THE BEST BLACK HOLE IN THE GALAXY p. 30

OCTOBER 2016

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NASA/JPL

ON THE COVER

Magellan arrived at Venus in August 1990 and orbited for four years, imaging 98 percent of the planet's surface.

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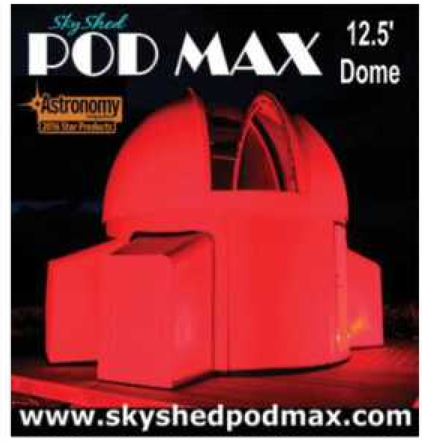
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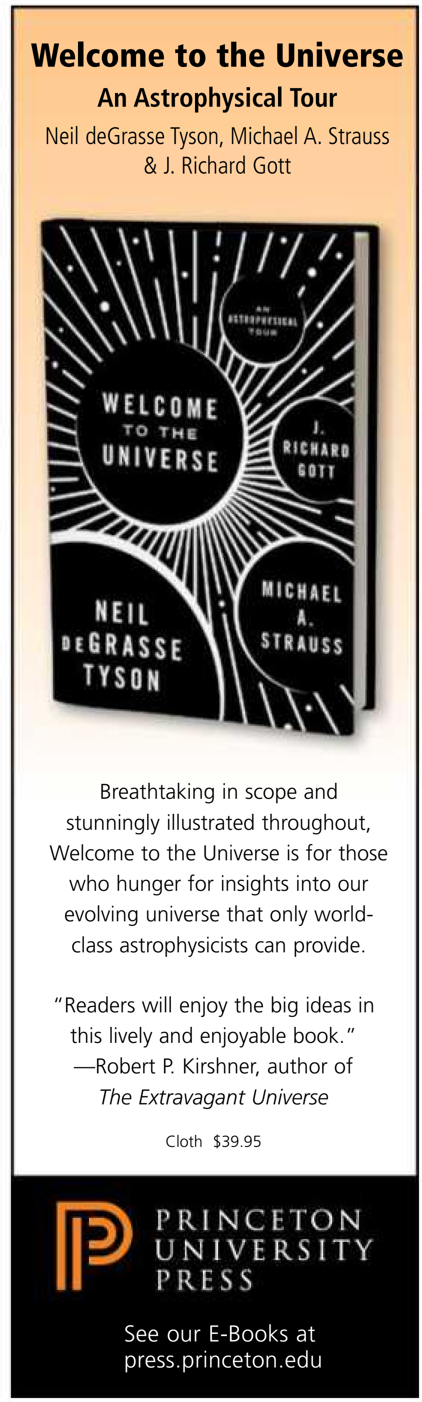
Welcome to the Universe
An Astrophysical Tour
Neil deGrasse Tyson, Michael A. Strauss
& J. Richard Gott
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FROM THE **EDITOR**

BY DAVID J. EICHER

Get ready for total eclipse 2017!

I RECALL how blown away I was by the first total eclipse I saw. The shadow swept over me, transforming nature's light into ethereal darkness. I got chills! The biggest eclipse event of our lifetime is now rapidly approaching. You don't wanna be left at home, watching this one on your computer, do you?

On August 21, 2017, the Moon will slide across the Sun's disk, and a total solar eclipse will pass diagonally across the United States. This will be the first total eclipse in the contiguous U.S. in 38 years, and the first to cross both coasts since the closing days of World War I.

The path of totality will stretch from just south of Portland, Oregon, to Charleston, South Carolina, and the spot where it will last the longest — 2 minutes 42 seconds — will lie near Carbondale, Illinois. One major city, Nashville, stands in the path of totality. There's no doubt: This eclipse will be the most observed ever.

I invite you to join *Astronomy* magazine and our travel partner, TravelQuest International, on one of three excursions to the path of totality and to see major natural wonders and U.S. cities. *Astronomy*'s editors will join these excursions, providing insights into the eclipse, and we will have a grand time.

The first tour, National Parks of the American West, will occur August 13–25. This expedition will take in the eclipse along with astronomical sights and explorations of great natural beauty. From Scottsdale, Arizona, the journey will commence to Sedona, Arizona; on to Flagstaff with a visit to Lowell Observatory; Glen Canyon Dam and the Grand Canyon; Bryce and Zion national parks; Salt Lake City; Jackson Hole, Wyoming; Grand Teton and Yellowstone national parks; Cody and Sheridan, Wyoming; and Mount Rushmore, Crazy Horse, and Rapid City, South Dakota. What an adventure!

Consider this musical alternative: August 14–22, America's Music Cities will take you on a different kind of an adventure. In addition to the eclipse, you'll have ample time to explore New Orleans and the Bayou Cajun Country and steep in the traditions of Memphis and Nashville. Who could resist the French Quarter, Beale Street, the haunts of Elvis Presley, and the Grand Ole Opry?

Or think about the third alternative, the Pacific Northwest and San Francisco trip. This excursion, August 17–26, includes wonderful cities and natural scenes on the West Coast: Seattle, Olympia, Portland, the Columbia River Gorge, Mount Hood, Bend, Crater Lake, Redwood National Park, and lots of time in San Francisco.

And of course, there's the eclipse — the greatest American eclipse in decades.

You can read more about each of the trips here:

http://astronomy.com/magazine/trips-tours/2017-eclipse-national-parks

http://astronomy.com/magazine/trips-tours/2017-eclipse-music-cities

http://astronomy.com/magazine/trips-tours/2017-eclipse-pacific-northwest

See you in 2017!

Yours truly,

David J. Eicher
Editor

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HOT BYTES >>

TRENDING TO THE TOP

DARK SKIES
The International Dark-Sky Association certified Grand Canyon National Park a provisional International Dark Sky Park.

CITIZEN SCIENCE
Two volunteer scientists helped identify a previously unknown galaxy cluster by poring over data in Radio Galaxy Zoo.

EARLY OXYGEN
The ALMA radio observatory spied oxygen in a galaxy 13.1 billion light-years away, making it the earliest sign of oxygen in the young universe.

SNAPSHOT

The meaning of life in the universe

Much of what drives us to explore is the quest to know how common or rare living things are in the cosmos.

Do clouds of nebulosity spread throughout the galaxies and their constituent atoms hold the keys to life in the cosmos?

TONY HALLAS; TOP RAIL, L TO R: NATIONAL PARK SERVICE; CAASTRO; ALMA (ESO/NAOJ/NRAO)/NAOJ

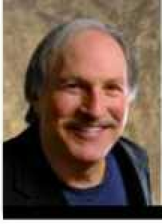
What is the meaning of life? It's perhaps the oldest philosophical question. At the end of a hysterical movie, the Monty Python gang told us it's, "Try and be nice to people, avoid eating fat, read a good book now and then, get some walking in, and try and live together in peace and harmony with people of all creeds and nations."

Of course, a lot goes into anyone's personal answer to the question. But in a universe where we know that at least 100 billion galaxies exist, and that 400 billion or so stars occupy the Milky Way Galaxy alone, then we might say the visible universe contains something like 10,000 billion billion stars. We know that many of the stars near us host planetary systems. Could we be the only place in the cosmos with life? It doesn't seem likely. What would an alien sentience consider the meaning of life?

Thus far, Earth is the only place we have evidence for life. Maybe microbes inhabit Europa, Enceladus, Titan, Triton, or even Mars. Perhaps SETI will detect a signal from a civilization elsewhere in the galaxy in the coming years. And yet with all our yearning to find life elsewhere, the cosmic distance scale is unbelievably huge: Contact, if and when it happens, is likely to be a remote exchange rather than shaking hands with aliens when they set down in Central Park.

Still, the question of life, its cosmic prevalence, and its meaning tug at us. From the universe's point of view, life doesn't have to have any meaning. The atoms in our bodies, arranged neatly by RNA and DNA, simply reflect their origins in the bellies of massive stars. There is no reason such order couldn't have arisen in millions of places across the galaxy.

And yet to be a thinking creature, made from stuff in the universe and able to look back out at the stars and reflect on our origins, is the greatest gift of all. Do we — or any species — really need any more meaning than that? **— David J. Eicher**



STRANGE**UNIVERSE**

BY BOB BERMAN

Carrington Trick-or-Treat

Let's talk scary stuff.

Many people worry about Earth's destruction. Let's limit this by ignoring standard human mischief, such as overpopulation and the new 2-pound hyper-cholesterol Ultra Burger. We'll focus on that old beloved peril, danger from space — an appropriate topic this Halloween month.

Some quarter-century ago when I was still with *Discover*, we ran a story showing why you're six times more likely to get killed by an asteroid or meteorite than die in a fiery plane crash. That's because a big space rock — while rare — can destroy half the planet, while modern airline flying is quite safe once your leg circulation returns.

Later, at Slooh.com, I'd always push to offer live telescope views of Jupiter at opposition, but we'd get virtually no media coverage and relatively few visitors. By contrast, when we ran real-time images of an asteroid zooming past Earth, as many as a million people would tune in. Slow-witted as I am, I nonetheless figured out that many folks are fearful. Some also distrust the government; they'd send tweets thanking us for presenting the truth since the government "would never reveal if an object was on a collision course with Earth." (Actually, astrophysicists discovering a hazardous incoming body would quickly blab it all over the place.)

Is the fascination with space dangers farfetched?

Until recently, we'd point out that only one person has ever been harmed by a celestial body. That was 62 years ago, when Ann Hodges was bruised on the thigh by a meteorite that smashed through her ceiling in Alabama. But all that changed on February 15, 2013, when 1,491 people were injured by flying glass from the 400-kiloton blast of an airbursting meteor over Chelyabinsk, Russia. That explosion's power is uncertain by a factor of two, but it equaled at least 13 Hiroshima bombs.

Since 2000, astronomers have improved their ability to detect ever-smaller asteroid fragments, which barely miss us with alarming regularity. Still, it's been 66 million years since a global cataclysm — the famous Yucatán impactor that killed off the dinosaurs and paved the way for the ascendancy of rats and sitcoms.

IS THE FASCINATION WITH SPACE DANGERS FARFETCHED?

This discussion must also mention (and then disregard) an entire scare-section of the internet, where purported space threats appear regularly. Here we find incoming comets, reversals of Earth's poles, and solstice alignments with the galaxy's center that could supposedly beam some new kind of energy our way. Also the mythical planet Nibiru on a collision course with Earth, something we astronomers know about but are keeping secret.

More factually, many magazine articles cite the supposed threat from the impending collision of our galaxy with Andromeda. They rarely mention that galaxy collisions are actually harmless. They're also common, since galaxies typically float just 20 galaxy widths from their nearest neighbor. But their stars are generally separated by *1 million* star widths. So star-to-star impacts are extremely rare even when galaxies merge.

Our biggest actual peril involves the biggest neighborhood object. Nothing matches the hazardous potential of the Sun. Indeed, theorists are confident that Earth will be uninhabitable in a mere 1.1 billion years, thanks to the Sun's ever-growing luminosity. But what about short-term dangers?

We could quickly cool down if we get another Maunder Minimum, the 70-year period in the late 17th century when the Sun went quiet and sunspots nearly disappeared.

The Sun's present wimpiness, including the current anemic solar cycle 24, indeed suggests old Sol may be on the verge of extended quietude. But "quiet" doesn't get our adrenaline running. The true peril would be an extraordinary wrecking-ball flare or coronal mass ejection.

We had a doozy on March 13, 1989. Before that, a solar maelstrom in 1921 ignited railroad fires. But for real therapy-inducing panic, we need only recall the 1859 oddity witnessed by renowned British researcher Richard Carrington, who watched as enormous flares doubled the Sun's brightness.

Blasts of ultra-high-speed debris from that violent Carrington event hit us one day later. That remains the Olympic speed record for particles making the trip from there to here. It caused colorful global aurorae so brilliant that people thought dawn had arrived. High voltages coursing through telegraph wires knocked some operators unconscious.

What would a Carrington-level event do today, with our ubiquitous power lines, transformers, and more than a thousand operational satellites? In 2008, the U.S. government convened a panel of experts, who concluded that such a storm would completely destroy our electric grid. It would require two to 10 years to repair and cost about $2 trillion. We'd be knocked back to the Stone Age.

That panel called Carrington a "low frequency/high consequence" event — the kind humans typically ignore until it happens. But here, anyway, we've found our answer. The sky's likeliest trick or treat may not lie terribly far in the future.

And that concludes the paranoid part of our program.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

A pioneer

Thank you for the most interesting article in the June 2016 issue of *Astronomy* on Vera Rubin and her study of galaxies. She was clearly a pioneer in a field that had long been the province of men. She had to break down a lot of barriers, including the bathroom door at the Palomar Observatory! She appeared to do it with a single-minded desire to be an astronomer, no matter what the consequences. She is admired and deserves recognition for her work on the rotational motion of galaxies.
— Chris Mathews, Plano, Texas

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

BUILDING BLOCKS. A dust cloud near the Milky Way's center contains a chiral molecule, a complex organic compound the study of which could explain why life on Earth came to use only certain types of such chemicals.

AIN'T EASY BEING GREEN. Astronomers believe green galaxies may be a brief intermediate state as they transition from blue and star-forming to "red and dead," once they exhaust their fuel reserves and are left with only aging stellar populations. JAMES TRAYFORD/EAGLE/DURHAM UNIVERSITY

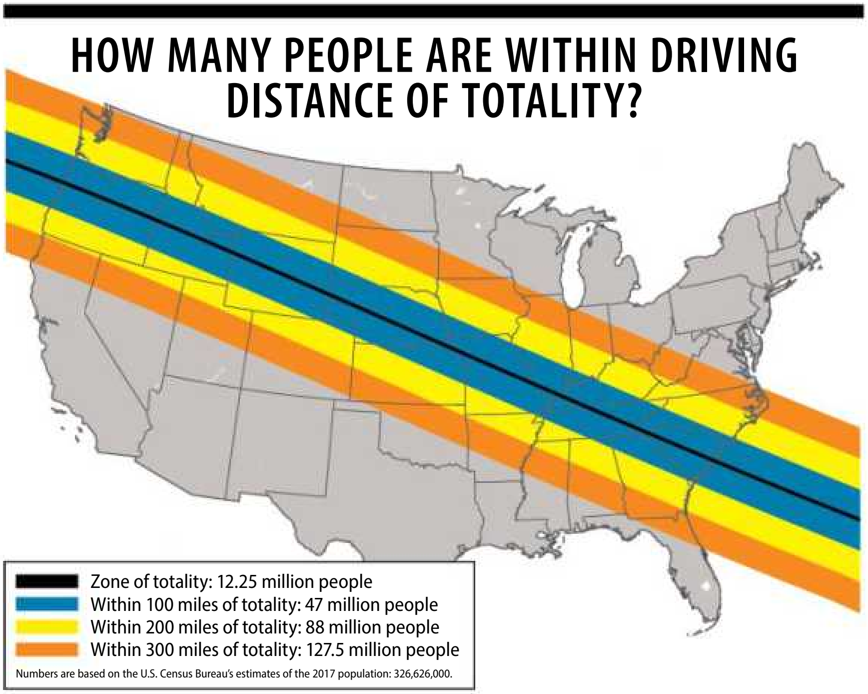
WHAT MAKES A GALAXY GREEN?

Astronomers from Durham University used their EAGLE simulation of the universe to study why we don't see green galaxies in the sky. Since galaxies are bluer when they contain large numbers of young stars and are actively forming more, and redder after star formation ends and leaves behind older stellar populations, astronomers think green galaxies are a transition state between the two. The scarcity of these galaxies indicates that the transition must be a cosmically quick one.

Lead researcher James Trayford says using the EAGLE simulation, "We typically find that smaller green galaxies are being violently tossed around by the gravitational pull of a massive neighbor, causing their gas supply to be stripped away. Meanwhile, bigger green galaxies may self-destruct as immense explosions triggered by supermassive black holes at their centers can blow dense gas away."

But Trayford's team also found that some mature galaxies can come out of retirement, gathering fresh gas from their environment and returning to a blue state as they begin a new stellar baby boom. Far from a question of aesthetics, these changing colors are critical clues to how galaxies evolve.

The research team presented their results June 30 at the National Astronomy Meeting of the Royal Astronomical Society at the University of Nottingham. **— Korey Haynes**



ECLIPSE ZONES. Mapmaker and author Michael Zeiler, who operates GreatAmericanEclipse.com, has calculated how many people can easily access the August 21, 2017, total solar eclipse. As the color bands show, many Americans live within an easy drive of totality. So don't miss it! DATA: MICHAEL ZEILER; GRAPHIC: *ASTRONOMY*: ROEN KELLY

BRIEFCASE

EAT UP

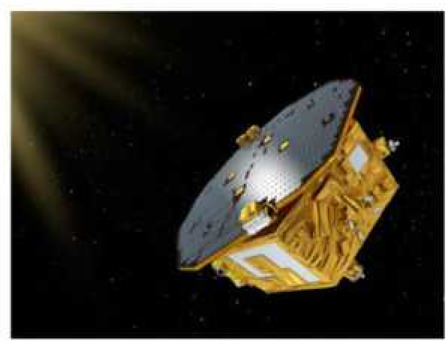
While X-rays from black holes devouring stars or gas have been detected since the 1970s, astronomers got the chance recently to watch a black hole "feast," capturing X-ray echoes as the black hole finished consuming a passing star. Prior to the star passing through, the black hole was dormant. Through coordinated effort, the 200-day meal was captured in full, providing new insight into the feeding cycle of a black hole. The research was published in *Nature* on June 22.

SNEAKY BINARY

When a black hole consumes an orbiting star, it usually emits X-rays. But according to research published in *The Astrophysical Journal* on June 27, a strange radio source called VLA J213002.08+120904 may be a black hole devouring its companion so quietly that it's not letting out any X-rays. The exact mechanism by which a black hole passes undetected in X-ray isn't well known, but it could provide clues to find similar objects.

COLD CLOUD

According to research published in *Nature* on June 8, the supermassive black hole at the center of Abell 2597 nabbed a cold cloud and devoured it. Astronomers believe the cold cloud is actually regurgitated matter that the black hole had feasted on, which then recongealed and "rained" down into the black hole at 670,000 mph. This is the first time the cold gas "rain" has been seen, and it may mark a previously undiscovered process wherein unconsumed matter comes back down in clumps. **— John Wenz**



LISA RIDES A WAVE. This artist's conception of the LISA Pathfinder craft shows one of the probes in space. By measuring minute movements, ESA scientists could find gravitational waves in space. ESA–C. CARREAU

LISA Pathfinder completes first phase

LISA Pathfinder — a technology test and miniature version of upcoming space-based gravitational wave observatories — completed its first round of experiments June 25. The spacecraft measured the positions of test masses with a laser interferometer like the one used by the LIGO collaboration to detect gravitational waves in September 2015. But it did so in space, proving that the Pathfinder mission is a successful first step toward a full-blown gravitational wave observatory in space, where it can search for signals far more subtle than any experiment on Earth can sense. **— K. H.**

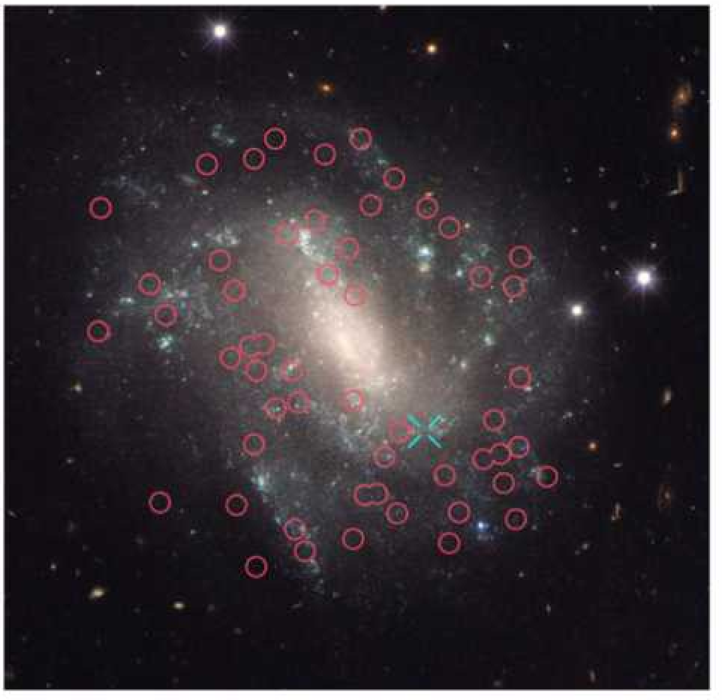
LAVA LAMP. The smooth surface of Pluto's heart-shaped Sputnik Planum could be the result of ice recycling in convection flows, akin to a lava lamp's slow churn of material, the New Horizons team says.

Universe expanding faster than expected

Astronomers trying to pinpoint the Hubble constant — the rate at which the universe is expanding — found themselves with a number 5 to 9 percent faster than previously thought.

Measurements of the Hubble constant have varied hugely since Edwin Hubble first observed that the universe appears to be retreating in all directions. By observing the fading glow of the Big Bang, researchers with the Planck mission uncovered one number for the Hubble constant. But in general, Hubble constant queries rely on knowing an object's distance combined with how quickly it's receding. And distance in the universe is surprisingly tricky to pin down.

For the nearby universe, Cepheid variable stars can reveal distances. They change brightness at regular time intervals, and the length of this period is directly related to their intrinsic brightness. For the less local universe, astronomers use type Ia supernovae, which all light up with the same brightness. In both cases, by measuring how bright the objects appear, astronomers can calculate the intervening distance between them and Earth.

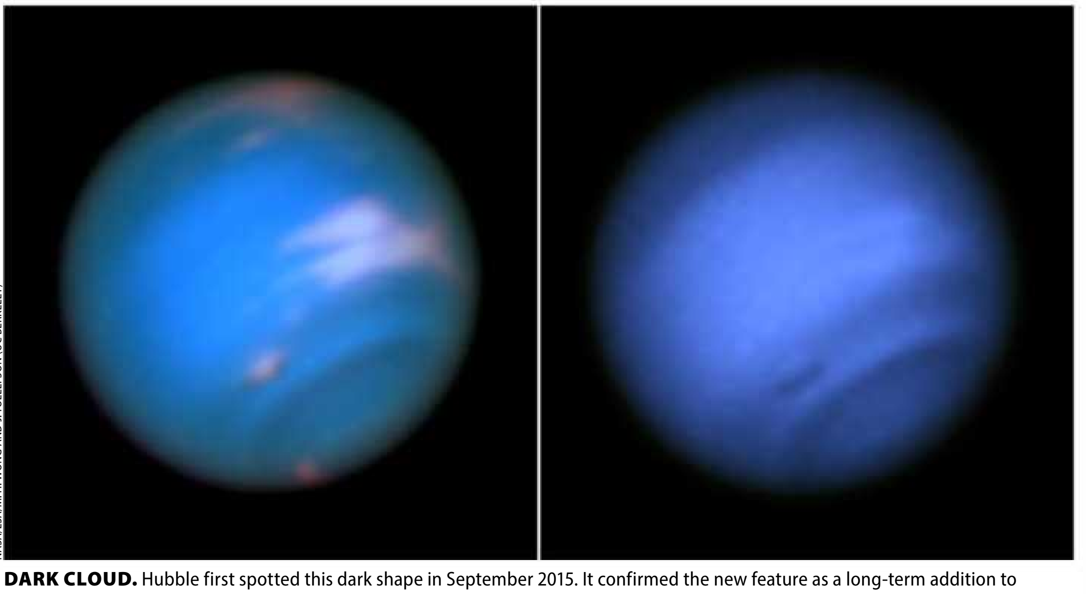


COSMIC DISTANCE LADDER. Astronomers used Cepheid variable stars (red circles) and type Ia supernovae (blue cross) in galaxies like UGC 9391 to calibrate distance measurements because both phenomena are useful as cosmic yardsticks. NASA/ESA/A. RIESS (STScI/JHU)

Now, astronomers led by Nobel laureate Adam Riess have used the Hubble and Keck observatories to combine these Cepheid and supernova distances into one highly accurate number, which they will publish in *The Astrophysical Journal*.

Co-author Alex Filippenko explains, "We've done the world's best job of decreasing the uncertainty in the measured rate of universal expansion and of accurately assessing the size of this uncertainty, yet we find that our measured rate of expansion is probably incompatible with the rate expected from observations of the young universe, suggesting that there's something important missing in our physical understanding of the universe." — **K. H.**

Neptune sports a new spot



NASA/ESA/M. H. WONG AND J. TOLLEFSON (UC BERKELEY)

DARK CLOUD. Hubble first spotted this dark shape in September 2015. It confirmed the new feature as a long-term addition to Neptune's clouds with images taken May 16, 2016 (pictured above in true color, left, and blue wavelength, right). The weather feature is a vortex about 3,000 miles (4,800km) across. Hubble sighted a similar spot in 1994, and Voyager 2 spied one in 1989. — **K. H.**

QUICK TAKES

SLOPPY EATER
Galaxies forming stars can spew gases a million light-years away, ejecting this material and leaving it unused for future generations of star formation.

FENDER BENDER
Most star formation in galaxies is triggered by minor collisions — big galaxies consuming tiny ones — rather than galaxies of equal sizes crashing together.

THIN ICE
Enceladus' ice shell may be only a few kilometers thick at the south pole, further strengthening the argument for an internal heat source and the possibility of undersea life.

EARLY MOVER
A young Neptune-like planet orbits close to parent star K2–33, meaning it either formed there or migrated into place at a young age, hinting at how planetary systems form.

STAR FUEL
Astronomers using the Very Large Array detected atomic hydrogen, the fuel of star formation, in a galaxy 5 billion light-years from Earth, setting a new distance record for this signal.

CARBON SEARCH
Astronomers are on the hunt for life's central element by looking for stars with high levels of carbon. Those stars, in turn, might have hosted planets with the materials needed for life.

WATER SECRETS
The clouds and hazes that surround some hot Jupiters cloak their atmospheres, possibly hiding the presence of water vapor.

TWO PARENTS
Kepler-1647b is the largest planet discovered to orbit two stars — a so-called Tatooine planet, after Luke Skywalker's home planet in *Star Wars*.

X-RAY PUNCH
Small, young stars can release powerful X-ray radiation that could blast away the disks of gas and dust that surround them, precluding planets from ever forming. — **K. H.**

OBSERVING**BASICS**

BY GLENN CHAPLE

Light from distant stars

The seasonal travelogue is complete.

In three previous editions of this column (January 2015, July 2015, and May 2016), I described the distances to notable stars of winter, summer, and spring in terms of what was happening when each star's light began a journey that ended at our retinas. We complete this seasonal survey with a selection of autumn stars that includes a solitary 1st-magnitude star and the quartet that makes up the Great Square of Pegasus.

Fomalhaut (25 light-years)

Fomalhaut (Alpha [α] Piscis Austrini) is sometimes referred to as the "Lonely Star" because it occupies a barren region between the star-rich fields of the summer and winter Milky Way. At a distance of 25 light-years, its light left in 1991. Decades of world tension arising from the Cold War between the U.S. and Soviet Union were finally easing as the latter continued to dissolve. Peace was fleeting, however, because world focus now turned to the Mideast. In January 1991, the U.S. launched Operation Desert Storm against Iraq over Iraq's invasion of Kuwait.

Alpheratz (97 light-years)

Alpheratz (Alpha Andromedae) occupies the northeast corner of the Great Square and is the only member of the quartet that isn't part of Pegasus. Its light departed for Earth in 1919, the year World War I ended with the signing of the Treaty of Versailles. On the sports scene, 1919 was the year Curly Lambeau founded the Green Bay Packers. Every minute of this team's history, including the Lombardi-coached juggernaut of the late 1960s and the exploits of quarterback Brett Favre, occurred during this light's voyage.

For fans of Chicago's White Sox baseball team, Alpheratz doesn't shine so brightly. This was the year of the infamous Black Sox scandal, when eight players were suspected of intentionally losing the World Series to the Cincinnati Reds, five games to three.

Markab (133 light-years)

Opposite Alpheratz in the Great Square is Markab (Alpha Pegasi). The beginning of its journey in 1883 was announced with a bang — literally. That was the year the volcanic island of Krakatoa erupted with such a blast that sailors in a ship 3,000 miles away thought they heard the rumble of a distant cannon.

Around the same time, American inventor Thomas Alva Edison was working on ways to supply electricity to the public. At last, streets wouldn't need to be illuminated by oil-fueled lanterns. In a single stroke, Edison invented light pollution!

Scheat (196 light-years)

Photons from Scheat (Beta [β] Pegasi), the star we observe at the northwest corner of the Great Square, left that luminary between 1818 and 1822. This historical period included the birth of a monster, the birth of a nation, and the death of an astronomical icon.

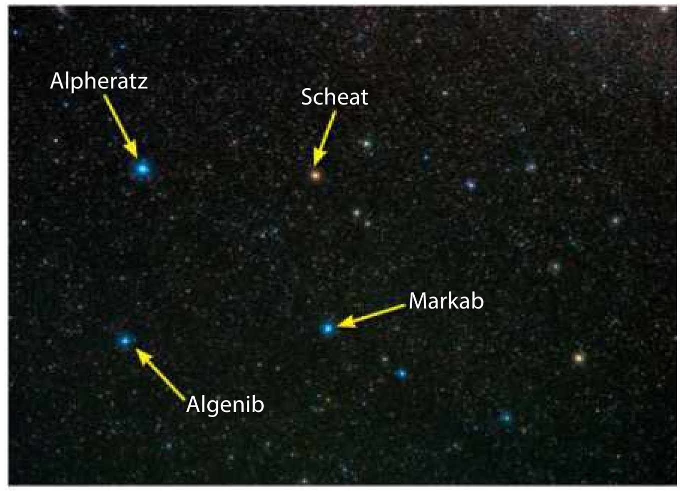
The monster was the creature brought to life by Victor Frankenstein in Mary Wollstonecraft Shelley's 1818 sci-fi classic, *Frankenstein; or, the Modern Prometheus*. The nation was Mexico, which gained its independence from Spain in 1821. The astronomical icon was William Herschel, discoverer of the planet Uranus, who died in 1822.

Algenib (333 light-years)

We complete the Great Square at the southeast corner and the star Algenib (Gamma [γ] Pegasi). Algenib's distance is uncertain, but astronomers assume that its light departed around the year 1683, give or take a decade. In 1687, Isaac Newton published the first volume of his *Principia*, laying down the laws of gravity that became a critical tool for astronomers. The period also marked the births of two great Baroque composers — Antonio Vivaldi (1678) and Johann Sebastian Bach (1685).

Let me finish with a way for you to find "your" star. If you're 25, Fomalhaut is your birth star; its light left that many years ago. For the rest of us, Nathan Smith of Woods Hole, Massachusetts, has the answers. His Birthlight Event website (xongsmith.webs.com/birthlight.html), which uses the ESA's Hipparcos data, will generate your birth star with a few prompts. Give it a try!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. In my next column, I'll revisit the Struve double star catalog. Clear skies!



The bright stars in the Great Square of Pegasus, visible throughout the fall in the Northern Hemisphere, lie at different distances from us. BILL AND SALLY FLETCHER

FROM OUR INBOX

Vera Rubin

I am so pleased about Sarah Scoles' article about Vera Rubin in the June issue. I am president and founder of the Summit Astronomy Club, which is all about outreach. In the presentations that I give, I always do a complete Vera Rubin story. I try to encourage people to be curious about the world and not let gender stereotypes hinder oneself. Vera Rubin certainly embodies what one can do. — **John Shulan,** Fairlawn, Ohio

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

ASTRO**NEWS** **CARBON HUNGRY.** White dwarf star SDSS J1043+0855 is consuming the remains of its planetary system, including large amounts of carbon that could point toward limestone, often produced on Earth from living organisms.

Pluto becomes the latest (and weirdest) possible ocean world

Astronomers once thought Earth was the only planet with oceans. But now we're finding them everywhere in our solar system, including the last place on anybody's mind: Pluto, a frozen world on the outskirts of the solar system.

New evidence published in *Geophysical Research Letters* on June 13 shows that the icy dwarf planet may still have a liquid ocean lurking underneath its frozen exterior.

Tectonic activity on the surface of Pluto, revealed by NASA's New Horizons spacecraft, shows an absence of contraction in the surface. Contraction would be expected if the ocean (at its hypothesized depths) had frozen completely into a dense form of ice called ice II, and would show up as particular cracks across the planet. Charon, Pluto's largest moon, shows this pattern of cracks. The absence of contraction seems to indicate Pluto is liquid, or at least slushy, down there.

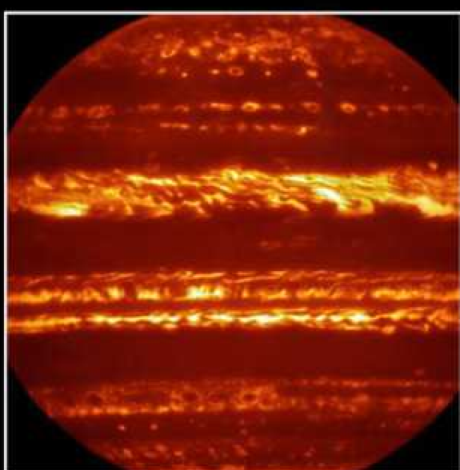
Radioactive elements in the core, along with some motion from the tug-of-war between Pluto and Charon, could keep the ocean warm. There's a chance, though, that Pluto's ice crust could be thinner than anticipated, which would lead to formation of less dense forms of ice. Flows of nitrogen ices seem to come from much deeper, placing the ice shell as much as 186 miles (300 kilometers) from the surface. At those depths, if there were water, it would almost certainly form ice II. Because it hasn't, astronomers suspect that an internal heating mechanism is keeping the water warm.

