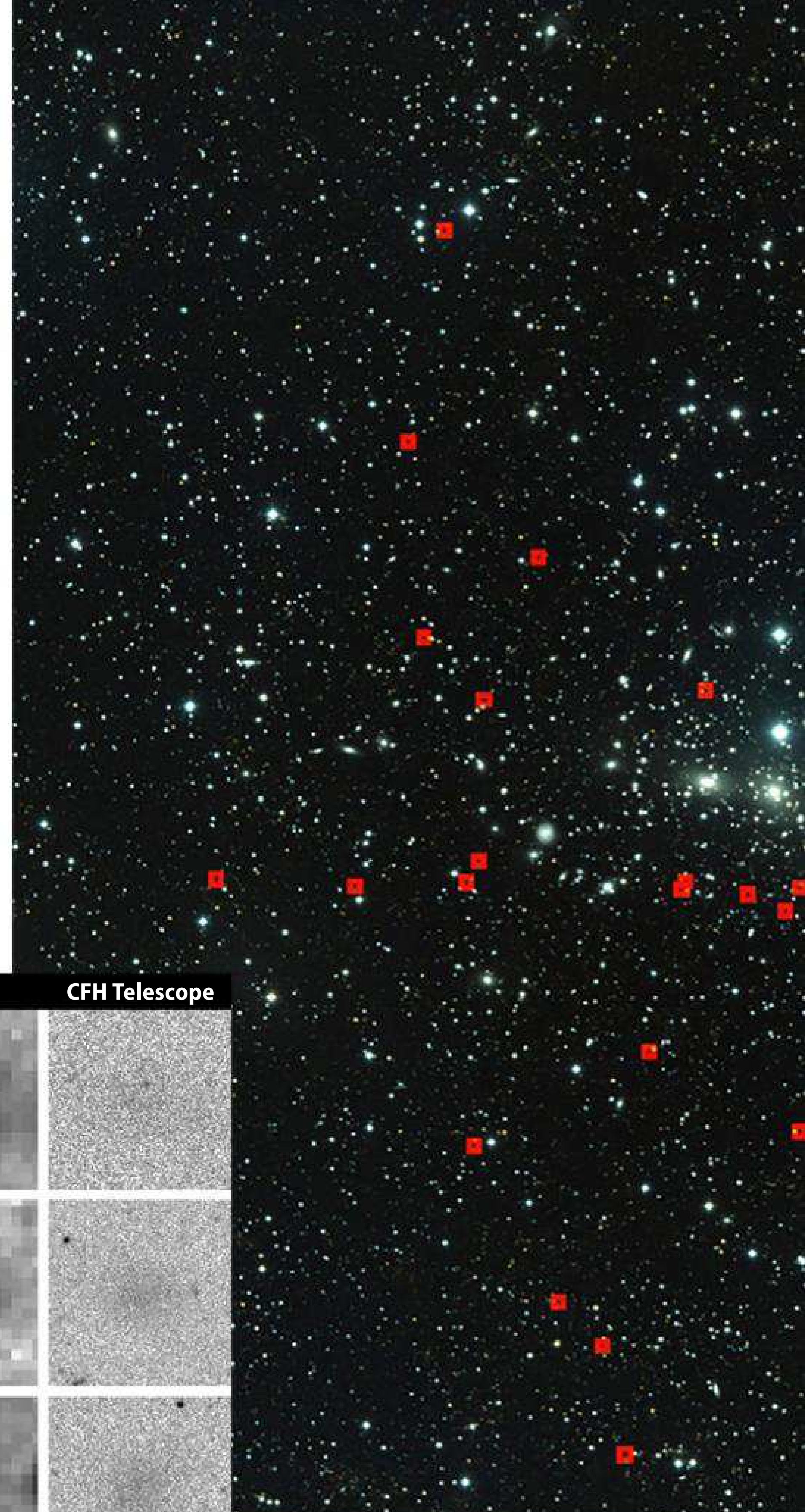
The novel Dragonfly telescope in New Mexico has helped researchers find dozens of previously unknown ultra-diffuse galaxies. Its current setup groups 24 large camera lenses in a cluster resembling a dragonfly eye. The lenses are actually commercially available 400mm telephoto lenses.

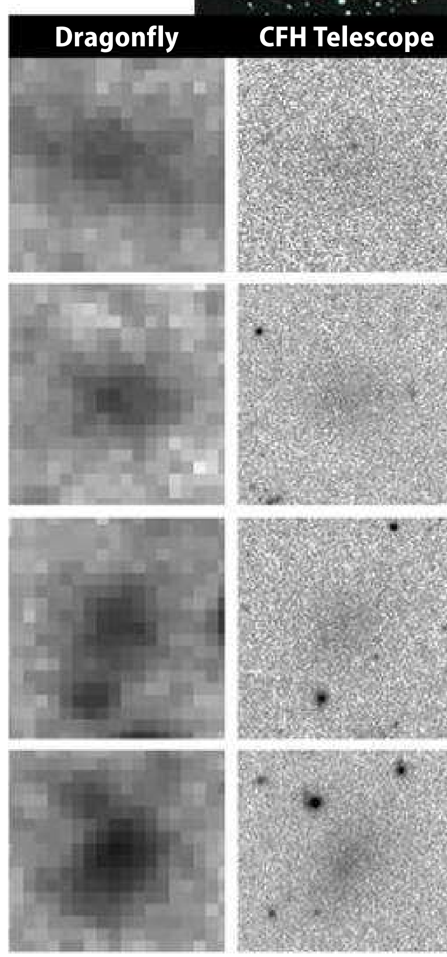


an insect's compound eye. Indeed, the project's name, Dragonfly, comes from van Dokkum's hobby of taking pictures of the insect.

Dragonfly's multiple lenses serve as checks on one another for stray light; their internal surfaces are treated with an anti-reflective coating. The lenses are hooked up to CCDs, which van Dokkum says are finally getting good enough to distinguish the universe's mostly ghostly galaxies. "Even now," he says, "we're only scratching the surface."

Traditional mirrored telescopes can still help. Inspired by van Dokkum's find, Stony Brook University's Jin Koda and colleagues looked through recent Coma Cluster observations from the 8.2-meter Subaru telescope in Hawaii. The researchers found 854 ultra-diffuse galaxies, with more than 300 stretching to the Milky Way's size. This boatload had gone unnoticed because astronomers previously assumed luminous traces of the galaxies in Coma indicated small, insignificant bodies, and not just the most visible central regions of otherwise very dim objects — the tips of galactic icebergs, as it were.





Red squares mark the location of 47 dim galaxies in the Coma Cluster. The inset shows Dragonfly's clear detection of the objects (left column) and their confirmation as diffuse objects as imaged by the much larger Canada-France-Hawaii Telescope.

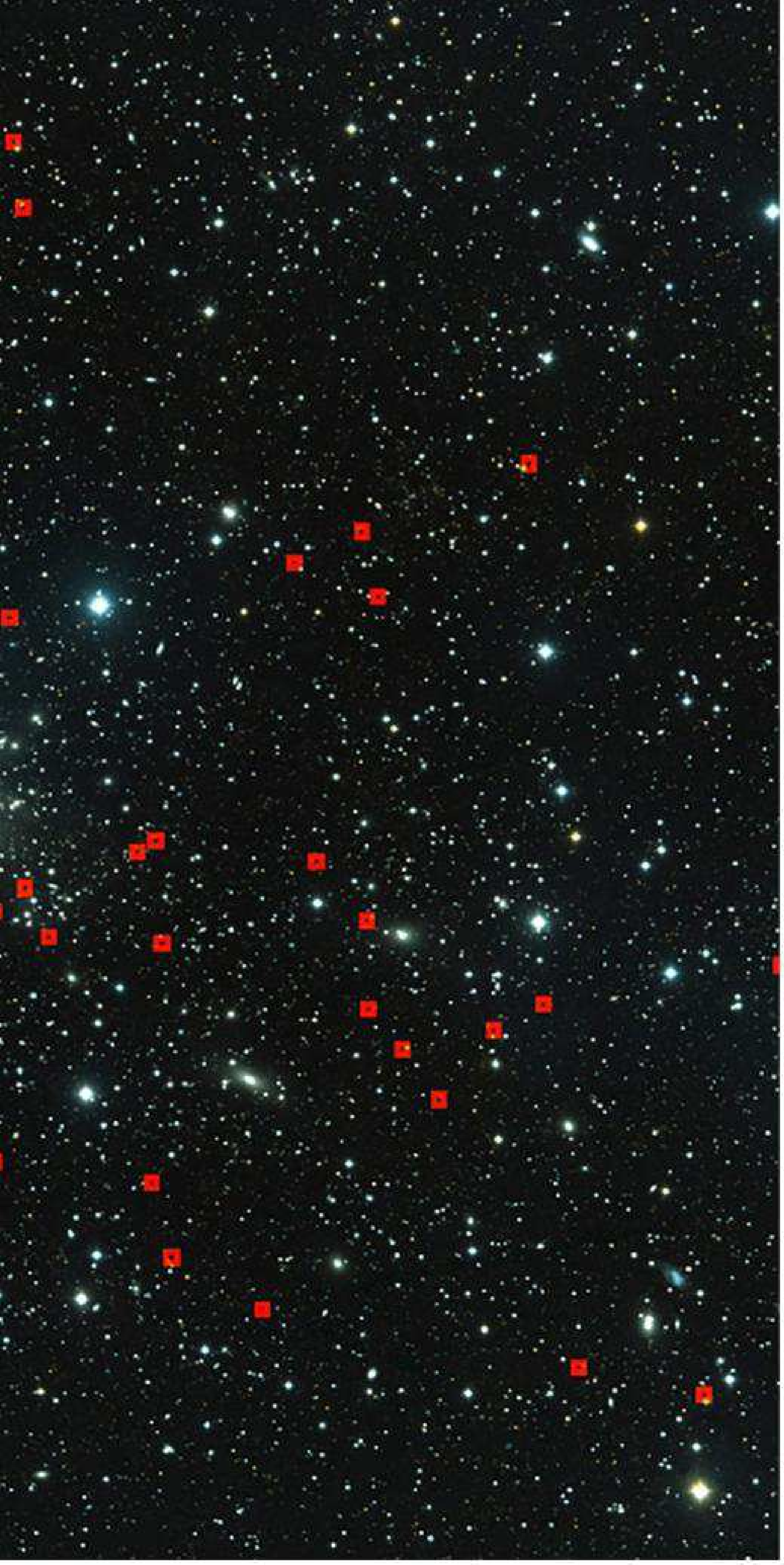
GRASPING IN THE DARK

The newfound dim galaxies in Coma are strange beasts, and they hark back to some of the faint galaxies first uncovered in the late 1980s. Almost entirely gasless, round and thinly stocked with old red stars, they have apparently survived for eons in a dense environment of visible galaxies. Those comparatively gas- and mass-rich conspicuous galaxies and their environs should have gravitationally pulled the inconspicuous galaxies to shreds by now — why they haven't is a mystery.

Astronomers also are not sure how the universe made these sorts of objects in the first place. "That's why this field is so exciting at this moment," says Koda. "We don't really know what these galaxies are." They might represent a population of "failed" galaxies. Although expansive, such failure-to-launch galaxies might have started out with insufficient amounts of normal matter, or somehow lost it, stifling the formation of new stars.

Assuming that's the case, the Coma Cluster's population of diffuse galaxies might be the opposite of galaxies like Malin 1. Those in the latter's class of low-surface-brightness galaxies are oddly bluish, thanks to the presence of newly made stars that are azure in color. These galaxies could be cosmic late bloomers, a kind of slowly evolving galaxy just now producing plentiful stars, billions of years after the Milky Way and others went through their peak periods of star-making. Arrested development, like in Coma, or delayed development à la Malin 1 — either way, the universe's faint galaxies don't mesh with conventional theory.

Dim galaxies also could force some rethinking about large-scale cosmic structure and its relation to dark matter. First theorized in the 1930s, dark matter does not emit light, betraying its existence solely through gravity. Its true identity remains a mystery, but astronomers know it outnumbers regular matter 5 to 1 and acts as gravitational glue, holding galaxies together. According to recent studies, dim galaxies like



P. VAN DOKKUM ET AL./ASTROPHYSICAL JOURNAL LETTERS/VOL. 798, NO. 2/JANUARY 7 2015 (2)

those strangely hardy ones in Coma look to be almost entirely made of the stuff. Astronomers suspect galaxies began as accumulations of dark matter in the early universe that acted as seedbeds for normal matter.

As the universe expanded, those dark matter seeds spread out into a "cosmic web," linking galaxy clusters at the densest points with thin filaments of dark matter. If we have only seen the brightest galaxies in the universe, we don't have the full picture about how matter and dark matter are truly distributed. "Low-surface-brightness galaxies are one of the keys to figuring out what the clumpiness of the cosmic web looks like," says NRAO's O'Neil. "They'll help us understand how the universe really did grow to be what it is."

Finally, by allowing for a more proper accounting of the matter content of the universe, dim galaxies could also help solve the long-standing "missing baryon problem." Although few cosmologists seriously doubt that normal matter, made of particles called baryons, makes up only about 5 percent of the universe's total mass-energy budget, the observable matter we know of is still only about half what we'd expect. "There could be a hell of a lot of stuff missing," says Disney, "and it could be in the form of hidden galaxies."

A SCANNER DARKLY

Increasingly, astronomers are, in a sense, seeing the dark. In July 2016, a team reported finding a humongous low-surface-brightness spiral galaxy, the first unearthed to rival Malin 1's size. Van Dokkum, meanwhile, is expanding the Dragonfly Telephoto Array to dig up more secretive galaxies. Stony Brook's Koda is optimistic. "There will be a lot of discoveries in the low-surface-brightness universe," he says, "because many people are now looking into it and trying to develop new techniques to find what's there."