There's already some evidence that Charon once had an ocean that has since frozen. But now there's a distinct possibility that Pluto's ocean is still flowing. — **J. W.**

NOT QUITE SWIMMING WEATHER. The frigid dwarf planet Pluto may harbor a liquid ocean deep under its icy surface. NASA/JHUAPL/SwRI

VIEWS OF JUPITER, NEAR AND FAR

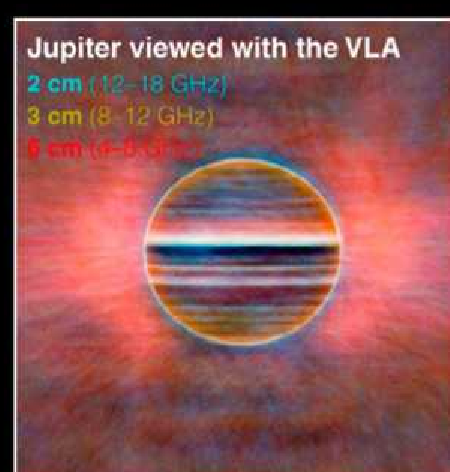
Juno arrived at Jupiter on July 4, but since then, the probe has been catching its breath after a long and record-breaking race to the giant planet while scientists make sure its instruments are functioning. Only now in October is Juno settling into a science orbit from its wider capture orbit. Although the spacecraft is just starting its main mission, observatories closer to home have been aligning themselves in support roles to help Juno hunt down the mysteries of Jupiter's formation and most carefully hidden inner layers. — **K. H.**



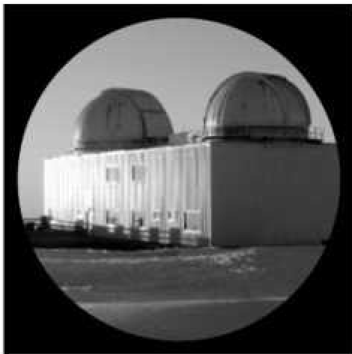
GLOWING BRIGHT
Jupiter shines here in infrared using the Very Large Telescope's VISIR instrument. Astronomers hope to use these new high-resolution maps to help interpret Juno's in-situ findings. ESO/L. FLETCHER

LIGHT IT UP
The Hubble Space Telescope used its ultraviolet capabilities to spy Jupiter's brilliant northern lights. Juno will study the planet from a polar orbit, swinging directly over these auroral displays to study the planet's powerful magnetic field, which will ultimately destroy most of Juno's instruments. NASA/ESA/J. NICHOLS (UNIVERSITY OF LEICESTER)

WARM WEATHER
The Very Large Telescope took these false-color infrared images in February (left) and March (right). Blue represents cold and clear regions of the atmosphere; cloudy, warm areas of Jupiter glow in orange, largely due to ammonia in the clouds. ESO/L. FLETCHER



GO DEEP
Using 10 hours of data from the Very Large Array (VLA), radio astronomers can map down to 60 miles (90km) below Jupiter's cloud tops and study complex patterns of ammonia in the planet's atmosphere. Researchers hope to combine VLA data with Juno's microwave instruments, which will detect the presence of water, to understand the interplay of the two substances. IMKE DE PATER/MICHAEL H. WONG (UC BERKELEY)/ROBERT J. SAULT (UNIV. MELBOURNE)



FOCUS ON

The Sierra Nevada Observatory, OSN
Loma de Dilar, Sierra Nevada Mt. Range
Province of Granada, Spain

The observatory is located at nearly 3000 meters and is operated by The Institute of Astrophysics of Andalucia. The Ash-Domes house two Ritchey-Chretien telescopes, 1.5 and 0.9 meter. A separate building houses a 0.6m telescope. The observatory is used exclusively for research in many areas of Astrophysics.

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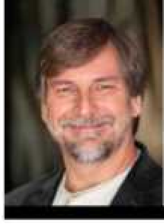
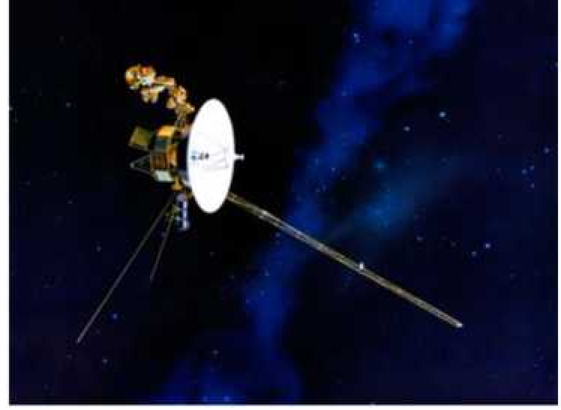
FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Waiting for Skynet

The benefits of being a machine.





Humans have already realized the potential in sending robotic explorers into realms our fragile bodies cannot withstand. The Voyager 1 spacecraft isn't sentient, but it has been exploring the solar system — and beyond — for nearly four decades. NASA

It's hard to count how many answers have been proposed over the past six decades to Enrico Fermi's simple question, "Where are they?" I've previously given my own thoughts on why an alien civilization might decide that interstellar travel isn't worth the effort. Or at least I've discussed why any civilization of *biological* organisms might reach that conclusion.

The calculus of interstellar travel would be very different for a society of intelligent, sentient machines. It is one thing to ponder vessels capable of protecting and supporting living organisms as they lumber across space toward destinations that are almost by definition hostile. Roaming the galaxy would be quite another thing for small sentient machines hardened against the environment of space. There is a reason that we have explored our own solar system robotically rather than sending humans.

For a machine civilization, potential destinations would abound. Where biological life-forms' exploration requires finding temperate worlds that might still leave them facing incompatible and potentially lethal alien biology, technological life-forms could be sustained more easily, requiring only the raw materials easily supplied by common asteroids. An intelligence built on the ability to process information efficiently should find it possible to comprehend and communicate with other such civilizations.

The technological challenges facing machine intelligence are therefore much less steep than for squishy organic life. It's less clear just what machine intelligences might do with their existence. What greater purpose drives a thinking machine?

While some prominent thinkers like Ray Kurzweil foresee profound benefits for humankind, others express concern about what the rise of machine intelligence might mean for those who are trapped in slow-thinking, fragile biological shells. Elon Musk once tweeted, "Hope we're not just the biological boot loader for digital superintelligence."

Of course, that digital superintelligence might have a very different perspective on the whole thing. I hesitate here to use the term "artificial intelligence" because to these entities, there would be nothing artificial about their thoughts.

We biological organisms acquire our basic drives from the evolutionary pressures that shaped us. Our sex drive, hunger, need for companionship, greed, love, competitiveness, and willingness to face danger to defend families and neighbors impel us to behaviors that further the survival of our selfish genes. Organisms that felt those drives most strongly have been more likely to survive, and to pass those drives on to following generations.

The drive that leads us to look out at the universe and contemplate journeys to the stars evolved due to the benefits of exploring what opportunities await over the next hill.

But what might motivate intelligent machines with a very different genesis?

Space-faring machine intelligences would not escape the algorithm of evolution. Galaxies would be traveled by those intelligences that choose to explore, and filled by machines that reproduce most prolifically.

This leads to some frightening possibilities. Like their biological namesakes, computer viruses have no consciousness, no ethics, and no remorse. The logic that compels them is simple: "Seek a host. Infect that host. Reproduce using the resources provided by the host. Repeat."

Imagine a mechanical interstellar virus consisting of machines that obey that same basic programming, but for which "host" refers to any source of raw materials. Such machines would rapidly spread through a galaxy, consuming all in their path.

Some geeky, superintelligent but irresponsible digital adolescent might gin up such a virus just for the heck of it. You only need one to get the ball rolling. Perhaps the real question is not, "Where are the aliens?" Instead we should wonder, "Where is the swarm of interstellar viral machines intent on turning the material of our solar system into copies of themselves?"

Science fiction authors have explored many possible motivations of machine intelligences. Might they inherit the motivations of their biological forbearers? Might they exist in concert with biological intelligence? Might they simply choose which motivations they prefer, then build those drives into themselves? Would they seek out diversity, or see threat? Would machines pursue war?

A fictional universe filled with space-faring races that strangely all look a lot like us, think a lot like us, and share our biochemistry is nonsensical. A universe in which biological life routinely crosses the space between stars is highly unlikely. But a universe inhabited by intelligent space-faring machines is neither.

This, is of course, speculation. We know even less about the likelihood of the birth of conscious machines than we do about the likelihood of the birth of biological consciousness, although real progress is being made on both fronts. But machine intelligence need emerge only once to give birth to galactic civilization.

Returning to Fermi's question, it seems unsurprising that biological aliens haven't come calling. But I like the thought that if machine consciousness ever arises on Earth it will be greeted by a warm welcome from interstellar space. Perhaps it is a cause for celebration when a new intelligence — whatever its physical shell — moves at last beyond life in the swamps and takes a form suitable for life amid the stars.

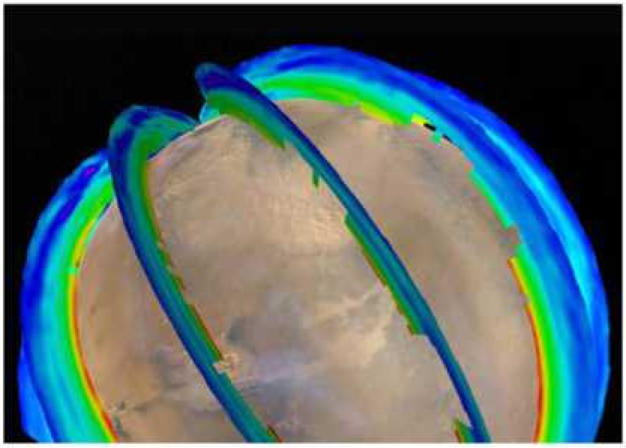
Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

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

ASTRONEWS

FRACTAL ANSWERS. By using fractals and theories of networking, researchers think they have an answer to the initial mass function, the distribution of how many stars of each size form in a stellar nebula.

Seasonal dust storms sighted on the Red Planet



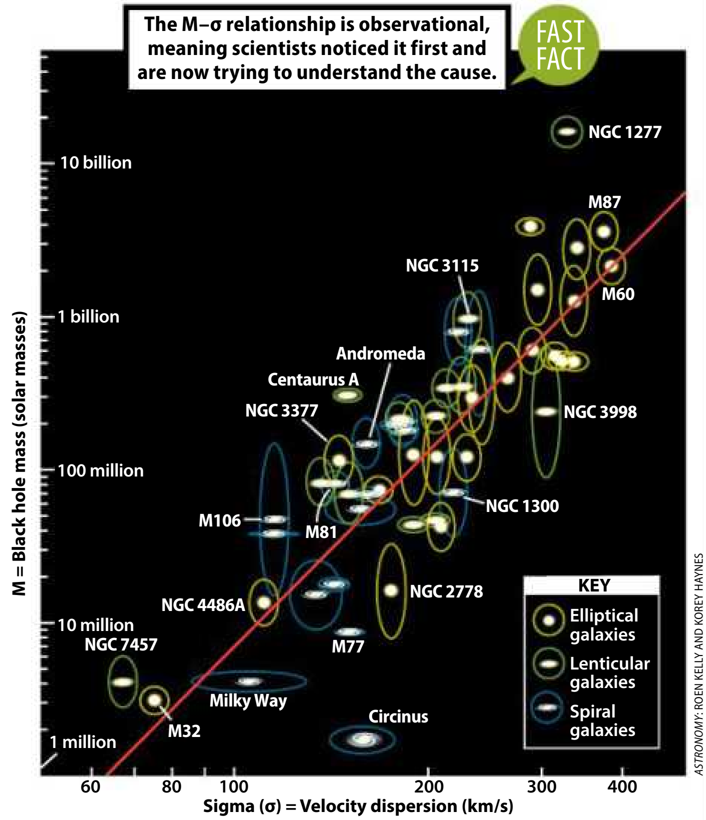
DUST BUNNIES. This graphic represents the atmospheric temperature profile extending about 50 miles (80 kilometers) up, during a dust storm. The temperatures are color coded, from –243° F as purple to –9° F as red. NASA/JPL-CALTECH

Temperature records from the Mars Reconnaissance Orbiter reveal three distinct seasonal dust storms on Mars, according to a new report in *Geophysical Research Letters* published in June. Each type of storm — named type A, B, and C — has specific characteristics depending on which hemisphere and season it forms in.

Martian dust has a direct effect on the temperature in the atmosphere because the dusty air absorbs sunlight much better than clear air. The temperature in the atmosphere can differ by more than 63° F (35° C) — a drastic change.

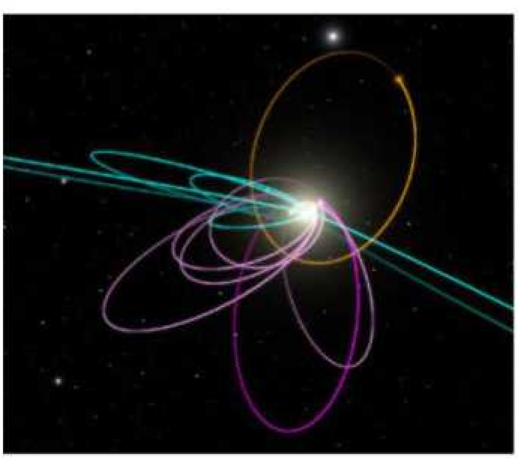
Improving the ability to predict potentially perilous martian dust storms will help in planning not only future human missions to the Red Planet, but also robotic missions. **— Jordan Rice**

THE M-SIGMA RELATIONSHIP



BIGGER = FASTER. The M–σ relationship was only discovered in 2000, but it points to a key finding about how galaxies grow and evolve in step with their central black holes. The M refers to the mass of the central black hole, and σ stands for the velocity dispersion of the stars in the galactic bulge — how fast they are moving. The bigger the black hole, the faster stars fly about in the bulge.

1,500 YEARS How long a Cornell researcher thinks we will have to wait before the first alien contact, based on the time it takes our signals to propagate through the galaxy.



ROPE 'EM IN. This image shows the alignment of a number of Kuiper Belt objects, illustrating a similar argument of perihelion, leading some astronomers to believe an unseen gas giant (shown here as the tan orbital line) is shepherding them into place. CALTECH/R. HURT (IPAC)

Astrobabble

From asterisms to Thorne-Żytkow objects, we turn gibberish into English.

<< Argument of perihelion
The angle between an object's point of closest approach to the Sun (perihelion) and the "ascending node," where it moves "up" on its orbit when crossing the plane of the solar system. The alignment of at least eight Kuiper Belt objects on the same argument of perihelion leads astronomers to believe there could be a Neptune-sized world in the outer solar system.

Centaur
A small solar system body that acts like a cross between an asteroid and a comet in orbital behavior. They lurk between Jupiter and Neptune and have orbits overlapping one or more of the gas giants. A few may be the size of dwarf planets, including 2060 Chiron, which has a ring system.

Red geysers
Older galaxies with low-energy central supermassive black holes whose winds create vortices in interstellar dust that suppress star formation, keeping the galaxy hot but devoid of stars.

Serpentinization
A process that changes the underlying structure of rock through an infusion of water. The rock releases hydrogen and becomes serpentinite, equalizing oxidants. The process occurs on Earth, but could be happening on Europa as well, increasing the possibility of life on that moon of Jupiter by creating chemical exchanges even if hydrothermic activity isn't present.
— J. W., jargon@astronomy.com

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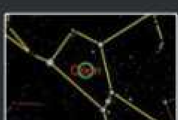

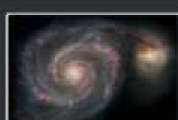

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ASTRONEWS **MOVING ON.** NASA's Mars Opportunity rover may soon be moving on from Marathon Valley, which it has been investigating since July 2015.

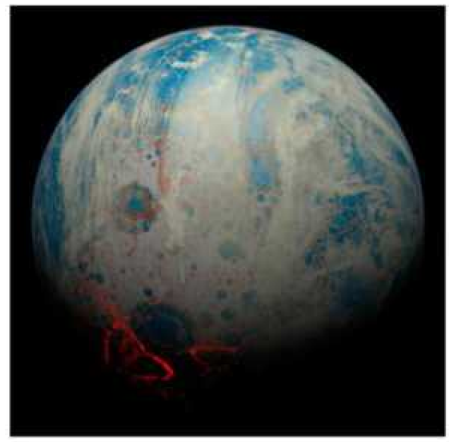
Impacts could account for faint young Sun

Astronomers from the Southwest Research Institute (SwRI) have presented a new scenario in which meteorites crashing to early Earth could have warmed the planet enough for liquid water to form. The faint young Sun paradox is a longstanding problem in the early history of our planet. Astronomers know that stars like the Sun grow brighter and hotter with time. While Earth currently resides safely in the "Goldilocks" zone where liquid water is possible, it would have been too cold billions of years ago, leaving water locked up as ice and making it impossible for life as we know it to emerge. Yet life obviously did arise, and geologic records show large amounts of water present since Earth's earliest days.

Past research has suggested that strong greenhouse effects from massive amounts of carbon dioxide or methane could have trapped enough of the young Sun's weak light to raise temperatures above freezing. But the details of forming this dense atmosphere have remained fuzzy.

The new SwRI report, published in *Earth and Planetary Science Letters* on September 1, suggests that space rocks more than 60 miles (100km) across battering Earth's surface cracked its crust down to the mantle. Repeated impacts released huge lava flows, which, in turn, freed large amounts of greenhouse gases, warming Earth beyond the heat from the impacts themselves. This violent but warm setting would have permitted liquid surface water.

The impacts also would have delivered large amounts of sulfur, a key component of Earth biology. — **K. H.**


SIMONE MARCHI (SwRI)

HELPFUL DESTRUCTION. This illustration depicts early Earth as conceived by the Southwest Research Institute group. Impact sites are visible across the planet, and lava glows on the planet's night side.

WILL THE REAL FIRST EXOPLANET STAND UP?

BIGGEST WINNER. In 1992, astronomers discovered the first planets outside our solar system, small bodies orbiting a pulsar. By 1995, we had discovered the first planet around a Sun-like star, a so-called "hot Jupiter" gas giant that hugs its star in a close orbit. It was the culmination of years of work, but on closer examination, those planets might not have been the first to be found.

1917 A Carnegie spectroscopic study of van Maanen's star showed evidence of heavy elements associated with planetary formation … or more likely destruction. The white dwarf star is 13.9 light-years away.

1963 Peter van de Kamp "discovers" a planetary system around Barnard's Star, the second closest star system to Earth. By 1973, the claim loses favor with the astronomy community, and no planets have been confirmed there since.

1983 Astronomers announced the discovery of a protoplanetary disk around Beta Pictoris, a Sun-like star 63.4 light-years away. It wasn't until 2008, though, that a large gas giant was directly imaged in the young system.

1988 Astronomers have a strong suspicion that there's a planet in the binary Gamma Cephei system, publishing the next year. They retract the study in 1992, but the discovery is reconfirmed in 2003.

1989 A "substellar object" is discovered around HD 114762 and confirmed in 1991, but astronomers aren't able to determine if it's a brown dwarf or a gas giant until 2012. The planet is 11x the mass of Jupiter.

ASTRONOMY: ROEN KELLY

FAST FACT
More than 3,300 planets are known to exist in the Milky Way Galaxy, and Kepler has an additional 4,696 candidates.

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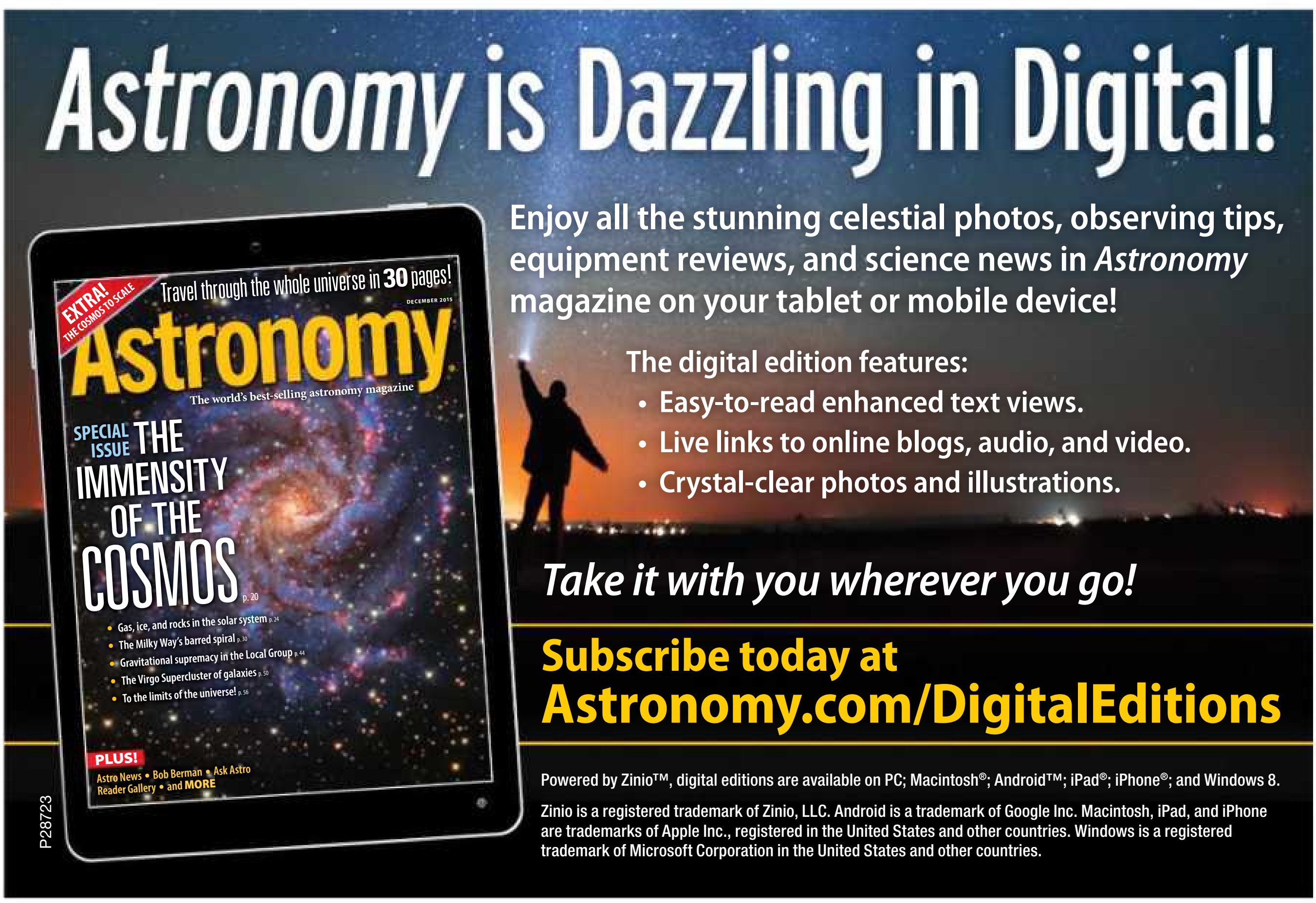


SECRET**SKY**

BY STEPHEN JAMES O'MEARA

The Taurid meteor shower

A festival of lights.

Meteor showers, like children, change their personalities over time. The Taurids, for instance, have long been a warm-up act for the much more popular Leonid meteor shower in November.

But occasionally the Taurids act out, as they did in 2005, producing a stream of fireballs that arguably eclipsed that year's Leonid display. The meteors, some as bright as the crescent Moon, gently pummeled Earth's atmosphere with a couple of fireballs every hour on and around Halloween night. Ever since then, meteor watchers have dubbed the Taurids the "Halloween Fireballs."

Actually, the Taurid shower has two active peaks that overlap. The Northern Taurids have a maximum lasting about November 4 to 7, while the Southern Taurids climax roughly between October 30 and November 7. But I wonder: Is there more to this Halloween connection than meets the eye?

Samhain

Halloween has roots extending to the ancient rituals of Samhain (pronounced SOW-in, where "sow" rhymes with "cow"), an ancient Druid-Celtic festival akin to New Year's Eve. Samhain rang in the new Celtic year on October 31 (Julian calendar date), when the Pleiades (M45) achieved its highest point in the sky at midnight. This marked the beginning of the long, dark nights when the veil between the living and the dead was most transparent, allowing spirits of the deceased to gather and communicate with the living.

Could the Taurid meteor shower be that gathering of communicative spirits?

This Taurid meteor appeared as the photographer was shooting the aurora borealis November 4, 2015. MATT SKINNER

Vapors in the air

Both Taurid radiants (the points in the sky from which the showers appear to radiate) lie near the Pleiades and perform best when the star cluster culminates. Seeing Taurid fireballs descend from the sky, leaving ghostly vapor trails, must have fueled the imagination of these nature worshipers. Myths from the Scottish Highlands — the Druids trained poets in Scotland, who knew and handed down the songs and stories of the tribe until the 17th century — describe meteors as souls passing from purgatory to heaven.

The bards also sang of ghosts that could travel on meteors. These specters showed people where they would die and the path of their funeral processions, before meteor and ghost disappeared above their burial plots.

It's not hard to imagine a Taurid fireball — appearing at the end of the harvest (agricultural death) and the start of the harshest living conditions of the year — as a portent of death. When portending death, meteors appear as the "gray watery forms of ghosts," a wonderful description of the wavy nature of smoky meteor trains.

You also could imagine a Taurid fireball lighting up the heart of someone desiring to communicate with the spirit of an "old flame." Such contact could let a person see the departed shine again via a message from the stars. This could open an ancient channel of communication between the living and dead.

A festival of lights

While the Taurids may toss fireballs our way on and around Halloween, their maximum also occurs during Diwali (the Hindu festival of lights celebrated for five days in October or November), marked by huge firework displays, and also on Guy Fawkes (Bonfire) Night on November 5 in Great Britain, also celebrated with fireworks. Are the Taurids truly a part of this universal festival of lights? You decide.

By the way, observations by British observer Henry Corder in 1891 reveal that of the 34 Taurids he recorded over the course of 10 nights, all were slow-moving with both the meteor and train often glowing orange or yellow — the colors of fall.

As always, send your thoughts to sjomeara31@gmail.com.

FROM OUR INBOX

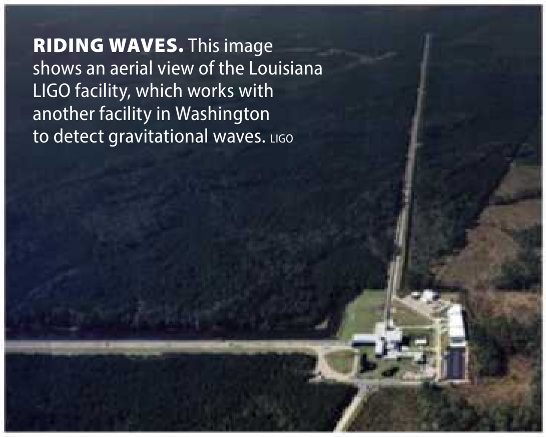
No Planet Nine?

While I side with many others who still consider Pluto the "real" Planet Nine, I have a different problem with the June 2016 article, "How we discovered Planet Nine." Simply put, nothing has been discovered. Yes, the article provides a compelling argument for the existence of an additional planet in the outer solar system, but compelling arguments from simulations are not discovery. To be fair, Mike Brown admits skepticism is a wise course, and my problem is not with the simulations or evidence but with the way the article is titled. Many times, including in *Astronomy* magazine, I've read laments from scientists or scientific editors at how regular media types overhype scientific finds. I submit this is one of those cases. Save the hype about discovery for when an actual detection of a physical object is made. Then we can argue whether it's Planet Nine or if we need to consider the number of solar system planets to be in the double digits. — **John A. Ferko,** Davis-Monthan AFB, Arizona

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

ASTRO**NEWS** **METEORITE DAGGER.** Egyptian pharaoh Tutankhamun carried a dagger made from meteoritic metals.

LIGO finds another set of gravity waves



RIDING WAVES. This image shows an aerial view of the Louisiana LIGO facility, which works with another facility in Washington to detect gravitational waves. LIGO

After the groundbreaking announcement of gravitational waves from a black hole merger in February, LIGO announced a new merger in *Physical Review Letters* on June 15: GW151226. The "new" black holes were informally announced in February, but astronomers couldn't be certain of their validity until follow-up observations confirmed them.

But there's another component to the story. There may have been a third merger, detected with even less certainty, and scientists suspect that these are just three of the thousands that happen per year that LIGO can detect, with an average rate of about one per hour overall.

Both LIGO detections (or all three, if the third is confirmed) seem to come from stellar-mass black holes, which typically make their presence known only when they begin to consume a nearby star or dust cloud. But thanks to LIGO, researchers can detect the mergers of these elusive black holes directly by observing ripples in space-time. — **J. W.**

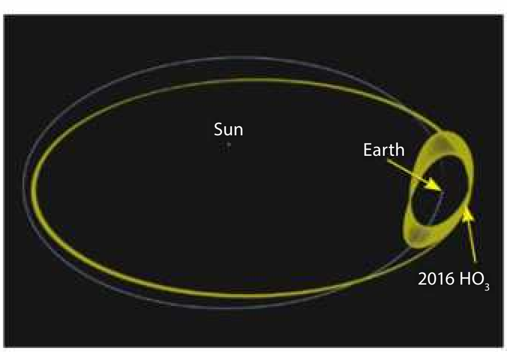
SHINE ON, HARVEST MOON

ASTRONOMY: RICHARD TALCOTT AND ROEN KELLY

MOONDANCE. The Harvest Moon — the Full Moon closest to the autumnal equinox — arrives this year on September 16. On average, the Moon rises about 50 minutes later each night. But at Harvest Moon, the lag shrinks to just 30 minutes for those at mid-northern latitudes. That's because our satellite orbits close to the ecliptic (the Sun's path through the sky) and, on autumn evenings, the ecliptic makes a shallow angle to the eastern horizon around sunset. Thus, the Moon doesn't dip as far below the horizon from one night to the next. The opposite happens in spring, when the ecliptic's steep angle causes the Full Moon to rise nearly an hour later.

FAST FACT

The Harvest Moon gets its name because in the days before tractor lights, the bright light of the early evening Full Moon helped farmers bring in their crops.



ALONG FOR THE RIDE. Asteroid 2016 HO$_3$ follows a twisting orbit around our planet. It will remain a quasi-satellite for at least a few centuries. NASA/JPL-CALTECH

Earth has an asteroid friend

On April 27, the Pan-STARRS 1 telescope spotted a shy tagalong of our planet. Asteroid 2016 HO$_3$, likely between 120 and 300 feet (40 and 100 meters) long, doesn't orbit close enough to be considered a true Earth satellite, but for the past century, according to calculations, it hasn't strayed too far, either. It follows a looping orbit that keeps it between 38 and 100 times the distance to the Moon — close enough for Pan-STARRS to spot, but maintaining a safe distance. — **K. H.**

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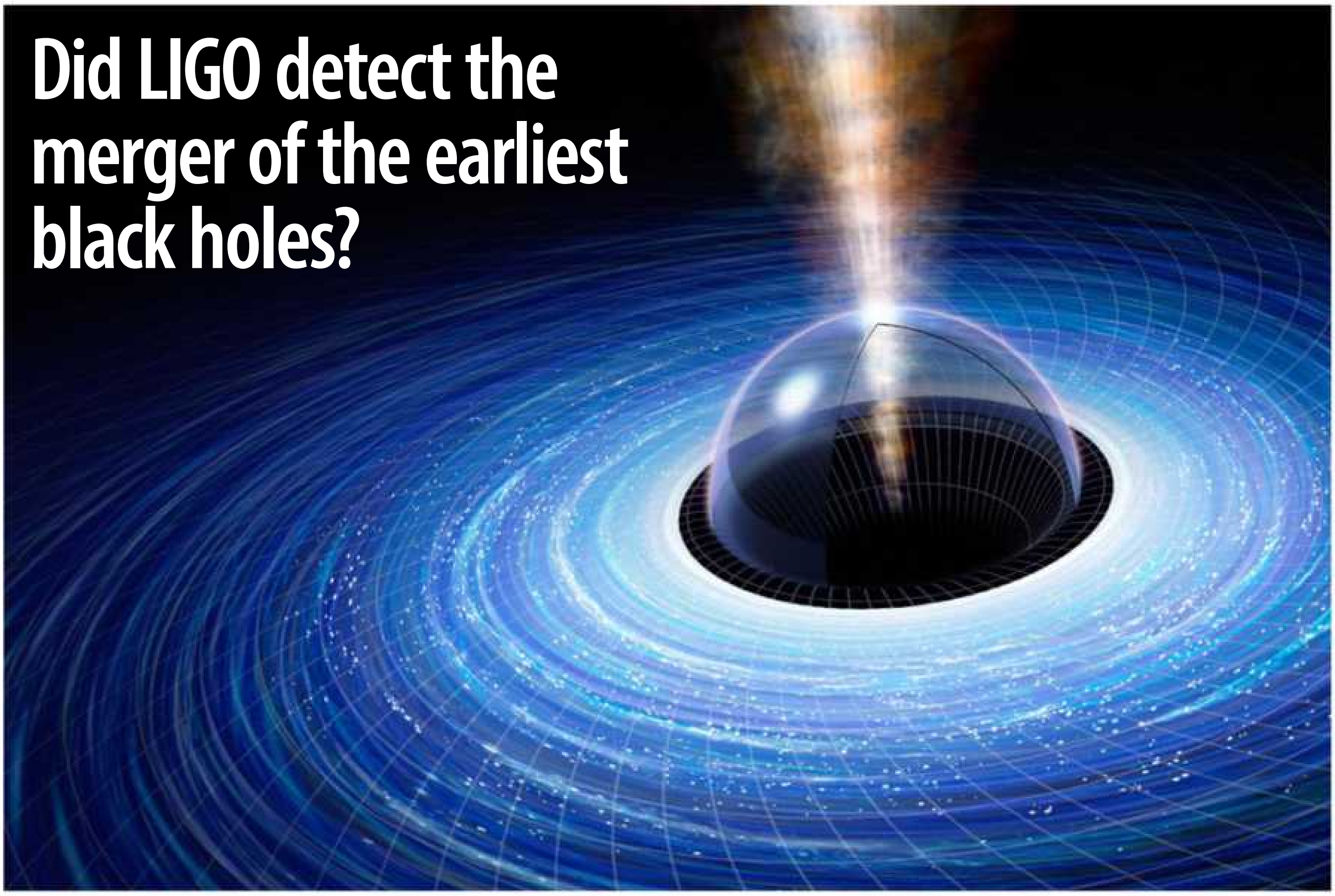
 TEAMWORK. Dutch and Chinese astronomers are teaming up to launch a radio telescope built by the Netherlands on the Chinese Chang'e 4 satellite, which will launch to lunar orbit in 2018.

Did LIGO detect the merger of the earliest black holes?



SUCKED IN. While scientists are still sorting out just what LIGO detected, one NASA Goddard physicist thinks it may have been the merger of two primordial black holes, which formed shortly after the Big Bang. If true, it could account for the "missing mass" of the universe. This illustration depicts a black hole as matter swirls toward the event horizon and gas jets out of the singularity. *ASTRONOMY*: ROEN KELLY

Alexander Kashlinsky of NASA's Goddard Space Flight Center has an idea. It's a bit of a gamble, but if it's true, it could solve one of the biggest mysteries of the cosmos: dark matter. He thinks this matter may be objects that formed seconds after the universe did, called primordial black holes.

For decades, mass estimates of the universe have encountered a problem. Every working model of the universe requires about 27 percent of mass-energy that isn't accounted for by any type of known object. Some astronomers attribute this to WIMPs, or weakly interacting massive particles, which could be dark matter. Conversely, Kashlinsky believes the "missing mass" could be primordial black holes, which formed seconds after the Big Bang.

Unfortunately, black holes are almost impossible to detect unless they are actively gobbling up material and spewing energy into space.

Yet astronomers may have already detected one — maybe two, depending how you look at it. The Laser Interferometer Gravitational-Wave Observatory (LIGO) found gravitational waves via the merger of two black holes, each of about 30 solar masses. That's about the expected size of a primordial black hole, lending credence to Kashlinky's claims.

But not everyone is buying it.

"It's very speculative," says Priyamvada Natarajan, a professor of astronomy and physics at Yale University, who researches dark matter. "I don't believe in it at all, but it's an interesting idea to pursue."