> Arrested development, like in Coma, or delayed development à la Malin 1 — either way, the universe's faint galaxies don't mesh with conventional theory.

Disney, for one, thinks a huge observing campaign with the upgraded VLA in New Mexico could finally give us a handle on the true population of invisible galaxies. Some dark galaxies, like those in the Coma cluster but with even less hydrogen, will be tougher to bring into the fold. While Bothun is skeptical that human technology could ever detect the darkest of galaxies, he is confident they are out there. "The logical extension of a low-surface-brightness galaxy is a dark galaxy," he says. "There is no reason to think they don't exist."

Looking back on the failed radio observations at the turn of the millennium, Disney is eager to make up for lost time and continue the search for the phantom universe's elusive galaxies. "I was the person who did more to get things wrong than anyone," says Disney. "I've just literally spent 40 years of my life on this, and I'd like to know the answer, one way or the other."

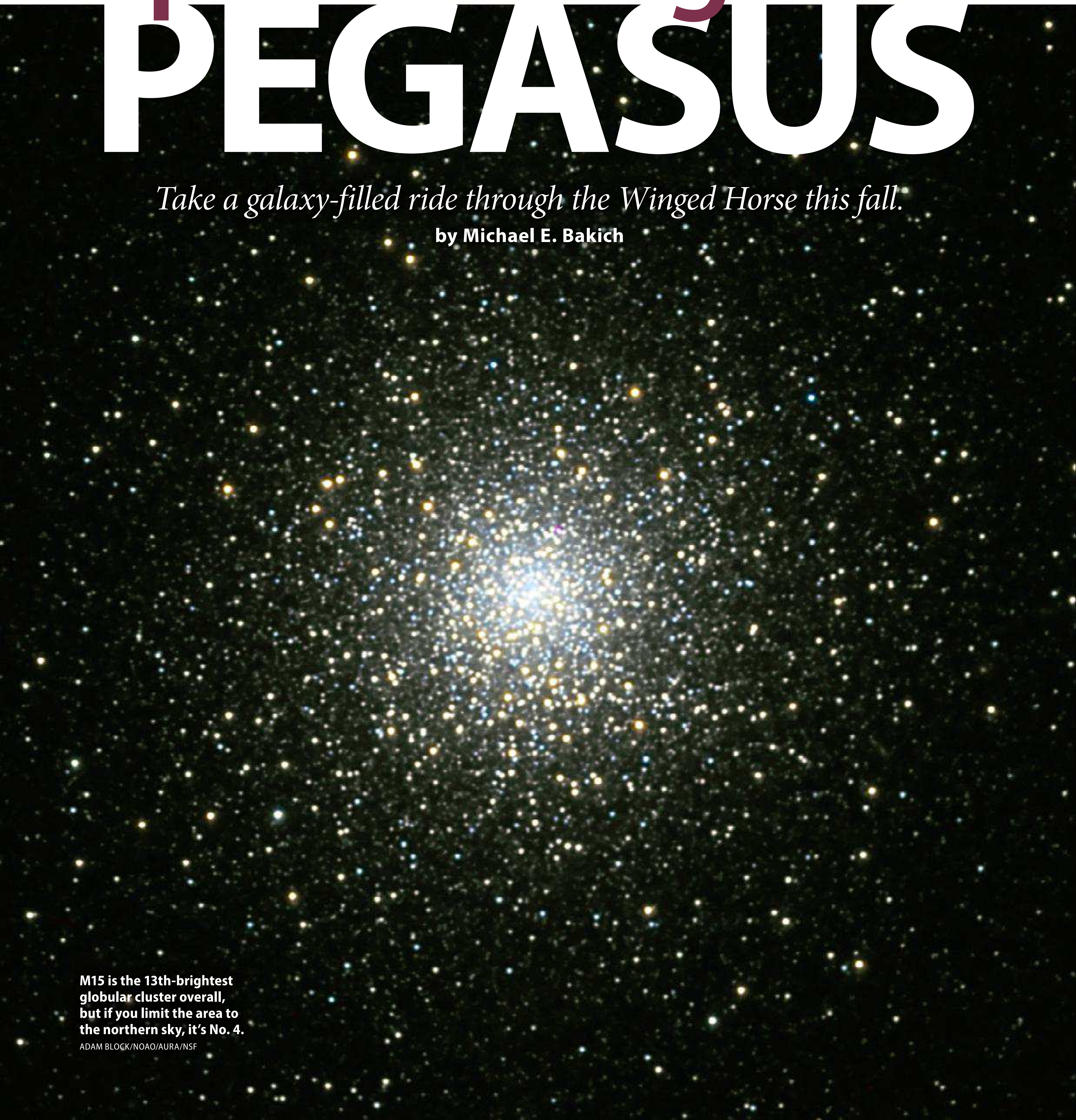
Disney considers it a real gift that we earthlings might one day be so lucky to behold the cosmos, flooded as we are in sun- and starlight. "In such a glare," says Disney, "it is a wonder we can do any astronomy at all."

Adam Hadhazy, *a freelance science writer based in New Jersey, also writes for* BBC Future *and* New Scientist, *among other publications.*

Spend a night in PEGASUS

Take a galaxy-filled ride through the Winged Horse this fall.

by Michael E. Bakich



M15 is the 13th-brightest globular cluster overall, but if you limit the area to the northern sky, it's No. 4.
ADAM BLOCK/NOAO/AURA/NSF

WHEN PEGASUS THE WINGED HORSE rides high in the autumn sky, it truly dominates the scene — not because of a host of brilliant stars, but because of its size. It's the seventh largest of the 88 star patterns we recognize, and it ranks as No. 2 in the fall, a bit more than 90 percent the size of Cetus the Whale.

From the northern latitudes where most amateur astronomers live, Pegasus climbs much higher. In fact, its central point in declination lies 30° farther north than that of Cetus. So, not only is the Horse easier to see, but its stars also lie far above the horizon, where the thick air distorts the view.

The most recognizable part of Pegasus is the Great Square, an asterism made up of four stars: Markab (Alpha [α] Pegasi), Scheat (Beta [β] Peg), Algenib (Gamma [γ] Peg), and Alpheratz (Alpha Andromedae) marking the northeast corner. Yes, Andromeda. Nobody said given names in observational astronomy were logical.

But I'll try to be logical in the way I lead you to the objects. Let's start at the western end of the constellation and move eastward. That way, if you begin observing when the first object is high in the sky, the other objects will literally rise into their best viewing positions.

Permit me to suggest a couple of tips. First, dress warmly, preferably in layers. You can always take a jacket or sweatshirt off. I don't recall ever feeling too hot to observe, but I've frozen on many a night when temperatures were "moderate." Remember, you're not doing anything but looking. Second, sit in a chair whose height places your eye near the eyepiece. Remember: Comfort is everything.

Ready, set, observe!

Our first target is Pegasus' odd duck. It's the only object on this list that's not a galaxy. **M15** ranks as autumn's showpiece globular cluster for Northern Hemisphere observers. From a dark site, those with sharp vision can spot this magnitude 6.2 object with their naked eyes. Don't be confused by the magnitude 6.1 star only 17' to the east. Confirm your sighting through your telescope. M15 has a diameter of 12.3'.

And speaking of telescopes, a 4-inch scope will resolve dozens of stars around M15's strikingly bright core. Look for the chains of stars that wind out from its center. These star patterns cause some observers to describe M15 as slightly oval.

Finding M15 is pretty easy. Use Theta (θ) and Epsilon (ε) Pegasi as pointers. Draw a line from Theta through Epsilon, and continue another 4°.

With a 10-inch or larger telescope, try for the challenge object within M15: **Pease 1**, the first planetary nebula found within a globular cluster. In 1928, American astronomer Francis Gladheim Pease discovered this object when he noticed an unusually bright "star" on a photographic plate taken with the 100-inch Hooker Telescope on Mount Wilson.

Look for this planetary nebula through an eyepiece that yields 200x or so, and use a nebula filter to suppress the brightness of the myriad stars surrounding Pease 1. Be aware of the sky conditions. You'll need good seeing to spot the tiny planetary, which lies about 1' northeast of M15's core.

Our next object, **NGC 7217**, is a spiral galaxy 1.9° south-southwest of magnitude 4.3 Pi^2 (π^2) Pegasi. It measures 3.5' by 3.1' and glows at magnitude 10.1. Through an 8-inch telescope, you'll see a bright central region that spans half the galaxy's diameter. The halo that surrounds the core is easy to see at high magnifications.

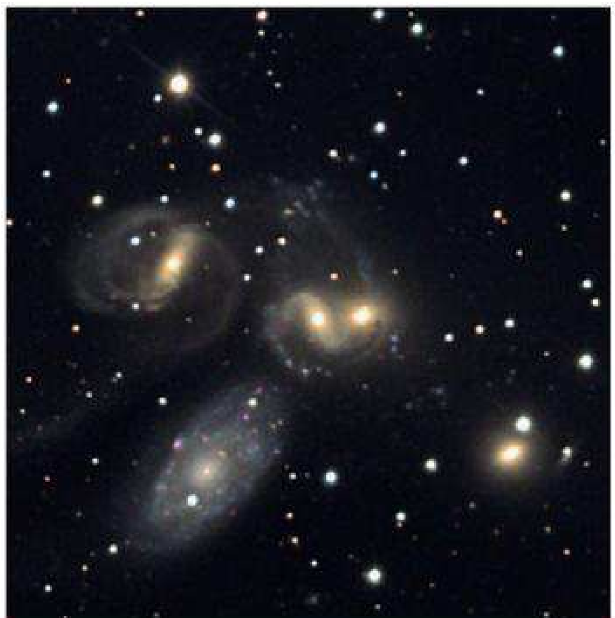
You'll see more detail as you observe through ever-larger telescopes — a mantra of amateur astronomy called "aperture rules." Few celestial objects demonstrate this better than our next target, **Stephan's Quintet**.

The magnificent spiral NGC 7331 is the main member of the Deer Lick Group. It's easy to see through medium-size scopes. The others? Not so much. R. JAY GABANY

This image of the Pegasus Dwarf (UGC 12613) is made up of 72 stacked exposures. Through the scope, search the area carefully for an ever-so-slightly brighter patch of sky. That's it! CHUCK KIMBALL

NGC 7217 is a spiral with tightly wound arms that circle the galaxy's nucleus from our point of view. Because it's small, it has a high surface brightness, so even a small scope will show it. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Amateur astronomers may notice a resemblance between spiral galaxy NGC 7814, shown here, and the Sombrero Galaxy (M104) in Virgo. The latter galaxy's dust lane is much easier to spot. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



Stephan's Quintet should not be approached lightly. The galaxies in this group are faint and close together. ADAM BLOCK/NOAO/AURA/NSF

French astronomer Édouard Stephan discovered this group in 1877. The five galaxies now carry the designations NGC 7317, NGC 7318A, NGC 7318B, NGC 7319, and NGC 7320.

Four of these galaxies — the exception being NGC 7320 — form a compact galaxy group, the first ever discovered. NGC 7320 belongs to the Pegasus Spur, a group of about three dozen galaxies, the brightest of which is magnitude 9.5 NGC 7331, which you'll read about later.

Although you can "see" Stephan's Quintet from a dark site through a 6-inch scope, a magnification of 50x will show you only a faint, clumpy glow 3' across. A 12-inch telescope, on the other hand, lets you identify the individual members.

At the Quintet's southwestern edge is magnitude 13.6 NGC 7317, which lies next to a 13th-magnitude foreground star. The colliding pair NGC 7318A and NGC 7318B lies 2' to the east. You'll need high magnification — above 200x — to "unmerge" them.

The brightest and largest member, NGC 7320, lies to the southeast and contains a 13th-magnitude foreground star in its halo. This galaxy shines at magnitude 12.6. NGC 7319, which sits at the group's northeastern edge, is the real test for visual observers. It glows softly at magnitude 13.1.

Deep-sky objects have some fanciful names, but usually they fit the view. For example, the Blue Snowball (NGC 7662) in Andromeda is blue and round; the Omega Nebula (M17) in Sagittarius looks like that Greek letter; and Gomez's Hamburger (IRAS 18059–3211), also in Sagittarius, looks like a sandwich.

But what's the story behind our next deep-sky object, the **Deer Lick Group**? In the 1980s, American amateur astronomer Tom Lorenzin bestowed the common name on this galaxy group to honor the Deer Lick Gap in the mountains of North Carolina. Apparently, Lorenzin had a memorable view of these galaxies from there.

The Deer Lick Group's brightest member is **NGC 7331**. Under a dark sky, you can spot this magnitude 9.5 spiral through binoculars. It measures 10.5' by 3.7', making it one-third the width of the Full Moon. Through a 10-inch scope with a low-power eyepiece, you'll see three galaxies to the east of NGC 7331 that form an equilateral triangle. These galaxies are not NGC 7331's companions, but instead lie much farther away.

USE AT LEAST A MEDIUM-SIZE SCOPE, AND EXERCISE PATIENCE TO COAX OUT THE GREAT DETAILS.

At 200x, the galaxy shows a glowing bright nucleus three times as long as it is wide. Larger scopes show that the western edge ends abruptly at a dust lane. On nights of good seeing, look for a spiral arm shining beyond this lane.

I'm certain you'll enjoy our next object, or should I say pair of objects? **NGC 7332** and **NGC 7339**, just 5' to its east, form a gorgeous pair of lens-shaped galaxies only 2.1° west of magnitude 4.0 Lambda (λ) Pegasi. NGC 7332 glows at magnitude 11.1 and measures 3.7' by 1.0'.

Both objects' lengths are triple their widths. Each has even illumination, but NGC 7332's core is a bit broader. You can tell them apart mainly by their brightnesses; NGC 7339 glows more faintly than its neighbor, at magnitude 12.2.

The next galaxy on my list is mainly for amateurs with large scopes. **NGC 7457** is a spiral galaxy 2.1° north-northwest of Scheat. It glows softly at magnitude 11.2 and measures 4.1' by 2.5'. Through an 8-inch telescope, it appears nearly rectangular, twice as long as it is wide, and oriented northwest to southeast.

If you were a bit disappointed by NGC 7457, allow me to make it up to you. **NGC 7479** is a showpiece galaxy through a large scope; it lies 2.9° south of Markab. A 10-inch telescope shows the barred spiral galaxy's odd structure.

With a magnitude of 10.8 and a size of 4.0' by 3.1', the galaxy exhibits a fairly high surface brightness. At low power, you'll see a bright core, the surrounding central bulge, and a bar elongated north to south. This galaxy's best feature is the single, tightly wound spiral arm curling to the west of the south end of the bar. The north end of the bar seems cut off.

Now head 2.6° northwest of magnitude 4.3 Theta Piscium to find the giant

NGC 7479, a beautiful barred spiral, appears a bit quirky. Its odd shape may be the result of a merger with a smaller galaxy less than 100 million years ago. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

NGC 7741 is another super example of a barred spiral. Note the seemingly bright double star to the galaxy's upper right. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

elliptical galaxy **NGC 7626**. It and its near-twin, NGC 7619, which lies just 7' to the west, are the brightest members of the Pegasus I galaxy cluster.

Despite being nearly 200 million light-years away, the two glow at magnitude 11.1. An 8-inch telescope shows each galaxy as a bright core immersed in a featureless halo. Both galaxies look slightly oval, measuring roughly 2.5' by 2.0'.

Next is another deep-sky treat that disproves the notion that you'll find nothing within Pegasus' Great Square. **NGC 7678** lies 1.2° southeast of magnitude 4.4 Upsilon (υ) Pegasi. It glows at magnitude 11.3 and measures 2.3' by 1.7'. This face-on spiral has tightly wrapped arms that only begin to reveal themselves through 14-inch scopes at high power. As you observe this object, note the isosceles triangle of 12th-magnitude stars that frame NGC 7678.

Everyone likes a challenge, right? Our next target, the **Pegasus Dwarf** (UGC 12613), isn't bright, but you should seek it out. Lying just below the Great Square, the Pegasus Dwarf is one of the most distant members of our Local Group of galaxies. At a distance of 5.7 million light-years, it sits a bit more than twice as far from us as the Andromeda Galaxy (M31).

Through a 10-inch telescope, this dwarf irregular galaxy appears as a magnitude 12.6 mist twice as long as it is wide (4.6' by 2.8'). Don't expect to see many details. You'll find it 5.8° due east of Markab.

As we continue our eastward trek through Pegasus, we come to the barred spiral galaxy **NGC 7741**. The easiest way to find it is to look 6.2° west-southwest from Alpheratz. The galaxy glows at magnitude 11.3 and measures 4.0' by 2.7'.

This target requires an 8-inch telescope to reveal its details. At 100x, NGC 7741 appears as a mottled, round haze. Move up to 250x, and you'll see the uniformly lit bar that extends east to west across the glow. Apertures of 18 inches or more show hints of the faint surrounding spiral arms.

A nice double star consisting of magnitude 9.8 GSC 2254:1685 and magnitude 11.9 GSC 2254:1349 lies at the northern edge of the halo and points to the galaxy's core. They're separated by about 20".

Our next target lies 2.6° west-northwest of magnitude 2.8 Algenib, and it's a good one: the magnitude 10.6 spiral galaxy **NGC 7814**. Small telescopes reveal this object's football shape (6.0' by 2.5'), but with more tapered ends. The central region spans a third of NGC 7814's length.

This galaxy does have a prominent dust lane captured by many astroimagers. You'll need a huge telescope to have even a slight chance to see it, however. Through a 20-inch scope, crank the magnification past 400x, and look for two thin lines that emanate from points outside the core and cross the galaxy's long axis.

The first two

I started this list with a bang (a naked-eye object), so I guess it's OK to end with a whimper. Those of you with 8-inch or larger telescopes who observe under a dark sky can search for spiral galaxy **NGC 1**. It's pretty small, measuring 1.7' by 1.2'.

I like pointing this object out to fellow amateur astronomers because few have seen the very first object in the *New General Catalogue*. Although NGC 1 lies in Pegasus, it sits really close to the constellation's border with Andromeda.

Look for this magnitude 12.9 object 1.4° south of bright Alpheratz. Don't expect to see much detail, but, hey, at least you can say you've observed the NGC's first object.

As you observe NGC 1, avert your gaze less than 2' south, and try to spot another faint spiral galaxy, **NGC 2**. At magnitude 14.2, this object poses more of a challenge than NGC 1. NGC 2 measures 1' by 0.6'.

Observing the many galaxies in Pegasus is such a rewarding pursuit, especially when you seek out a dark site, use at least a medium-size scope, and exercise patience to coax out the great details you'll see.

Senior Editor **Michael E. Bakich** *appreciates terrestrial horses but is a much bigger fan of the one in the sky.*

Take your hobby to the NEXT LEVEL

Get more deeply involved with amateur astronomy by linking up with one of these organizations. **by Mike Reynolds**

As amateur astronomers, we enjoy looking at objects through our binoculars and telescopes. Maybe studying the Moon, the Sun, or other solar system objects appeals to us. Or perhaps we enjoy timing occultations, observing variable stars, or finding faint deep-sky objects, like nebulae and galaxies.

It's all great fun. But some of us would like to participate in more structured programs and possibly contribute data to professional astronomers. A number of organizations around the world can tutor us in observational techniques and data collection. Others can take what we find and use it to advance a particular astronomical field. Let's take a look at 11 of these organizations based in the United States, and learn a little about their history, what they do, and what you can learn from them and contribute to them.

Mike Reynolds *is a contributing editor of* Astronomy. *He is based in Jacksonville, Florida.*

American Astronomical Society (AAS)

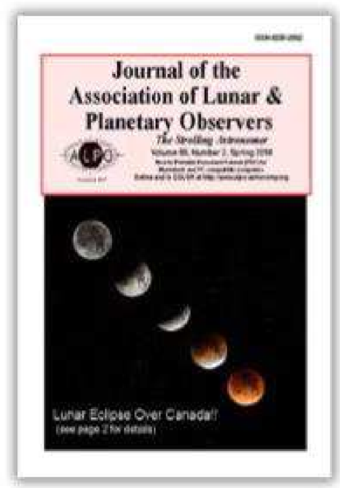
www.aas.org

The AAS is a professional organization whose members are actively engaged in astronomy or a related field of science. Several American astronomers, chief among them George Ellery Hale, founded the AAS in 1899. It is divided into six divisions, such as the Division for Planetary Sciences and the Solar Physics Division, because most professionals specialize in one specific astronomical field.

In partnership with the Astronomical Society of the Pacific, AAS members educate

Association of Lunar and Planetary Observers (ALPO)

www.alpo-astronomy.org



ALPO publishes the *Journal of the Association of Lunar & Planetary Observers* four times a year. BRADEN OTTENBREIT OF SASKATCHEWAN, CANADA

American amateur astronomer Walter Haas founded ALPO in 1947, with the goal of an academic study of the solar system promoting observations of its objects and events. These run the gamut from the Sun, planets, and the Moon, to comets, meteors and meteorites, satellite transits, and eclipses.

ALPO coordinators lend their support to observers through projects and programs, observing techniques, and observation submission. The latter includes drawings and sketches, images, written reports, and data. Coordinators also prepare reports, such as a Mars apparition report, for publication. Members often work closely with professional astronomers, many of which are ALPO members.

The group holds a conference once a year, often joining with other organizations. ALPO publishes a quarterly journal, the *Journal of the Association of Lunar & Planetary Observers* (JALPO). JALPO is also known by the name Haas originally gave the publication: *The Strolling Astronomer.* In addition, ALPO publishes *ALPO Monographs* on special topics or conference proceedings, and it posts a podcast, called *Observers Notebook*, on a variety of topics.

both newly minted astronomers and the general public. The AAS had a strong presence leading up to the 2017 United States total solar eclipse, and in collecting and analyzing amateurs' eclipse images and data.

The organization holds two main conferences a year, and its divisions put on additional meetings. The AAS produces five professional journals, including *The Astrophysical Journal*.

The American Astronomical Society has been going strong since 1899. This photograph shows attendees at the organization's 32nd meeting, in August 1924 at Dartmouth College. Among the notable attendees are Sir Arthur Eddington and Annie Jump Cannon, in the front row fifth and sixth from the left, respectively. HISTORICAL ASTRONOMY DIVISION/AMERICAN ASTRONOMICAL SOCIETY

American Association of Variable Star Observers (AAVSO)

www.aavso.org

Amateur astronomer William Tyler Olcott started the AAVSO in 1911, two years after attending a talk about variable stars given by the longtime director of Harvard College Observatory, Edward Charles Pickering. The AAVSO collects variable star data through observations made mostly by the amateur astronomy community. This information allows the organization to construct well-documented light curves that depict variations in star brightness, and those data are made available to professional and amateur astronomers worldwide.

The AAVSO's current database contains more than 20 million variable star brightness estimates. About 2,000 amateurs and professionals contribute observations each year.

In addition to boasting a strong observational program, the AAVSO engages in educational and public outreach activities. The National Science Foundation has awarded the organization two grants to conduct citizen astronomy — non-scientists collecting and analyzing observations.

The group usually holds two meetings a year, in spring and fall. It publishes the *Journal of the American Association of Variable Star Observers* (JAAVSO), and on AAVSO's website, you can find guides on visual observations, CCD and DSLR imaging, and more. Many AAVSO publications have been translated into other languages, cementing the organization's international reach.

If you're interested in meteors and meteor showers, consider joining or contributing observations to the American Meteor Society. JEFF DAI

American Meteor Society (AMS)

www.amsmeteors.org

The AMS, founded as an AAS offshoot by Charles P. Olivier at the Leander McCormick Observatory in 1911, coordinates the efforts of both amateur and professional astronomers interested in meteor astronomy. For several years, Olivier published catalogs of hourly meteor rates based on observations by AMS members. The group collects observations on sporadic (random) meteors, meteor showers, fireballs and bolides, and phenomena related to meteors. It also collects radio meteor data and encourages meteor spectroscopy.

The AMS publishes submitted observations and analysis in its quarterly journal, *Meteor Trails*.

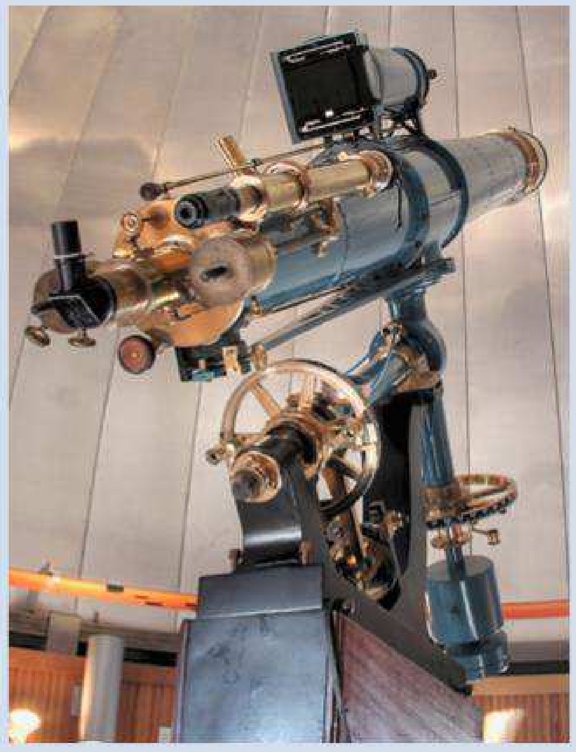
Antique Telescope Society (ATS)

www.webari.com/oldscope

The creation of a group dedicated to the study of antique telescopes, instruments, books, and atlases started with conversations between telescope collectors Bart Fried, Bob Ariail, John Briggs, and Ken Launie. Fried took the idea and founded the ATS in 1991, with its first meeting at the United States Naval Observatory in Washington, D.C.

Perhaps you own an old telescope or other piece of vintage astronomical equipment, and you want to learn more about it. Or maybe the idea of collecting a few science-related antiques appeals to you. If so, you owe it to yourself to check out the ATS.