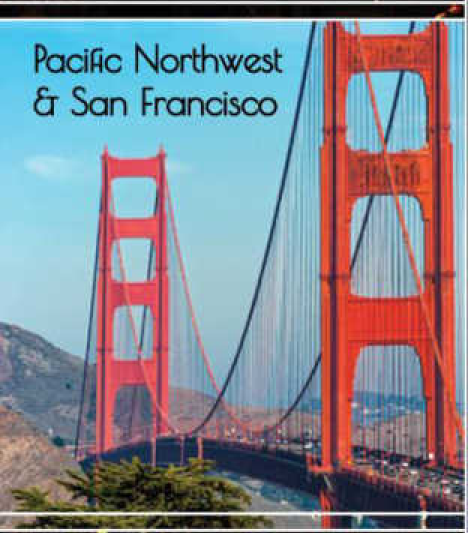
One source of disagreement is something called soft X-ray excess from the universe's first billion years. Natarajan's research also focuses on early population black holes, particularly direct collapse models (those formed from clouds of gas and not the end states of stars). She believes that they could account for the X-ray glow without invoking exotic primordial black holes and dark matter. And indeed, members of this direct collapse class of black holes may also have been spotted. Several NASA telescopes have detected candidates.

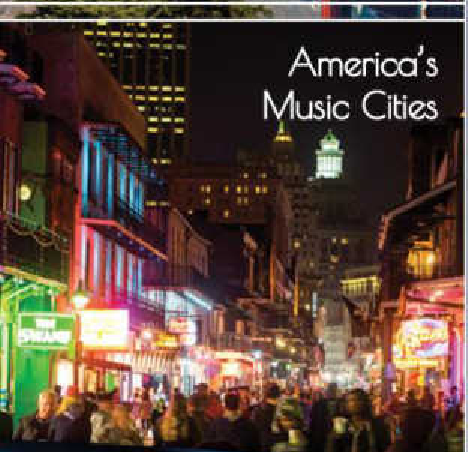
If they are the source of the X-ray excess, then Kashlinky's idea is robbed of one of its strongest lines of evidence.

Natarajan still believes dark matter is a particle called a neutralino. "We haven't detected the particle yet, which is the conundrum, which is why the field is open for speculation," Natarajan says. She points to promising — but unconfirmed — results from an Italian agency called DAMA, which detected a weak neutralino that never repeated. Like LIGO, DAMA is upgrading its equipment to improve its detections.

It's also possible that multiple forms of dark matter exist; that reality is a smorgasbord of different concepts. But both Natarajan and Kashlinsky dismiss this possibility.

For now, researchers simply hunt for either. LIGO may detect more primordial black holes and bolster Kashlinsky's claim. DAMA may find a promising dark matter particle. Many physicists are, for now, waiting and watching. — **J. W.**





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New missions aim to untangle the mysteries of how the planet's scorching surface and violent clouds came to be. **by Jesse Emspak**

VENUS REVISITED

THE FIRST SPACECRAFT TO PULL into Venus' orbit in nearly a decade arrived in December 2015, hailing from Japan. Akatsuki was five years late for its rendezvous, but Venus has gotten used to waiting. The European Space Agency's (ESA) Venus Express visited the thickly shrouded world in April 2006, and that was the first mission to Venus since NASA's Magellan arrived in 1990. Named for the Roman goddess of love, Venus wasn't feeling much of that from space agencies on Earth. Our planet's more favored neighbor, Mars, had hosted roughly a dozen visitors in the same period.

"Venus exploration is behind schedule," says David Grinspoon, senior scientist at the Planetary Science Institute in Washington, D.C., and author of the book *Venus Revealed*. "Our understanding of Venus is about the same as it was with Mars in the 1970s."

Some planetary scientists are trying to change that. For years, Venus lost out to Mars because of the tantalizing possibility of finding life on the Red Planet. Yet in some respects, Venus is more similar to Earth than Mars is, and our inner neighbor might have much to tell us about our past, our future, and even current exoplanets.

Venus wasn't always so unloved. From 1960 to 1984, more than 20 spacecraft investigated Venus — nearly as many as Mars up to that point. The USSR's Venera and Vega programs resulted in no less than 18 orbiters and landers (though not all missions were successful), and the U.S. added five spacecraft.

Two new NASA missions to Venus are in advanced planning stages, with their fates to be decided this year. Both ESA and the Russian Space Agency have designs on the drawing board. And of course, there's the current science from Akatsuki finally streaming to Earth. All in all, things are looking up for Venus exploration, and upcoming missions — mostly orbiters but some with plans for landers or craft that will dive into the atmosphere — could answer fundamental questions that planetary scientists still have about Venus, and provide hard evidence to nail down their current theories.

The twin paradox

Venus is often referred to as Earth's twin for a reason: The two planets' most basic physical properties are nearly identical. "If we found Venus around a sunlike star,

Jesse Emspak *is a science writer who lives in New York.*

Magellan arrived at Venus in August 1990 and orbited for four years, imaging 98 percent of the planet's surface. NASA/JPL

The VERITAS spacecraft, if selected by NASA for approval, would fly in the early 2020s. Like the previous Magellan mission, VERITAS would orbit Venus, but it would study the planet in much greater detail. NASA/JPL-CALTECH

The proposed DAVINCI spacecraft would parachute to Venus' surface, taking data during an hourlong descent. NASA/GSFC

[astronomers would] be jumping up and down saying we found another Earth," says Colin Wilson, deputy project scientist on Venus Express.

How similar are they? Venus has a radius of 3,760 miles (6,050 kilometers), and Earth's radius is 3,960 miles (6,370km). Venus' mass is 82 percent that of Earth, and its surface gravity is 91 percent of the terrestrial norm. The two planets' densities are also almost identical. That means their bulk composition should be about the same, especially since both planets formed in the same region of the solar nebula. Their evolution also should have been similar.

But thanks to subtle differences, that didn't happen. Present-day Earth has liquid water and an atmosphere dominated by nitrogen and oxygen. Argon accounts for nearly 1 percent, but carbon dioxide and other gases exist only in trace amounts. The Venus of today is covered by a dense atmosphere — 90 times more massive than Earth's — consisting of 97 percent carbon dioxide, with the rest as nitrogen and trace gases. Carbon dioxide is a powerful greenhouse gas that keeps Venus' surface temperature at an average of 864° F (462° C). A visitor to Venus could pour a glass of liquid zinc or lead.

Unlike Earth, Venus' surface is invisible from above — at least in visible light. It's covered with highly reflective sulfuric acid clouds that never break. On Venus, the Sun is a diffuse splotch of brightness, appearing as it does on an overcast day on Earth. That bright patch takes 117 Earth-days to cross the sky. Venus takes 243 Earth-days to make a complete rotation — longer than the planet's year, which is 225 Earth-days. The daylight period is shortened slightly because the planet has a retrograde rotation — the Sun rises in the west. The slow rotation also means Venus lacks a magnetic field of any significance.

When it rains on Venus, the droplets evaporate before they reach the ground. Besides a forecast of "cloudy with a chance of sulfuric acid rain," there doesn't seem to be much in the way of weather at ground level. Surface pressures are so high — 90-plus atmospheres — that it's like being underneath more than half a mile (900m) of ocean, and the carbon dioxide there begins to behave as a supercritical fluid, a strange hybrid of liquid and gas.

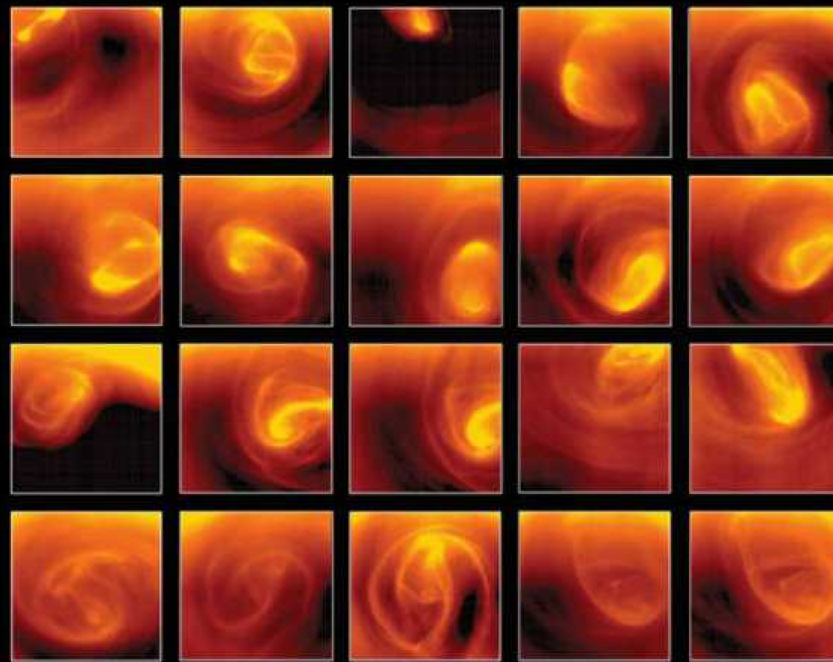
Previous missions found that Venus' terrain is as varied as Earth's. Highland regions called tesserae consist of ridges and folds in the crust that extend for miles and form tile-like patterns. The lowlands seem to be basalts, cut with what might be lava channels. Some mountains appear peaked with a kind of metallic "frost," and even features that look like dune fields exist. Some areas have coronae — pancake-like structures that can spread over 100 miles (160km).

Venus also is bone-dry. If the planet did form with similar amounts of water as Earth, as seems likely, it's clear that water isn't there anymore.

How did Venus become a toxic hellscape while Earth stayed relatively cool? The prevailing model is that Venus' water turned into vapor as the Sun, which was much dimmer billions of years ago, brightened and warmed the planet. While there's some debate as to whether Venus ever shared Earth's vast oceans, it seems likely the planet was cool enough for substantial liquid water in its early days. But as the temperature climbed, any water evaporated, and once it reached the upper atmosphere, the Sun's ultraviolet light broke apart water (H_2O), and it quickly reformed into hydrogen (H_2), hydroxide (OH), and oxygen (O_2). Much of the oxygen stayed aloft because it is less dense than carbon dioxide, but some descended and reacted with surface rocks. Absent any biology to take the carbon dioxide out of the air and replace it with oxygen, as on Earth, the water and carbon dioxide — powerful heat-trapping gases — caused a runaway greenhouse effect.

The situation wasn't helped by the planet's slow rotation. On Earth, our relatively rapid spin creates a dynamo effect in our planet's iron core. This in turn generates a magnetic field that protects our home world from the solar wind, the stream of energetic particles the Sun flings in all directions. As the wind whipped by unprotected Venus, it stripped the hydrogen from the atmosphere, leaving fewer ingredients for the planet to have any hope of reforming its water, even if conditions were to miraculously become more temperate.

Yet the data from Venus Express and the Magellan probe don't seem to tell the whole story — and that's where the new missions come in.

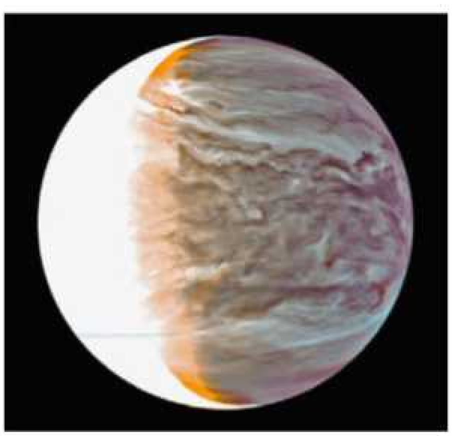


The Venus Express mission imaged clouds swirling above Venus' south pole at dizzying speeds. The high-altitude clouds, like those seen here, can travel 60 times faster than the planet rotates, contributing to the polar vortex Venus Express studied in detail during its eight-year stay. ESA/VIRTIS-VENUS EXPRESS/INAF-IAPS/LESIA-OBS. PARIS/G. PICCIONI

Many mission options

NASA is considering two missions this year. The Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) will focus on atmospheric chemistry. It involves an atmospheric probe — "Huygens for Venus," quips Lori Glaze, a scientist at NASA's Goddard Space Flight Center and the mission's principal investigator — that will measure the atmosphere's makeup at different layers during an hourlong descent to the venusian surface.

"It doesn't need to survive hitting the surface," Glaze says. She notes that the Pioneer Venus and Vega missions looked at the atmosphere, but they couldn't give scientists a good handle on the composition with respect to altitude, and that's what's needed to understand the kinds of reactions that occur in Venus' cloudy skies.



The Akatsuki space probe, launched by Japan's space agency, entered venusian orbit in December 2015. By March, the spacecraft was sending images back to Earth from its infrared cameras, and in April it officially assumed full science observations. This image shows Venus' night side from one of Akatsuki's two near-infrared cameras. JAXA

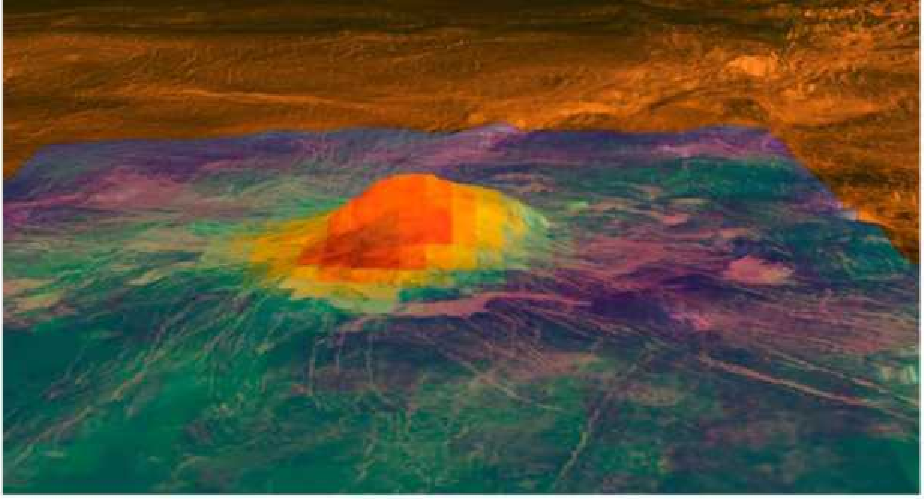
NASA's other option is the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission. The VERITAS orbiter would operate similar to Magellan, but the big difference would be that its radars will have much better resolution, able to spot features as small as about 100 feet (30m) across compared with Magellan's more than 300 feet (100m). It also will measure the planet's gravity and how the surface emits heat, which means it can see "inside" some geological formations and discover, for example, whether the coronae are filled with magma. VERITAS also will be able to measure how the composition of surface rocks differs.

"We'll be looking for surface mineralogy variations," says Suzanne Smrekar of the Jet Propulsion Laboratory, the principal investigator on VERITAS. "We're trying to understand chemical variation, if there are continents like on Earth, active volcanism . . . also to see if there are tectonic features, and to try to understand thermal evolution — temperature variations in the lithosphere." NASA will decide in September 2016 whether DAVINCI, VERITAS, or both will fly.

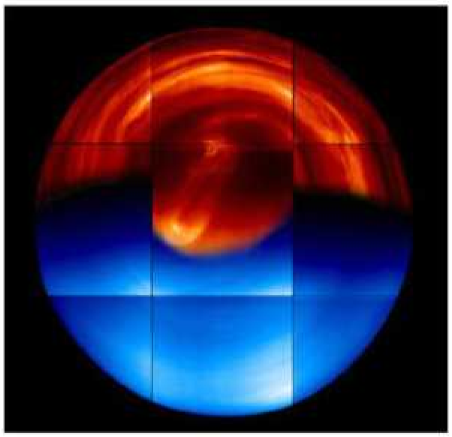
From ESA, there's EnVision, an orbiter also equipped with advanced radar, and it likely won't launch until 2029, says Richard Ghail, a lecturer in engineering geology at Imperial College London, who proposed the mission. Aside from a more advanced set of radars than Magellan, EnVision will be able to "spotlight" small areas to image them in greater detail. "Instead of 100-meter [300 feet] resolution, we can get down to 6 meters [20 feet]," Ghail says. That is enough to see day-to-day changes on the surface. Spotlighting can get that resolution down to 10 feet (3m).

While there is some overlap with a craft like VERITAS, Ghail says having the VERITAS mission go actually would free up EnVision to do more spotlighting of specific areas and less global-scale mapping, since VERITAS will have accomplished that already.

The Russian proposal is called Venera D. This spacecraft would bear some resemblance to the Vega missions because it involves a combined orbiter and lander. It might even include a balloon probe, also like the Vega missions. Like many missions before it, Venera D would focus on Venus' atmosphere and investigate the origins of the planet's unusual atmospheric rotation



Venus' Idunn Mons is likely an active volcano, with infrared imaging revealing hot spots along the peak's summit and cascading over the side in flows. ESA/NASA/JPL



Venus Express' cameras sent back many views of Venus, revealing different layers of the planet's clouds. Here, the spacecraft imaged the night side in infrared (upper, red layer), showing clouds lower in the atmosphere, about 28 miles (45 kilometers) in altitude. Clouds closer to 40 miles (60km) appear in ultraviolet imaging (lower, blue) on the planet's day side. ESA/VIRTIS-VENUSX IASF-INAF, OBSERVATOIRE DE PARIS (R. HUESO, UNIV. BILBAO)

as well as its chemistry. The lander would allow for soil analysis, provided it survives long enough. The longest any lander has lasted on Venus was barely two hours — a record held by the Soviet Venera 13 mission, so history is on Russia's side. The Russian Space Agency hasn't made any firm commitments to the mission, but if it did, it would be the first post-Soviet planetary mission of its kind. Launch wouldn't happen any earlier than 2024.

Venus now

Current Venus research is already on a delayed schedule. Japan's Akatsuki probe was supposed to arrive at Venus in 2010, but it missed its orbital insertion. Instead, it took a cruise around the Sun for five years until engineers could steer it into an alternate orbit, more elliptical than originally planned. Recovering the spacecraft at all was a major achievement. Akatsuki currently orbits Venus in a 13-day ellipse that takes it from closest approach at 260 miles (400km) out to 273,000 miles (440,000km). Sanjay Limaye, senior scientist at the Space Science and Engineering Center of the University of Wisconsin-Madison, says science goals actually will be enhanced by the improvised orbit, which allows for longer periods of observation as Akatsuki swings out to its farthest position.

Two of Akatsuki's cameras work in the near-infrared and study the planet's surface, the motion of clouds, and the particles that comprise them. A long-wave infrared camera tracks the temperatures at the cloud tops, about 40 miles (65km) above the planet's surface. The other two instruments are an ultraviolet imager and a lightning and airglow camera. Venus Express showed tantalizing glimpses of what might have been lightning in Venus' clouds, so Akatsuki will try to clinch those observations.

One of the problems Akatsuki will study is the "superrotation" of the atmosphere. Venus' atmosphere zooms around the planet at hundreds of kilometers per hour in the upper regions. That's not unusual — other planets show the same thing from time to time. But why the superrotation should be orders of magnitude faster than the planet's rotation is unexplained. "We cannot yet accurately model superrotation numerically," Limaye says. Akatsuki can help tackle this question by creating a better picture of how the upper atmosphere differs from the lower and how the two interact.

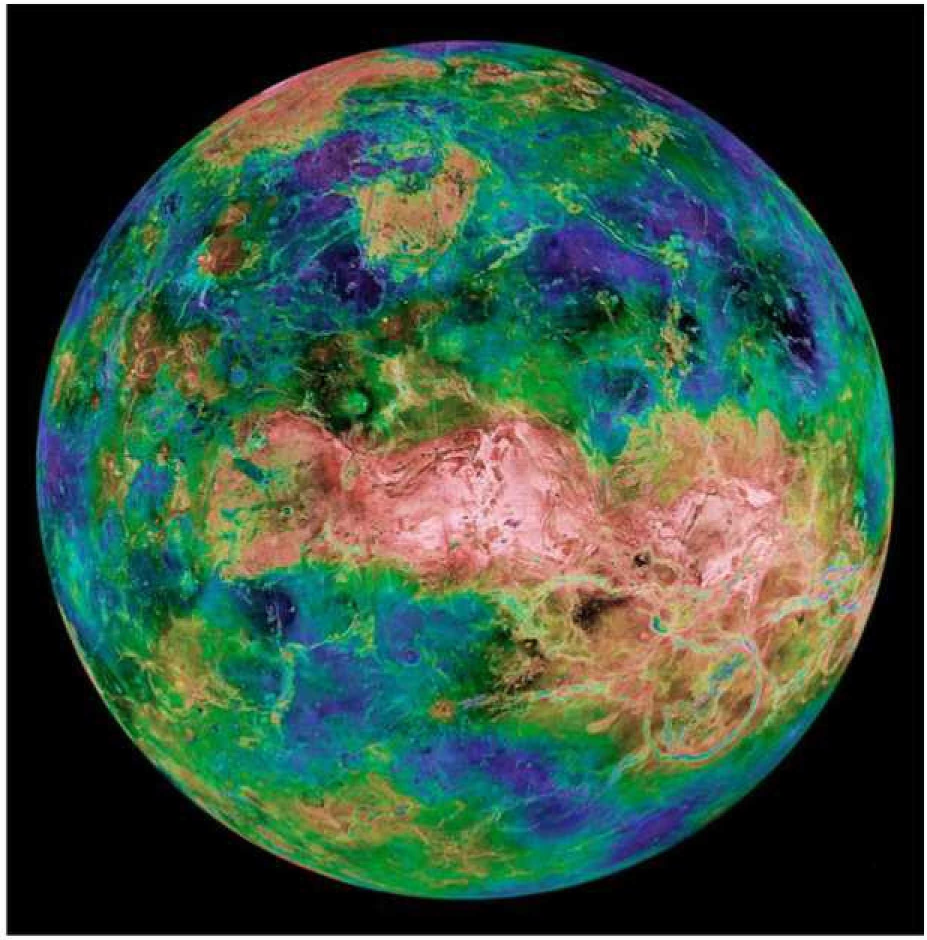
A smoking gun for volcanism

Venus Express and Pioneer Venus both found sulfur compounds — primarily sulfur dioxide, which must continually enter the atmosphere somehow in order to be observed, because sunlight breaks it up fairly quickly. "That provides pretty good evidence that Venus is volcanically active," Grinspoon says. "There's a lot of sulfur dioxide in the atmosphere, and that sulfur would not stay without a source." Volcanism on the surface would do it. But Venus Express hasn't provided the smoking gun, as it were. "We see a lot of volcanoes, but we don't know if they are still active," Grinspoon adds.

There are three strong lines of evidence of active volcanoes on Venus, Wilson says. First is the way the detected sulfur behaves. In the first year of Venus Express' observations, sulfur levels spiked and then decreased tenfold over five to six years. That points to a source that "burped" sulfur, as volcanoes do. A second clue is the infrared surface emission. Darker surfaces emit more heat as infrared radiation (think about asphalt on a hot day), and fresh unweathered basalts — such as from recently spewed and hardened volcanic

Venera 13 survived on Venus for 2 hours, 7 minutes, and took this picture of the venusian surface (and parts of itself) on March 1, 1982. The Vega missions in June 1985 also deployed landers, but Vega 1's instruments activated while it was still 12 miles (20km) above the surface, so it returned only limited data. Vega 2 successfully transmitted data from the surface, but lasted only 56 minutes. NASA HISTORY OFFICE

Venus Express captured this image of clouds in 2011, five years into its planned two-year investigation. It finally plunged to its end in 2014, after five mission extensions. ESA/MPS/DLR/IDA



Researchers constructed this elevation map of Venus using mosaicked data from Magellan. Blue represents lower elevations and red higher elevations. NASA/JPL/USGS

material — are dark. Venus Express' cameras also caught some changes in surface temperature that looked like signs of recent lava flows. Finally, images from Magellan's radar maps show features that look pretty clearly like volcanoes, and even lava.

But none of these is absolute proof, Glaze says. What's needed is a picture from one day to the next, or one week to the next, showing the changes in topography. That could show that volcanoes are active today, as opposed to in the distant past.

Volcanic activity is a big piece of the overall Venus puzzle because it offers a way to resurface the planet periodically. Previous imaging missions showed Venus doesn't have many impact craters. Assuming the craters are randomly distributed, that means something made older ones disappear — the surface is getting rebuilt every so often, perhaps as little as every couple of hundred million years or as much as 750 million to 800 million years. And given that the craters are on average hundreds of miles apart, whatever is resurfacing the planet also must exist in the same well-distributed pattern, Ghail says.

If there are active volcanoes — and Ghail thinks there are — then this resurfacing is a constant, steady process. But if volcanoes aren't currently active, then the resurfacing is likely to be something big and sudden, covering huge chunks of the planet. VERITAS and EnVision could go a long way toward providing a clear answer.

Where's the water?

The other big question mark is water. Venus Express' atmospheric analyses showed the ratio of deuterium (hydrogen that carries an extra neutron) to ordinary hydrogen is quite large, and that hydroxide is in the atmosphere. Ordinary hydrogen is lighter than deuterium, and a high ratio of deuterium should mean the primordial hydrogen was stripped away somehow, probably by the solar wind. The hydroxide is a product of the dissociation, or chemical breakup, of water by ultraviolet light. But Venus surprised the scientists. "We'd expect it to lose water faster," says Wilson. "But the escape rate is less than on Earth. That came as a surprise." Further atmospheric and geological studies might shed some light on this by narrowing down the rate of outgassing water from the surface, for example.

Speaking of water, geological tests by VERITAS can help scientists understand better how much water Venus has now. Such tests also could reveal if Venus once had something like plate tectonics or formed a surface resembling that of early Earth. By looking closely at what kind of rock makes up some of the higher-altitude terrain, such as the tesserae, it will be possible to see if it is made of crust that looks like continents on Earth. "That is critical to answering the question," Smrekar says. "What you're measuring is surface temperature in relation to the composition of rock. Basalt is a dark rock, granite is a light rock, and they have different temperatures as a function of altitude."

To make granite, you need water. "If you don't have water, you end up with things that approach granite but never get that far," Ghail notes. Finding granite, therefore, would mean Venus once had oceans — or at least enough water to allow for the reactions that make granite.

Ghail says the way the higher terrain looks — such as Aphrodite, Lakshmi, and Ishtar Terra — is tantalizing. "Aphrodite looks like ancient, heavily formed continental-like material," he says. Furthermore, these regions seem to cover about the same area that geologists think was covered by continental crusts on Earth soon after it formed and the first oceans filled up.

Knowing what Venus was like in the distant past will offer a lot of insight into why Earth's twin grew up so different from its temperate sister. "Venus, in my mind, is an incredibly rich place to learn about Earth," Glaze says. "The planets are so similar — how did biology form here and not there?"

A BRIEF HISTORY OF BLACK HOLES

The 1964 discovery of Cygnus X-1 filled in a missing piece of Einstein's puzzle and widened our understanding of the universe.

by Jeremy Schnittman

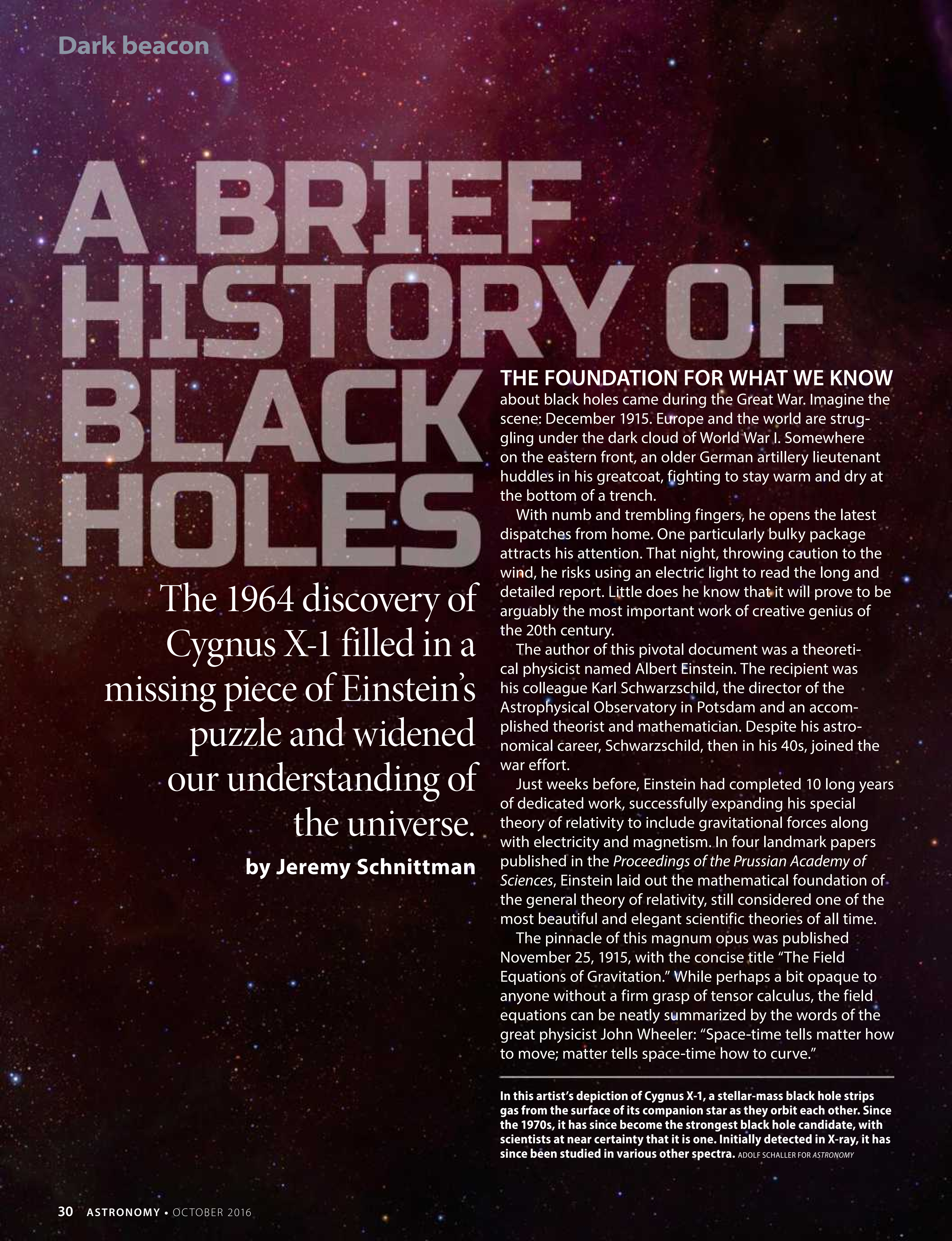
THE FOUNDATION FOR WHAT WE KNOW about black holes came during the Great War. Imagine the scene: December 1915. Europe and the world are struggling under the dark cloud of World War I. Somewhere on the eastern front, an older German artillery lieutenant huddles in his greatcoat, fighting to stay warm and dry at the bottom of a trench.

With numb and trembling fingers, he opens the latest dispatches from home. One particularly bulky package attracts his attention. That night, throwing caution to the wind, he risks using an electric light to read the long and detailed report. Little does he know that it will prove to be arguably the most important work of creative genius of the 20th century.

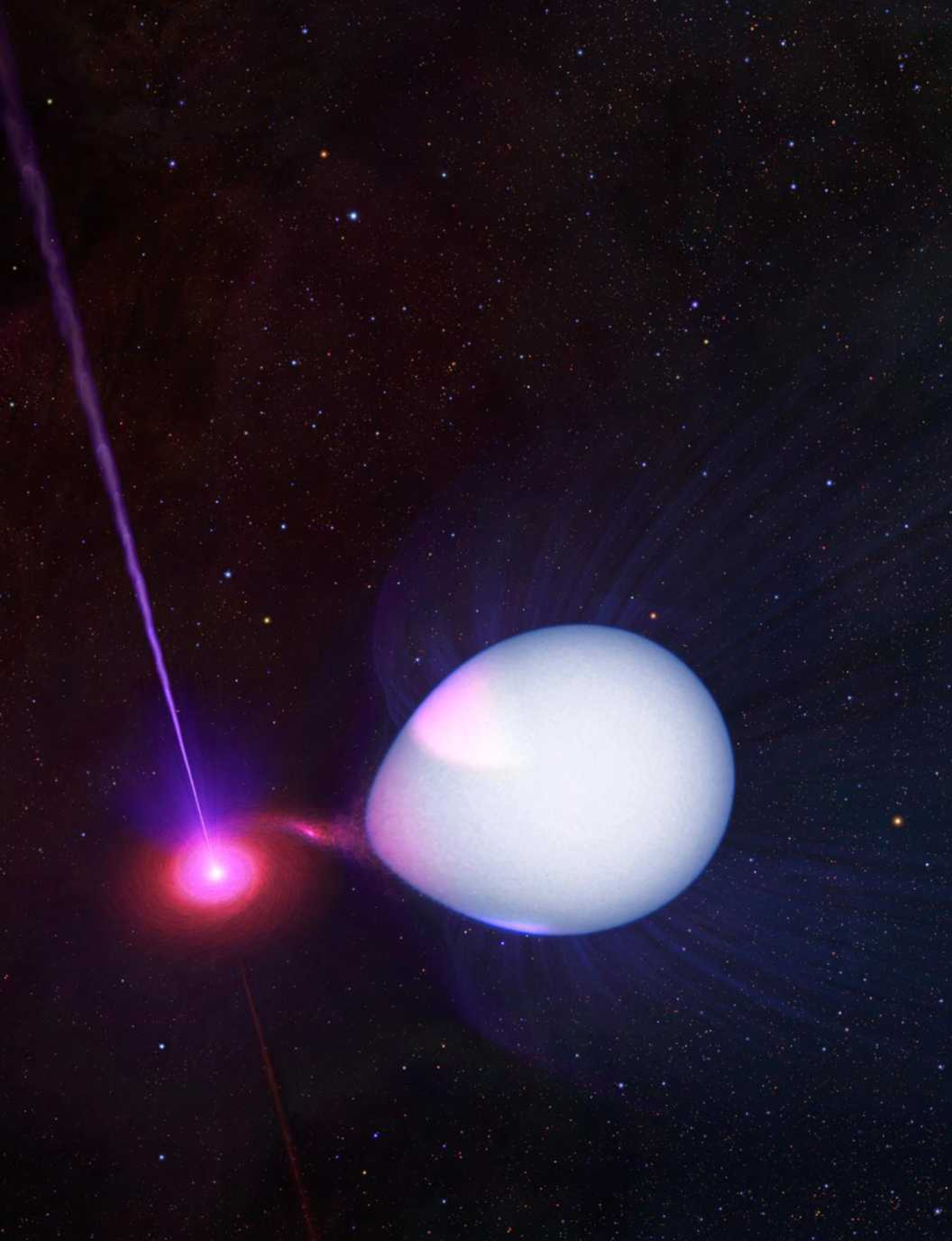
The author of this pivotal document was a theoretical physicist named Albert Einstein. The recipient was his colleague Karl Schwarzschild, the director of the Astrophysical Observatory in Potsdam and an accomplished theorist and mathematician. Despite his astronomical career, Schwarzschild, then in his 40s, joined the war effort.

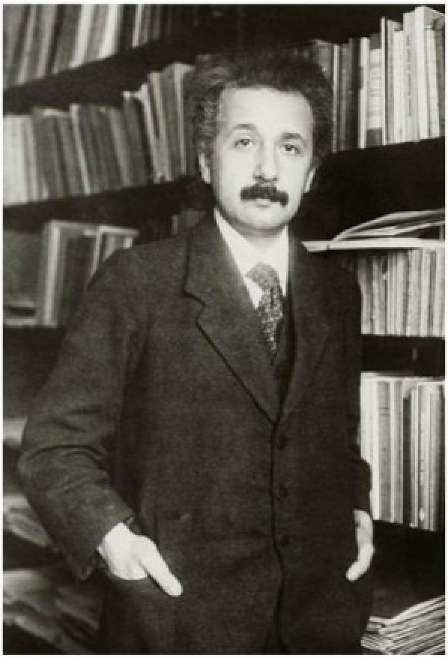
Just weeks before, Einstein had completed 10 long years of dedicated work, successfully expanding his special theory of relativity to include gravitational forces along with electricity and magnetism. In four landmark papers published in the *Proceedings of the Prussian Academy of Sciences*, Einstein laid out the mathematical foundation of the general theory of relativity, still considered one of the most beautiful and elegant scientific theories of all time.

The pinnacle of this magnum opus was published November 25, 1915, with the concise title "The Field Equations of Gravitation." While perhaps a bit opaque to anyone without a firm grasp of tensor calculus, the field equations can be neatly summarized by the words of the great physicist John Wheeler: "Space-time tells matter how to move; matter tells space-time how to curve."

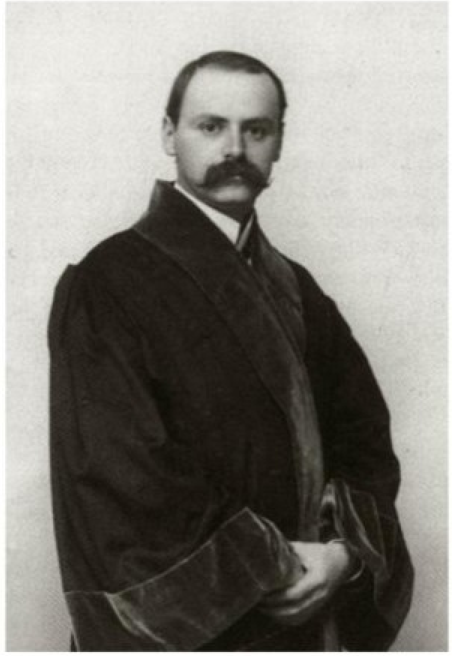


In this artist's depiction of Cygnus X-1, a stellar-mass black hole strips gas from the surface of its companion star as they orbit each other. Since the 1970s, it has since become the strongest black hole candidate, with scientists at near certainty that it is one. Initially detected in X-ray, it has since been studied in various other spectra. ADOLF SCHALLER FOR *ASTRONOMY*





Albert Einstein developed his theory of gravity, known as general relativity, in 1915. ALBERT EINSTEIN ARCHIVES



EMILIO SEGRE ARCHIVES

Karl Schwarzschild developed the idea for black holes from relativity's equations in 1916, just a year after Einstein published his theory.

Much like M. C. Escher's famous picture of two hands sketching each other, the circular reasoning of Einstein's field equations makes them both elegant, yet also notoriously difficult to solve. At the root of this difficulty is Einstein's far more famous equation $E=mc^2$, which states that energy and matter are interchangeable. Because gravity is a form of energy, it can behave like matter, creating yet more gravity. Mathematically speaking, general relativity is a nonlinear system. And nonlinear systems are really hard to solve.

It's easy to imagine Einstein's shock when, amid a dreadful war, Schwarzschild wrote back within a matter of days, describing the first known solution to Einstein's field equations. Schwarzschild modestly writes, "As you see, the war treated me kindly enough, in spite of the heavy gunfire, to allow me to get away from it all and take this walk in the land of your ideas." Einstein responds, "I have read your paper with the utmost interest. I had not expected that one could formulate the exact solution of the problem in such a simple way. I liked very much your mathematical treatment of the subject."

Tragically, less than a year later, Schwarzschild succumbed to a skin disease contracted on the front, joining the millions of WWI fatalities due to disease. He left behind a solution that completely describes how space-time is warped outside a spherical object like a planet or star. One of the features of this mathematical solution is that for very compact, high-density stars, it becomes much harder to escape the gravitational field of the star. Eventually, there comes a point where every particle, even light, becomes gravitationally trapped. This point of no escape is called the event horizon. As one approaches the event horizon, time slows to a complete standstill.

For this reason, early physicists studying these bizarre objects often called them "frozen stars." Today, we know them by the name first used by Wheeler in 1967: black holes. Even though the event horizon played an integral part in Schwarzschild's solution, it took many years before black holes were accepted as anything other than a mathematical curiosity. Most of the world's leading experts in general relativity in the first half of the 20th century were absolutely convinced that black holes could never form in reality. Arthur Eddington insisted, "There should be a law of nature to prevent a star from behaving in this absurd way."

Complicating the issue was the concurrent development of quantum mechanics, a new field almost entirely characterized by cases of nature behaving absurdly. Physicists working at the intersection of quantum mechanics and general relativity began to appreciate how both fields were critically important to understanding very massive and dense stars. But the bizarre nature of these new branches of physics strained even the most gifted intuition, so that even 50 years after Schwarzschild's landmark paper, there was still no consensus on the existence of black holes.

Finding the unseeable

One thing was clear: If black holes did exist, they were most likely formed by the collapse of massive stars, unable to support their own weight after running out of nuclear fuel. The question most astronomers were focused on was, "How do we find them?" After all, black holes give off no light of their own. Astronomy needs light, and to make light, you generally need matter — the hotter and brighter, the better.

Fortuitously, the late 1960s marked the dawn of X-ray astronomy with a series of sounding rockets and satellites that could get above Earth's atmosphere, which otherwise blocks out all celestial X-rays.

During a short rocket flight in 1964, astronomers discovered one of the brightest X-ray sources in the sky, in the constellation Cygnus, dubbed Cygnus X-1 (Cyg X-1 for short). However, it didn't coincide with any particularly bright optical or radio source, leaving its physical origin a mystery. When NASA's Uhuru X-ray Explorer Satellite was launched in 1970, more detailed observations became possible, narrowing the uncertainty of its location. One of the first remarkable discoveries was Cyg X-1's rapid variability, on timescales shorter than a second. This strongly suggested that the physical size of the X-ray-emitting region was quite compact, much smaller than a typical star. What could possibly pack so much power into such a small area?

Within a year, a stellar counterpart to Cyg X-1 was identified, allowing astronomers to confirm it as a binary system and estimate the mass of the companion by measuring the Doppler shift of the orbiting star's spectrum. The answer was a whopping 15 times the mass of the Sun, far

But the bizarre nature of these new branches of physics strained even the most gifted intuition, so that even 50 years after Schwarzschild's landmark paper, there was still no consensus on the existence of black holes.

Cygnus X-1 (the brighter of the stars by the arrow) lies in a rich field near the plane of the Milky Way, and doesn't look like much at visible wavelengths. NOAO/AURA/NSF

Cygnus X-1 first came to notice when astronomers found it to be an intense source of X-rays. In this view from the Chandra X-ray Observatory, the high-energy radiation is colored blue. NASA/CXC/CFA

exceeding any theoretical limit for white dwarfs or neutron stars. Altogether, the rapid time variability, large X-ray luminosity, and high mass estimate combined to make Cyg X-1 an excellent candidate for the first stellar-mass black hole. (Strong evidence for supermassive black holes also had been building for years, thanks largely to Maarten Schmidt's study of quasars. Their tremendous brightness and great distances combined to make a strong case for black hole accretion, the only imaginable energy source capable of such incredible luminosity.)

As more sensitive X-ray telescopes were launched in subsequent years, the case only grew stronger. We have now seen X-ray variability from Cyg X-1 on timescales as short as a millisecond, confining the emission region to an extent of hundreds of kilometers, just a few times the size of the event horizon. By observing X-rays from black holes, we can directly probe the properties of space-time predicted by general relativity.

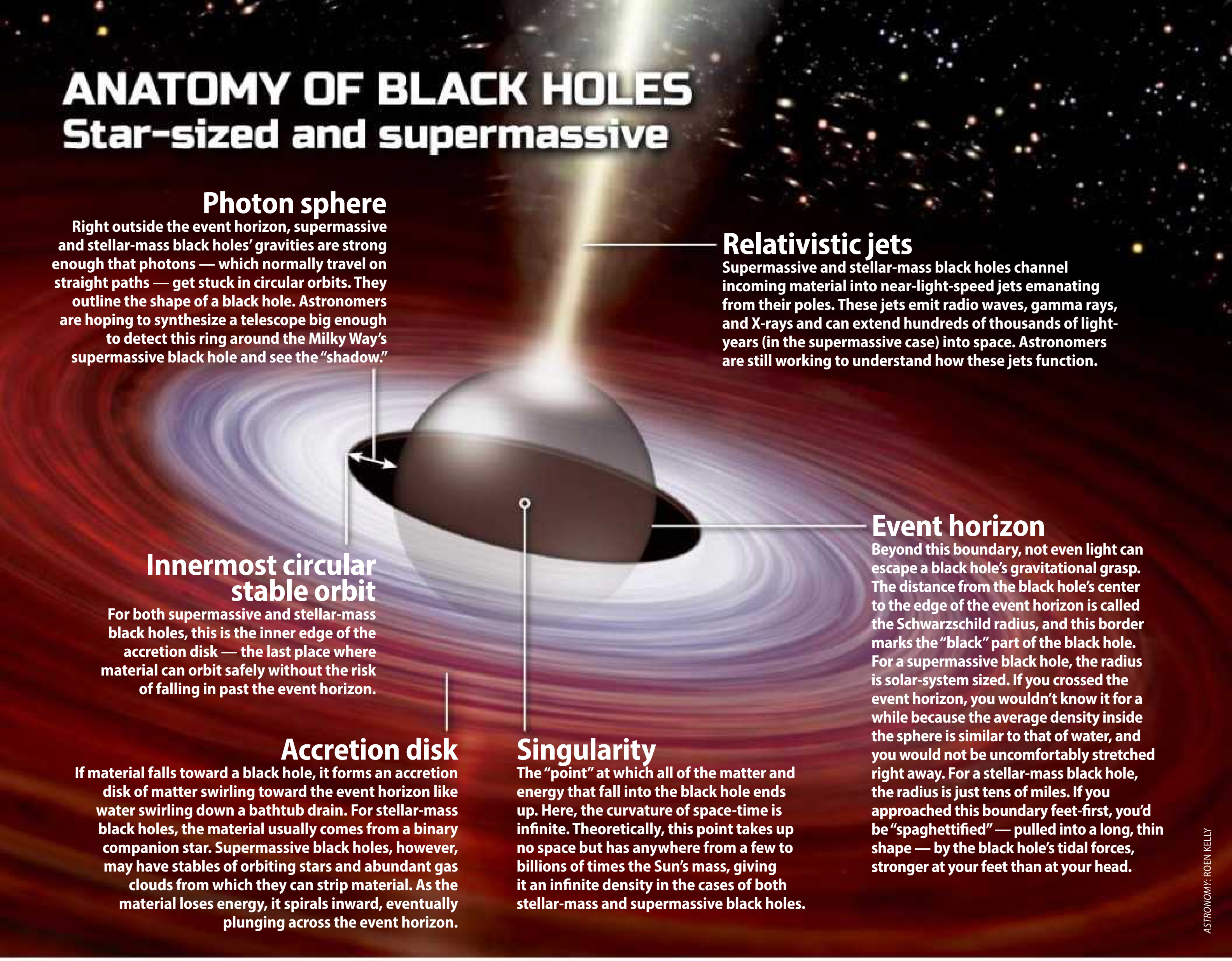
Staring down an event horizon

While stellar-mass black holes are some of the brightest X-ray sources in the sky, they are also some of the most fickle. In the 40-plus years since the discovery that Cyg X-1 is likely a black hole, only a few dozen more black hole candidates have been identified. Most of those have only been detectable during short, unpredictable outbursts lasting a month or so before they disappear again for decades. Compare that with their supermassive counterparts: The Sloan Digital Sky Survey alone has identified more than 100,000 quasars (the energetic centers of young, distant galaxies), each powered by an accreting supermassive black hole.

In addition to this most common "quiescent" behavior, astronomers have identified three other major states exhibited by stellar-mass black holes: hard, soft, and intermediate. These names describe the observable properties of the X-ray spectra in each state. We aren't yet entirely certain what physical mechanisms drive these different behaviors, but they are likely tied to two things: how much gas the black hole is accreting, and how strong the magnetic fields embedded in the gas are.

In astronomical jargon, a "hard" spectrum means we see more high-energy X-rays than low-energy, and "soft" is the opposite. Of course, even "low-energy" is a relative term, as these photons come from an accretion disk that is at a temperature of millions of degrees, compared with the corona, which boasts a temperature in excess of 1 billion degrees!

The intermediate state shows evidence of a thin, cool accretion disk surrounded by a hot, diffuse corona like the surface of our own Sun. In this state, the high-



energy X-rays coming from the corona shine down on the disk. Some of these X-rays get absorbed by the trace amounts of iron mixed in the disk's gases. The iron then shines just like the fluorescent gas in a neon light, giving off more X-rays at very specific wavelengths. Because the gas in the disk is orbiting the black hole at nearly the speed of light, the X-rays coming from the disk experience extreme Doppler shifts, appearing to a distant observer at shorter wavelengths when the gas is moving toward the observer and longer wavelengths when moving away. By carefully measuring the wavelengths of the X-rays from an accreting black hole, we can measure how fast all the gas is orbiting around it.

Original spin

Considering the first solution to Einstein's field equations took Schwarzschild less than a week to derive, it must have felt like an eternity to wait nearly a half-century before the next black hole solution was discovered by New Zealander Roy Kerr in 1963. (Another solution, the Reissner-Nordstrom black hole, was published almost immediately after Schwarzschild's, but also is limited to spherically symmetric systems and mathematically almost identical.) Kerr made his formulation while at the University of Texas at Austin.

Unlike Schwarzschild black holes, Kerr black holes spin; they retain the angular momentum from the pre-supernova star from which they were born. This is extremely important astrophysically, since we know that nearly every celestial object rotates, from moons to planets to galaxies. So it is natural to expect that black holes rotate, too.

Evidence for this spin shows in how the black hole pulls everything around the horizon, essentially sweeping up space-time itself into a swirling vortex. This allows gas to move ever faster as it spirals closer and closer to the horizon, leading to more extreme Doppler shifts, and thus larger offsets in the X-ray spectra. In just the past few years since the launch of NASA's NuSTAR X-ray telescope, we have been able to use these spectra to measure spins of multiple black holes with unprecedented accuracy. NuSTAR's ability to see X-rays covering a much wider range of energies compared with previous missions also allows us to rule out other alternative models — like X-ray absorption by interstellar gas clouds — that had been proposed to explain the shape of the spectrum.

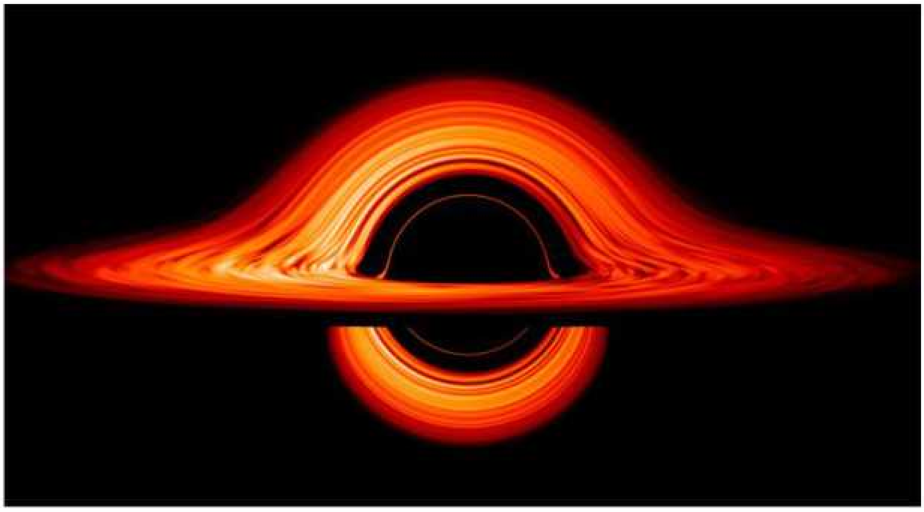
Measuring black hole spins not only teaches us about general relativity, but it also provides important insight into how massive stars evolve and collapse in supernovae. Because many of these binary systems are quite young (at least by cosmic standards — Cyg X-1 is "only" a few million years old), whatever spin we measure today is essentially the same spin that came from the original formation. From this point of view, they truly are "frozen stars," retaining a near-perfect memory of their violent birth.

An outrageous legacy

General relativity is one of the few fields in modern physics where theory has driven experimentation for almost the entire century. Einstein had a unique talent for not only proposing brilliant and fruitful thought experiments, but also real experiments that could test his theories. Perhaps his most famous prediction was how the gravity of the Sun would deflect the light from distant stars, an effect confirmed with spectacular success in 1919 during a solar eclipse, propelling Einstein to international celebrity. More impressive still was the 40-plus years between Schwarzschild's (unintentional) prediction of black holes and the discovery of Cyg X-1.

To borrow a phrase from theoretical physicist Kip Thorne, perhaps the most outrageous piece of Einstein's legacy was his prediction of gravitational waves, made a century ago, and triumphantly confirmed just this year by the Laser Interferometer Gravitational-wave Observatory (LIGO). In addition to confirming the basic idea that the "fabric" of space-time is not just a metaphor but a tangible substance, the LIGO discovery also provided a new test of general relativity in the most extreme environment — just outside a black hole. There were some surprises in store, as well: the discovery of stellar-mass black holes 30 times the mass of the Sun, twice as big as any seen before. For the cherry on top, LIGO was even able to measure the spin of the final black hole at 70 percent of the maximum Kerr limit, arguably the most accurate and precise measure of spin to date.

Building on this unprecedented track record of success, most astrophysicists fully believe that general relativity's description of the nature of black holes is the correct one. Lingering questions attempt to use our knowledge of black holes to improve our understanding of how gas, magnetic fields, and X-rays behave in the presence of such a tremendous gravitational force. This is the messy part of black hole research — Astronomer Royal Martin Rees famously described it as "mud wrestling" — and one where observation has been far ahead of theory for decades.



This simulation gives a realistic depiction of a black accretion disk, including the light-bending effects of relativity. NASA/JEREMY SCHNITTMAN

The first puzzle came right on the heels of the first detection of Cyg X-1. In 1973, from the most basic laws of conservation of energy and angular momentum, Igor Novikov and Kip Thorne derived a brilliant and elegant description of how gas slowly spirals in toward a black hole, releasing its gravitational potential energy as heat and radiation at temperatures of millions of degrees.

There are only two problems with the Novikov-Thorne model: It doesn't work in theory, and it doesn't work in practice. It doesn't work in theory because it doesn't explain how exactly the gas loses angular momentum. It doesn't work in practice because it doesn't agree with observations of high-energy X-rays coming from billion-degree gas.

In addition to confirming the basic idea that the "fabric" of space-time is not just a metaphor but a tangible substance, the LIGO discovery also provided a new test of general relativity in the most extreme environment – just outside a black hole.

Hot ionized gas experiences almost no friction or viscosity, so it should simply go around and around on perfectly circular orbits forever, never getting any closer to the event horizon. Novikov and Thorne fully appreciated this problem, and they absorbed it into their theory with a simple fudge factor, leaving the details to later work. In the end, it took almost 20 years to find the answer. In 1991, Steve Balbus and John Hawley discovered a powerful instability that comes from the twisting and pulling of magnetic field lines embedded in an accretion disk. Ionized gas is an excellent electrical conductor, which means it also can generate powerful magnetic fields. These fields, in turn, can pull back on the gas, slowing it down and allowing it to spiral in toward the black hole.

By 2001, supercomputers had become powerful enough to adequately simulate the Balbus-Hawley instability in accretion disks around realistic black holes, fully confirming their predictions. It took yet another decade before the simulations were sophisticated enough to include the effects of radiation, and study the interplay between the disk and corona. In doing so, we have finally reached the point where, starting from the most fundamental laws of nature, we can explain how the high-energy X-rays, first seen in 1971, are actually generated around real black holes.

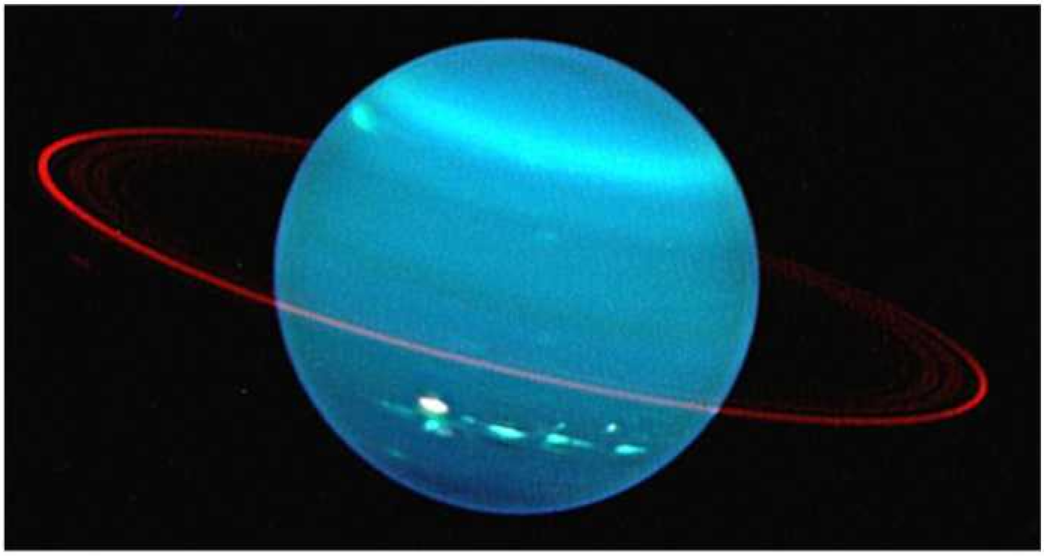
In exactly 100 years, black holes have progressed from being a mathematical curiosity, to the subject of purely theoretical physics, to a central area of astronomy research, where theory and computer simulations confront experiments and observations on a daily basis. With the recent opening of the gravitational-wave window on the universe, in the coming years we fully expect to learn even more about the birth, life, and death of these remarkable objects. One thing we can say for certain: We will continue to be surprised by nature's exotic imagination!

Jeremy Schnittman *is an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

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

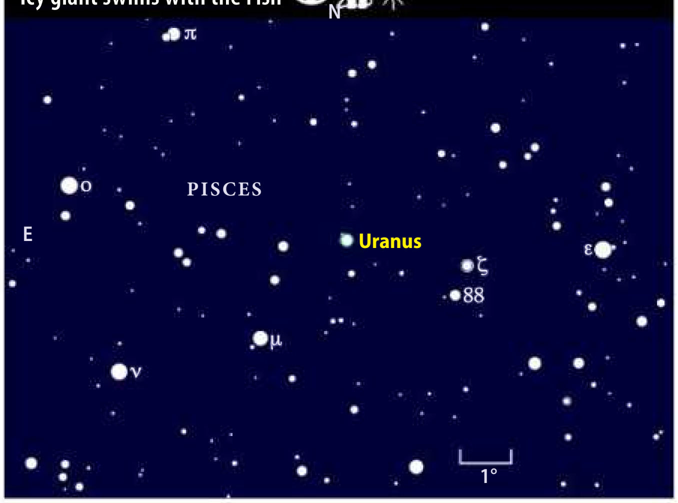
October 2016: Uranus peaks in Pisces



Uranus' blue-green hue comes thanks to methane in its atmosphere, which absorbs red light. This Keck Telescope image also captures cloud bands, storms, and a faint ring. LAWRENCE SROMOVSKY (UNIVERSITY OF WISCONSIN)/W. M. KECK OBSERVATORY

October nights bring long hours of dark skies punctuated by wandering planets, streaking meteors, and an exceptional occultation. Venus brightens the evening sky along with Mars and Saturn, while early risers get treated to views of Mercury and Jupiter. Uranus bridges the gap between evening and morning as it shines at its best all night long. For viewers who prefer more ephemeral events, the Orionid meteor shower lights up the predawn sky on the 21st and the Moon passes through the Hyades star cluster — and directly in front of Aldebaran — the night of October 18/19.

Icy giant swims with the Fish



You can find Uranus among the background stars of Pisces the Fish when it reaches opposition in mid-October. ALL ILLUSTRATIONS: *ASTRONOMY*: RICK JOHNSON

Planet watchers can start their night soon after sundown, when **Venus** appears low in the southwest. The "evening star" shines at magnitude –3.9 and jumps out of the bright twilight. The planet stands nearly 10° above the horizon a half-hour after sunset. A slender waxing crescent Moon passes 5° above Venus on October 3.

The view of Venus through a telescope doesn't change much during October. On the 1st, its disk spans 12" and appears 85 percent lit. By month's end, the planet measures 14" across and the Sun illuminates 78 percent of its Earth-facing hemisphere.

Venus calls three constellations home during October. It spends the first half of the month among the background stars of Libra. It then crosses into Scorpius on the 17th and Ophiuchus on the 24th. And on the 25th, the brilliant world stands 3° due north of Scorpius' orange-red luminary, 1st-magnitude Antares.

That same evening, **Saturn** lies 5° east-northeast of Venus. The inner planet's eastward motion relative to the background stars carries it 3° south of the ringed planet the evenings of October 29 and 30. Look for magnitude 0.5 Saturn to the upper right of Venus.

Saturn doesn't look as spectacular through a telescope this month as it did during the spring and summer. Its lower altitude means that we view it through more of the distorting effects of our planet's atmospheric turbulence, resulting in poor "seeing." Still, the view is worth the effort. Saturn's disk measures 16" across in mid-October while the rings span 35" and tilt 26° to our line of sight. The dark Cassini Division that separates the outer A ring from the brighter B ring should appear conspicuous in decent seeing.

You also should see several of Saturn's satellites. The brightest, 8th-magnitude Titan, shows up easily through any scope. It orbits the planet in 16 days and slides due south of Saturn on October 2 and 18 and north of the planet on October 11 and 27. The ringed world's three 10th-magnitude moons — Tethys, Dione, and Rhea — are a bit harder to see with the planet so low. Still, a 4-inch instrument with good optics should pick them up on most 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.*

RISING**MOON**

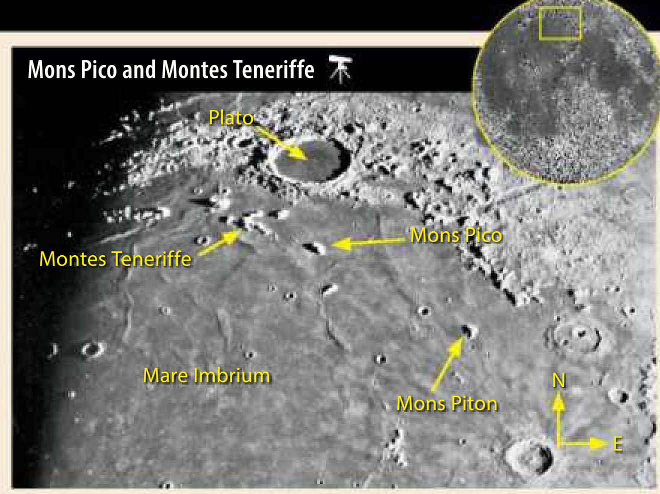
Poking through the Sea of Rains

One night after the Moon appears half-lit, at First Quarter phase on the evening of October 8, the Sun begins to rise over the lava fields of Mare Imbrium (the Sea of Rains). The returning sunlight illuminates a series of dramatic and mostly isolated mountain peaks just south of the large oval crater Plato.

One of the best examples is Mons Pico, which rises 1.5 miles above Imbrium's floor. Throughout the evening of October 9, Pico's shadow clearly shortens. Then, look a bit to the west and you'll see the long triangular shadows cast by the peaks of Montes Teneriffe. Thanks to the lower Sun angle here, these shadows retreat even more quickly. You can notice changes in their lengths in as little as 15 minutes.

Astronomers used to think these mountains were volcanic, but unmanned missions in the 1960s brought a fresh perspective. Oddly enough, the breakthrough came not from close-up images of Mare Imbrium but from photos of Mare Orientale to the west. From Earth, we see only half of this feature at a steeply inclined angle.

The concentric rings of mountains surrounding Orientale were not disturbed by lava flows like Imbrium's. Scientists inferred that only the tallest peaks of Imbrium's original mountains — such as Mons Pico and Montes Teneriffe — survived the lava floods that filled the lowlands. Mons Piton to Pico's southeast is another survivor.



A few prominent mountain peaks rise above the lava plains of Mare Imbrium south of Plato Crater. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

As Venus and Saturn dip toward the horizon, shift your focus up to Mars. The Red Planet lies among the rich star fields of Sagittarius. In early October, the magnitude 0.1 world is a magnificent sight posed against a stunning backdrop. On the 1st, it lies in the same binocular field as the Lagoon Nebula (M8), which stands 2.5° to the northwest.

The planet moves 0.8° south of 7th-magnitude globular cluster M28 on October 5. Lambda (λ) Sagittarii, the 3rd-magnitude red giant star that marks the top of Sagittarius' Teapot asterism, resides in the same low-power telescopic field. The next evening, Mars passes 0.2° south of this star.

The planet skims 4' south of the 9th-magnitude globular NGC 6638 on October 7. Mars rounds out its encounters with globulars on the 9th, when it appears 1.6° south of 5th-magnitude M22. You'll want to view these vistas soon after the sky darkens while Sagittarius is still reasonably high.

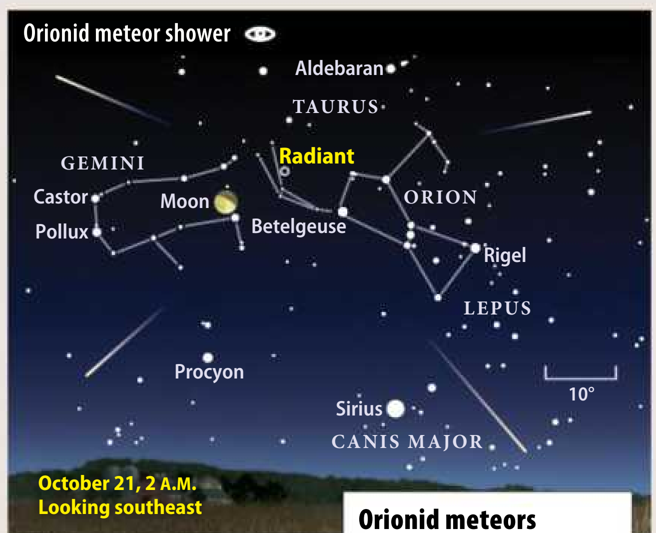
— Continued on page 42

METEORWATCH

The Hunter battles a bright Moon

October's morning sky lights up as Earth's atmosphere incinerates bits of comet debris. The Orionid meteor shower peaks before dawn on October 21. Unfortunately, a waning gibbous Moon shares the sky, likely cutting the observed number in half from an expected peak of 15 meteors per hour. But don't give up. If you position yourself with the Moon at your back (preferably behind some trees or buildings), you'll increase the chances for a good show.

Orionid meteors stem from debris left behind by Comet 1P/Halley during its regular visits to the inner solar system. Although Halley last visited 30 years ago, the debris spreads pretty evenly along the orbit. The Orionids appear to radiate from near the right elbow of Orion the Hunter.



A waning gibbous Moon interferes with this year's Orionid shower, though attentive viewers still should see the brightest meteors.

Orionid meteors

Active dates: Oct. 2–Nov. 7
Peak: October 21
Moon at peak: Waning gibbous
Maximum rate at peak: 15 meteors/hour

October also features the minor Southern Taurid shower, which derives from Comet 2P/Encke. Its peak arrives on the 10th, when the Moon is absent from the prime observing hours after midnight. Observers under a dark sky can expect to see up to 5 meteors per hour.

OBSERVING HIGHLIGHT Keep watch the night of October 18/19 as the gibbous Moon passes through the Hyades star cluster and occults Aldebaran.