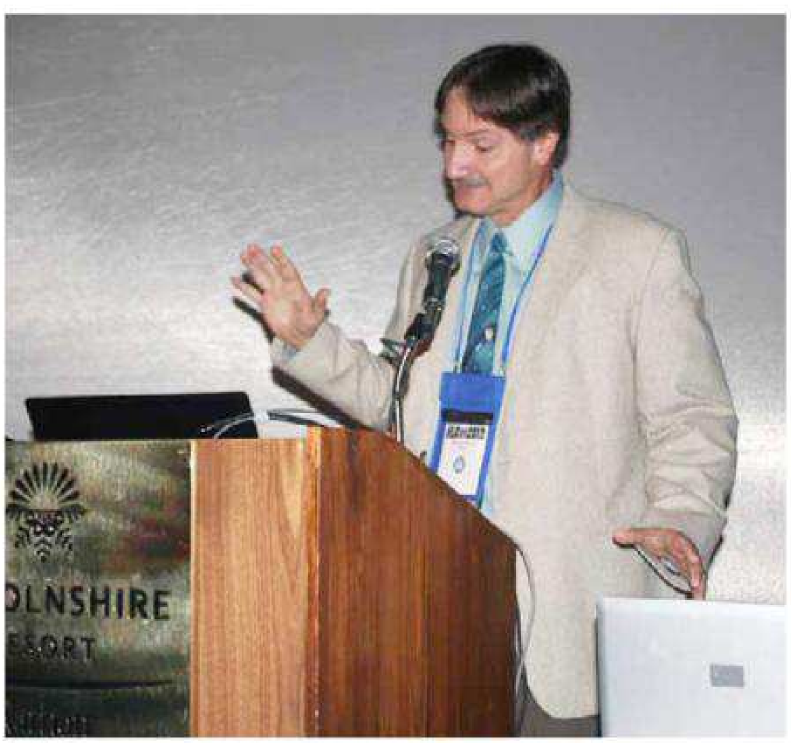
The organization has held its conference at historic venues, including Lick Observatory, Mount Wilson Observatory, Yerkes Observatory, and Lord Rosse's observatory at Birr Castle in Ireland. The ATS publishes the *Journal of the Antique Telescope Society* and maintains a website referencing telescope articles with numerous links to other websites.



The 8-inch Alvan Clark refractor at the Chabot Space & Science Center in Oakland, California, has been highlighted by the Antique Telescope Society. WIKIMEDIA COMMONS

Astronomical League (AL)

www.astroleague.org



***Astronomy* Senior Editor Michael E. Bakich delivers the opening talk at the Astronomical League convention in Lincolnshire, Illinois, July 4, 2012. Bakich gave an entertaining roundup of the first 150 years of amateur astronomy.** DAVID J. EICHER

The concept of an astronomical federation traces its roots back to 1939, when AAS members met at the American Museum of Natural History in New York City. The AL was officially founded in 1947, with Harvard College Observatory director Harlow Shapley serving as its first president.

The AL's primary objectives are to promote astronomy through education, observation, and research, and to serve as a communications conduit for amateur astronomy clubs. More than 240 astronomy clubs in the United States belong to the League, and there are many more members at large. If your local club belongs to the AL, then you are a member.

The AL is perhaps best known for its observing programs. One of the first and most popular is the Messier Observing Program. A member follows guidelines for making and recording observations, submits a report, and (after verification) receives a certificate and pin. The AL now offers more than 60 observing programs, including ones featuring active galactic nuclei, binocular observing, deep-sky objects, and outreach. Several programs target beginners and those who observe from brightly lit locations.

At the AL's annual meeting, participants can hear presentations on observing projects, equipment, club activities, outreach, and the like. Each year there are 10 regional meetings. The AL's main publication, the *Reflector*, appears quarterly.

Astronomical Society of the Pacific (ASP)

www.astrosociety.org

The ASP was founded after the January 1, 1889, total solar eclipse. At a post-eclipse meeting, an idea to form a society was presented by Edward Singleton Holden, Lick Observatory's first director. Today, the ASP has members in some 40 countries.

The ASP has developed and made available many educational resources for a variety of audiences. If you need an activity or program, the ASP is one of the first places to explore.

The ASP often works directly with the AAS and NASA. ASP programs include Project ASTRO, which pairs amateur astronomers with classroom teachers, and the Night Sky Network, a program with the Jet Propulsion Laboratory that supports more than 450 astronomy clubs in public outreach activities.

The ASP hosts meetings during the year. Several ASP publications are available, including the *Universe in the Classroom* newsletter, and *Mercury*, the ASP's quarterly online periodical.

Astronomers Without Borders (AWB)

www.astronomerswithoutborders.org

Founded in 2007 by American amateur astronomer Mike Simmons and Iranian-American astronaut Anousheh Ansari, AWB is spreading astronomy to Third World countries through the support of individuals and companies in developed countries. AWB appeals to those with more resources to help the organization address various needs, such as telescopes and training. AWB works to foster these relationships through an interest in the night sky.

AWB has seen success and support for many of its objectives. During the International Year of Astronomy in 2009, AWB sponsored a number of events, including The World at Night, a program to create and exhibit stunning landscape astrophotos and time-lapse videos of the world's most beautiful and historic sites against a nighttime backdrop. Each April, the group organizes Global Astronomy Month, the world's largest celebration of the field.

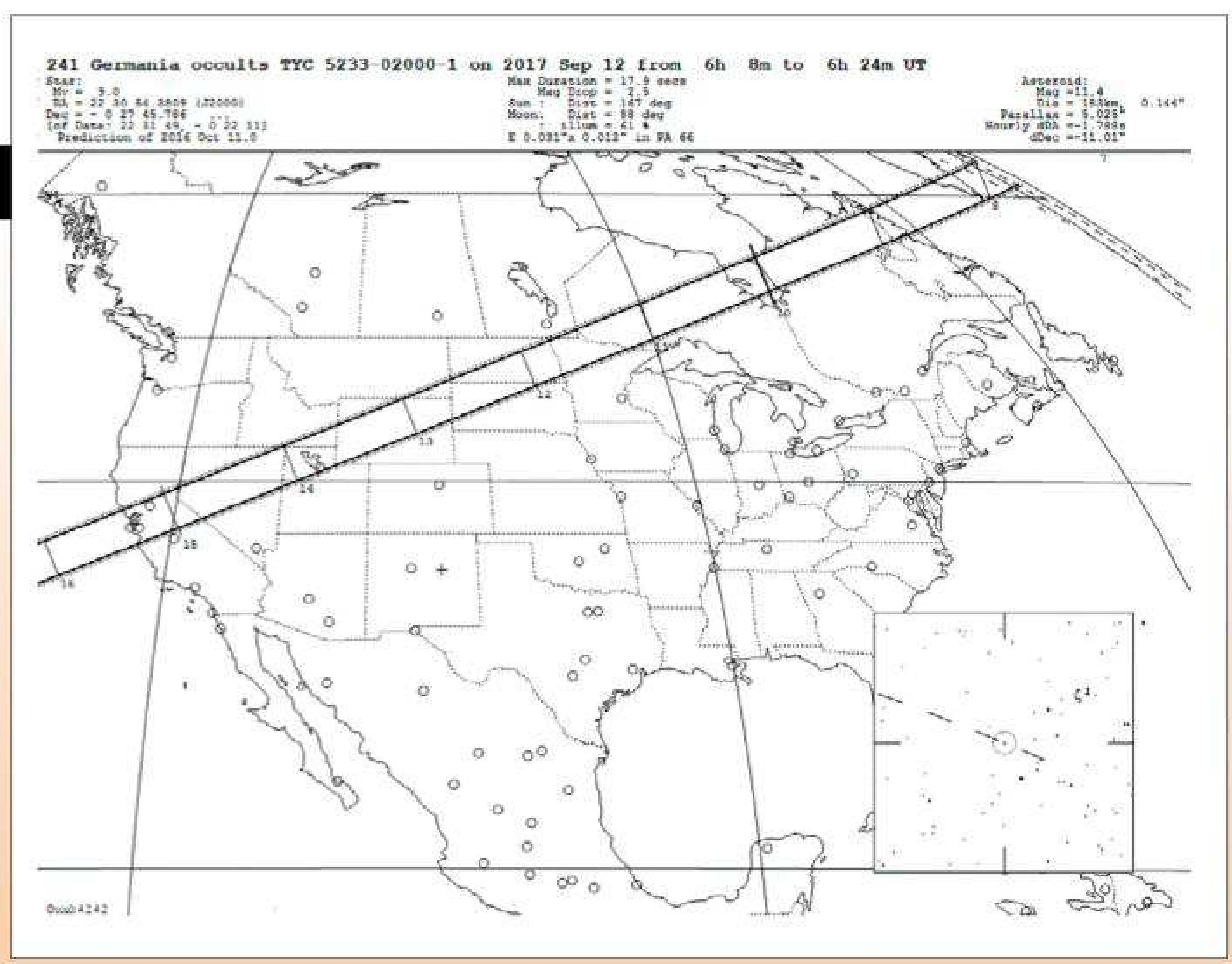
Astroimagers around the world create images — like this one of the Milky Way rising in Amboseli National Park in Kenya — for The World at Night, a program created by Astronomers Without Borders. AMIRREZA KAMKAR

International Occultation Timing Association (IOTA)

www.occultations.org

IOTA was founded in 1983 from a growing interest in the amateur astronomy community for observing occultations. Inspired by David Dunham, who observed the first predicted grazing occultation during his doctoral studies, IOTA members observe and record occultations, providing information on lunar limb profiles, suspected double stars, asteroid shapes and orbits, and more.

IOTA conducts an annual meeting, often joining with other organizations. IOTA's website provides a wealth of information, from the group's *Journal of Occultation Astronomy* to observing manuals and equipment recommendations. IOTA also makes available — at no charge — a downloadable program to predict occultations for specific locations.



Occult, the primary software from the International Occultation Timing Association, is available for free. It predicts the circumstances of lunar and asteroid occultations, occultations of planetary moons, and more. IOTA

The International Dark-Sky Association works to preserve and protect the night sky through the use of proper lighting. This view of Paris, taken by the crew of the International Space Station, shows what the organization is up against. NASA

International Dark-Sky Association (IDA)

www.darksky.org

American amateur astronomers David Crawford and Tim Hunter founded the IDA in 1988. Its goal is to "preserve and protect the nighttime environment and our heritage of dark skies through environmentally responsible outdoor lighting." The IDA does this through several initiatives, from education to working with architects and municipalities.

The IDA doesn't just focus on dark skies for observing. There are other consequences to light pollution, and the organization has done an outstanding job at bringing research to the forefront. Wildlife conservation, human health, and even lighting for safer neighborhoods are important aspects of the IDA's work. The group also has certified a number of International Dark Sky Places around the world.

The IDA holds an annual meeting and sponsors numerous chapters. Information about light pollution, public outreach, lighting recommendations, and political advocacy is available on the IDA website.

Society for Astronomical Sciences (SAS)

www.socastrosci.org

The SAS formed in 1998 as the western wing of the International Amateur-Professional Photoelectric Photometry organization, which was founded in 1980. It took on its present name in 2003, one year after incorporating. The SAS is another example of professional-amateur collaborations, with a collection of solid astronomical data at its core.

Most SAS work focuses on the photometry of asteroids and variable stars, astrometry of asteroids and visual double stars, variable star and transient source spectroscopy, polarimetry, and speckle interferometry.

The SAS holds an annual symposium, often meeting with other organizations. Symposiums feature professional astronomers and workshops on specific programs and projects. The organization publishes an online newsletter, and its website contains many videos.

Start contributing

If you're not involved in any of these organizations, how do you determine which is right for your interests and activities?

First, explore their websites, where you'll find a trove of information. Perhaps request or download one of the organization's journals. Does it spark your interest? Is there training or advice readily available if needed? Attend a conference. That way, you can hear talks, meet members, and see if that group meets your needs. Finally, see if what you're observing now is a match with the observations any of these organizations are requesting.

I strongly urge you to contribute whatever you can. Getting involved with a larger organization will enhance your enjoyment of astronomy.

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NEW PRODUCTS

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

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Auburn, California

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$349
530.823.7796
www.stellarvue.com

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Celestron
Torrance, California

Celestron's NexYZ 3-Axis Universal Smartphone Adapter connects a phone to your telescope, binoculars, and more. It works with a wide range of phones and features three directional knobs to align your phone's camera with the eyepiece. The adapter fits eyepieces from 35 to 60mm in diameter.

$59.95
310.328.9560
www.celestron.com

CMOS camera

QHYCCD
Santa Barbara, California

The QHY294C uses the Sony STARVIS 11.7-megapixel IMX294CJK Exmor R back-illuminated 4/3-inch color sensor. The camera features a 4,144x2,822 pixel array, a full-resolution rate up to 19 frames per second, and a USB 3.0 port. Two-stage cooling lowers the sensor temperature 72 degrees Fahrenheit (40 C) below ambient.

$1,095
805.308.6976
www.qhyccd.com

8-inch reflector

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Landsberg, Germany

Omegon's 8-inch ProDob reflector has a 1,200-millimeter focal length, which produces an f/6 system. It includes a wood rocker box, a 2-inch Crayford focuser, a finder scope, an eyepiece tray, and a 32mm eyepiece (37.5x). Total weight is 51.6 pounds (23.4 kilograms).

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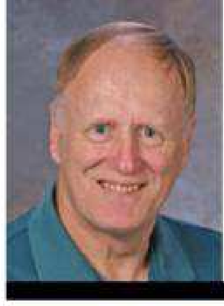

OBSERVING**BASICS**

BY GLENN CHAPLE

Big city scopes

Join the grass-roots #popscope movement to bring stargazing to metropolitan areas all over the world.

Urban astronomy. Now there's an oxymoron! Light pollution. Limited open space. Why would anyone bother to set up a telescope in places like New York City, Philadelphia, or Boston? Everyone knows the night sky is a playground exclusively for folks in suburban and rural locales.

Fortunately for city dwellers, there are dedicated souls who do what they can to bring astronomy to metropolitan areas. In the 1970s, John Dobson and the San Francisco Sidewalk Astronomers routinely set up telescopes at strategic spots in the Bay Area and treated the locals to views of the night sky. For decades, Herman Heyn has put on one-man star parties in Baltimore. Dobson's and Heyn's urban outreach efforts are mentioned in my October 2010 column "Creating a community."

And now we have a grass-roots movement called #popscope. As its website (popscope.org) notes, "#Popscope is an urban movement that aims to reconnect communities to the night sky — and to each other — by hosting free, 'pop-up' astronomy nights in public spaces."

#Popscope began when Viva Dadwal and Michael O'Shea — civil servants and astronomy enthusiasts in Ottawa, Ontario — decided to set up a telescope in the city's downtown and offer passers-by a view of Jupiter. The year was 2012, and the event was a huge success. "We were encouraged by this positive outlook and enthusiasm for astronomy, and we wondered what could happen if we extended the opportunity to look through a telescope to other residents across Ottawa," O'Shea notes. More of these pop-up events followed, and within two short years, #popscope was born.

In 2014, Dadwal moved to Baltimore, where she established another branch of #popscope. Today, thanks to the tireless efforts of an army of volunteers, #popscope chapters exist in Ottawa, Philadelphia, Baltimore, Jacksonville, New York, and Boston — and they have not gone unnoticed. For example, the Baltimore chapter, which hosts multiple events each month, has secured several grants and awards, even a letter from the city's mayor voicing her support of the program. Fledgling chapters are forming in Chicago, San Diego, and Montreal. Each group is run by volunteers with support from local civic organizations and astronomy clubs.

The aim of #popscope is threefold: encourage social interactions that challenge norms and spatial boundaries; contribute to discourse about how public spaces are used and allocated; and educate diverse communities about science and astronomy. The last is a key objective because many minorities dwell in urban environments where opportunities to explore the night sky are limited. The organization is also blind to social class; #popscope offers the passer-by — whether a homeless individual or a wealthy businessperson — the same opportunity to view the Moon, Jupiter and its Galilean moons, or Saturn and its glorious rings through a telescope.

Security guard Aftab Arif takes a moment to peek through a telescope during a #popscope event held on a pier in Dubai's historic Al Seef district, located in the United Arab Emirates. PHOTO COURTESY OF #POPSCOPE (VIVA DADWAL)

#Popscope conducts outreach in a variety of ways. Besides evening pop-up events, daytime solar viewing sessions are conducted at local schools. Since these events are free to attend, they are an extremely valuable asset to cash-strapped school systems.

"#Popscope is an urban movement that aims to reconnect communities to the night sky — and to each other."

Before setting up a #popscope event, chapter members coordinate with community leaders to select sites that are both inclusive and safe. The events are then publicized through #popscope's Facebook, Twitter, and Instagram accounts.

Can #popscope help bring true peace and harmony between people of different races, religions, or economic backgrounds? Perhaps not, but it can help bring people together under trying circumstances. In the wake of the death of Freddie Gray, a black man who died of injuries while in police custody in Baltimore, a #popscope event was held in Penn Station. "One evening, equipped with a telescope and a splash of humility, we decided to 'pop-up' at the train station," Dadwal wrote in a blog post that appeared on *The Huffington Post* website. "Hoping to find some common ground and inspiration, we invited passers-by to look beyond our differences and into the shared universe."

What can you do to help the movement? If you live in one of the aforementioned #popscope cities, contact a member and offer to join the team. If there is no chapter, start one! Most cities are home to at least one astronomy club. Each club should make #popscope an integral part of its outreach program. For more information, check out its website or engage with them on Twitter (@bmorepopscope).

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

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

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FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Giants fall hard

Professional scientific journals deserve an ignominious death.

WATCHER PANYAJUN/DREAMSTIME

In Research Land, publish or perish is the law of the jungle. That's not a bad thing. Research is pointless if nobody hears about it. And when it comes time to get jobs, promotions, tenure, raises, and professional accolades, peer-reviewed publications are the coin of the realm.

So how come a slew of prominent researchers working on artificial intelligence is staging a revolt, boycotting *Nature Machine Intelligence*, a new journal from an ultra-prestigious publisher? How can they get away with such impudence, and why would they try?

All that work

For starters, journal publication is a boatload of work that can take forever. When your paper lands on a journal editor's desk, they have to find a bona fide expert in your field to review it. For a referee, that means days going over your paper with a fine-tooth comb, then writing up a thorough assessment of its strengths and weaknesses. What credit or compensation does the anonymous referee get for doing yeoman's work? Nada.

Fortunately for publishers, researchers have trouble saying no to anything. So after a few tries, the editor finds a sucker, er, a good referee. When your paper arrives, the grossly overcommitted referee puts it on the "Important" pile, where it stays until the editor sends a gentle reminder that the report was due a month ago. Whoops! Time to get started! (I hate to admit it, but … um … guilty.) You can bet the family jewels that the referee will want modifications, which means another pile of work for you and your colleagues.

But eventually, hooray — your paper is accepted for publication! Now begins the potentially lengthy process of getting it into print.

Open a scholarly journal and look at the submission, acceptance, and publication dates of a few papers. Don't be surprised that the process can literally take years.

Ouch! Research moves fast these days, and it's getting faster. By the time your groundbreaking work arrives in mailboxes, you hope it hasn't become passé, or even irrelevant.

Worse yet, a lot of work never gets published at all. In particular, who wants to jump through all those hoops just to publish a paper that says, "It didn't work"? That's catastrophic. Falsification of expectations is the bedrock of scientific knowledge.

The culture of science has to change for new models of publishing to gain acceptance.

If the current process of publication is so bad for science, why does it persist? Easy. There's an 800-pound gorilla in the room with dollar signs for eyes. Scientific publishing is a $25 billion-a-year business. That's a lot of zeros. With researchers doing all the work for free, then buying back access to their own research, scientific journals are what you might call a racket. In 2010, Elsevier, one of the industry's largest publishers, had a profit margin of 36 percent, netting them $960 million! That's a breathtaking return in anybody's book.

Things have changed

Maybe it's no wonder that researchers are starting to balk, especially since alternatives are popping up organically. In 1991, Paul Ginsparg, a physicist at Cornell University, started a repository where researchers can directly post their work. By 2016, his site, arXiv.org, was adding papers at a rate of over 10,000 a month in astronomy, physics, mathematics, and a few other fields. Add your paper to arXiv.org, and it is available instantly. Is it any surprise that these days people read arXiv.org while *The Astrophysical Journal* collects dust on the shelf?

What about peer review, you ask? Publishers beat that drum loudly. Post your preprints, they say. We'll keep the job of getting papers refereed and giving them our seal of approval. Huh? Pay $25 billion a year for somebody to inefficiently moderate conversations between authors and reviewers. Come again?

There are better ways. ArXiv.org already has moderators who look after the legitimacy of posted papers. Why not go a step further? Let experts who really care about a paper offer their own comments, some of which moderators flag as the equivalent of refereed reports. As comments, related research reports, cross-links and the like accumulate (including failed attempts to replicate results), the paper and its associated thread become a living document, timely from the start and perpetually relevant as the field advances. Add blockchain (the technology behind cryptocurrencies) to the mix, and you have ironclad security for the whole ball of wax.

The culture of science has to change for new models of publishing to gain acceptance, but $25 billion a year seems ample incentive for even the oldest dogs to learn some new tricks! Let there be no doubt that traditional publishers will fight tooth and nail to keep their gravy train steaming along, but it's past time for the mighty to fall. Journal publishers might heed the immortal words of Nobel Laureate Bob Dylan as they ponder the coming revolution. "It'll soon shake your windows and rattle your walls / For the times they are a-changin'."

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

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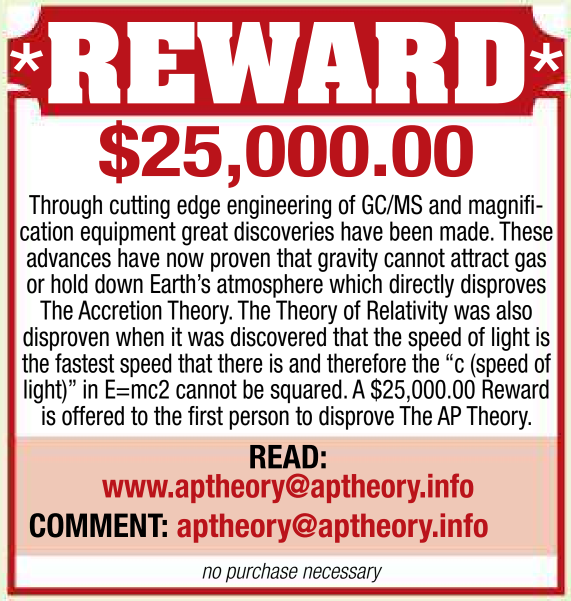
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BINOCULARUNIVERSE

BY PHIL HARRINGTON

The other Andromeda

Seek out treasures beyond the galaxy.

Andromeda holds two bright stars in Alpheratz (α) and Mirach (β), which offer a stunning color contrast. TONY HALLAS

The mere mention to an amateur astronomer of the constellation Andromeda will probably conjure up images of M31, the Andromeda Galaxy. While that is a wonder to behold through telescopes and binoculars alike (see my December 2016 column to find out more), this month, I want to examine the other Andromeda — that is, worthwhile targets that are often bypassed because M31 is so captivating. There is more to meet the eye within the bounds of our celestial princess, if you know where to look.

Let's begin with the constellation's two brightest stars, **Alpheratz** (Alpha [α] Andromedae) and **Mirach** (Beta [β] Andromedae). The two are separated by 14°, or about two binocular fields. Compare one against the other; they are great examples of color contrast. Alpheratz, a hot type B subgiant star, has a blistering surface temperature of 13,000 kelvins (23,000 degrees Fahrenheit or 12,700 degrees Celsius). That's about twice our Sun's. It lies 97 light-years away from our solar system. Mirach is a larger, cooler class M red giant twice as far away as Alpheratz. Its surface temperature is believed to be only 3,800 K (6,400 F or 3,500 C), or about half the Sun's. Their color difference should be immediately apparent with binoculars, but if not, slightly defocusing the images will intensify the effect.

Our next Andromedan targets are most easily found by referencing the neighboring constellation to the east, Triangulum. From Mirach, scan 12°, or again about two fields, due east to Beta and Delta (δ) Trianguli. From there, extend a line to the northwest from Delta through Beta, and back across the border into Andromeda. About a binocular field beyond Beta, you'll spot a colorful binocular double star. The brighter of the pair is **56 Andromedae**, a yellow giant star. Its neighbor, cataloged as SAO 55102, is just 3.5' to the northwest. Despite appearances, they are actually nowhere near each other in space. While 56 And is 316 light-years from us, SAO 55102 is another 605 light-years farther still.

You'll also notice a third 6th-magnitude star, SAO 55082, 14' to the pair's southwest. All three create a slender triangle of 6th-magnitude stars that easily fits into the same binocular field.

When he gazed toward that triangle through his binoculars, the late deep-sky devotee John Davis imagined a golf putter. He saw the triangle as the putter's blade. Its handle is formed from five additional stars extending for 1.5° northwest from the triangle's tip. The handle ends at 6th-magnitude SAO 66630, another orange star.

Now, look for a soft glow less than a degree northeast of 56 Andromedae. See it? It will look like a round, grayish smudge of light about as large as the Full Moon. That's open cluster **NGC 752**. With an overall magnitude of 5.7, it is faintly visible to the eye alone with clear, dark skies. The cluster is home to about 60 stars, none of which is brighter than 9th magnitude. A few faint specks just might peek out with 50mm binoculars, while about a dozen show themselves through 70mm and larger apertures. The remaining stars seem just beyond the limit of visibility, blending together to make the cluster appear "granular."

Our last stop this month is more challenging than the rest. Planetary nebula **NGC 7662**, nicknamed the Blue Snowball, lies in the northwestern section of the constellation. Beginning at Alpheratz, scan about 16° to the north-northwest until you come to three 4th-magnitude stars — Iota (ι), Kappa (κ), and Lambda (λ) Andromedae — set in a distinctive north-south arc. From Iota, the arc's southernmost star, slide 2° west to 6th-magnitude 13 Andromedae. NGC 7662 is just half a degree farther southwest. Although it looks faint, its color should give it away. Look for a pale blue 8th-magnitude "star." Of course, there are many lookalikes in the same area. If you can't determine which is the planetary by its color, try alternating between direct vision and averted vision as you examine each point. The planetary will appear to blink, while stars will not. At 12x and higher magnifications, NGC 7662 will begin to reveal its nature by displaying a tiny, elliptical disk.

Do you have a favorite binocular object? I'd love to hear about it and share your observations in a future column. Drop me a line through my website, philharrington.net. Until next month, remember that two eyes are better than one.

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

The bright open cluster NGC 752 is a delight for binocular owners. ANTHONY AYIOMAMITIS

Planetary nebula NGC 7662, sometimes called the Blue Snowball, offers observers the blue-green remains of a Sun-like star that has ceased to exist. DEREK SANTIAGO

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TIDAL HEATING

Q: SATURN'S MOONS (ENCELADUS, FOR EXAMPLE) ARE HEATED BY GRAVITATIONAL FLEXING. HOW DOES THIS PROCESS WORK?