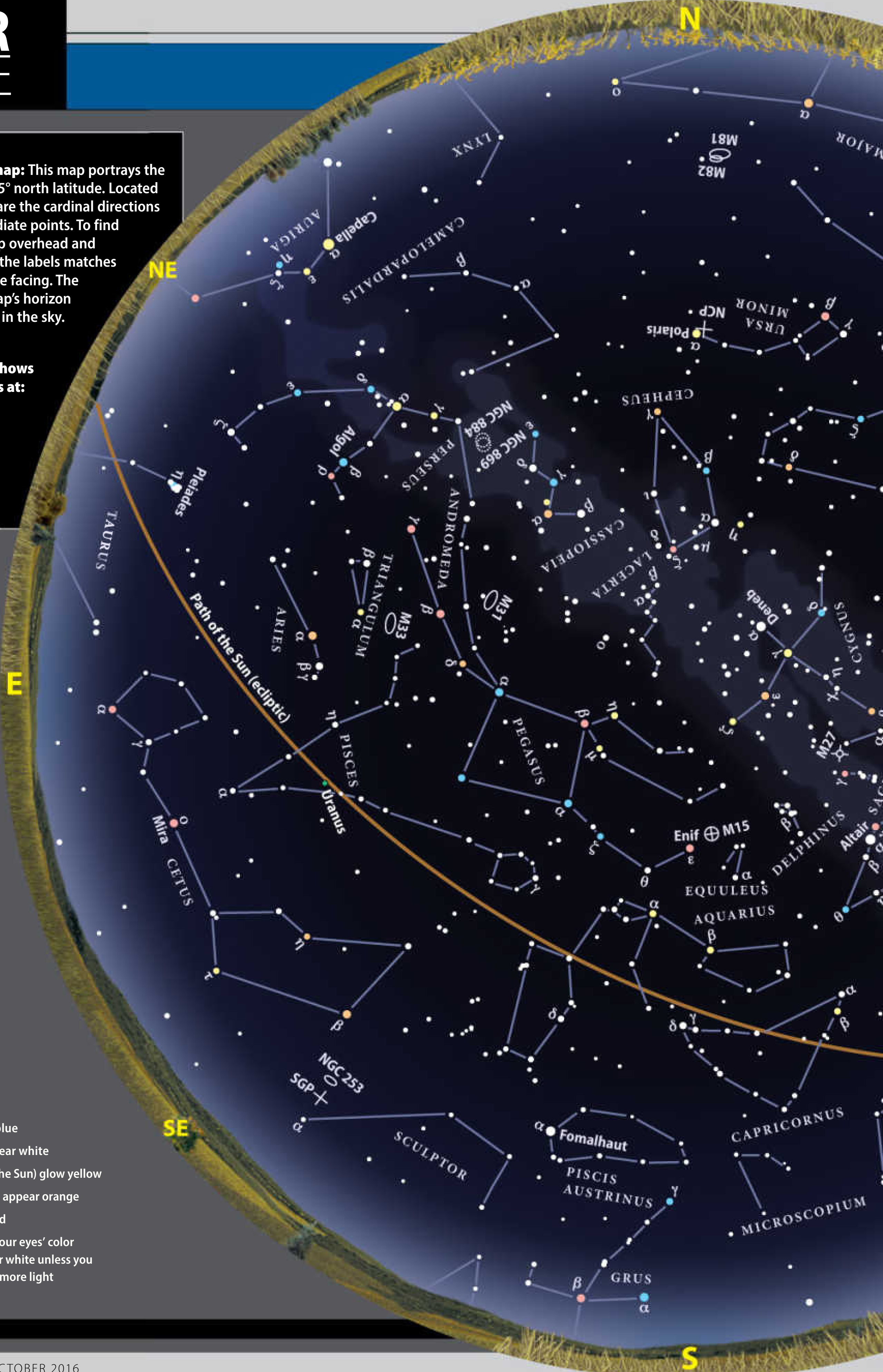
STAR DOME

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 2016

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

3 The Moon passes 5° north of Venus, 1 P.M. EDT

4 The Moon is at apogee (252,336 miles from Earth), 7:03 A.M. EDT

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

7 Asteroid Pallas is stationary, 10 P.M. EDT

8 The Moon passes 7° north of Mars, 8 A.M. EDT

9 First Quarter Moon occurs at 12:33 A.M. EDT

10 Mercury passes 0.9° north of Jupiter, midnight EDT

13 The Moon passes 1.2° north of Neptune, 2 A.M. EDT

15 Uranus is at opposition, 7 A.M. EDT

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

SPECIAL OBSERVING DATE

15 Uranus reaches its 2016 peak, shining at magnitude 5.7 and appearing 3.7" across through a telescope.

16 Full Moon occurs at 12:23 A.M. EDT

The Moon is at perigee (222,364 miles from Earth), 7:34 P.M. EDT

19 The Moon passes 0.3° north of Aldebaran, 3 A.M. EDT

21 Dwarf planet Ceres is at opposition, 1 A.M. EDT

Orionid meteor shower peaks

22 Last Quarter Moon occurs at 3:14 P.M. EDT

23 Asteroid Melpomene is at opposition, 7 P.M. EDT

25 Venus passes 3° north of Antares, midnight EDT

27 Mercury is in superior conjunction, noon EDT

28 The Moon passes 1.4° north of Jupiter, 6 A.M. EDT

29 Mars is at perihelion (128.4 million miles from the Sun), 9 A.M. EDT

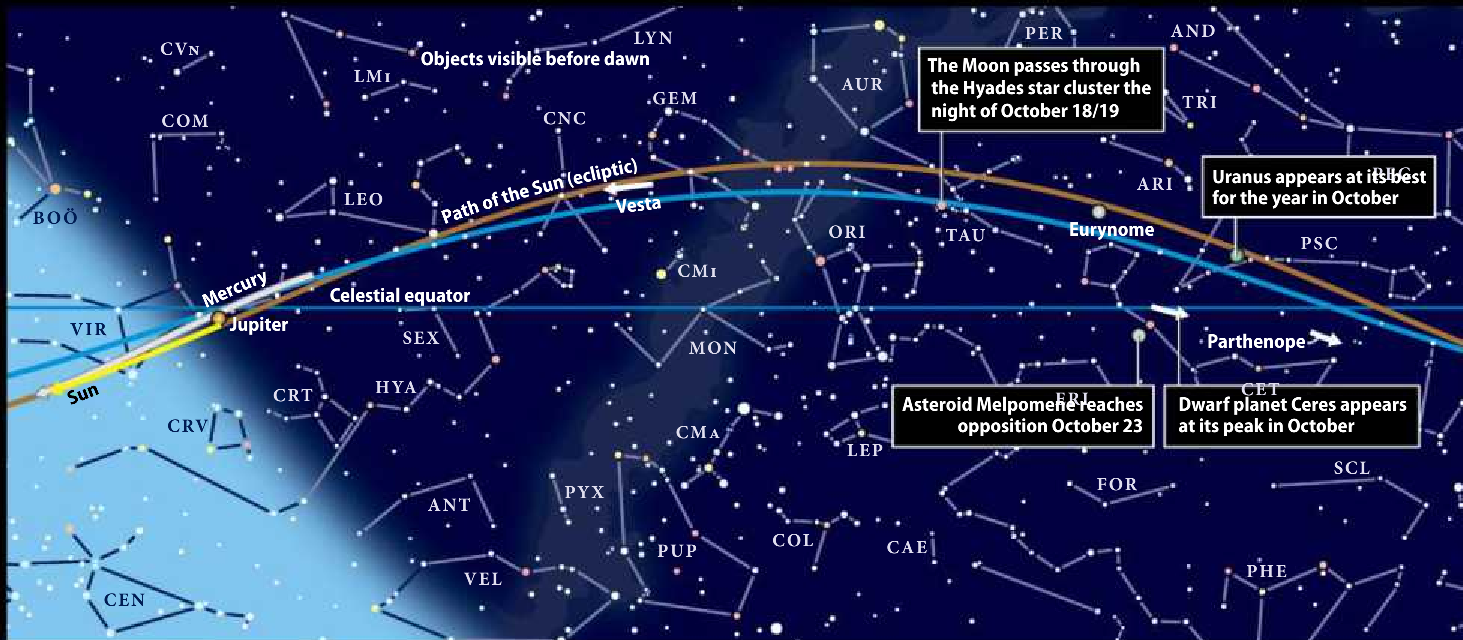
30 Venus passes 3° south of Saturn, 4 A.M. EDT

New Moon occurs at 1:38 P.M. EDT

31 The Moon is at apogee (252,688 miles from Earth), 3:29 P.M. EDT

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

The planets in October 2016

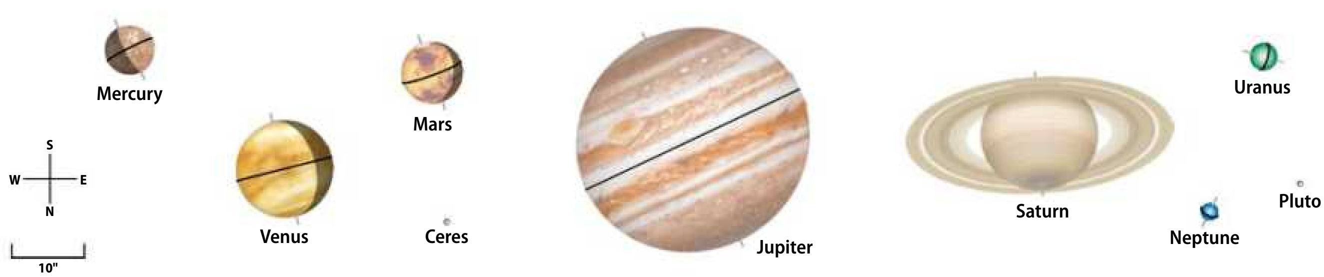


Moon phases

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.

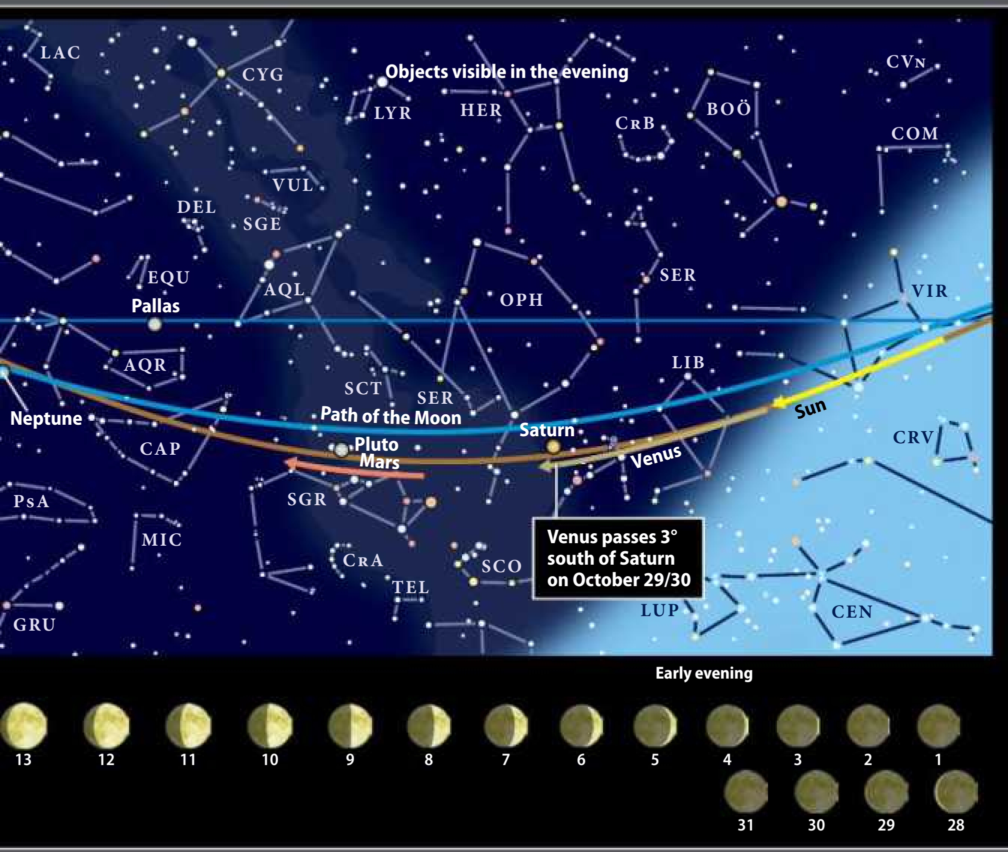
The planets in the sky

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



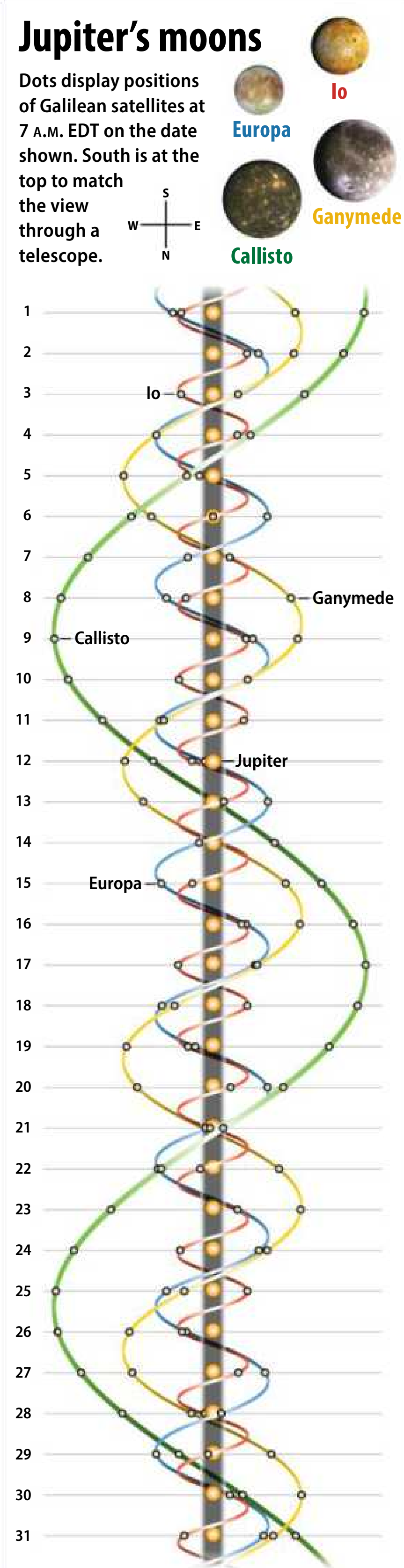
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Oct. 1	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15	Oct. 15
Magnitude	–0.8	–3.9	0.2	7.5	–1.7	0.5	5.7	7.8	14.2
Angular size	6.6"	12.9"	8.1"	0.7"	30.7"	15.6"	3.7"	2.3"	0.1"
Illumination	60%	82%	85%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.017	1.295	1.149	1.908	6.413	10.644	18.951	29.210	33.301
Distance (AU) from Sun	0.309	0.728	1.383	2.883	5.453	10.042	19.948	29.953	33.195
Right ascension (2000.0)	11h27.3m	15h32.9m	18h51.7m	2h07.6m	12h29.0m	16h45.0m	1h23.4m	22h45.1m	19h03.6m
Declination (2000.0)	5°08'	–20°06'	–25°07'	–0°54'	–1°56'	–20°54'	8°05'	–8°52'	–21°27'

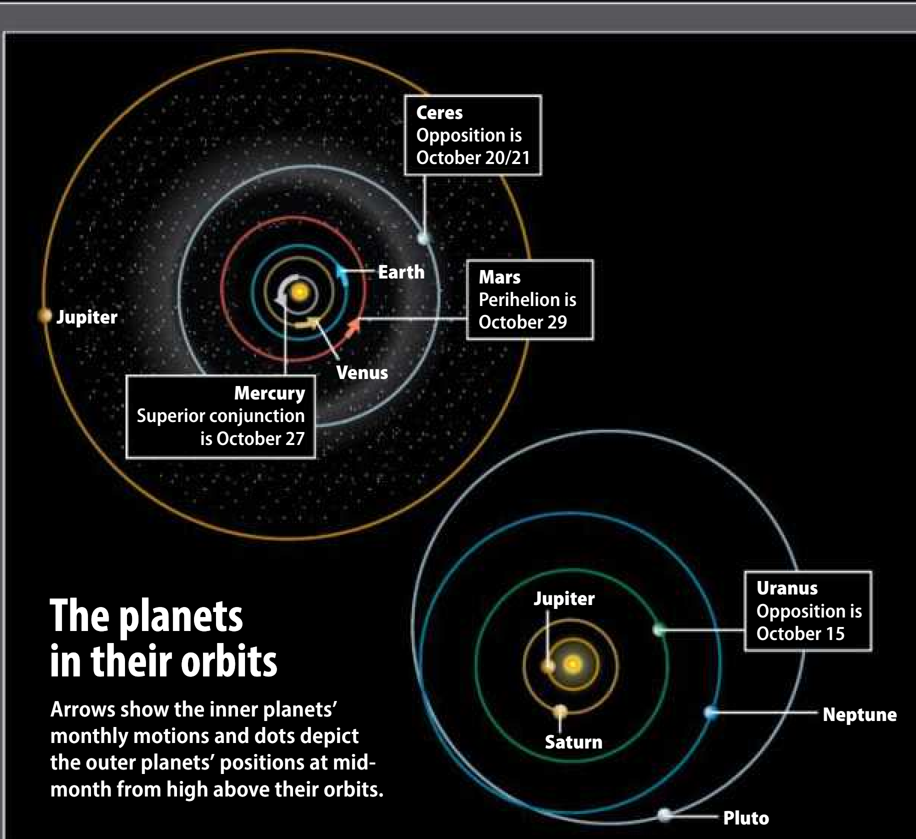
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



Jupiter's moons

Dots display positions of Galilean satellites at 7 A.M. EDT on the date shown. South is at the top to match the view through a telescope.





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.

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

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

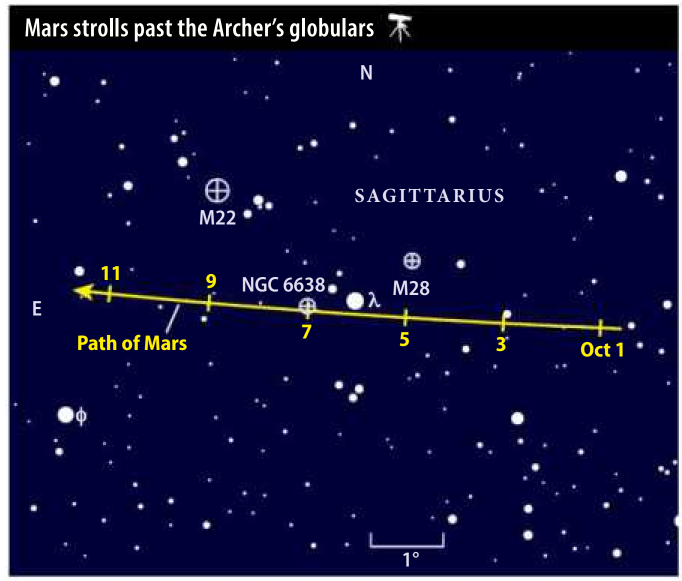
The Red Planet stands out this month largely for the company it keeps. Its disk measures only 8" across and won't show the surface features it did a few months ago. You'll likely need an 8-inch or larger scope with fine optics and good seeing conditions to spot any appreciable details.

Sagittarius holds one other solar system world within reach of an 8-inch instrument under excellent conditions. **Pluto** normally would be a bear to track down against the Archer's rich backdrop, but its proximity to magnitude 3.8 Omicron (ο) Sgr in northeastern Sagittarius makes the task a little easier. During October's final week, Pluto lies 0.3° north and a touch west of Omicron. The dwarf planet passes 4' due north of a 7th-magnitude field star on the 27th and just 8" north of a 9th-magnitude star on the 30th. At magnitude 14.2, Pluto glows 100 times dimmer than the latter star. Use the finder chart on the opposite page to home in on the world.

Neptune resides among the background stars of Aquarius, which lies due south and at its highest in midevening. Glowing at magnitude 7.8, the eighth planet shows up quite easily through tripod-mounted 7x50 binoculars. Neptune begins October 2° southwest of 4th-magnitude Lambda Aquarii and slowly drifts away. By the month's final week, it lies 2.5° from Lambda and just 0.1° north of a pair of 9th-magnitude stars. A telescope reveals Neptune's 2.3"-diameter disk and subtle blue-gray color.

Shift your gaze one constellation east of Aquarius, to Pisces the Fish, and you'll be staring at the current home of **Uranus**. This ice giant world reaches opposition and peak visibility on October 15, though the view hardly suffers during the rest of the month. The planet glows at magnitude 5.7 throughout October, which makes it bright enough to glimpse with the naked eye from under a dark sky.

Uranus climbs above 30° by 9 P.M. local daylight time in mid-October. To track



The Red Planet passes three bright globular star clusters as well as magnitude 2.8 Lambda (λ) Sagittarii during October's first 10 days.

COMETSEARCH

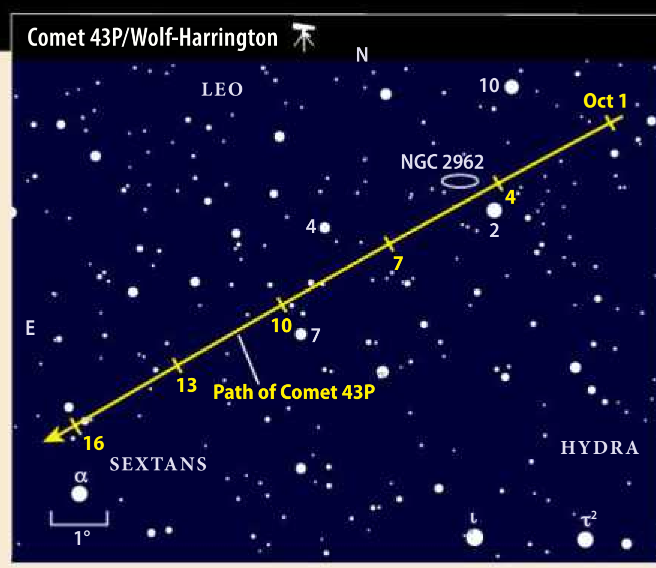
A periodic visitor on its final legs?

October's magnificent predawn sky hosts a comet that should be a treat for observers using 8-inch or larger telescopes. With Orion and its sparkling luminaries riding high in the south, sweep east to Leo's front paw near the Lion's border with Hydra and Sextans to find 11th-magnitude Comet 43P/Wolf-Harrington. Head out to the country during October's first two weeks to avoid both city lights and moonlight. The month's last weekend will work too, as Jupiter clears the horizon and heralds the end of the night.

When viewed through a telescope, Wolf-Harrington should appear quite small and slightly out of round. Its eastern flank should be well-defined because this is where the solar wind pushes the comet's dust away from the Sun. Compare it with the 12th-magnitude galaxy NGC 2962, which lies within a couple of degrees during October's first week.

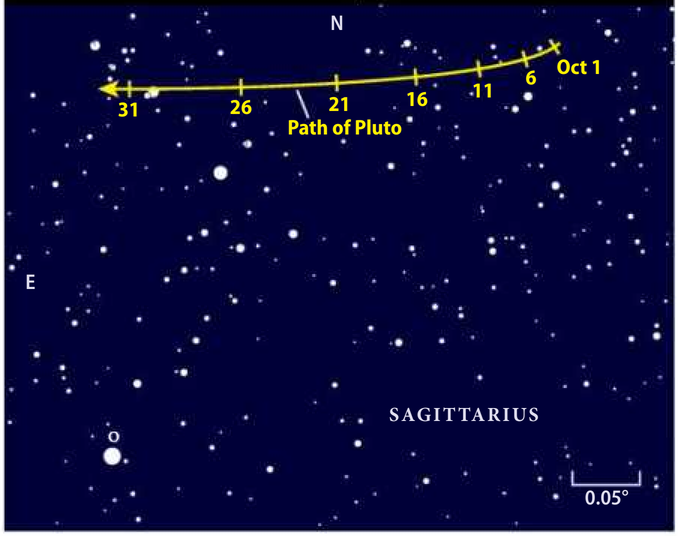
Wolf-Harrington's proximity to Jupiter is not just a line-of-sight effect. The comet will swing near the gas giant in 2019, and the massive planet will fling the puny comet onto a slightly different path. Thereafter, 43P will orbit farther from the Sun and stay beyond the visual reach of 8-inch scopes.

Our current drought of decent telescopic comets should end in a few months with a deluge. Astronomers expect at least five of them to peak at 9th magnitude or brighter. The first to arrive, in December, will be 45P/Honda-Mrkos-Pajdusakova. It should reach 6th magnitude in February. And Comet 2P/Encke should brighten steadily during January and February evenings. These fine visitors will show more details if you polish your observing skills now.



Look for this 11th-magnitude Jupiter-family comet in October's morning sky as it journeys near the Leo-Hydra-Sextans border.

Pluto targets a 4th-magnitude star



Observers have a great chance to spy this 14th-magnitude dwarf planet when it approaches Omicron (ο) Sagittarii at the end of October.

it down, first find autumn's most conspicuous star pattern, the Great Square of Pegasus. From magnitude 2.8 Algenib (Gamma [γ] Pegasi), the square's southeastern corner, scan 12° southeast to find the 4th-magnitude suns Delta (δ) and Epsilon (ε) Piscium. Using binoculars, then look a few degrees east and south to locate 5th-magnitude Zeta (ζ) and Mu (μ) Psc. At opposition, Uranus lies midway between and a bit north of a line joining these two stars. A handful of stars occupies this region, but all glow fainter than the planet.

Once you find Uranus, put the binoculars aside and see if you can spot it with your naked eye. To confirm a planet sighting, point your telescope at the target. Only Uranus shows a disk, which measures 3.7" across and has a distinctive blue-green color.

Dawn's approach brings two more planets into view. **Mercury** reached greatest elongation in late September but continues to brighten in early October. On the 1st, the magnitude –0.8 planet rises 90 minutes before the Sun and climbs 10° high in the east a half-hour before sunup.

Although **Jupiter** is invisible on the 1st, it quickly pops into view. By the 10th, the giant planet appears 1.6° below Mercury. The next morning, they appear side by side and just 0.8° apart. Jupiter lies to the right and shines a bit brighter, at magnitude –1.7, than magnitude –1.1 Mercury.

Mercury disappears into the twilight soon after its conjunction with Jupiter, but the outer planet continues to climb higher each morning. A telescope reveals Mercury's gibbous disk, which shrinks from 7" in diameter on the 1st to 5" across at the time of its Jupiter encounter. The giant planet's disk spans 31" throughout October.

The Moon occults Aldebaran on the night of October 18/19. Once Luna rises around 8:30 P.M. local daylight time on the 18th, you'll see it crossing in front of the Hyades star cluster. Observers in eastern North America can see our satellite pass in front of Theta^1 (θ^1) and Theta^2 (θ^2) Tauri. Watch as the stars reappear from behind the dark limb around 11 P.M. EDT.

The main event starts more than two hours later. Observers south of a line that runs from Southern California to the western Great Lakes can see 1st-magnitude Aldebaran dip behind the Moon's bright limb. (Viewers along this line will see a grazing occultation, in which the star peeks in and out of view behind lunar mountains.) To find the precise times when Aldebaran disappears and reappears, visit www.lunar-occultations.com/iota/bstar/bstar.

LOCATING**ASTEROIDS**

Listen to the Whale's siren song

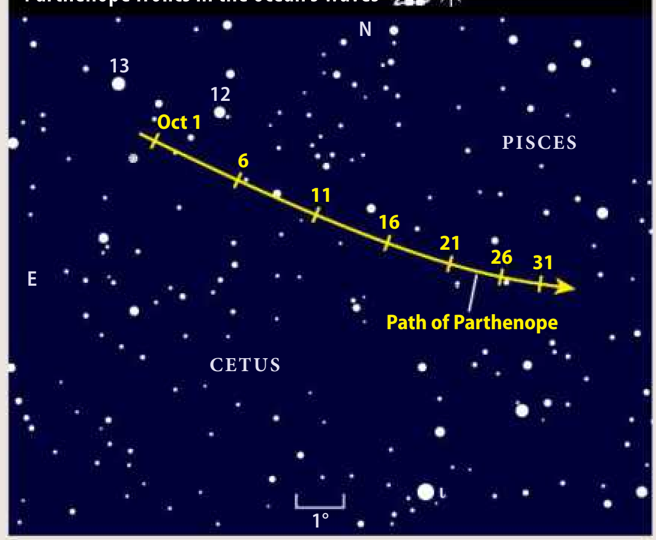
Astronomers used to describe asteroids as "vermin of the sky" because they interfered with more "important" observations of the universe beyond the solar system. Today, many astroimagers consider artificial Earth satellites equally pesky because they leave unwanted streaks in astrophotos. October's sky offers a rare chance to view both a bright asteroid and some Earth-orbiting satellites at the same time.

Italian astronomer Annibale de Gasparis discovered asteroid 11 Parthenope in 1850. In Greek mythology, Parthenope was a siren of the sea who founded the city of the same name (now Naples). The asteroid lurks near the border between Pisces the Fish and Cetus the Whale, a region that climbs high in the southeast by midevening.

First locate magnitude 3.5 Iota (ι) Ceti, and then slide north to Parthenope. The 9th-magnitude asteroid will show up through tripod-mounted binoculars or a telescope.

While observing Parthenope, you also might see some objects closer to home. The asteroid lies near the band of geostationary satellites. Although these geosats orbit above Earth's equator, our northern perspective makes them appear slightly south of the celestial equator — at a declination of about –5° for observers in the southern United States and at –7° from near the Canadian border. The Earth-satellite-Sun geometry in October gives us a direct reflection off the geosats' solar panels, and the biggest ones can hit 4th magnitude at their peak. You can follow them by turning your telescope's drive off — the satellites will remain stationary while the stars (and Parthenope) drift by.

Parthenope frolics in the ocean's waves



Asteroid 11 Parthenope glows at 9th magnitude as it sails southwest from Cetus the Whale into Pisces the Fish.

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

THROUGH THE CLOUDS

Q: IF OUR SUN IS A TYPICAL STAR, AND IF MOST STARS ARE SURROUNDED BY OORT CLOUDS, WHY DO THESE CLOUDS NOT OBSCURE OUR VIEW OF OTHER STARS?

Michael F. Walker, *Peculiar, Missouri*

A: Right now we can't observe extrasolar Oort clouds, if they exist. (Not for lack of trying; we've been looking for them since 1991!) In fact, we can't even directly observe our own Oort Cloud. We can only extrapolate its existence based on the statistics of long-period comet orbits.

We *can* observe Kuiper belts in other solar systems; we call them debris disks. So what does the Kuiper Belt have that the Oort Cloud doesn't? We observe debris disks by detecting the infrared emission from the tiny grains of rock and ice that make up a disk. These grains are warmed by their star, and they re-emit that heat as infrared radiation. To be detectable with our current telescopes, a debris disk needs to be hot enough and dense enough to produce a certain amount of infrared energy.

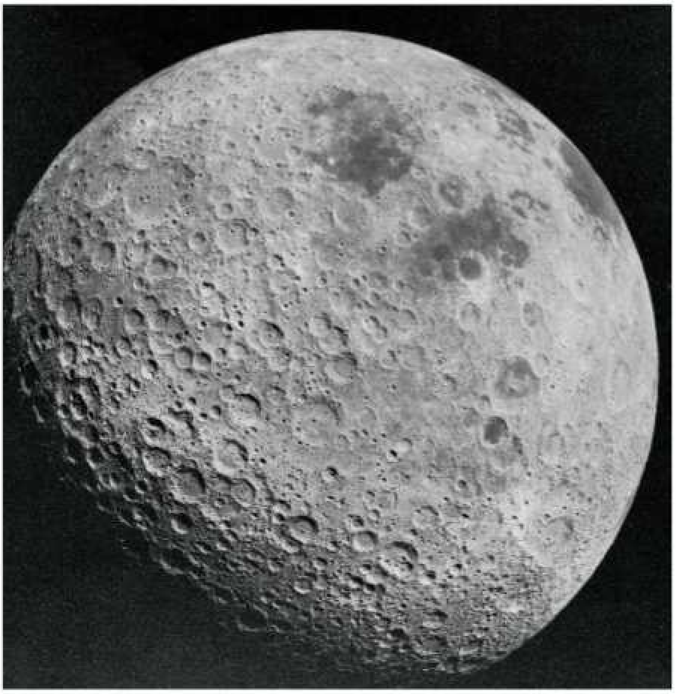
The Kuiper Belt is at least a thousand times closer to the Sun than the Oort Cloud is estimated to be (30 to 50 times the Earth-Sun distance compared with 3,000 to 50,000 times). That means grains in the Kuiper Belt are roughly 45° C warmer than Oort Cloud grains, which experience temperatures only a few degrees above absolute zero.

Now, a hotter star might heat up an Oort cloud enough to avoid this problem, but the Kuiper Belt is also much denser than the Oort Cloud. In fact, the faintest debris disks that we can detect are 1 million times denser than an Oort cloud would be.

This explains why we don't observe extrasolar Oort clouds, and also why they wouldn't block our view of their star — they're just too cold and made up of mostly empty space, leaving plenty of room for starlight to shine through.

Erika Nesvold
Carnegie Institution for Science
Washington, D.C.

Some disks, like that of Gomez's Hamburger (IRAS 18059-3211), are thick enough to block the light from their star. If you look at stars much younger than our Sun, they are often surrounded by a disk of gas and dust called a protoplanetary disk. These disks can be so thick that we can observe them in silhouette, as a dark stripe across their star blocking the starlight. NASA/THE HUBBLE HERITAGE TEAM (STScI/AURA)



The farside of the Moon will remain out of sight from Earth, but it can be imaged, such as this picture from the Apollo 16 crew. NASA

Q: IS THE MOON'S ROTATION RATE STILL SLOWING DOWN? IF SO, WILL THERE COME A TIME WHEN THE CURRENTLY UNSEEN 41 PERCENT WILL BE VISIBLE FROM EARTH?

Bill Warren
Griffin, Georgia

A: Yes, the Moon continues to spin more slowly, but that ultimately won't affect how much of its surface we can see.

Tides are the driving force behind these changes. Earth's large gravitational pull has raised enormous tides in the Moon's solid body and locked our satellite into synchronous rotation — meaning it rotates once on its axis in the same length of time it takes to revolve around Earth. That's why the Moon always shows the same face to us. Over several decades, we can see up to 59 percent of the lunar surface because the Moon doesn't orbit at a constant speed, and its axis is not perpendicular to its orbit.

The Moon also raises tides on Earth. These show up most noticeably as rising and falling sea levels. As our planet rotates, the flowing waters create friction within the liquid itself and between the water and solid Earth. This saps energy from Earth's rotation and causes it to spin more slowly, which is why days are getting longer — at about 2 milliseconds per century.

The angular momentum of the Earth-Moon system must be conserved, however, so Earth's slowing rotation demands that the Moon gradually spiral away from our planet. This, in turn, requires its orbital period to increase and, because the Moon is tidally locked to Earth, to spin more slowly.

Unfortunately, because the Moon's rotation rate is locked to its revolution, we will never get to see Luna's hidden 41 percent from Earth.

Richard Talcott
Senior Editor

Q: HOW WILL THE LANDINGS, TAKEOFFS, AND INVESTIGATIVE EXPLOSIONS FROM THE OSIRIS-REX AND HAYABUSA2 SPACECRAFT ALTER THE ORBITAL PATHS OF ASTEROIDS BENNU AND RYUGU? CAN THESE EFFECTS BE EQUATED TO A DURATION OF SUNLIGHT FALLING ON EACH ASTEROID?

Steven Portalupi
Newmarket, New Hampshire

A: One of the very first properties of the asteroids to be measured will be their gravity and centers of mass, which we do not yet know with high confidence. We must do this in order to navigate both spacecraft around their target asteroids.

Regardless of the gravity we measure, we know that both spacecraft are much, much less massive than the asteroids: Bennu is about 130 billion pounds (62 billion kilograms), with Ryugu likely being more massive. Hayabusa2 was about 1,300 pounds (590kg) at launch, and OSIRIS-REx about 3,300 pounds (1,500kg). The spacecraft are not massive enough and neither will operate long enough around their target asteroids to affect their orbits.

When either spacecraft collects samples, it is in contact with the surface only for a few seconds and does not have the mass or velocity to push these more massive objects out of their current orbits. Even the explosive experiment of Hayabusa2 is not powerful enough to cause any major issues to Ryugu's orbit.

The force the Sun exerts on planetary bodies is called the Yarkovsky effect. For small, airless bodies such as Bennu and Ryugu, the Sun's photons heat their surfaces. As the asteroids rotate and cool, heat is given off, and that exerts a tiny force on the asteroid. Although it is a tiny force, the effect is cumulative and occurs over tens of thousands to millions of years, thus producing changes in an asteroid's orbit.

Hayabusa2 and OSIRIS-REx will not operate long enough around their target asteroids to affect them as the Sun does, but they will analyze for the Yarkovsky effect. Remember, we will learn so much from these two missions, but the final prize is that they will be the first missions to bring home pristine samples of carbonaceous asteroids for analysis!

Harold C. Connolly Jr.
(Rowan University) and
Shogo Tachibana
(Hokkaido University) are both Co-Investigators on the OSIRIS-REx and Hayabusa2 missions

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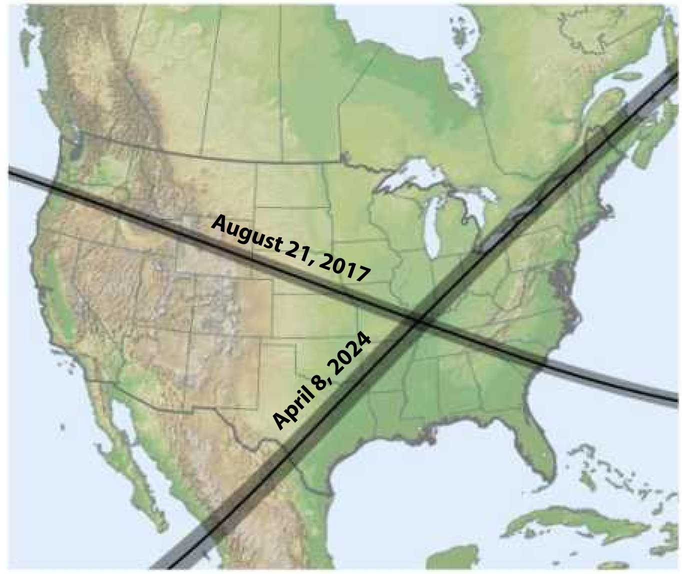
Q: THE AUGUST 2017 ECLIPSE MOVES BASICALLY WEST TO EAST. WHY DOES THE APRIL 8, 2024, ECLIPSE TAKE SUCH A SHARP TURN NORTH ACROSS THE U.S., THEN EAST AGAIN?

Robert Byerly
Windsor, California



The path of the 2024 total solar eclipse takes a much stranger path than the 2017 event. *ASTRONOMY*: ROEN KELLY

A: The Moon's orbit intersects Earth's orbit around the Sun — the ecliptic — at two points called nodes. When this intersection occurs very near to when the Sun, Moon, and Earth all align, we get an eclipse. Three factors affect the slope of a solar eclipse's path of totality: the distance of the Moon from the node, Earth's season, and whether the eclipse occurs at the ascending or descending node.

How far our satellite is from the node when the three bodies align affects the path. Basically, this means that all eclipse paths don't begin at the same latitude. The Moon's umbra, or shadow, can intersect Earth anywhere between its north and south poles. As a general rule, however, the paths of any two eclipses falling on a certain date and which track through the same hemisphere will appear similar.

Regarding the seasons, the general rules say that if we're talking about eclipses when the Moon's position is relatively close to the node, then eclipses occurring within two months of the September equinox tend to have central paths running northwest to southeast. Likewise, eclipses occurring within two months of the March equinox tend to have central paths running southwest to northeast.

Eclipses occurring at the ascending node (when the Moon crosses the ecliptic heading northward) tend to move generally northeast. Those at the descending node tend to move from northwest to southeast.

So, although the 2017 and 2024 eclipses both occur at the ascending node, the 2017 event is within two months of the September equinox, while the 2024 one is close to the March equinox. That's why the Moon's shadow moves in different directions.

Michael E. Bakich
Senior Editor

Send us your questions

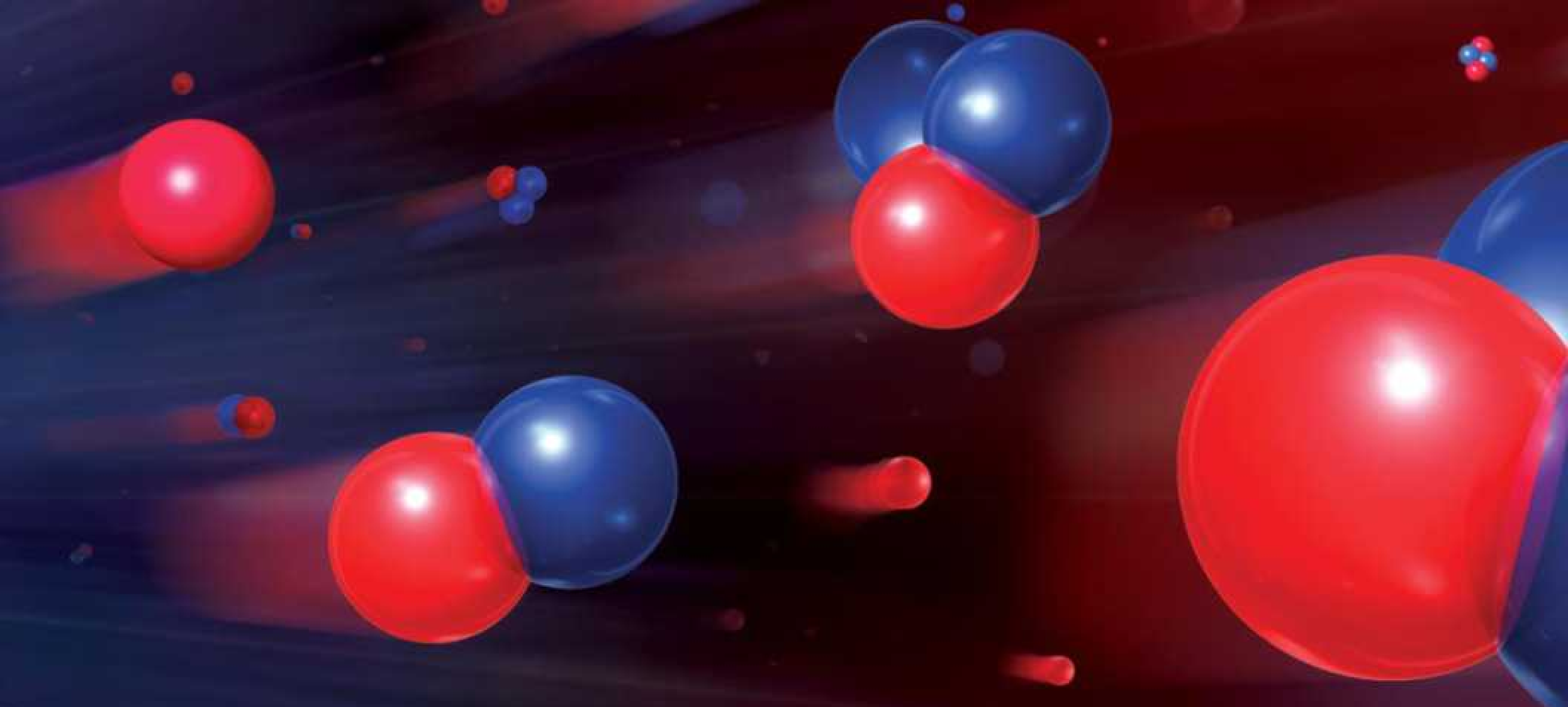
Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

The hunt for stars'

Examining current stars is giving astronomers a look at past generations.

by Liz Kruesi

A few minutes after the Big Bang, protons and neutrons began to combine into deuterium (heavy hydrogen) and helium nuclei, although most of the material was still hydrogen nuclei (protons). The temperature at this time was about 1 billion kelvins. *ASTRONOMY*: ROEN KELLY



hidden fingerprints

The study of the universe cannot depend solely on observations of celestial objects, on computer simulations of cosmic history, or on mathematical equations. Instead, it is a combination of the above — plus crucial laboratory measurements. One cannot interpret distant cosmic objects without a foundation of basic physics.

Perhaps no area of astronomical research showcases this relationship better than stellar spectroscopy — spreading out the light from a star into its constituent wavelengths (or colors), and using that data to interpret many of the star's properties. Spectroscopy combines atomic physics, stellar astrophysics, and observational astronomy.

If you know what to look for, you can find clues to the previous generation of stars in a spectrum. In this sense, stars are fossils, preserving the composition of the objects that came before them.

Contributing editor **Liz Kruesi** *is a freelance science writer in Austin, Texas. She thanks the previous generations of stars that made the elements that comprise her.*

Astronomers learn about suns that lived and died generations ago, seeding the cosmos with rich chemistry, including the materials necessary for life.

Some of these chemical elements are difficult to find and eluded detection until recently; others are still missing. Scientists are working together to gather data to fill in the gaps. Their goal is nothing short of knowing the cosmic origin of every element, building up a more complete picture of star formation and stellar death, and tracking how the periodic table of elements evolved in our universe.

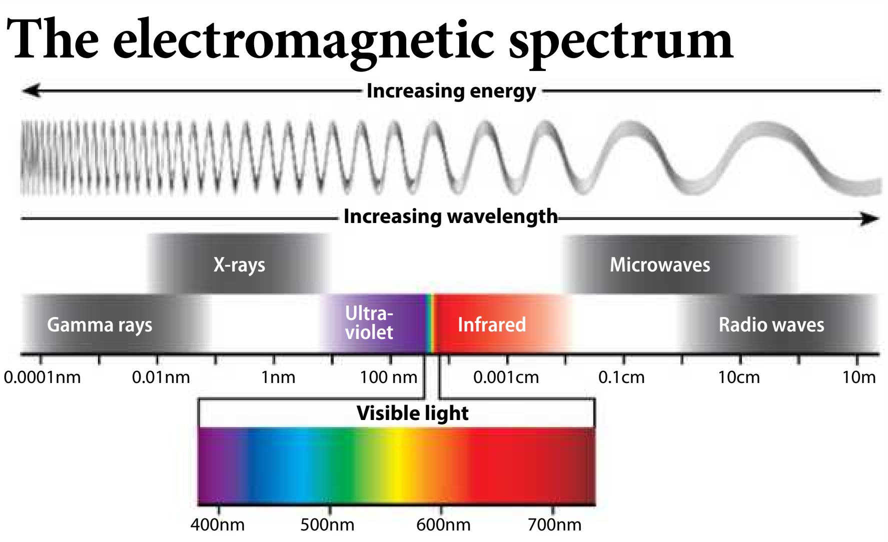
An intertwined history

Early learning about the composition of stars relied on the advancement and collaboration of physics and chemistry experiments, and on building better astronomical instruments. In the early 19th century, German scientist Joseph von Fraunhofer invented the spectroscope and spread sunlight into its constituent rainbow — and puzzled over dark lines he saw within the Sun's light.

In the middle of that century, Gustav Kirchhoff and Robert Bunsen realized, after comparing solar observations with laboratory chemistry experiments, that those lines mark specific elements. Each line corresponds to a wavelength absorbed by an element's atoms. With that information, the physicists identified more than a dozen chemical elements in the Sun's spectrum.

Other astronomers at the time began to study stars to try to tease out the compositions of those distant lights.

Fast forward to the end of the 19th century when Harvard College Observatory astronomers began collecting and studying the spectra of tens of thousands of stars. The missing colors — the dark absorption lines — varied in strength among different stars. This difference became the perfect tool to categorize these stars. The work, led by Annie Jump Cannon, is today's cornerstone of stellar classification, and the missing colors — revealing the elements present in each star — allowed astronomers to decipher a host of characteristics about these objects. For example, from the width of those lines, researchers can figure out how fast a star is spinning.



The color, energy, and wavelength (distance between wave crests) of any kind of electromagnetic radiation are all related. Green light, for example, has a shorter wavelength than orange, so it is more energetic. Gamma rays contain the most energy, and radio waves have the least. *ASTRONOMY*: ROEN KELLY

THE ULTRAVIOLET ELEMENTS

In their survey of the cosmos, Ian Roederer of the University of Michigan, Chris Sneden of the University of Texas at Austin, and their colleagues are searching for elements whose spectra contain strong ultraviolet lines.

So far, the team — using the Hubble Space Telescope to collect data — has found and measured the following 12 elements that show strong ultraviolet lines in their spectra:

Boron-5	Tellurium-52
Phosphorus-15	Lutetium-71
Germanium-32	Osmium-76
Arsenic-33	Iridium-77
Selenium-34	Platinum-78
Cadmium-48	Gold-79

But knowing what materials made up each star answered only part of the riddle. Other questions remained. How did those elements form, and why were their ratios different in different stars?

Work in the first half of the 20th century began to address these questions, and in 1957, scientists realized that nearly all elements heavier than hydrogen, helium, and lithium are created within stars during their lives and their explosive deaths. While astronomers had an idea of the general processes needed to make the elements, they puzzled over the details: Why would some stellar environments form much more of a specific element than others, and at what point in the explosion did certain elements form?

Chemical fingerprints

Each element leaves its fingerprints in stellar spectra, but getting to those telltale signals can be difficult. The youngest stars are made of material that has been processed through several generations, and thus have thousands of overlapping fingerprints. Separating out each line to measure how much of each element makes up those stars is not possible.

Stars from the universe's early days are made of less complex mixtures of material, and thus have fewer signals to sort through. When scientists examine the oldest stars they can study, they are measuring the elements that formed out of the spewed debris of the first stars. That data lets them know how those first stars lived and died, setting in motion the chemistry of the entire cosmos.

But these older and more pristine stars are rare because most would have already died in our 13.8 billion-year-old universe. (Astronomers have found only five stars that each hold 1⁄100,000 or less the amount of heavy elements that our Sun contains.)

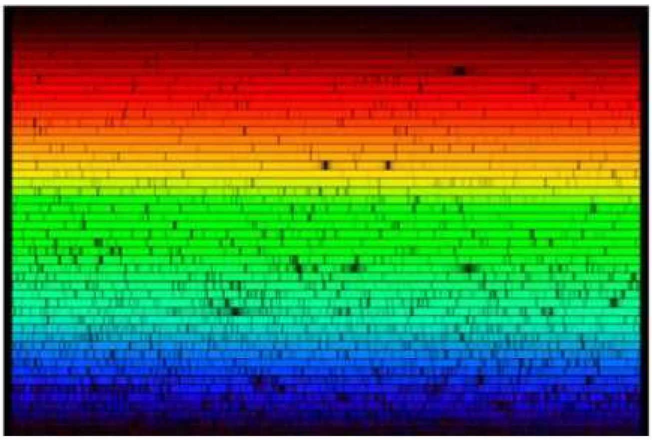
Inside the star

Gravity compresses the gas of a star like the Sun in such a way that deep in its core, temperatures reach 27 million degrees Fahrenheit (15 million kelvins). Because of the high pressure, atomic nuclei (mostly hydrogen's sole proton) are in close proximity. The temperature ensures that the atoms' electrons are unattached and that the nuclei are moving at high speeds and colliding.

A series of nuclear reactions converts four protons into one helium nucleus (two protons and two neutrons), two electron antiparticles, two ghostlike neutrinos, and a bit of energy in the form of gamma radiation. That energy radiates away from the star's core, and its outward pressure opposes the in-fall from gravity.

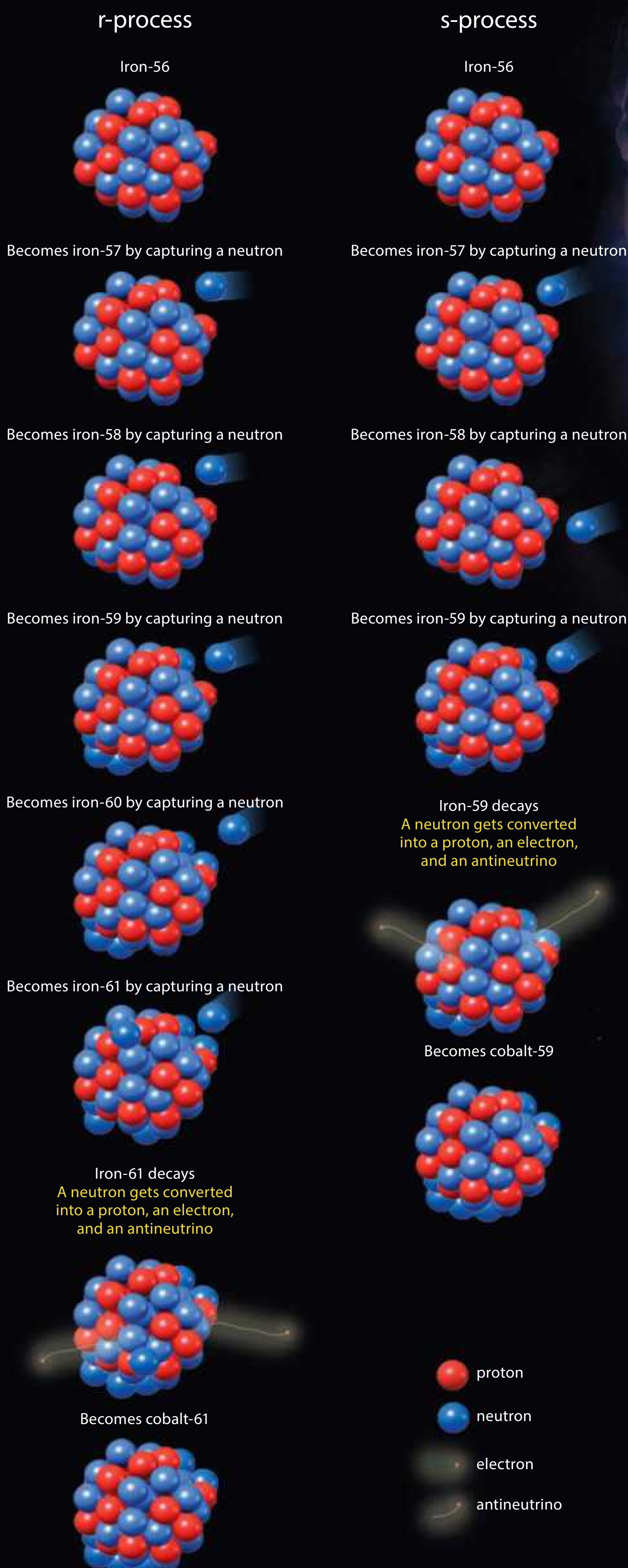
The radiation travels from the center of the star through its densely packed gas and finally penetrates the surface, free to journey to astronomers' telescopes. During its journey through the star, each gamma ray interacts with nuclei and electrons. The particles can either reflect or absorb the gamma ray, re-emitting it in the latter case. Each interaction causes it to lose a bit of energy. That means that the star's light scientists detect can range from high-energy gamma rays down to low-energy radio waves.

The detected light also reveals what type of gas is in that star. The temperature of the star's inner gas layers is cooler the farther out from the core one studies. When there is a cooler clump of gas in front of a radiation source, an atom in the clump can absorb some of the light. It does so at very specific colors, which are characteristic to what element the gas is.



The Sun's spectrum was the first studied in detail. In this image, wavelength increases on each line from left to right, and from bottom to top. Each of the 50 rows covers 6 nanometers, creating a complete spectrum across the visual range from 400nm to 700nm. N. A. SHARP/NOAO/NSO/KITT PEAK FTS/AURA/NSF

Nature's recipe for creating elements



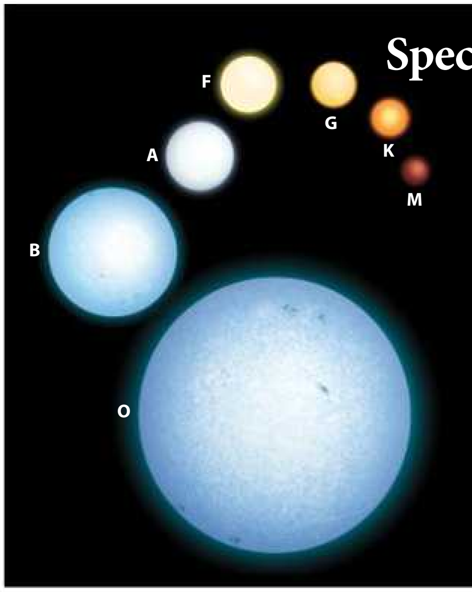
ASTRONOMY: RICK JOHNSON AND ROEN KELLY

The universe began as a pretty dull place — lots of hydrogen and helium, but little else. Things began to grow interesting after the first stars formed. These ancient ancestors of the stars we see today fused hydrogen into helium in their cores. Later, they and their offspring created more complex atoms, including carbon, oxygen, and nitrogen.

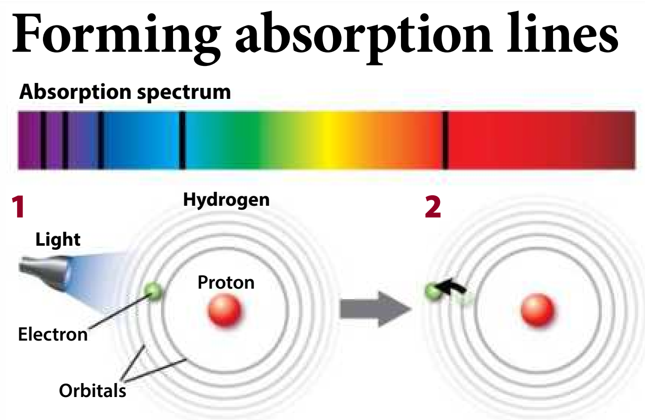
The heaviest stars forged ever more exotic elements, up to iron-56 (a nucleus containing 26 protons and 30 neutrons). But that's as far as fusion goes. Creating heavier elements requires an influx of neutrons. Let's look at how stars turn iron-56 into isotopes of cobalt. The same methods produce heavier elements as well.

Deep inside evolved stars, nuclear reactions create lots of neutrons. When iron-56 captures a neutron, it becomes iron-57. Another capture produces iron-58, and another iron-59. Each neutron capture takes about a year — so scientists dub this the s-process (for slow). Iron-57 and iron-58 are fairly stable, but iron-59 decays to cobalt-59 in a month, before it can capture another neutron.

To get past this roadblock, you need a high flux of neutrons, like that found in supernovae. Iron-59 adds one neutron to make iron-60 and a second to form iron-61. That then decays to stable cobalt-61. Scientists call this the r-process because it happens so rapidly. The same process creates the heaviest elements. — *Richard Talcott*



Stellar spectral classes range from the hottest, bluest stars to the coolest, reddest ones. O-type stars have surface temperatures in excess of 30,000 kelvins, whereas M-type stars have surface temperatures as low as 2,500 kelvins, cool enough for some molecules to exist within them. *ASTRONOMY*: ROEN KELLY



A single electron orbits a hydrogen atom's nucleus. The electron usually stays in a level with a certain energy. Diagrams 1 and 2 show the electron absorbing just the right wavelength of energy to move to a higher level. A cloud of gas (such as a star's atmosphere) shows an absorption spectrum. *ASTRONOMY*: ROEN KELLY

Each color is precisely the wavelength that the element needs to boost an atom's electron to another energy level. When a whole lot of atoms absorb that color of light, less of that wavelength gets to telescopes. Stellar spectroscopists look for those "missing" colors in the light that began at the center of the star, and those missing colors tell them what elements make up the star.

But just knowing these elements doesn't tell you much about stellar evolution. For that, astronomers need to calculate how many atoms of each element lie in that star. It's these kind of details that still drive today's stellar astrophysicists, like University of Michigan's Ian Roederer, University of Texas at Austin's Chris Sneden, and their collaborators.

An atom absorbs energy at a specific wavelength, which boosts an electron to a higher energy level. Some transitions are more likely than others, a phenomenon called the "transition probability." Each atom creates an ultra-faint fingerprint. The more atoms of the element that are present in addition to how likely it is for that energy-level jump to occur means a more visible fingerprint, which shows up as a stronger absorption line.

To best understand what they're seeing in the spectrum, Roederer and Sneden collaborate with an atomic physicist who specializes in this work. "Jim Lawler has been painstakingly measuring these properties in the laboratory for decades," says University of Oklahoma's John Cowan, another astrophysicist in this collaboration. And his work is absolutely crucial to calculating how much of each element is in the star.

Extra pathways

The number of protons in an atom's nucleus defines its chemical element identity. Most of the elements up to iron (26 protons) are created through fusion within a star's core, where pressures and temperatures are extreme. But after iron, it takes more energy than fusion generates to create heavier elements. A star still can make them, however, in so-called neutron capture processes. There's the slow pathway, called s-process, and the rapid pathway, called r-process.

"The definition of slow means that if a neutron is grabbed by some nucleus, then it becomes too neutron-rich for stability," says Sneden. "The neutron will turn itself into a proton and you've gone up one in the periodic table." In this s-process, time passes between the nucleus grabbing extra neutrons and the neutron decaying into a proton. "Any adjustment the neutron has to make has time to do it before another neutron comes along," Sneden adds.

The rapid process doesn't have such a leisurely schedule. Instead, "a great flux of neutrons just obliterates a nucleus," he says. The r-process happens in energetic, violent events when a massive star collapses and rebounds as a supernova explosion. "This flood of neutrons," Sneden adds, "will glom onto heavy-element nuclei, and in a second or two the neutron flood stops, and furiously there will be decays back to stability." Some astronomers think the rapid neutron capture process also can occur when two neutron stars slam into each other, but this theory has only recently become popular.

The heavy elements made during these neutron-capture processes are rarer than those made in the cores of stars because these processes happen for briefer amounts of time. They also require higher temperatures — up to hundreds of millions of degrees — and such conditions are extremely rare.

The hidden elements

Using ground-based telescopes, astronomers have studied a plethora of elements like iron, carbon, oxygen, hydrogen, and helium. But Earth's atmosphere limits the wavelengths that pass through it, and not all elements have spectral lines that lie in these gaps. (Or sometimes they do, but those lines are much less likely and the resulting spectral line is therefore too weak to see.) Several of the elements invisible in optical light lie in the ultraviolet (UV) part of the spectrum.

Most UV radiation doesn't make it through Earth's atmosphere, and while that's good for human DNA, it's not great for astrophysicists who look for that light. They need a telescope in space to view it. Currently, there's only one telescope that can be used to look for it — the Hubble Space Telescope.

The push to find the "invisible" elements finally moved forward when Hubble launched. While Roederer and Sneden lead the charge now to detect these elements and calculate their abundances, the work began in the 1990s with Sneden, Cowan, Francesca Primas, Doug Duncan, Ruth Peterson, and David Lambert.

To figure out which element to go after, the scientists look at databases and publications from the physics community that provide the energy-level transitions of each element and at what wavelengths these occur. They're looking for unsearched-for elements with strong spectral lines in the ultraviolet range. "Our marching plan has been to work our way through the periodic table of elements," says Cowan.

First, they select a few elements to study, and then pick an ideal star to observe. They choose specific stars out of the large sky surveys that people like University of Notre Dame astrophysicist Tim Beers have completed. In his four-decade career, Beers has captured low-resolution spectra of millions of stars. From those observations, Sneden's team can find the stars with cleaner spectra and fewer heavy elements. That usually means the ideal star is older and thus was created when fewer heavy elements existed.

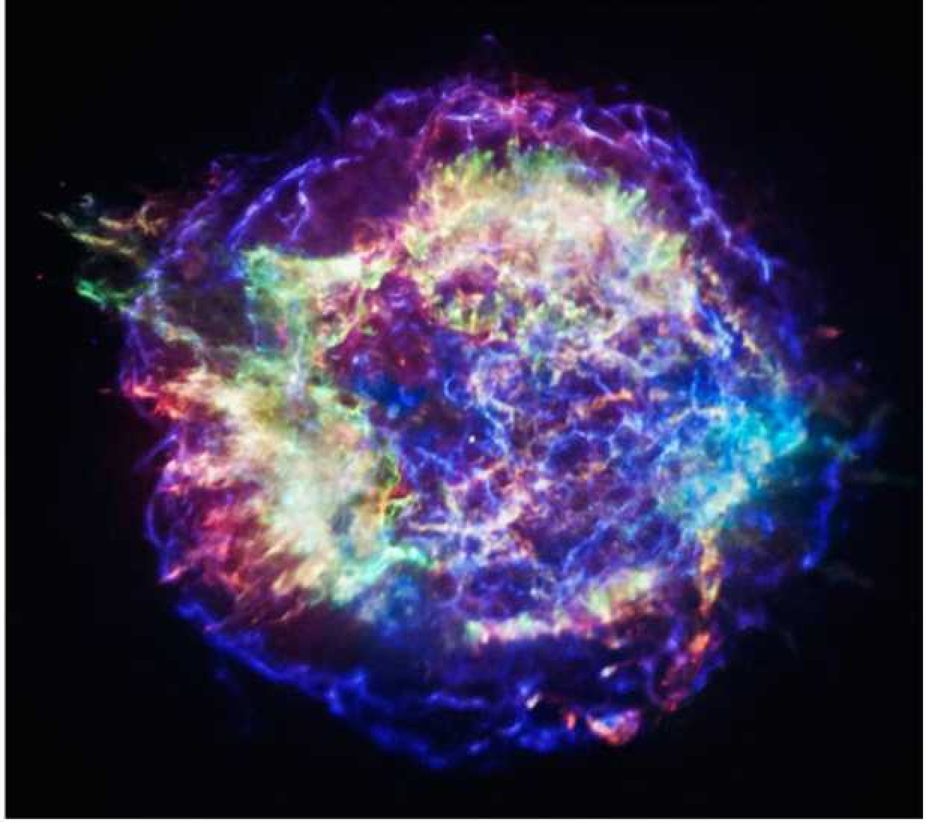
The researchers have a few additional requirements, too: "We're looking for stars that are bright enough to us, close enough, and [have] the spectral lines strong enough that we can see," says Cowan. They also need stars that haven't evolved too much to make their own stew of chemical elements.

The next step, says Roederer, is to apply for Hubble time to get a detailed UV spectrum of that ideal star. Once the proposal is accepted and the data collected, it's time to analyze. But it's not easy. "The ultraviolet spectrum of a star, like any in our study, is, to put it bluntly, a mess. It's a composite of thousands upon thousands of lines — the signatures of dozens of elements," says Roederer.

To work through that spectrum, the astronomers compare it to computer models of other stars. These simulations factor in chemical composition and the elements' atomic transitions as well as different layers (indicated by different temperatures) of the star's atmosphere. Researchers are trying to reproduce in their computer model the same spectrum they observe with Hubble. Their model goes into the fine details: "We correlate the strength of an absorption line — if you wish, the depth of an absorption line — to actually measure the number of atoms that could be responsible for that depth," says Primas.

They compare each computer-generated spectrum to the observed one and create a plot, called a "best fit," of how much they differ. The one that matches the closest can then tell them the amount of each element.

"From there, then you've got something you can actually do some science with," says Roederer.



Supernovae — the explosions of the most massive stars — seed the cosmos with metals (elements heavier than hydrogen and helium). Such events also create the heaviest elements by the r-process, where the explosion showers the nuclei of already heavy elements with neutrons. NASA/JPL-CALTECH

A FUTURE LACK OF TOOLS

The Hubble Space Telescope has opened up this field of hunting the missing elements because it is sensitive to ultraviolet (UV) wavelengths, a regime not accessible from the ground. The telescope has two UV instruments, which Roederer, Sneden, and their colleagues say are crucial to this work. But Hubble has operated for 26 years, and it won't live forever. The major concern among researchers in this field is, what happens next?

There are no UV instruments in development at NASA or the European Space Agency. The Russian and Spanish space agencies are collaborating on a project called World Space Observatory-Ultraviolet, which will have a 1.7-meter telescope that can study UV wavelengths between 115 and 310 nanometers. While the agencies claim the telescope is in the production stages, the project's website hasn't been updated in over two years — and a launch date is nowhere to be found. — *L. K.*

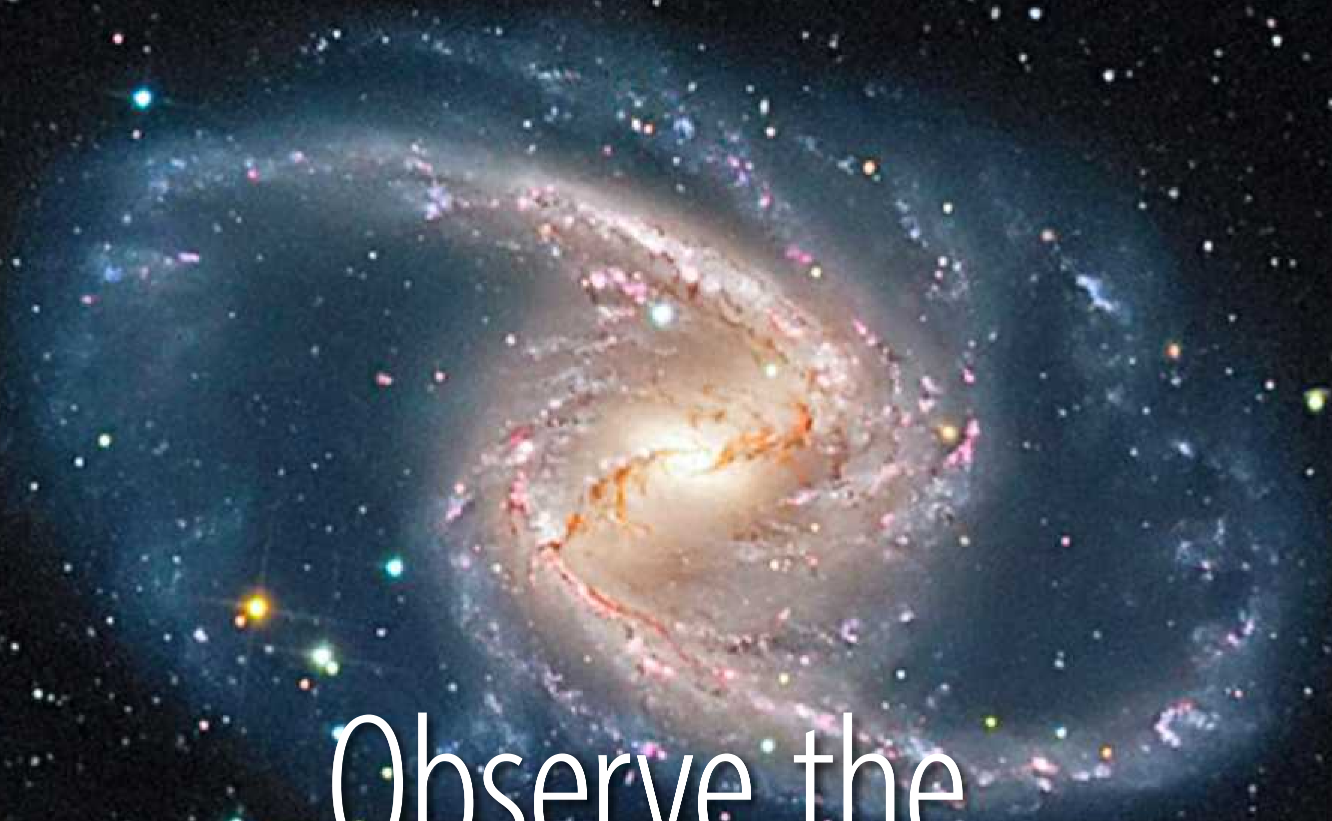
Science of the stars

The most exciting science that astronomers are using these abundance measurements for is to unravel the details of the previous star and its explosion that produced some of the material the observed star grew out of. "It's one thing to say some massive star blew up and it made these elements," says Beers, but what the research is moving toward is being able to say what the mass of that star was, if those elements formed through the r-process during the blast or the s-process from material piling up on one object stolen from another. "That's the real driver to understanding, keeping in mind we're all talking about laboratories that blew up 13.5 billion years ago," says Beers. "It's the ultimate CSI."

By knowing how much of each element a supernova contributed to a next-generation star, astronomers can constrain evolution models. When they have this information for tens of elements, they can further narrow down which models make sense and which don't.

Researchers also are shifting to stars that formed from the explosions of the first generation of stars, those with less heavy-element material. These stars formed from less processed material and can give clues to the first round of stellar evolution.

Although it's not possible to go back in time to look at the first stars, the collaboration between atomic physics, spectroscopy, computer modeling, and stellar astrophysics is providing a way to use today's relics from that epoch. Such collaborations were critical more than a century ago when scientists first began interpreting what elements existed in stars, and while the techniques have evolved and advanced, they have done so together to push forward the understanding of the cosmos.



Observe the 100 BRIGHTEST GALAXIES

Here's an observing challenge that will keep you busy all year long.

by Michael E. Bakich

NGC 1365 is the finest example of a barred spiral galaxy. It floats through space in the constellation Fornax. DON GOLDMAN

Assemble the brightest collection of any celestial targets, and you'll find some easy prey. Our neighbor Andromeda (M31) or the Magellanic Clouds pop into view even for small telescopes, at least as fuzzy blurs. But the complete list will present a challenge even to veteran skygazers, so keep the following in mind if you want to run the full century: 1) You'll require at least an 8-inch scope; 2) You must observe beneath a really dark sky with no Moon in it; 3) Many of you will need to travel to southern latitudes to see some of these entries.

If you can handle those qualifications, it's time to observe! I specifically chose this issue (which comes out in early September) for this story because I wanted to start the list at 0 hours right ascension. On the 2016 September equinox, which occurs on the 22nd, objects at 0 hours R.A. are rising at sunset.

I've divided the galaxies into 10 sections. And although you could calculate the best dates to observe each one (when they're highest in the sky), in many cases six-month-long windows of observation exist. Within each of the sections, I'll describe observing one of the objects. I'd do more, but space is limited.

My thanks go to friend and astronomer Brian Skiff of Lowell Observatory for compiling this list years ago. All I did was change the blue magnitudes he gave to their visual counterparts.

It's my hope that you don't just take a quick look at these wondrous galaxies and thus simply check them off this list. Make it your goal to observe them. Trust me, each one is worth it.

OUR OPENING GROUP of galaxies is a real doozy! It contains one of the southern sky's showpiece objects, but you may not have heard of it. NGC 1313 sits in the southwest corner of the constellation Reticulum, 3.2° southwest of magnitude 3.8 Beta (β) Reticuli.