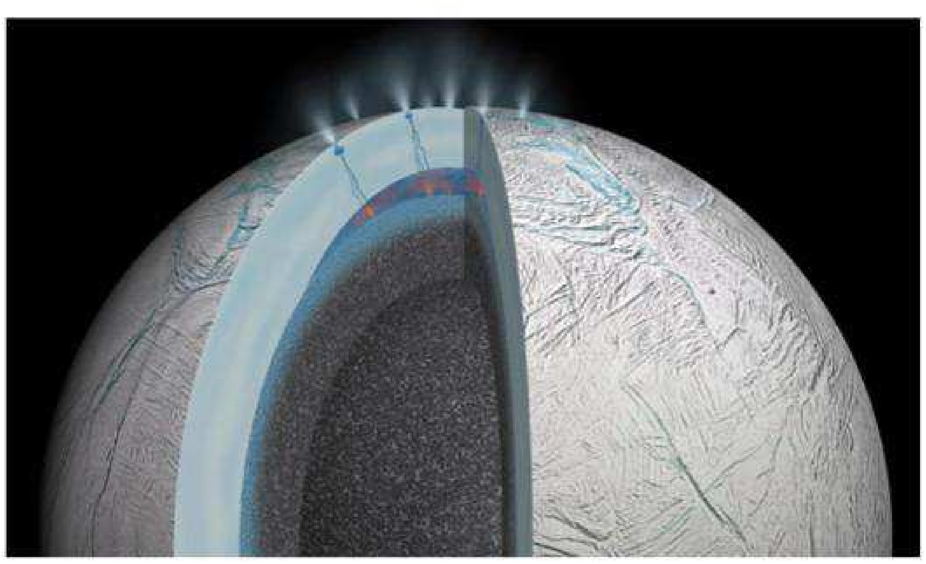
John C. Mackey, *Bloomington, Indiana*

A: Gravity is the force of attraction between two objects. Its effects play an interesting role between a giant planet such as Jupiter or Saturn and their numerous moons — for instance, the Galilean moons Io, Europa, Ganymede, and Callisto, or the saturnian moons Titan and Enceladus.

Gravitational forces differ on the sides of the moon nearest and farthest from the planet, and their strength changes during the course of the satellite's orbit. This creates internal friction that heats the interior of the moon. There is more or less constant flexing and heating between Jupiter and Saturn and their major moons.

In the case of Enceladus, the Cassini spacecraft detected geysers or jets spewing material from the surface into space. These geysers are most likely caused by tidal heating and the formation of chambers, similar to magma chambers but filled with water and volatiles instead of molten rock, that flex due to tides. Hence, gravitational flexing and tidal heating provide the energy that powers the jets of Enceladus.

Anezina Solomonidou
European Space Agency
Research Fellow, Madrid, Spain



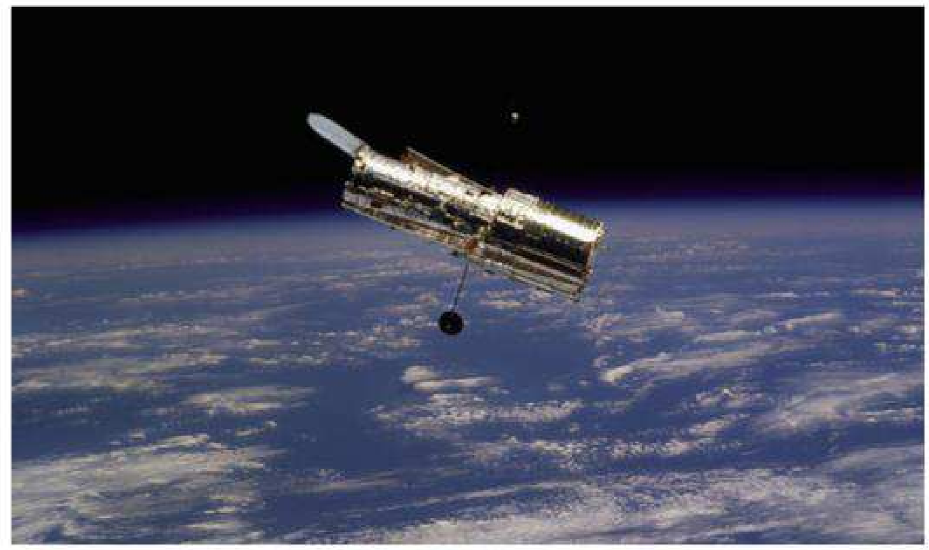
Active vents on Enceladus are driven by the tidal heating and gravitational flexing that occurs as the moon circles Saturn, causing chambers of liquid water and volatiles to erupt, as in this artist's rendering. NASA/JPL-CALTECH

Q: WHAT WILL HAPPEN TO HUBBLE ONCE THE JAMES WEBB SPACE TELESCOPE BECOMES OPERATIONAL?

Ralph Winrich
Dunkirk, Wisconsin

A: In 2016, NASA announced a five-year extension of science operations with the Hubble Space Telescope (HST). This means that, unless the telescope suffers a catastrophic failure that renders all its instruments unusable, HST will continue operating at least through June 30, 2021.

The James Webb Space Telescope (JWST) is currently scheduled to launch March 30, 2021, and won't begin observing right away, as it requires time to reach its final orbit, unfold its sunshield and mirror, and undergo instrument cooling and testing. So these two telescopes may have only limited overlap, if any, should NASA decide to cease operating HST after 2021.



The Hubble Space Telescope, photographed from the space shuttle *Discovery*, is in a low-Earth orbit that will decay in the mid-2030s without further boosts, ending the telescope's mission regardless of funding. NASA

Regardless, the two telescopes are complementary, not competing. HST has limited capabilities at near-infrared wavelengths, from 0.8 to 2.5 micrometers. JWST will observe from 0.6 to 28 micrometers, covering much more of the infrared universe than Hubble. But HST's optimal wavelength range is from 0.1 to 0.8 micrometer — the ultraviolet (UV) and optical range of the spectrum. This is important because Earth's atmosphere blocks most UV light, meaning Hubble can observe at wavelengths that we can't see from Earth and won't be covered by JWST.

HST will eventually experience enough atmospheric drag from its low orbit that it will crash to Earth; this is projected to occur by the mid-2030s. NASA plans to use a rocket to perform a controlled de-orbit, which will ensure any debris that doesn't burn up will land in an uninhabited area when HST's mission is finally complete.

When will that be? According to the European Space Agency's HST website, www.spacetelescope.org, "As such, there is no set date for Hubble's retirement. Hubble will continue to work for as long as its components operate and it provides a good service to the scientific community."

Alison Klesman
Associate Editor

Q: WHAT PERCENTAGE OF EXTRASOLAR PLANETS GO COUNTERCLOCKWISE AROUND THEIR SUNS?

Tom Henrichs
Milwaukee, Wisconsin

A: This is an interesting question, and the answer tells us something important about how planets form, as astronomers believe whether a planet travels clockwise or counterclockwise around its star is linked to its history.

First, it's useful to define "counterclockwise" for an orbit or object in space, since we see exoplanets and their stars from all angles! For a rotating body, we define "up" along its axis of rotation, such that it rotates counterclockwise when viewed right-way-up. For planetary orbits, we set "up" perpendicular to the plane of the orbit, so that when viewed right-way-up, the planet travels counterclockwise around its star.

Hot Jupiters are giant

planets close to their parent stars, with orbital periods of one to 10 days. These planets could not have formed in place — there is not enough material that close to a star in a protoplanetary disk to create such a massive planet. Instead, astronomers think hot Jupiters form at roughly the distance of present-day Jupiter and Saturn from the Sun. They then migrate inward over millions of years to reach the close-in orbits we see today.

One unresolved question is how this migration occurs. There are two possible scenarios. First, hot Jupiters can migrate inward due to drag from the protoplanetary disk material that remains after they form. A planet affected by this kind of "disk migration" would have a present-day orbit closely aligned with the orientation of the protoplanetary disk. Second, hot Jupiters can move inward via "scattering migration," where they gravitationally interact with another nearby giant planet, or with a more distant companion of their host star. In this scenario, hot Jupiters develop highly eccentric, cometlike orbits.

Because of the influence of tides, over hundreds of millions of years such orbits transform into the nearly circular hot Jupiter orbits we see today. Critically, scattering migration is chaotic and would randomize the orbital orientations of hot Jupiters, so they would rarely align with the old protoplanetary disk.

Because those disks were cleared out several billion years ago, we instead use the parent star's rotation to determine how the planets migrated inward. Conservation of angular momentum forces protoplanetary material into a disk extending away from the equator of the parent star, aligning it with the star's rotation.

Astronomers can measure the spin-orbit angle between a hot Jupiter's orbital orientation and the rotation axis of its parent star. By convention we define "up" to lie along the stellar rotation axis. A spin-orbit angle near 0° means the planet's orbit is closely aligned with the star's rotation (and traveling counterclockwise), while a spin-orbit angle of 180° means the planet is orbiting opposite the star's rotation (and traveling clockwise).

So finally, what are the numbers? We have 74 hot Jupiters with measured spin-orbit angles, as of this writing. Of those, 49 planets, or 66 percent, have spin-orbit angles less than 30° and are orbiting counterclockwise. The other 25 planets are nearly evenly spread out from 30° to 180°, with two orbiting almost opposite the direction of their star's rotation.

This means that while most hot Jupiters (66 percent) migrate inward via disk migration, one-third of the hot Jupiters we see were thrown inward by some sort of scattering process.

Thomas Beatty
Assistant Research Professor, Department of Astronomy & Astrophysics, Penn State, University Park, Pennsylvania

Q: SINCE THE MILKY WAY IS A FLAT DISK, IT SHOULD APPEAR AS A STRAIGHT LINE ACROSS THE SKY. HOWEVER, IN PHOTOS SUCH AS ON PAGES 50–51 OF THE APRIL ISSUE, IT IS A CURVED ARC. WHY?

Russ Williams
St. Charles, Missouri

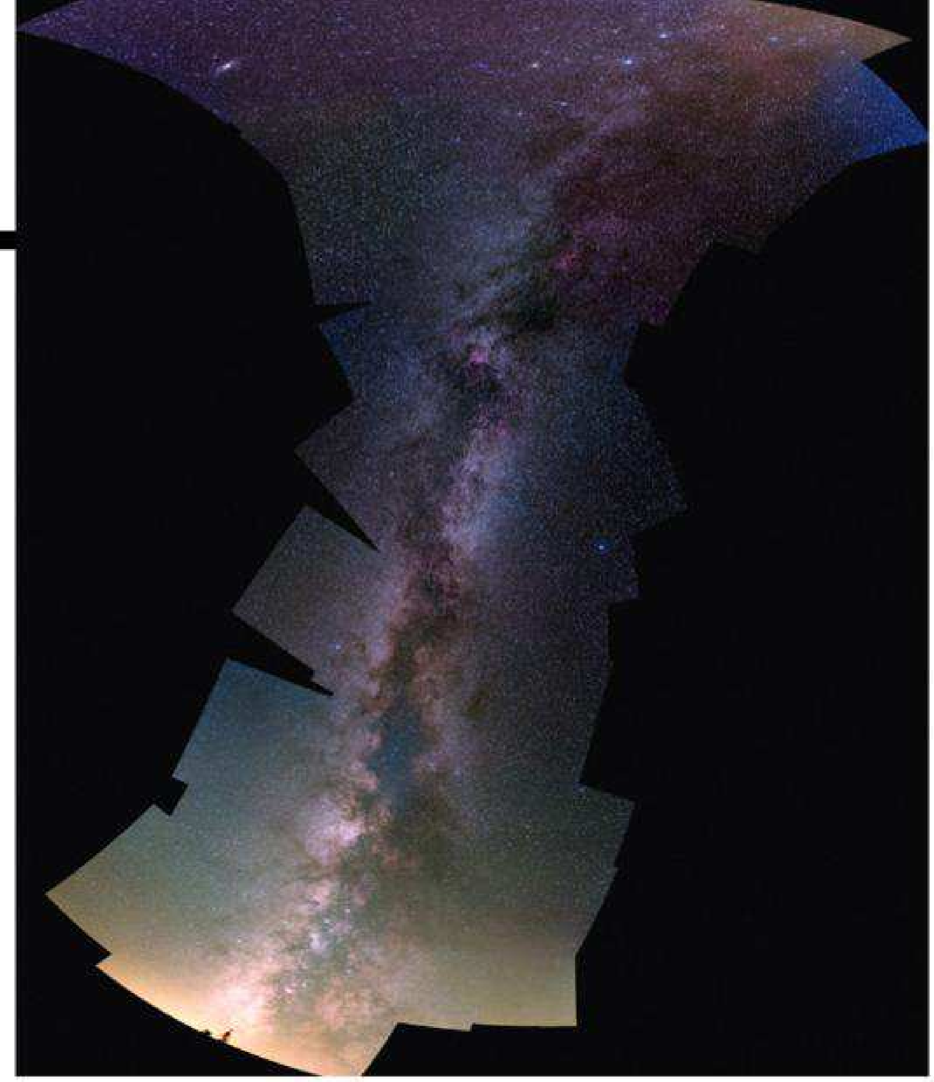
A: When viewed edge-on, such as from our solar system's position within the galaxy, the disk of the Milky Way does indeed appear as a straight line across the sky. The arc you reference in many photographs is an artifact arising from the way these images are processed afterward by the photographer.

You simply cannot see the entire sky at once, nor can you photograph it in one shot with a standard lens. Most full-sky photographs, including the one you note, are panoramas made up of several images stitched together. Each individual image captures only a portion of the sky (and landscape), and in each single shot, the Milky Way does appear straight. But when these images are stitched together, the photographer must introduce distortion to turn them into a single square or rectangular photo. This is because the final photo is a flat projection of a curved sphere, which introduces distortion that ultimately makes the Milky Way appear curved in order to make the horizon appear flat.

Alternatively, some images are taken with a fisheye lens, which itself produces distortion in order to image an extremely wide field in one shot.

There is one caveat: The Milky Way appears straightest when it is most directly overhead. *Astronomy* senior editor Rich Talcott points out, "The plane of the Milky Way projects as a great circle onto the celestial sphere (as does the ecliptic, which we are also in). So both the Milky Way and the ecliptic appear as large circles in the sky (which, if they happen to pass overhead, will appear as straight lines). But if the circles reach a peak altitude of only, say, 30°, they're going to look like arcs to the naked eye."