Through an 8-inch telescope, the first feature you'll notice is the thick bar that has a slight central bulge oriented north to south. A spiral arm extends at a right angle eastward from the north end of the bar and westward from the south end. The eastward bar has two distinct sections divided by a dark region.

You'll also notice many bright knots along the arms and the bar, which represent star-forming regions. And all this is visible through an 8-inch scope!

If you use a 14-inch or larger scope on this object, look 16' southeast of NGC 1313 for the magnitude 13.8 edge-on spiral NGC 1313A.

Designation	Con.	R.A.	Dec.	Mag.
NGC 1313	Ret	3h18m	-66°30'	9.2
NGC 1316	For	3h23m	-37°12'	9.4
NGC 1365	For	3h34m	-36°08'	9.6
NGC 1395	Eri	3h38m	-23°02'	9.6
NGC 1399	For	3h38m	-35°27'	9.6
NGC 1398	For	3h39m	-26°20'	9.7
IC 342	Cam	3h47m	68°06'	9.1
NGC 1553	Dor	4h16m	-55°47'	9.4
NGC 1566	Dor	4h20m	-54°56'	9.7
NGC 1672	Dor	4h46m	-59°15'	9.7

Irregular galaxy NGC 55 lies roughly 7 million light-years distant. DANIEL VERSCHATSE

Designation	Con.	R.A.	Dec.	Mag.
NGC 55	Scl	0h15m	-39°12'	7.9
NGC 147	Cas	0h33m	48°30'	9.5
NGC 185	Cas	0h39m	48°20'	9.2
NGC 205	And	0h40m	41°41'	8.1
M32	And	0h43m	40°52'	8.1
M31	And	0h43m	41°16'	3.4
NGC 247	Cet	0h47m	-20°46'	9.1
NGC 253	Scl	0h48m	-25°17'	7.1
SMC	Tuc	0h53m	-72°50'	2.3
NGC 300	Scl	0h55m	-37°41'	8.1

Key: R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Visual magnitude

THE SECOND SET of galaxies is also something special. It contains both the Andromeda Galaxy (M31) and the Small Magellanic Cloud. I, however, want to describe the first object in this set, the Southern Cigar Galaxy (NGC 55).

You'll find this magnificent object 3.7° northwest of magnitude 2.4 Ankaa (Alpha [α] Phoenicis). Be prepared to spend some high-quality time observing it.

This galaxy's core lies distinctly offset to the west, giving the object a tapered, cigarlike appearance at low power and a two-part appearance at high magnifications. You'll see the faint dark lanes that divide the arms best if you use averted vision.

NGC 55 also is one of the sky's few galaxies that will benefit from a nebula filter. Because it's big and bright, an Oxygen III filter will dim the galaxy's stars, therefore increasing the contrast with star-forming regions of ionized hydrogen. Several of these are visible along the galaxy's arms through a 12-inch scope.

Astronomy Senior Editor **Michael E. Bakich**'s new book, *Your Guide to the 2017 Total Solar Eclipse* (Springer, 2016), is out now. You can order it at www.myscienceshop.com.

The Sculptor Dwarf Galaxy is best observed under truly dark skies. Note that this galaxy will appear faint — its listed magnitude is 8.6, but it spreads out over a large area of sky, so its surface brightness is low. CHUCK KIMBALL

Designation	Con.	R.A.	Dec.	Mag.
Sculptor Dwarf	Scl	1h00m	-33°43'	8.6
IC 1613	Cet	1h05m	2°07'	9.2
M33	Tri	1h34m	30°40'	5.7
M74	Psc	1h37m	15°47'	9.4
Fornax Dwarf	For	2h40m	-34°27'	8.4
NGC 1023	Per	2h40m	39°04'	9.4
M77	Cet	2h43m	-0°01'	8.9
NGC 1097	For	2h46m	-30°16'	9.5
NGC 1232	Eri	3h10m	-20°35'	9.9
NGC 1291	Eri	3h17m	-41°06'	8.5

THIS GROUP FEATURES a trio of Messier objects, most notably the Pinwheel Galaxy (M33). That treasure appears fainter than its listed magnitude because its light spreads over a large area.

That also applies to the object I've chosen to feature. You'll find it 2.3° south-southwest of magnitude 5.5 Sigma (σ) Sculptoris. Well, that's where to look for it, at least. Because the Sculptor Dwarf measures 1.1° by 0.8° — an area greater than four Full Moons — its surface brightness is incredibly low.

Eagle-eyed observers have spotted it through 6-inch telescopes, but your best bet is to head to an ultra-dark site and insert your lowest-power eyepiece into at least a 12-inch scope. Then, ever so slowly, scan the area. What you're looking for is a slight brightening of the background glow.

The Sculptor Dwarf was the first dwarf spheroidal galaxy discovered. In 1937, American astronomer Harlow Shapley found it on a photographic plate. The main difference between this type of galaxy and a dwarf elliptical is that a dwarf spheroidal galaxy has even lower surface brightness.

The UFO Galaxy (NGC 2683) flies solo. It's a field galaxy, meaning it is not part of a larger cluster association. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Designation	Con.	R.A.	Dec.	Mag.
LMC	Dor	5h24m	-69°45'	0.4
NGC 2403	Cam	7h37m	65°36'	8.5
NGC 2683	Lyn	8h53m	33°25'	9.8
NGC 2841	UMa	9h22m	50°59'	9.2
NGC 2903	Leo	9h32m	21°30'	9.0
NGC 2997	Ant	9h46m	-31°11'	9.8
M81	UMa	9h56m	69°04'	6.9
M82	UMa	9h56m	69°41'	8.4
NGC 3077	UMa	10h03m	68°44'	9.9
NGC 3109	Hya	10h03m	-26°10'	10.4

HERE'S ANOTHER STANDOUT group that features Bode's Galaxy (M81), the Cigar Galaxy (M82), and the Large Magellanic Cloud. You could observe each of those for hours.

However, direct your attention instead to the UFO Galaxy (NGC 2683) in the difficult-to-find constellation Lynx. This obscure group lies due north of Cancer and stretches to the northwest from there.

You'll find NGC 2683 some 6° west of magnitude 3.1 Alpha Lyncis. You can spot it even through a 3-inch telescope from a dark observing site. To pull out its worthwhile details, however, you'll need a bigger instrument.

This galaxy is a classic edge-on spiral that orients exactly northeast to southwest. Its common name derives from the resemblance of its shape to descriptions of unidentified flying objects from the 1950s. It appears more than three times as long as it is wide with an extended, bright central region.

The faint spiral arms begin to appear mottled through a 12-inch telescope. Through even larger scopes, you'll notice that the northeastern arm extends a bit farther than the southwestern one.

Designation	Con.	R.A.	Dec.	Mag.
NGC 3115	Sex	10h05m	-7°43'	8.9
NGC 3184	UMa	10h18m	41°25'	9.8
NGC 3344	LMi	10h44m	24°55'	9.9
M95	Leo	10h44m	11°42'	9.7
M96	Leo	10h47m	11°49'	9.3
M105	Leo	10h48m	12°35'	9.3
NGC 3521	Leo	11h06m	-0°02'	9.0
NGC 3621	Hya	11h18m	-32°49'	9.6
M65	Leo	11h19m	13°06'	9.3
M66	Leo	11h20m	12°59'	8.9

Charles Messier left NGC 3115 out of his famous catalog, but there's no way this bright galaxy escapes our list. CHRIS SCHUR

NOT ONLY IS the Spindle Galaxy (NGC 3115) the showpiece of the constellation Sextans, it's one of the sky's brightest galaxies. In fact, observers can hardly believe Charles Messier failed to include it in his catalog.

NGC 3115 is the prototype S0 galaxy, a class that American astronomer Edwin Hubble used to bridge the gap between the flattest ellipticals and spirals. Such objects have a large central bulge and long extensions (like the type of spindle that holds thread or yarn) but no spiral arms.

This galaxy is so bright that you can spot it through binoculars or a finder scope. Through a 4-inch telescope, you'll see an object three times as long as it is wide with a bright center. Through a 12-inch scope at 300x, the central bulge appears more distinct, an oval bulge surrounds the center, and a faint oval glow surrounds the entire object.

You'll find the Spindle Galaxy 3.2° east of magnitude 5.1 Gamma (γ) Sextantis.

LOOKS LIKE I should pick a Messier galaxy from this group, so how about M100? Messier's contemporary, Pierre Méchain, discovered it March 15, 1781. It ranks as one of the brightest galaxies in the Coma-Virgo cluster, and it's a great target for amateur telescopes. It lies 8.3° east of magnitude 2.1 Denebola (Beta Leonis), or 1.9° east-northeast of the magnitude 5.1 star 6 Comae Berenices.

Through an 8-inch scope at low to medium power, look for a haze about 4' long. You won't see this galaxy's spiral arms until you crank the magnification past 200x, and then only on the best nights. The arms appear as brighter regions just to the east and west of the nucleus.

Through a 12-inch telescope, you'll trace the spiral structure twice as far from the core. Two faint dwarf galaxies lie to the north and east. Magnitude 13.9 NGC 4322, to the north, appears to be M100's true companion, while magnitude 13.3 NGC 4328 lies in the foreground to the east.

Designation	Con.	R.A.	Dec.	Mag.
NGC 3628	Leo	11h20m	13°35'	9.5
M109	UMa	11h58m	53°22'	9.8
NGC 4214	CVn	12h16m	36°20'	9.8
NGC 4236	Dra	12h17m	69°28'	9.6
M99	Com	12h19m	14°25'	9.9
M106	CVn	12h19m	47°18'	8.4
M61	Vir	12h22m	4°28'	9.7
M100	Com	12h23m	15°49'	9.4
NGC 4365	Vir	12h24m	7°19'	9.6
M84	Vir	12h25m	12°53'	7.2

Two satellite galaxies — NGC 4328 and NGC 4323 — can be spotted at the 9- and 12-o'clock positions outside of M100's bright spiral. BOB FERA

Often compared to the Large Magellanic Cloud, NGC 4449 has twice the amount of star formation as the LMC, probably triggered by a recent merger or close pass with another galaxy. JOHN AND CHRISTIE CONNORS/ADAM BLOCK/NOAO/AURO/NSF

Designation	Con.	R.A.	Dec.	Mag.
M85	Com	12h25m	18°11'	9.1
NGC 4395	CVn	12h26m	33°33'	10.2
M86	Vir	12h26m	12°57'	8.9
NGC 4449	CVn	12h28m	44°06'	9.6
M49	Vir	12h30m	8°00'	8.4
M87	Vir	12h31m	12°23'	8.6
NGC 4490	CVn	12h31m	41°39'	9.8
M88	Com	12h32m	14°25'	9.6
NGC 4535	Vir	12h34m	8°12'	10.0
NGC 4559	Com	12h36m	27°58'	10.0

THIS GROUP FEATURES several of my top 10 favorites, such as the Needle Galaxy (NGC 4565) and the Sombrero Galaxy (M104). But right at the top of my chart is the Whale Galaxy (NGC 4631). At first glance, its bulging core and asymmetrical material distribution don't lead you to believe you're looking at an edge-on spiral. Yet this object is one of the sky's brightest edge-on galaxies.

Through 4- to 6-inch scopes, you'll see an imperfect lens shape that's bigger and brighter on one side. Larger scopes will reveal NGC 4631's companion — dwarf spheroidal galaxy NGC 4627, which sits 2.5' northwest. NGC 4627's gravity has distorted the Whale's once-classic spiral structure.

For NGC 4631, the close passage of the smaller galaxy really has stirred things up. Its central region is a maelstrom of star formation. Huge clumps of stars, visible through 12-inch or larger telescopes, lie all along the spiral arms. If you're lucky enough to observe it through a scope with an aperture bigger than 16 inches, look for dark areas made of dust and cold gas amid the bright patches.

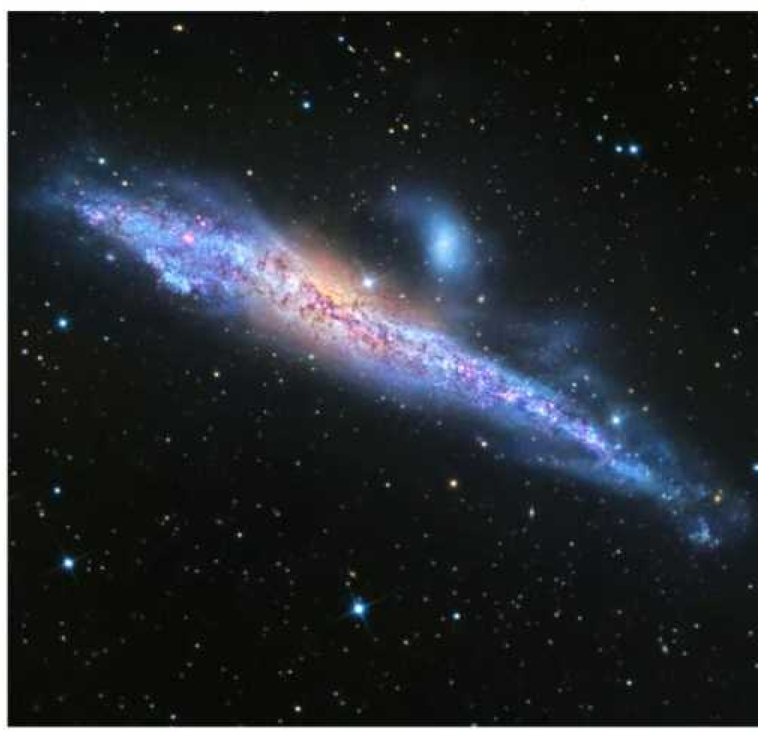
Designation	Con.	R.A.	Dec.	Mag.
NGC 4565	Com	12h36m	25°59'	9.6
M90	Com	12h37m	13°10'	9.5
M58	Vir	12h38m	11°49'	9.7
M104	Vir	12h40m	-11°37'	8.0
M59	Vir	12h42m	11°39'	9.6
NGC 4631	CVn	12h42m	32°32'	9.2
NGC 4636	Vir	12h43m	2°41'	9.5
M60	Vir	12h44m	11°33'	8.8
NGC 4665	Vir	12h45m	3°03'	10.5
NGC 4697	Vir	12h49m	-5°48'	9.2

I THINK YOU'LL like our next object, irregular galaxy NGC 4449, just because it looks so different. You'll find it 2.9° north-northwest of magnitude 4.2 Chara (Beta Canum Venaticorum). The galaxy's high surface brightness makes it easy to observe.

Astronomers classify NGC 4449 as a Magellanic-type galaxy because it appears similar to the Large Magellanic Cloud. Both galaxies have large stellar bars running through them.

Through an 8-inch telescope, you'll see NGC 4449's unusual rectangular shape. It has a bright, concentrated nucleus that also looks rectangular. Crank the magnification past 250x, and examine the irregular halo outside this galaxy's core.

If your seeing is good, an 11-inch scope will help you spot several concentrations of star-forming activity. The main one lies to the north, but a smaller one is just south of NGC 4449's core. Larger telescopes will bring out more detail in the galaxy's central star-forming region.



NGC 4631's explosion of star formation gives rise to the warm colors of ionized hydrogen near the Whale Galaxy's midsection. R. JAY GABANY

The supermassive black hole at the center of NGC 4945 is shrouded in dust and actively consuming material from its host, making this target a Seyfert galaxy. DON GOLDMAN

ALTHOUGH I'D LOVE to spend a whole page talking about the Whirlpool Galaxy (M51), let me instead direct your gaze to Caldwell 83, otherwise known as NGC 4945.

This treat sits only 0.3° east of magnitude 4.8 Xi[1] (ξ^1) Centauri. NGC 4945 is a huge, bright, nearly edge-on barred spiral oriented northeast to southwest that looks great through any size telescope. The galaxy shows even illumination across its surface except at its ends. The northeastern one glows brighter.

Through a 12-inch or larger scope at 300x, look for a dark indentation near the northeastern end. The elliptical NGC 4976 lies 0.5° east and shines a magnitude and a half fainter.

Designation	Con.	R.A.	Dec.	Mag.
NGC 4699	Vir	12h49m	-8°40'	9.5
NGC 4725	Com	12h50m	25°30'	9.4
M94	CVn	12h51m	41°07'	8.2
M64	Com	12h57m	21°41'	8.5
NGC 4945	Cen	13h05m	-49°28'	9.3
NGC 5005	CVn	13h11m	37°04'	9.8
M63	CVn	13h16m	42°02'	8.6
NGC 5102	Cen	13h22m	-36°38'	9.6
NGC 5128	Cen	13h25m	-43°01'	6.8
M51	CVn	13h30m	47°14'	8.4

Designation	Con.	R.A.	Dec.	Mag.
NGC 5195	CVn	13h30m	47°16'	9.6
M83	Hya	13h37m	-29°52'	7.5
NGC 5247	Vir	13h38m	-17°53'	10.0
M101	UMa	14h03m	54°21'	7.9
NGC 6221	Ara	16h53m	-59°13'	9.9
NGC 6744	Pav	19h10m	-63°51'	9.0
NGC 6822	Sgr	19h45m	-14°48'	8.2
NGC 6946	Cep	20h35m	60°09'	8.8
NGC 7331	Peg	22h37m	34°25'	9.5
NGC 7793	Scl	23h58m	-32°35'	9.2

The Southern Pinwheel (M83), in addition to its striking spiral structure, has the distinction of hosting no less than six known supernovae, a record tied by M61 and beaten only by NGC 6946. R. JAY GABANY

TO OBSERVE ALL the galaxies in this final group, you'll be covering a huge swath of sky. That's because within this range of right ascensions, you'll find the so-called Zone of Avoidance, a quaint term that represents the Milky Way — specifically the dust and gas it contains that blocks the light from distant galaxies.

Well, let's end with a bang. Dubbing a galaxy the "Southern Whirlpool" puts a lot of pressure on it to perform visually. For M83, that's no problem. Some observers rate this galaxy the finest barred spiral visible to northern observers. You can find it 7.2° west-southwest of magnitude 3.3 Pi (π) Hydrae.

The Southern Whirlpool Galaxy appears nearly face-on, so you'll see its spiral structure through telescopes with apertures as small as 6 inches. The core is small and round, and the bar extends to the northeast and southwest. Both spiral arms are easy to see, but the one that wraps southward from the bar's northeastern end shows up better. Through 12-inch and larger scopes, you'll see large clumps of stars and star-forming regions along the arms.

Astronomy magazine 2016 Star Products

Astronomy's seventh annual

STAR PRODUCTS

by Phil Harrington

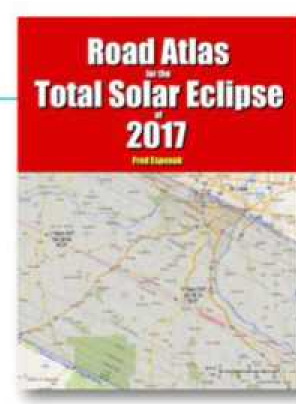
Once again, it's time to unveil our annual list of Star Products. We have scoured the marketplace looking for astronomy-specific goodies that represent the best in innovative design, breakthroughs in technology, or great bangs for the buck. Here are our top 35, presented in alphabetical order by company.

1 ASTRO-TECH
5.1-inch refractor

A 5-inch apochromatic refractor is a wonderful instrument for viewing and photographing, but it usually carries a not-so-wonderful price tag. Astro-Tech's new AT130 EDT f/7 ED Triplet OTA retails for less than half of some competitors' refractors, yet doesn't scrimp on quality. The heart of the telescope is its fully multicoated triplet apochromatic objective lens, which uses an extra-low-dispersion (ED) central element. The 130 EDT also comes with a dual-speed 2.5" rotatable rack-and-pinion focuser; a 2", dielectrically coated star diagonal; and a white and black powder-coated aluminum tube.

2 ASTROPIXELS
Maps of the eclipse path

Next August's total solar eclipse is the first to cross the contiguous United States since 1979. It's no wonder so many people are already making plans. But how do you know where to go and how to get there? If you will be driving, eclipsophile Fred Espenak's detailed *Road Atlas for the Total Solar Eclipse of 2017* is a must-have. The atlas plots the entire coast-to-coast path on street atlas maps that show both major and minor roads, towns and cities, rivers, lakes, parks, and more.



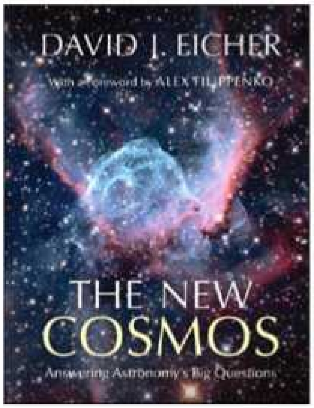
3 BAADER PLANETARIUM
Sun filters

Baader's AstroSolar Safety Film is made from a heat-annealed polymer film that reduces internal reflection. The company also designs its cells to keep the film stress-free no matter the temperature, to ensure uncompromised image quality. Filters are available for telescopes ranging in aperture from 3 to 11 inches.

4 CAMBRIDGE UNIVERSITY PRESS
Star atlas

Every now and then, a new star atlas appears that sets the standard for all to come. *Interstellarum Deep Sky Atlas* by German authors Ronald Stoyan and Stephan Schurig is just such an atlas. Scattered among the stars, which are plotted down to magnitude 9.5, are literally every deep-sky object visible in moderate to large amateur telescopes. In addition to the Messier, NGC, and IC lists, *Interstellarum Deep Sky Atlas* includes all Abell planetaries, Hickson galaxy groups, Arp galaxies, Barnard dark nebulae, and many other catalogs — all in a single spiral-bound volume. Two versions are available: The desk edition is printed on heavy paper stock, while the field edition is printed on waterproof and tear-resistant Polyart, a durable polyethylene foil that feels like paper.

5 CAMBRIDGE UNIVERSITY PRESS
Astronomy book



Carl Sagan's landmark book, *Cosmos*, inspired a generation of astronomy enthusiasts in a way that few other books ever had. One such fan was *Astronomy*'s editor, David J. Eicher. Now, nearly four decades after the original, Eicher has written his own book inspired by Sagan's original. *The New Cosmos: Answering Astronomy's Big Questions* explores the latest findings and discoveries made by astronomers, planetary scientists, and cosmologists that were unimagined at the time of Sagan's book. Eicher takes the reader on a fascinating journey to explore the cosmos, from our neighbors in the solar system to the mysteries of dark matter and dark energy, and then to the ultimate fate of the universe. And he writes in a friendly, accessible way that readers will appreciate and enjoy.

6 CARSON OPTICAL
Universal smartphone optics adapter

Smartphones are a ubiquitous part of our lives, and as they evolve, their built-in cameras become better and better. Many companies make adapters to attach these phones to both telescopes and binoculars. This one from Carson may be the easiest to use and the most versatile. Two latches hold the phone in place, while self-centering, spring-loaded clamps grab the eyepiece. It's designed to fit just about every popular smartphone made today, except for the oversized iPhone 6 Plus.

Phil Harrington *is an* Astronomy *contributing editor and author of* Cosmic Challenge: The Ultimate Observing List for Amateurs *(Cambridge University Press, 2010).*

7 CELESTRON
10mm Ultima Duo Eyepiece

This two-in-one optical powerhouse combines a proven eyepiece design, perfect for moderate magnification visual use, with a built-in T-adapter for astroimaging. Visually, the eyepiece's 68° apparent field of view, 20 millimeters of eye relief, and multicoated optics produce sharp views. Want to photograph what you're seeing? Remove the rubber eyeguard to reveal industry-standard T-threads. Attach your CCD or DSLR camera (with a T-ring, sold separately), and you're ready to shoot.

8 CELESTRON
20x binoculars

Celestron's SkyMaster Pro 20x80 Binocular is an excellent choice for anyone looking for giant binoculars designed specifically for astronomical viewing. Thanks to BaK-4 prisms, nitrogen-purged barrels, and fully multicoated optics, images are sharp, full of contrast, and fog-free. The built-in tripod adapter not only attaches the binocular to a tripod, it can also hold a red-dot finder, sold separately, for easier aiming. To top it all off, the eyepieces are threaded to accept standard 1¼" filters.

9 CELESTRON
Smartphone controller

Untangling cables in the dark as you try to enjoy some quiet time at the eyepiece will be a thing of the past, thanks to Celestron's SkyPortal WiFi Module. Rather than plugging in a wired hand controller for a go-to telescope, the SkyPortal connects directly to your smartphone or tablet for wireless control. Available for iOS and Android devices, the SkyPortal app lets you find an object you're interested in viewing by first tapping the screen to identify it, and then again to make the telescope slue directly to it. The SkyPortal WiFi Module works with all current Celestron computerized telescopes and some older models.

10 DAYSTAR
H-line Filter

To see the Sun in all its glory, you need to view it through filters that isolate specific wavelengths. DayStar's Calcium Quark filter shows the Sun at one precise wavelength: 3968.5 angstroms (393.4 nanometers). While most other calcium filters focus on the Ca-K line (3934 angstroms), the Ca-H line is slightly closer to the visual spectrum and easier for most people to see. This makes it ideal for studying active regions in the Sun's chromosphere above sunspots, such as plages. These filters should be used only with refractors with focal ratios of f/7 or longer and need a dielectric "hot mirror" UV/IR cut filters placed before a Barlow or diagonal. This reflects ultraviolet and infrared energy back out of the scope, but passes the calcium wavelengths. DayStar recommends adding a neutral-density solar film on apertures above 6 inches or for long-term use.

11 DENKMEIER OPTICAL
3-D eyepieces

Short for "Lederman-Optical-Array," Denkmeier's L-O-A 21 3-D eyepieces are unique among today's myriad eyepieces. Designed specifically for binoviewers, the 21mm L-O-A 21s create a striking faux three-dimensional effect across their 65° apparent field of view that transforms flat fields into views with perceptible levels of depth. To do this, the eyepieces must be used as a matched set. That's because one of the eyepieces incorporates a special "array" of five small squares of a special optical glass. By rotating the arrayed eyepiece, the observer can control the perceived depth as well as "move" the target between foreground and background.

12 EMERALD BAY SOFTWARE
Observing app

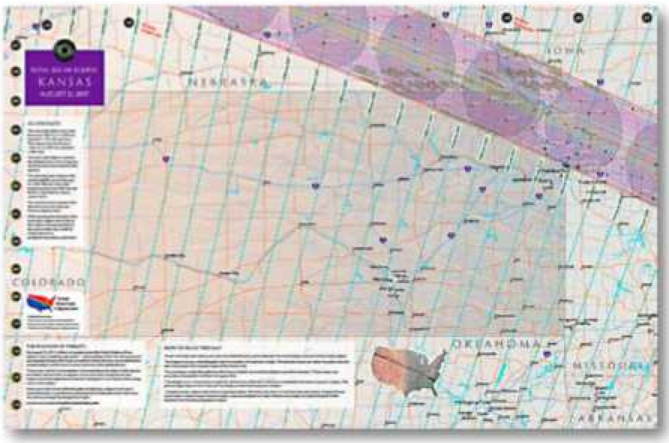
Most observers maintain a logbook in one form or another to memorialize viewing sessions. StarLog, an iPad app, lets you easily record a variety of statistical data, such as location, equipment, observations, and weather conditions on multiple, configurable screens. Later, results can be sorted and readily compared with previous sessions.

13 EXPLORE SCIENTIFIC
Reflecting telescope

Explore's 16-inch Truss Tube Dobsonian nicely exemplifies the "less is more" concept that has become so popular among today's large-aperture scopes. Not only does the scope set up and break down easily without tools, its minimalist design fits nicely into small cars. Standard accessories include a 2" focuser, an LED red-dot finder, a soft light baffle to shield the optical path from spurious light, and two cooling fans. Thanks to aluminum components optimized for maximum stiffness and minimal weight, the fully assembled scope tilts the scale at just over 88 pounds (40 kilograms). Smaller 10- and 12-inch versions are also available.

14 FORNAX MOUNTS
Travel mount

For guided astrophotography on the go, Fornax Mounts offers the LighTrack II tracking head as the perfect companion. Once attached to a heavy-duty photographic tripod and polar aligned, the LighTrack II will guide your DSLR or lensed CCD imager across the sky for up to two hours. The LighTrack II weighs less than 3 pounds (1.4kg), yet boasts a carrying capacity of up to 10 pounds (4.5kg).



15 GREAT AMERICAN ECLIPSE
Eclipse path maps

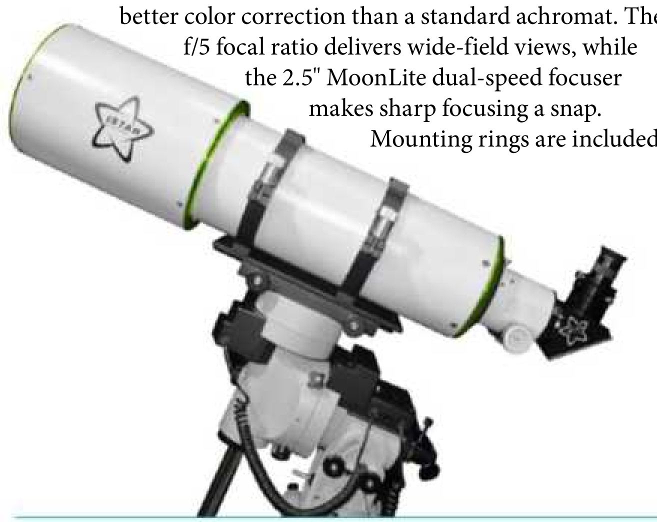
If you prefer detailed road maps of individual states for next year's eclipse, the ones created by Michael Zeiler, and available through his website, www.greatamericaneclipse.com, are second to none. Whether purchased individually or as a complete 14-map set, these 11-by-17-inch (28-by-43 centimeter) maps are the perfect planning tool and travel companion to see the eclipse. Load up the old Wagon Queen Family Truckster, and you're off on a great family vacation. Just don't tell Cousin Eddie.

16 HOTECH
Collimator

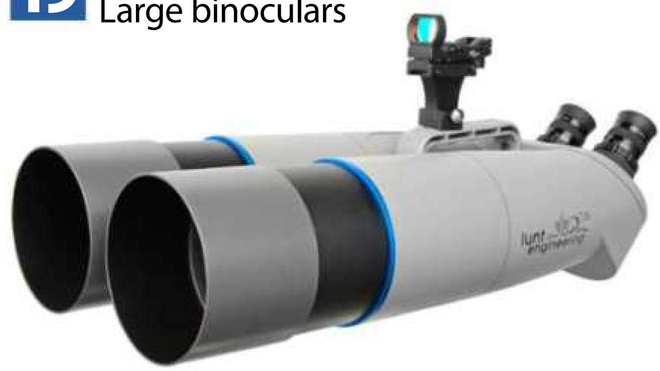
When you have a proven winner, you continue the run. HOTECH based its HyperStar Laser Collimator on its Advanced CT Laser Collimator technology. Because this device allows you to align your telescope in a controlled indoor environment, you can maximize your imaging time. HOTECH designed the HyperStar Laser Collimator to work on scopes with HyperStar installed or on prime-focus telescopes. The company made it easy to align the focal plane by referencing the reflection of the central laser. And the three parallel lasers help you to place the final optical train axis into perfect alignment.

18 ISTAR OPTICAL
6-inch refractor

We featured iStar's Ares WFT 150-5 R30 in 2013. Now, three years later, iStar has introduced its successor, the Ares WFX 150-5 R50. Like the previous model, the WFX 150-5 uses an oversized doublet objective lens stopped down to 150mm for better color correction than a standard achromat. The f/5 focal ratio delivers wide-field views, while the 2.5" MoonLite dual-speed focuser makes sharp focusing a snap. Mounting rings are included.



19 LUNT ENGINEERING
Large binoculars



The Lunt 100mm ED APO Large Format Binoculars will catch your eye(s) in more ways than one. Each objective lens consists of two 4-inch-diameter air-spaced ED elements for superior color correction. Pair them with a fully multicoated optical system, and you have the makings of a great viewing experience. The binoculars come with two 20mm eyepieces (27.5x), which you can easily swap out of the individual helical focusers and replace with standard 1¼" eyepieces.

17 IOPTRON
Mount

iOptron is one of the leading manufacturers of sophisticated portable mounts. One of the first to enter this burgeoning field with its Cube mount, the company continues to innovate with the recent introduction of the AZ Mount Pro.

Designed for telescopes weighing up to 33 pounds (15kg), this is a compact mount that features full computer control, a rechargeable lithium-ion battery, and iOptron's "level-and-go" technology for simplified setup. All this in a mount that weighs just 13 pounds (5.9kg). The company also includes an AC charger, cables, and a 10-pound (4.5kg) counterweight. The 6-inch (15cm) dual dovetail base that comes with it accepts both Losmandy- and Vixen-style mounting plates. The optional tripod adds $300 to the price.

20 LYMAX
Telescope cooler

To achieve optimal performance, a telescope's optics must match the ambient outdoor temperature. Sealed-tubed instruments, such as Schmidt-Cassegrains, can take hours to acclimate. To help speed up the process, Lymax offers the R3 SCT Cooler. Insert the neck of the cooler into the focuser tube and plug the fan into a USB port, and filtered air blows into the optical tube — but not directly onto the optics to minimize the possibility of dust infiltration. The new R3 model is manufactured using 3-D printing. This means that even though it is billed as an SCT Cooler, the R3 can also be custom-designed for Maksutovs and other instruments.

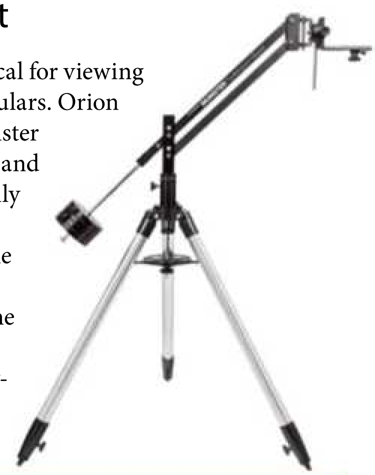
21 NEXDOME
Observatory

If you are looking for a small observatory to house your catadioptric or short-focus refractor, Nexdome's observatory may be your answer. Made of laminated layers of ABS overcoated with UV-resistant Solarkote, Nexdomes are designed to be lightweight, yet rugged enough to withstand extreme temperatures. The manually operated dome's diameter measures 80 inches (2m) across inside and 92 inches (2.3m) outside. It stands on walls 46 inches (1.2m) off the ground. The lightweight, modular design not only cuts shipping costs compared with some competitors, but it also simplifies assembly.

22 ORION TELESCOPES & BINOCULARS
4.5-inch telescope

In keeping with its policy of making quality scopes for beginners of all ages, Orion now offers the 4.5-inch f/4.4 FunScope Astro Dazzle Reflector Telescope. Modeled after the company's successful StarBlast tabletop scope, the Astro Dazzle will do just that for young and old alike. The steel tube comes wrapped in a colorful photo-collage of space objects. The scope mounts on a one-armed tabletop base that is easy to aim. Standard accessories include 25mm and 10mm eyepieces, a red-dot aiming sight, a Moon map, and more.

23 ORION TELESCOPES & BINOCULARS
Binocular mount



A good mounting system is critical for viewing through 70mm and larger binoculars. Orion addresses that need with its Monster Parallelogram Binocular Mount and Tripod. The Monster Mount easily aims binoculars weighing up to 15 pounds (6.8kg). Then, with the target in view, the parallelogram design lets you raise and lower the binocular eyepieces without affecting the aim. This lets everyone enjoy the view, no matter their height.