Alison Klesman
Associate Editor



This panorama, which incorporates more than 50 images shot through a 50mm lens, shows the "straight Milky Way" as it appears overhead from Mount Rainier National Park. Some distortion from editing remains visible at the edges. MATT DIETERICH

Send us your questions

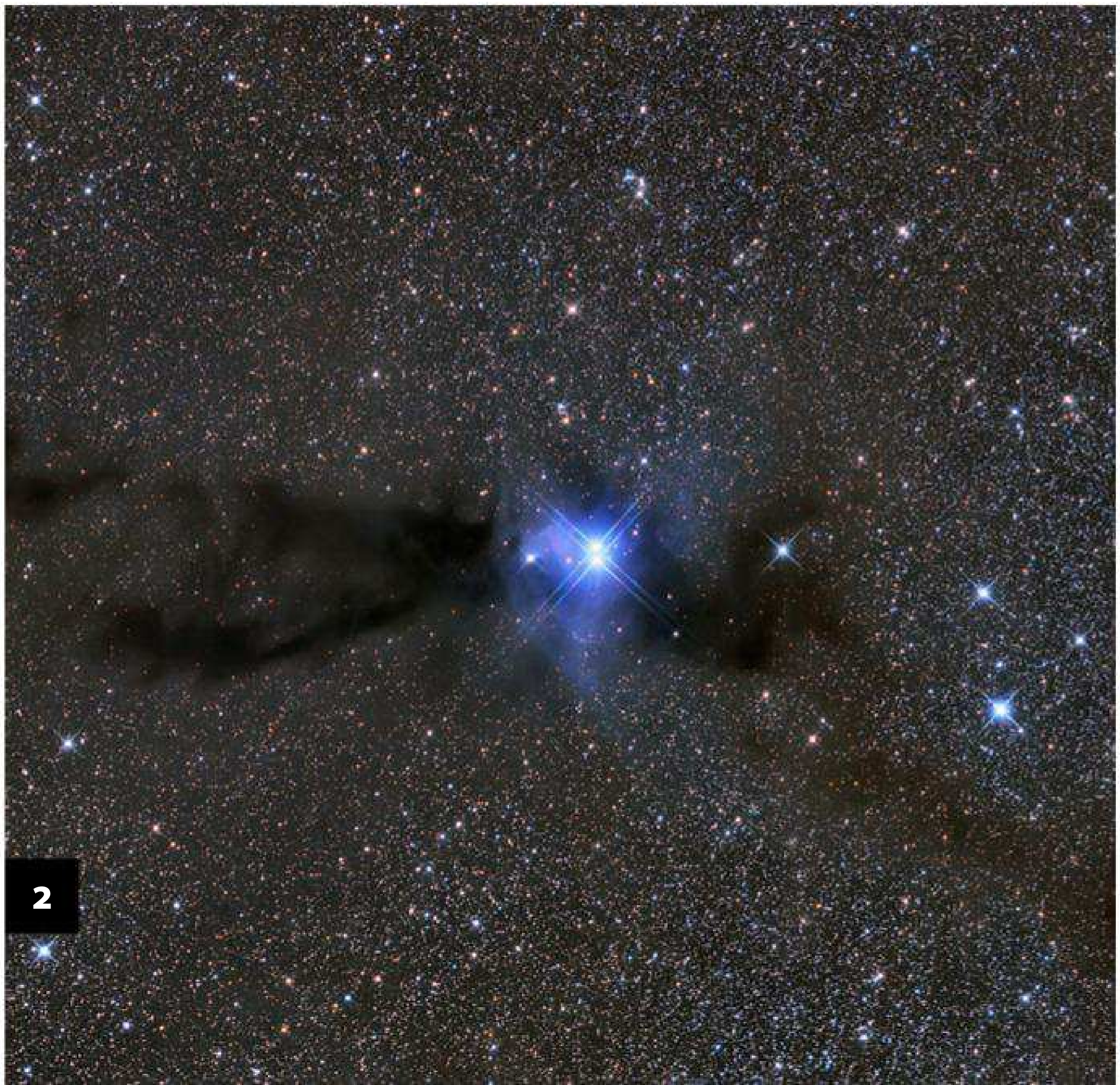
Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

READER GALLERY


1

1. A BIT FISHY
IC 1795, often called the Fish Head Nebula, is a star-forming region some 6,000 light-years away in the constellation Cassiopeia. The photographer captured and combined 20 hours of exposures, 10.5 of which were through a Hydrogen-alpha filter, which passes a particular wavelength of red light that's created when hydrogen atoms release energy they absorbed from nearby stars. *• Rodney Pommier*

2. BLUE LIGHT IN THE DARK
Bernes 149 is a blue reflection nebula in the constellation Scorpius. It lies within the Lupus 3 molecular cloud, a dark nebula that also is a star-forming region. Bernes 149 lies about 500 light-years away. *• Gerald Rhemann*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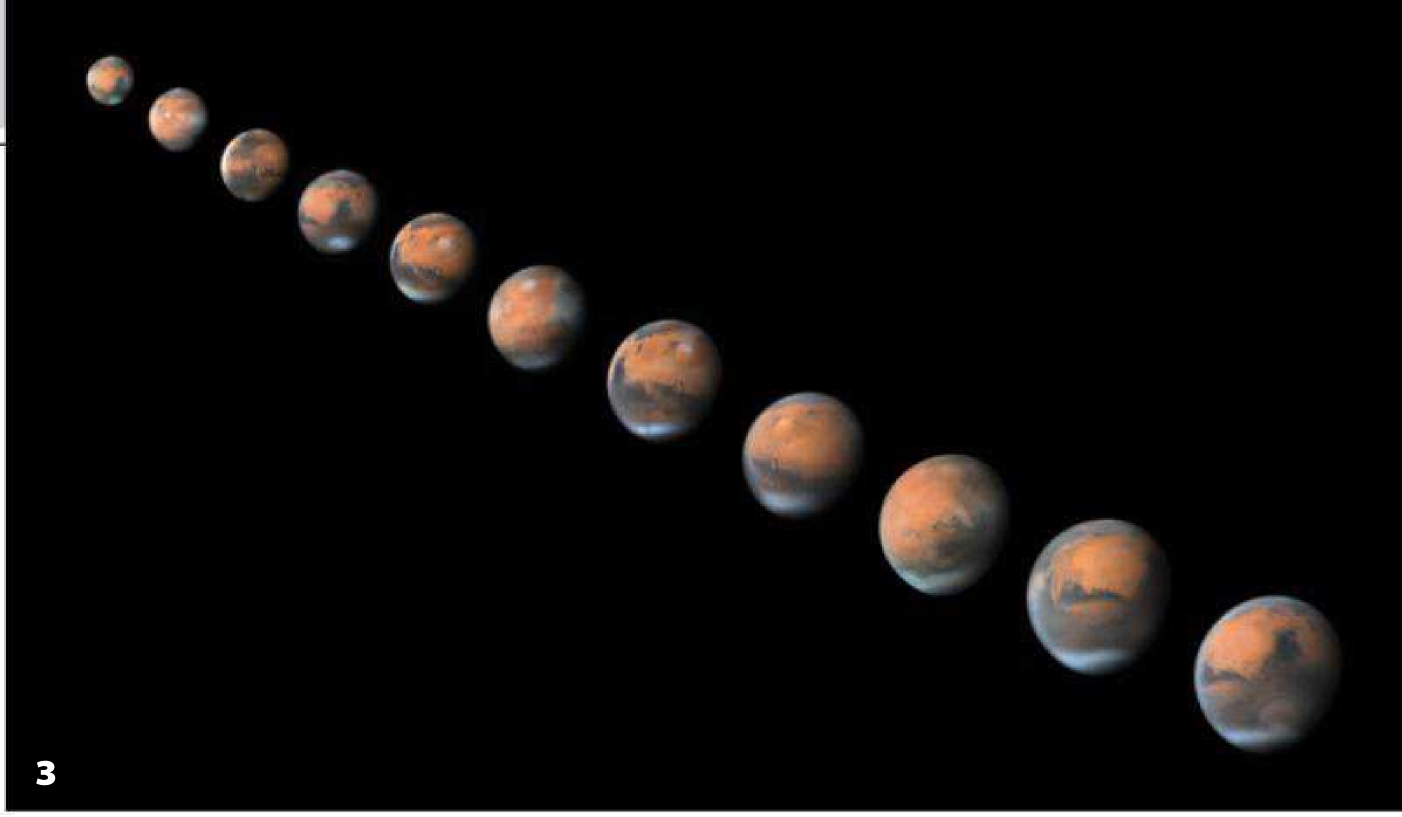

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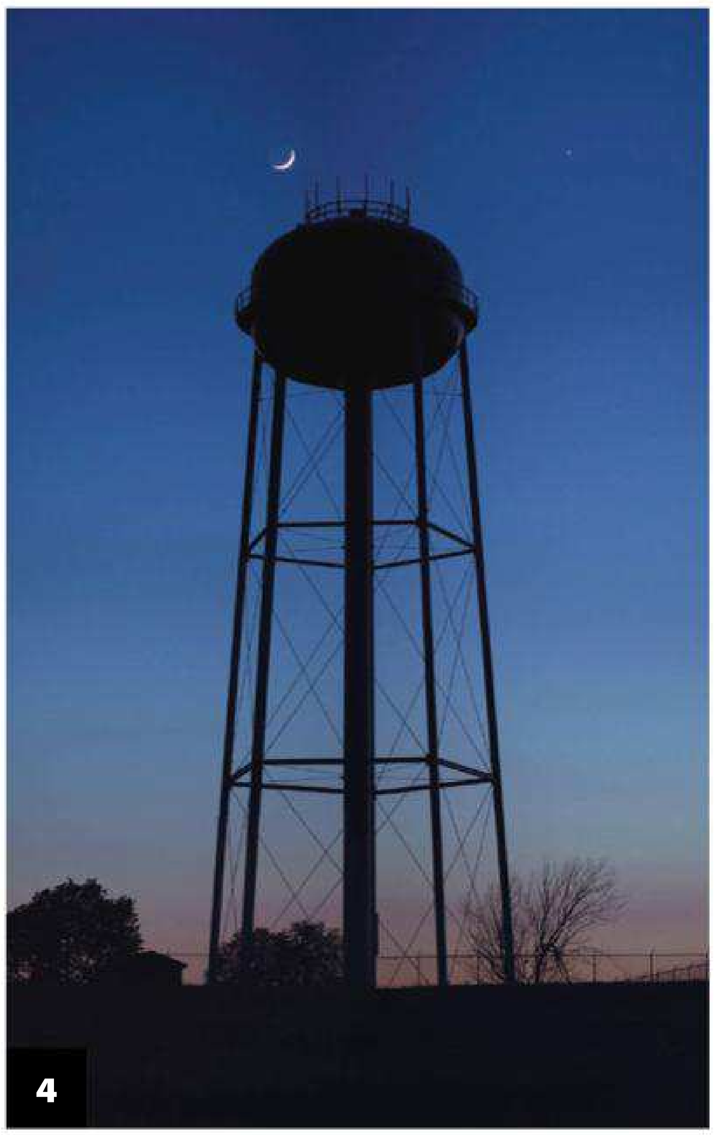

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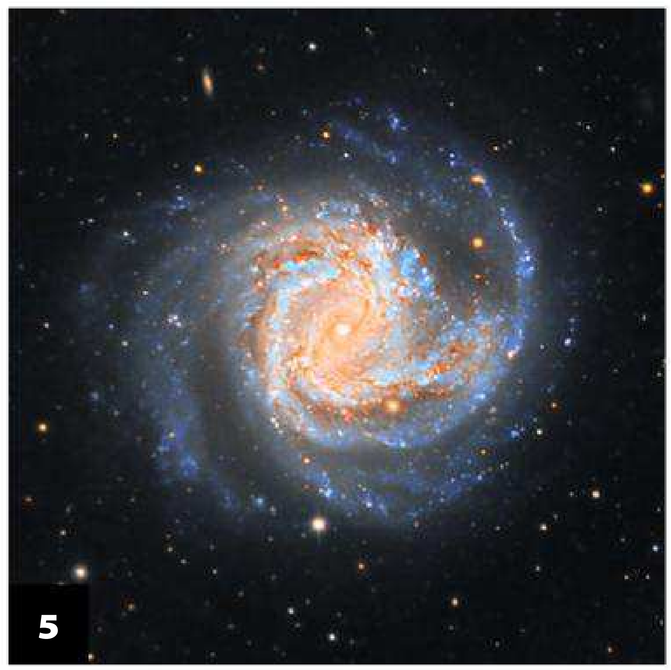

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3. MARS ATTACKS!
This montage — beginning in late January and progressing through late April 2018 — shows how Mars appears to grow in size as it approaches Earth. During this time period, its distance from our planet decreased from 176.5 million to 80.2 million miles (284 million to 129 million kilometers), and its angular diameter grew from 4.8" to 10.8". • ***Damian Peach***

4. MEET ME AT THE TOWER
Venus stands about 6° from the 10-percent-illuminated crescent Moon on May 17, 2018. The photographer captured them on either side of the DeKalb County water tower in Missouri. • ***Jared Bowens***

5. THE AMAZING COLOSSAL GALAXY
M61 in Virgo is one of the largest galaxies in the Virgo Cluster, a massive group containing more than 1,300 members. Classified as a starburst galaxy, M61 is undergoing a high rate of star-forming activity. This intermediate barred spiral has a diameter of 100,000 light-years and lies 52 million light-years from Earth. • ***Star Shadows Remote Observatory (W. Keller, M. Hanson, S. Mazlin, R. Parker, T. Tse, P. Proulx)***

6. HAPPY TRAILS
The Zhuhai Grand Theater is the first and only opera house at sea in China. This picture is a stack of nearly one hundred 30-second exposures. Look between and above the two structures to find the star trails of the constellation Orion and the bright star Sirius (Alpha [α] Canis Majoris). • ***Likai Lin***

7. HELLO, STEVE
Steve is an atmospheric phenomenon caused by a narrow ribbon of hot gas at a temperature of 5,400 degrees Fahrenheit (3,000 degrees Celsius) some 300 miles above Earth's surface. Steve, which usually lasts between 20 and 60 minutes, can stretch for hundreds or even thousands of miles. This panorama combines seven exposures. • ***Krista Trinder***

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.

Vela's victims of violence

Some 500 million years ago, two spiral galaxies in Vela the Sails rammed into each other. The impact forever changed their destinies. Although none of the galaxies' stars likely collided, vast clouds of gas and dust did. This triggered a burst of star formation that dominates the merged object — peculiar galaxy NGC 3256 — we see in this Hubble Space Telescope image. More than 1,000 bright star clusters litter the galaxy's dust-cloaked central region. The collision also unleashed tidal forces that drew out long streamers of stars. NGC 3256 lies in the Hydra-Centaurus Supercluster, some 120 million light-years from Earth. NASA/ESA/HUBBLE

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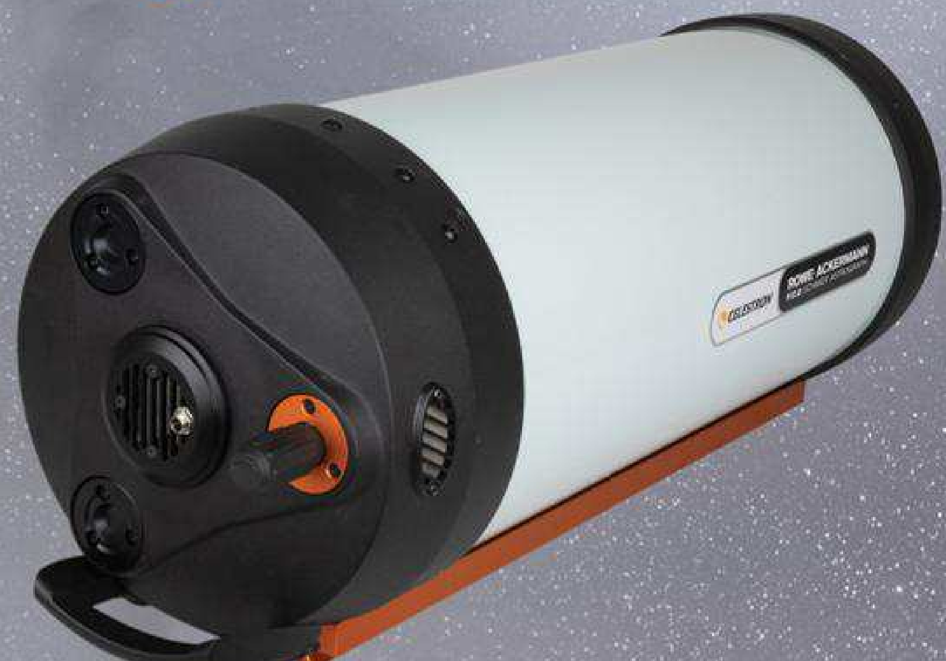

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

December 2018: Mars points to Neptune

December nights are the shortest of the year. The hours of darkness dwindle to a precious few, especially for those who live farther south. And after the long wait for twilight to deepen after sunset, only two bright planets grace the evening sky.

You'll get a final chance to view **Saturn** before it disappears in the Sun's glow in early December. The ringed planet lies in northwestern Sagittarius and appears low in the west-southwest about an hour after sundown. It shines brightly, however, at magnitude 0.5, and stands out nicely against the fading twilight.

Saturn dips lower with each passing day, so plan to target it through your telescope during December's first week. The distant world's disk measures 15" across the equator, while the expansive rings span 35" and tilt 26° to our line of sight.

Mars appears much higher in the evening sky. In early December, it stands halfway to the zenith in the west-northwest as twilight fades to darkness. Shining at magnitude 0.0, the ruddy world dominates the relatively dim background stars of Aquarius the Water-bearer. A telescope reveals Mars' 9.3"-diameter disk and, under steady viewing conditions, perhaps a few subtle surface details.

The planet travels eastward against the starry backdrop during December, crossing into Pisces the Fish on the 22nd. This motion causes it to descend, and by month's end it stands one-third of the way to the zenith as twilight ends.

Mars also retreats from Earth this month, growing noticeably dimmer and smaller as it goes. On the 31st, it shines at magnitude 0.4 and spans 7.5". Sadly, the great views we had of Mars this past winter are but a memory by summer.

The Red Planet's eastward trek presents observers with a splendid opportunity to spot **Neptune** on the evening of December 7. The distant world glows at magnitude 7.9, so you'll need binoculars or a telescope to identify it. Through a scope at low power, it appears as a blue-gray point of light next to the brighter planet. At 11h UT, Neptune lies 5.5' east of Mars; four hours later, Neptune appears 2.5' due south of Mars. If you crank the power up, you'll notice the ice giant sports a disk 2.3" in diameter.

The rest of the naked-eye planets congregate in the morning sky. Dazzling **Venus** dominates the eastern sky before dawn. It rises two hours before the Sun in early December, when it appears about one binocular field to the lower right of blue-white Spica, Virgo the Maiden's brightest star. But this 1st-magnitude sun offers no competition for Venus, which peaks at magnitude –4.9 — some 250 times Spica's brightness — in early December. Although the planet dims slightly, to magnitude –4.6, by month's end, it also gains altitude.

A telescope reveals startling changes to Venus' appearance during December. On the 1st, the inner planet appears 41" across and about one-quarter lit. By the end of the year, Venus spans 27" and the Sun illuminates nearly half of its disk.

As December progresses, two more planets emerge into morning twilight. **Mercury** reaches greatest elongation December 15, when it lies 21° west of the Sun and stands 7° high in the east-southeast a half-hour before sunrise. Shining at magnitude –0.5, the planet should show up nicely to the naked eye and will be a cinch to see through binoculars. A telescope reveals a slightly gibbous disk measuring 7" across.

As Mercury heads back toward the horizon after greatest elongation, it meets up with **Jupiter**. On December 21, the two planets pass less than 1° from each other and will make a splendid pair through binoculars. Although magnitude –1.8 Jupiter gains a bit more altitude by year's end, its 32"-diameter disk won't show much detail because its light has to pass through so much of Earth's atmosphere. Better views will come in another month or two.

The starry sky

On December 21 (or 22, depending on your longitude), the Sun reaches its most southerly position of the year at a declination of –23.44°. This happens every year, of course, and it marks the moment of the December solstice. In the Southern Hemisphere, this is the summer solstice, and it coincides with the longest day of the year; in the Northern Hemisphere, it is the winter solstice and the shortest day.

The long days coincide with extended periods of twilight, which grow more noticeable the farther south you live. Astronomers consider the sky to be completely dark when the Sun's center lies 18° or more below the horizon. The farther south you go in December, the more time it takes for the Sun to dip that low. The sky's blueness lingers longer, and it starts up again just a few hours later. For those of you at mid-southern latitudes, gaze to the south during evening twilight and watch Crux the Cross along with Alpha (α) and Beta (β) Centauri sweep from right to left not far above the horizon. You'll get a stark demonstration of how long it takes for complete darkness to fall.

The prolonged twilight raises an intriguing question: Is there a latitude beyond which twilight never ends? You bet — everywhere south of 48.5° south latitude experiences all-night twilight on the solstice.

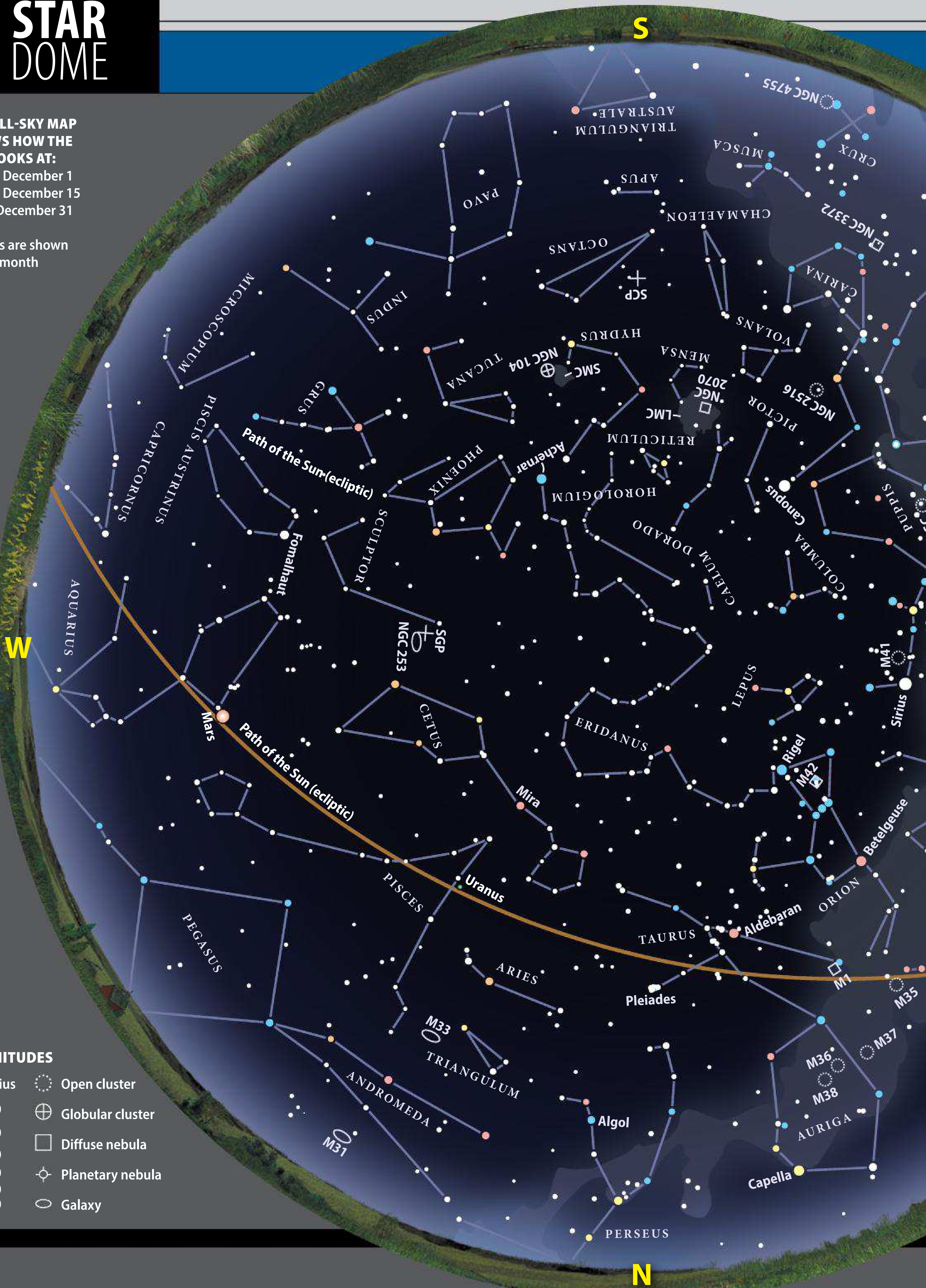
Outside Antarctica, however, there aren't many places in the Southern Hemisphere where you can stand on solid ground at those latitudes. The southern tip of Chile and Argentina provides the best option. Punta Arenas, Chile, for example, lies at a latitude of 53° south.

An even more extreme case greets those who venture to the Antarctic Circle at 66.5° south latitude. From there, the Sun remains above the horizon for a full 24 hours on the solstice — truly the land of the midnight Sun.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
11 P.M. December 1
10 P.M. December 15
9 P.M. December 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

DECEMBER 2018

Calendar of events

2 Venus is at greatest brilliancy (magnitude –4.9), 4h UT

3 The Moon passes 4° north of Venus, 19h UT

5 The Moon passes 1.9° north of Mercury, 21h UT

6 Mercury is stationary, 20h UT

7 New Moon occurs at 7h20m UT

Mars passes 0.04° north of Neptune, 15h UT

Asteroid Eros is at opposition, 17h UT

8 Asteroid Harmonia is at opposition, 19h UT

9 The Moon passes 1.1° north of Saturn, 5h UT

10 The Moon passes 0.7° north of Pluto, 4h UT

12 The Moon is at apogee (405,177 kilometers from Earth), 12h25m UT

14 Geminid meteor shower peaks

The Moon passes 3° south of Neptune, 14h UT

The Moon passes 4° south of Mars, 23h UT

15 First Quarter Moon occurs at 11h49m UT

Mercury is at greatest western elongation (21°), 12h UT

18 The Moon passes 5° south of Uranus, 4h UT

20 Jupiter passes 5° north of Antares, 2h UT

21 Mercury passes 6° north of Antares, 8h UT

Mercury passes 0.9° north of Jupiter, 15h UT

Summer solstice occurs at 22h23m UT

22 Full Moon occurs at 17h49m UT

24 The Moon is at perigee (361,061 kilometers from Earth), 9h49m UT

27 Asteroid Juno is stationary, 15h UT

28 Asteroid Hebe is at opposition, 2h UT

29 Last Quarter Moon occurs at 9h34m UT

Astronomy magazine

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