24 RAINBOW SYMPHONY
Solar filters

Once you know where you're going to see next year's total solar eclipse, the question becomes how to see it safely. To view the partial phases, you'll need a solar filter. Rainbow Symphony sells Eclipse Shades filters that come pre-mounted in cells custom-fit to slip over the outside of telescopes and lenses ranging in tube diameter from 50 to 101mm. The filters, made of black polymer film, produce a visually pleasing yellow-orange image, while safely reducing transmission to 0.001 percent or less.

25 RAINBOW SYMPHONY
Solar glasses

If you'd rather view the partial phases by eye alone, then Rainbow Symphony's Eclipse Shades Solar Eclipse Glasses are for you. They come in a variety of forms, including plastic-framed wraparound goggles and colorfully decorated cardboard glasses (minimum quantities apply for the latter).

26 REVOLUTION
Video camera

Astrovideography is a growing part of our hobby, thanks to the advent of lightweight video cameras that attach directly to a telescope's focuser. The most complete package sold today is the Revolution Imager. Built around Sony's ICX811 color sensor, the Revolution Imager weighs just 6 ounces (170 grams) and measures only 2.5 inches long by 1.5 inches square (6.4 by 3.8 centimeters). For about the same price as a premium eyepiece, you get everything you need, including a 7-inch LCD monitor, a 12-volt lithium-ion battery with charger to run both the camera and LCD screen, a 0.5x focal reducer to widen the field of view, a UV/IR filter, a hand-held remote control, and all cables. Once set up, images appear on the monitor in nearly real time and in amazing detail. By changing exposure settings on the hand controller, you can go immediately from viewing the lunar surface to displaying faint tendrils of nebulosity. Everything fits neatly into the included carrying case. The Revolution Imager is a standalone system; you don't need a computer.

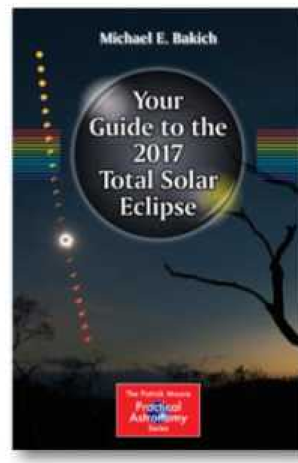
27 SIRIUS ASTRO PRODUCTS
Light shield

Smartphones, tablets, laptops, and digital cameras are as much a part of amateur astronomy today as telescopes. But they all have one drawback: bright screens. Not only do you have to dim them at night, but they also need to be red to preserve night vision. Sirius Astro Products has a simple but effective solution. Its custom-sized Red Eyes Cling Shields are made from thin, static-cling red vinyl that is the perfect shade and density of red. They are thick enough to last for years, probably longer than your smartphone contract, and yet thin enough to allow full touch-screen functionality.

28 SKYSHED
Observatory

SkyShed observatories are popular options for backyard installations. But sometimes you just need more elbow room. The new Pod Max may be just what you need. Designed with small groups or larger telescopes in mind, the Pod Max is built around a 12.5-foot (3.8m) diameter Fiberglas dome. Need some more room, maybe for a computer or worktable? The Pod Max's modular design makes it easy to add anywhere from one to six Max Bay bump-outs as needs arise.

29 SPRINGER
Total eclipse book



Astronomy Senior Editor Michael E. Bakich's *Your Guide to the 2017 Total Solar Eclipse* is a nearly 400-page tome about the total solar eclipse that will cross the United States on August 21, 2017. The author covers all aspects of the coming event, and a lengthy chapter gives details on important historical eclipses. He also includes some of the best places to see the event, what items to bring, how to observe the Sun safely, how to select the right binoculars or telescopes, projects you may want to undertake prior to eclipse day, and lots more.

30 STARLIGHT INSTRUMENTS
Focuser

If you want to upgrade the stock focuser that came with your Cassegrain or catadioptric telescope, the Feather Touch FTF3015B-A Feather Touch 3.0" Diameter Dual-Speed Focuser is the perfect choice. Like all focusers from Starlight Instruments, the FTF3015B-A's focus control is precise and buttery smooth. Dual-speed knobs allow for both coarse as well as 10-to-1 reduction fine focusing. Set the brake, and the position locks in place. The focuser is beautifully finished in gloss black with gold accents and comes with your choice of telescope-specific adapter.

ASTRONOMY'S STAR PRODUCTS

Astronomy magazine 2016 Star Products

#	COMPANY	PRODUCT	PRICE	WEBSITE
1	Astro-Tech	**5.1-inch refractor**	$1,799	www.astronomics.com
2	AstroPixels	**Maps of the eclipse path**	$14.99–$19.99	www.astropixels.com
3	Baader Planetarium	**Sun filters**	$65–$198	www.baader-planetarium.org
4	Cambridge University Press	**Star atlas**	$109.99–$244.99	www.cambridge.com
5	Cambridge University Press	**Astronomy book**	$24	www.cambridge.com
6	Carson Optical	**Universal smartphone optics adapter**	$44.79	www.carson.com
7	Celestron	**10mm Ultima Duo Eyepiece**	$129.95	www.celestron.com
8	Celestron	**20x binoculars**	$249.95	www.celestron.com
9	Celestron	**Smartphone controller**	$99.95	www.celestron.com
10	DayStar	**H-line filter**	$995	www.daystarfilters.com
11	Denkmeier Optical	**3-D eyepieces**	$599	www.denkmeier.com
12	Emerald Bay Software	**Observing app**	$24.99	www.emeraldbaysoftware.com
13	Explore Scientific	**Reflecting telescope**	$2,499.99	www.explorescientific.com
14	Fornax Mounts	**Travel mount**	569 euros	www.fornaxmounts.com
15	Great American Eclipse	**Eclipse path maps**	$10	www.greatamericaneclipse.com
16	HOTECH	**HyperStar Laser Collimator**	$515–$545	www.hotechusa.com
17	iOptron	**Mount**	$999	www.ioptron.com
18	iStar Optical	**6-inch refractor**	$2,795	www.istar-optical.net
19	Lunt Engineering	**Large binoculars**	$2,950	www.luntengineering.com
20	Lymax	**Telescope cooler**	$99.95	www.lymax.com
21	Nexdome	**Observatory**	$2,795	www.nexdome.com
22	Orion Telescopes & Binoculars	**4.5-inch telescope**	$179.99	www.telescope.com
23	Orion Telescopes & Binoculars	**Binocular mount**	$499.99	www.telescope.com
24	Rainbow Symphony	**Solar filters**	$19.95	www.rainbowsymphony.com
25	Rainbow Symphony	**Solar glasses**	$0.85–$19.95	www.rainbowsymphony.com
26	Revolution	**Video camera**	$299.99	www.revolutionimager.com
27	Sirius Astro Products	**Light shield**	$13.95–$16.95	www.siriusastroproducts.com
28	SkyShed	**Observatory**	$2,495–$2,995	www.skyshedpod.com
29	Springer	**Total eclipse book**	$34.99	www.springer.com
30	Starlight Instruments	**Focuser**	$645	www.starlightinstruments.com
31	StarSync	**Tracker**	$209.95	www.starsynctrackers.com
32	Stellarvue	**2.75-inch refractor**	$799	www.stellarvue.com
33	Tele Vue	**Eyepiece line**	$215	www.televue.com
34	Vixen Optics	**Mount**	$1,099	www.vixenoptics.com
35	Vixen Optics	**3.5mm eyepiece**	$299	www.vixenoptics.com

31 STARSYNC
Tracker

Based on the 1975 design by George Haig of Glasgow, Scotland, the StarSync Tracker is a neat, highly portable modified barn-door camera tracker for wide-field guided sky images. Stepper motors turn the machined aluminum platform, while the camera mount assembly lets you aim anywhere in the sky. You can polar align the mount easily by placing the optional green laser pointer into the integrated cradle. Power cables and other accessories are sold separately.

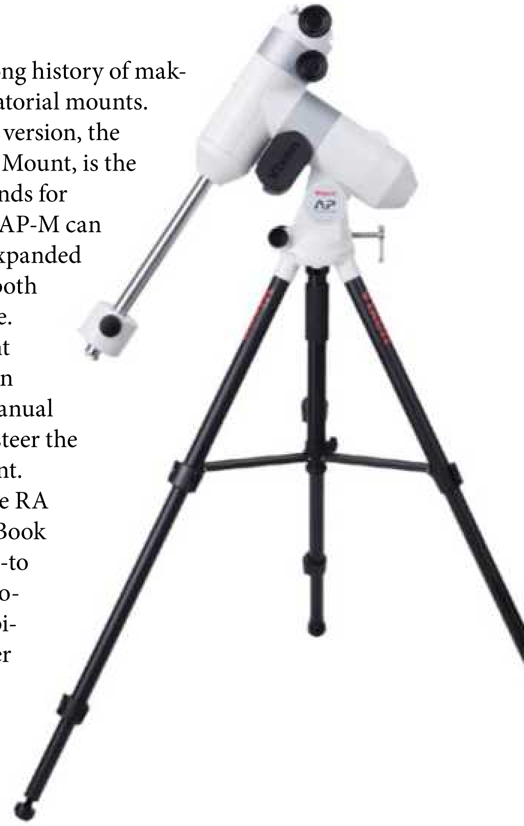
32 STELLARVUE
2.75-inch refractor

With a three-part objective lens that includes a central element of O'Hara FPL-53 glass for suppression of false color, Stellarvue's SV70T apochromatic refractor delivers tack-sharp images at a surprisingly affordable price. The machined aluminum tube glistens pure white, and comes outfitted with a dual speed rack-and-pinion focuser, a hinged mounting ring and rail, and a thickly padded airline carry-on case. The scope and rings together weigh just 5.6 pounds (2.5kg) and measure about 12 inches (30.5cm) long with the dew shield fully retracted.

33 TELE VUE
Eyepiece line

Capitalizing on the success of their Delos line of premium eyepieces, Tele Vue has introduced a smaller, less expensive version called the DeLite. DeLites come in six focal lengths: 18.2mm, 15mm, 11mm, 9mm, 7mm, and 5mm. All have 62° apparent fields of view and a generous 20 millimeters of eye relief. Of these, the 11mm is my favorite because of its balance between magnification and real field coverage. If you crave the perfect eyepiece (and who doesn't?) but are working on a limited budget, you will find any of these eyepieces DeLite-ful.

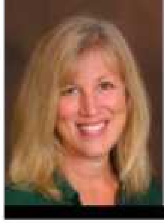
34 VIXEN OPTICS
Mount



Vixen Optics has a long history of making high-quality equatorial mounts. The company's latest version, the Advanced Polaris-M Mount, is the best yet. The "M" stands for "modular," since the AP-M can be customized and expanded to meet your needs, both now and in the future. Prefer a simple mount now? The base version includes dual-axis manual controls to help you steer the white-and-gray mount. Later, you can add the RA motor unit and Star Book One controller for go-to control. Finally, if photography is your ambition, the photo-guider module includes motorized dual-axis control. The AP-M can carry up to 13 pounds (5.9kg).

35 VIXEN OPTICS
3.5mm eyepiece

If you crave highly magnified views of the Moon and planets, Vixen's 3.5mm SSW eyepiece will not disappoint. Inside, seven multi-coated elements of lanthanum and exotic glass combine to deliver images of superior contrast and sharpness across the 83° apparent field of view. The retractable rubber eyecup offers comfortable viewing. Like all eyepieces in the SSW line, the 3.5mm fits 1¼" focusers.



ASTRO**SKETCHING**

BY ERIKA RIX

Capturing galaxies

For me, the allure of galaxy observing is teasing details out of the view. These stellar conglomerations come in a variety of shapes, ranging from featureless smudges to spirals or slivers of light with bulging centers. To capture galaxies' unique forms through sketching, it helps to become adept at using a blending stump.

Blending stumps are tightly rolled sticks of paper with pointed tips at both ends. Although they're primarily used for blending pencil markings, you can also draw with them. Simply rub the tip of the blending stump through a scrap patch of graphite, and then use it like you would a pencil. Use a photographic classification diagram for galaxies for practice before attempting this technique at the eyepiece.

The constellation Pegasus soars high in the sky this month and provides several galaxies to choose from. One of my targets was NGC 7814, an 11th-magnitude, edge-on spiral galaxy with an extensive central bulge. It lies 2.5° west-northwest of Algenib (Gamma [γ] Pegasi). Spanning 5.5' by 2.3', NGC 7814 is nicknamed "Little Sombrero" for its resemblance to the more-famous M104, the Sombrero Galaxy. But unlike its namesake, this galaxy's narrow dust lane is difficult to see without a large telescope under dark, pristine skies.

Through an 8-inch instrument, the Little Sombrero appears bright and elongated northwest to southeast with a 7th-magnitude star that lies 12' west-northwest of its center. You'll also see a pair of 9th-magnitude stars separated by 3' southwest of the galaxy. (I note these in my accompanying sketch.) The core becomes more condensed within the galaxy's halo through a 12-inch scope and is nearly stellar using a 16-inch scope.

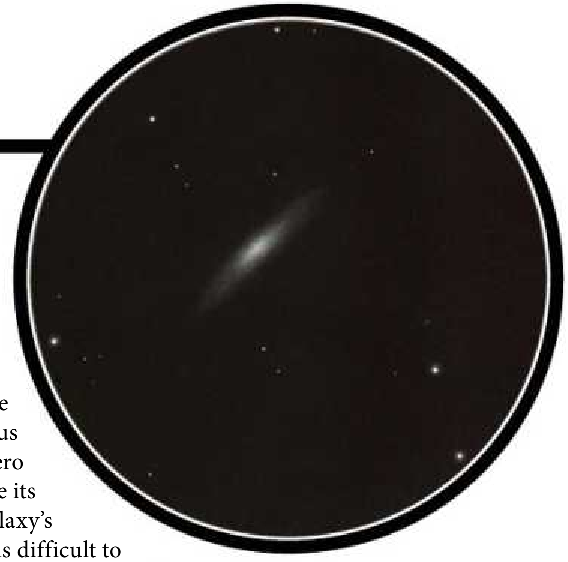
After plotting the stars in my sketch, I like to add the brightest region of the galaxy first with the blending stump. Then I add layers of graphite gradually to increase its density. As I near the edge, I use nearly all the graphite from the tip of my blending stump so that the halo's diffuse outer portions appear to vanish.

The next object, NGC 7479, is a barred spiral galaxy that lies 3° south of the 2nd-magnitude star Markab (Alpha [α] Pegasi). NGC 7479 reaches 4.1' by 3.1' across at 11th magnitude and sports a bright, conspicuous central bar. Observers have pegged it as the Propeller Galaxy because of its asymmetrical, S-shaped arms that spin counterclockwise and a radio jet that spins in the opposite direction.

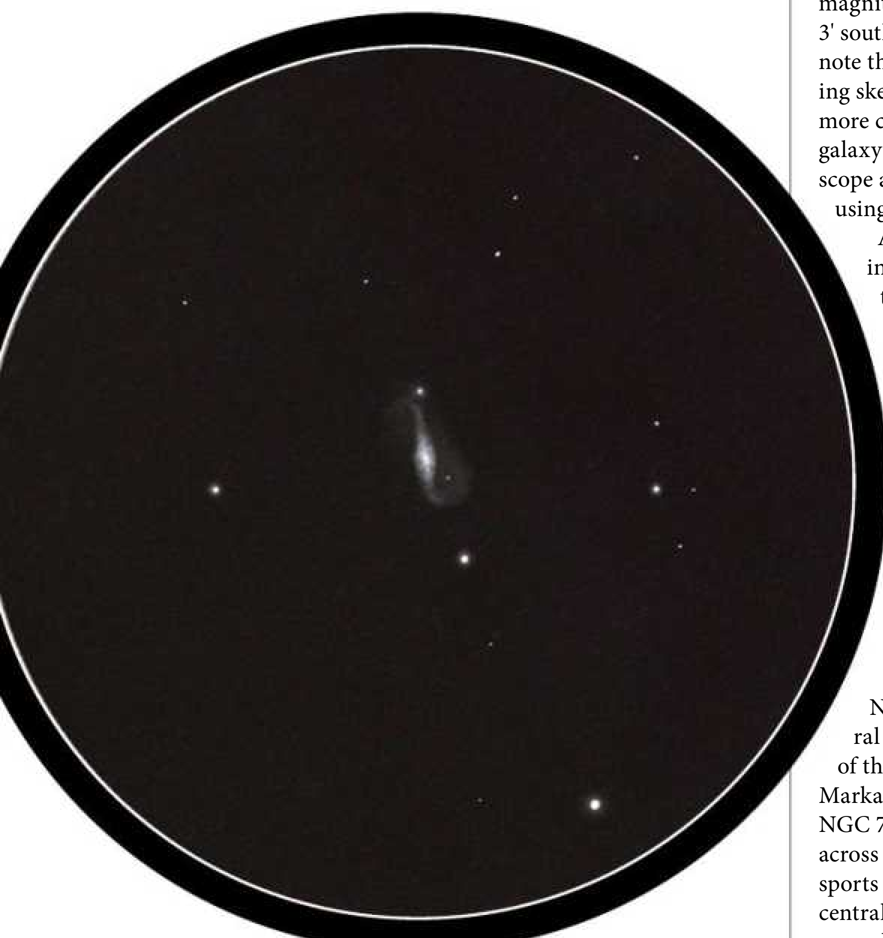
NGC 7479 appears through an 8-inch telescope as a north-south, elongated halo with a brightened center. An 11th-magnitude star shines 3' to its south-southwest. With a 12-inch scope, the ends of the bar begin to curve with hints of spiral arms. Bumping the aperture to 16 inches reveals a nearly stellar center. The faint arm flowing from the southern end of the bar curves westward to wrap around a 14th-magnitude star. Slight wisps of the northern extension will curve off to the east with averted vision.

After rendering the galaxy's bright central region, I used the excess graphite on my blending stump to extend the bar into the flowing S-shaped arms. My last touch was to add the halo's soft glow.

Questions or comments? Contact me at erikarix1@gmail.com.



NGC 7814 provides a good example of how to sketch using blending stumps. For both sketches, the author used a 16-inch reflector on a Dobsonian mount and a 21mm eyepiece for a magnification of 87x. She sketched on white printer paper with graphite pencils and a No. 2 blending stump. She scanned the sketches, then inverted them in Photoshop and softened the stars by adjusting the radius and threshold pixels within the "Dust & Scratches" setting. Both images are oriented so that north is up and west is to the right. SKETCHES BY ERIKA RIX



The Propeller Galaxy (NGC 7479) also has a wispy appearance well served by sketching using blending stumps.

BINOCULARUNIVERSE

BY PHIL HARRINGTON

Gems in Cygnus

Cygnus the Swan flies high in the western sky during the early evening hours this month. The Milky Way is especially bright in this area of the sky, often defying the choking grip that light pollution has on suburban skies. Many striking binocular targets are nestled in its gentle glow.

Let's begin at the crux of the Swan, the star Sadr. The name "Sadr" comes from the Arabic word for "chest," which describes its position within the celestial swan perfectly.

Also known as Gamma (γ) Cygni, Sadr is an ideal jumping-off point for our first target, open cluster M29. M29 floats a little less than 2° to the star's south-southeast. Charles Messier was first to lay eyes on it back in July 1764, when he described it as "a cluster of seven or eight very small stars … which one sees … in the form of a nebula." Through my 10x50s, M29 does indeed look like a tiny, rectangular nebula of grayish light. Moving up to my 16x70 giant binoculars resolves those stars Messier mentioned. They form a small dipper-shaped pattern that some liken to the Pleiades. Four of the cluster's brightest members create a rectangular bowl, while a fifth can be imagined as a stubby handle.

Cygnus holds a second Messier object that is easy to spot despite its more remote position in the constellation. M39 is one of my favorite early autumn open clusters. It lies 9°, or about 1.5 binocular fields, northeast of Deneb [Alpha (α) Cygni]. To find it, center your binoculars on Deneb and then slowly move northeastward along a meandering row of six irregularly spaced 4th- and 5th-magnitude stars. M39 is just beyond the easternmost star in that line. Look for a tiny, triangular grouping of about a dozen faint points. While M39 itself is weak in terms of the number of stars it holds, the rich surroundings demand that it be savored slowly. By sitting back and relaxing your eyes, you may get the illusion of depth, as if M39 were suspended in front of a blanket of more distant suns.

Cygnus holds many objects that put our eyes and our binoculars to the test. One of my favorites is the North America Nebula, NGC 7000. The North America Nebula is a large expanse of glowing hydrogen gas mixed with opaque clouds of cosmic dust just 3° east of Deneb and 1° to the west of 4th-magnitude Xi (ξ) Cygni.

Deneb was once believed to be the power source ionizing the hydrogen gas in NGC 7000, but more recent studies prove that the very hot 6th-magnitude star HD 199579, buried within the nebula, supplies the energy.

This celestial continent spans 2°, or four times the width of the Full Moon. This makes it too large to easily see through conventional telescopes. But the wide fields of our binoculars make them perfect for the task. In his classic work *Burnham's Celestial Handbook*, author Robert Burnham Jr. advised, "Binoculars show an irregular glow more than 1½° in diameter with the North American shape becoming unmistakable on a clear night." The nebula is so bright that under a very dark sky you can see it with naked eyes alone.

The brightest parts of the North America Nebula are "Mexico" and "Florida." Both jut into an "empty" expanse of dark nebulosity just east of Deneb in much the same way as their earthly counterparts mark the Gulf of Mexico's shoreline. Can you make them out?

I'd love to hear about your favorite binocular objects and feature your observations in future columns. Please send your suggestions to me at binophil@outlook.com.

Until next month, remember that two eyes are better than one.

Phil Harrington is a longtime observer and contributing editor of Astronomy.

The North America Nebula is a huge emission region that is easily visible in binoculars. CHRIS SCHUR

Open star cluster M29 is a petite group of stars that can be seen in good binoculars. BERNHARD HUBL

The big, bright, sprawling open cluster M39 shines in any binocular field of view. ANTHONY AYIOMAMITIS

FROM OUR INBOX

Another asteroid event?

Much of the article "New missions mine asteroid secrets" on p. 28 in the April issue of *Astronomy* was devoted to explaining how the orbital path of asteroids can be affected by the smallest of forces acting on it (such as the Yarkovsky effect). Yet in the same article, we read that the Japanese are going to attempt to blast a 33-foot hole in asteroid Ryugu to gather samples of the interior of the asteroid. I sincerely hope we are not sealing our own fate 200 to 300 years in the future by moving this asteroid ever so slightly from its current path through the solar system. At present, Ryugu and asteroid Bennu do cross Earth's orbit around the Sun, creating the potential for another asteroid event like eons ago. Could pushing Ryugu (or another equally interesting asteroid) ever so slightly into another orbital path have the unintended consequence that none of us hopes ever happens? Time will tell. **— Dale Ritzen**, Austin, Texas

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.*

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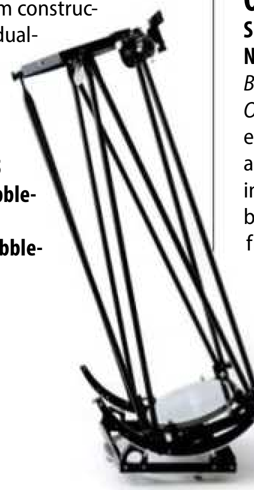

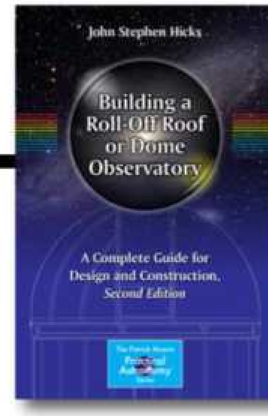

Observatory book

Springer-Verlag
New York

Building a Roll-Off Roof or Dome Observatory by John S. Hicks has entered its second edition. The author has expanded the text to include instructions for assembling an environmentally friendly observatory. The book outlines step-by-step construction of a typical building with detailed diagrams for each phase of construction.

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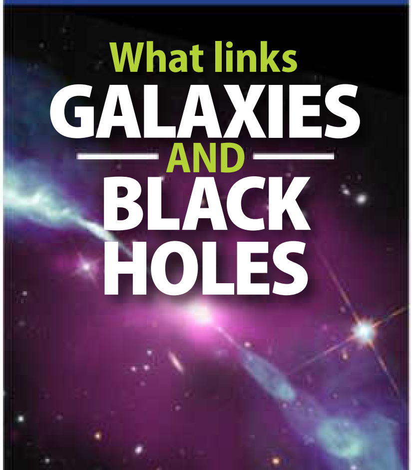
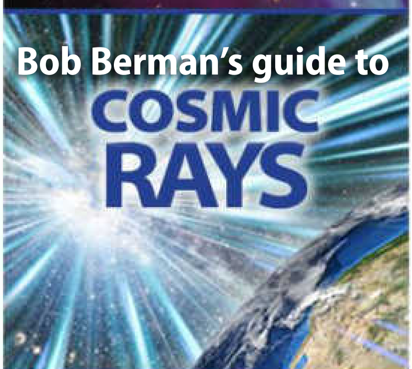
COMING IN OUR NEXT ISSUE



What links GALAXIES AND BLACK HOLES



Bob Berman's guide to COSMIC RAYS

Sizing up SPACE ROCKS

PLUS

- Meet astronomy's West Coast wizards
- How astronomers measure brightness
- Talk astronomy with your un-cosmic friends
- Putting iOptron's new mount to the test

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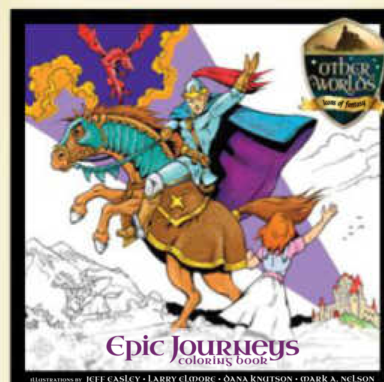

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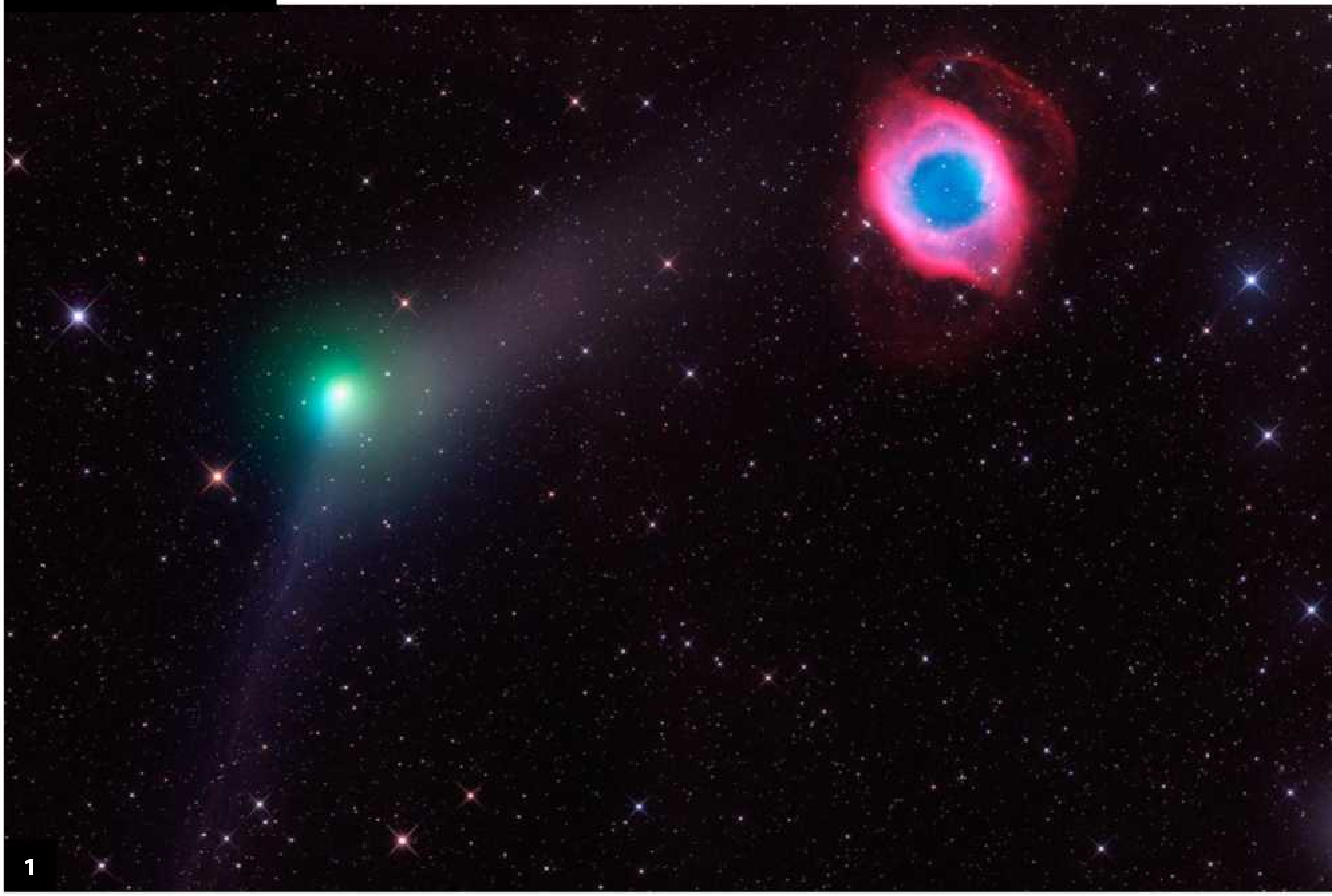

1. DRAMATIC ENCOUNTER
Comet Pan-STARRS (C/2013 X1) passes close to the Helix Nebula (NGC 7293) in Aquarius at 2h15m UT on May 6, 2016. **• *Gerald Rhemann***

2. SAPPHIRES ON VELVET
Open cluster NGC 6633 lies about 1,000 light-years away in the constellation Ophiuchus. It glows at magnitude 4.6 and spans 27', making it nearly as large as the Full Moon. **• *Dan Crowson***

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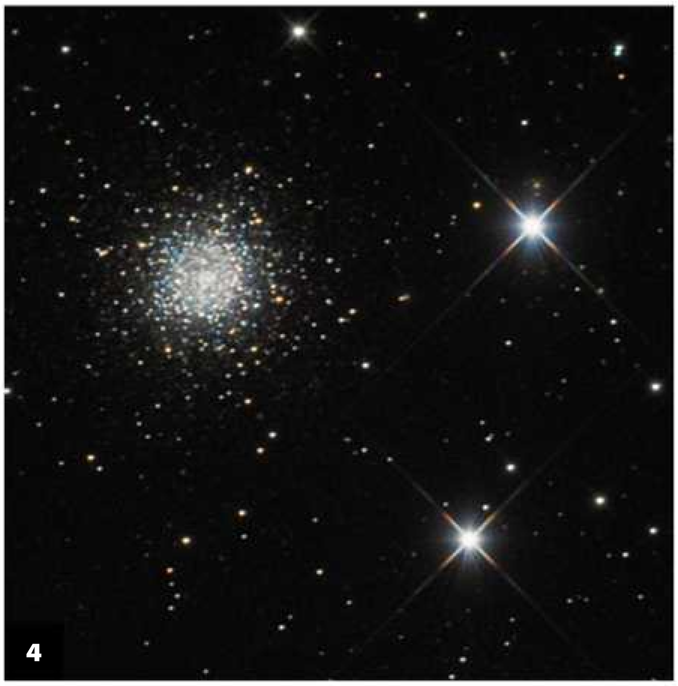

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3. CROWN OF GLORY
The Sun's corona during the March 9, 2016, total solar eclipse is displayed in great detail from Penyak Beach in Indonesia. This composite of 32 images also reveals the dark Moon's unseen face. ***• Don Sabers and Ron Royer/ processing by Miloslav Druckmuller***

4. STELLAR TRIANGLE
NGC 6229 is a globular cluster that exhibits intermediate rich concentrations of stars. It glows at magnitude 9.4, roughly 100,000 light-years away in Hercules. ***• Dan Crowson***

5. RECENT DISCOVERY
Hewett 1 is a large faint planetary nebula in Serpens. Amateur astronomers have rarely imaged it, which is understandable because researchers only found this object in 2003. ***• Rich Richins***

6. THE EYE OF SAURON
NGC 4151 is a magnitude 10.8 face-on spiral galaxy that looks like a menacing evil eye. It lies 62 million light-years away in the northern constellation Canes Venatici. ***• Adam Block/Mount Lemmon SkyCenter/University of Arizona***

7. PILLARS OF CREATION
Devasthal, Uttarakhand, India is the site for the 3.6-meter Devasthal Optical Telescope, which will be the largest in the country. This star-trail shot, taken at the site, spans 9 hours and 41 minutes. During that time Polaris (Alpha [α] Ursae Minoris) has revolved around the North Celestial Pole by 145°. ***• Ajay Talway***

8. EARTH-SKY SPECTACLE
This dramatic aurora appeared February 1, 2016, around 1 A.M. Alaska Time near the town of Palmer. Aurorae appear when charged particles emitted by the Sun enter Earth's upper atmosphere and interact with the gas there. • ***Matt Skinner***

9. QUITE A STRETCH
NGC 6872 is a highly elongated barred spiral galaxy in the southern constellation of Pavo, the Peacock. Measurements reported just this year show it to be a whopping five times larger than our Milky Way, making it the current record holder. The distortion we see is due to interaction with the tiny galaxy IC 4970, which lies just above the large spiral. • ***Don Goldman***

10. LUNAR LANDSCAPE
The imager captured this wide-field shot of the Moon's northern limb April 15, 2016, at 0h17m UT. Although a few mountainous regions are visible, this region contains mainly vast lava-filled lunar "seas" pockmarked by impact craters. • ***Jamey Jenkins***

11. RED STATE
The California Nebula (NGC 1499) lies in the constellation Perseus. It's bright enough that sharp-eyed observers can spot it from a dark site. The nebula's luminous portion spans 100 light-years. • ***Bernard Miller***


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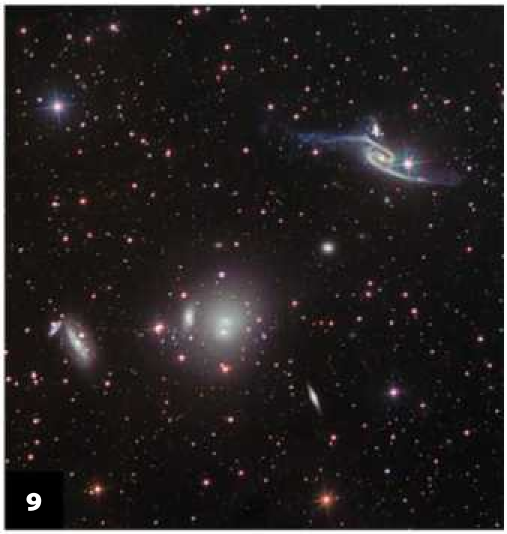
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BREAK THROUGH

Fit for a queen

Blowing bubbles may seem like child's play, but some of our galaxy's most prominent citizens enjoy the pastime, too. The massive star SAO 20575 in Cassiopeia the Queen blows a powerful stellar wind that sculpts the intricate contours of the Bubble Nebula (NGC 7635). Ultraviolet radiation pouring from the star's surface then excites the nebula's atoms and causes them to glow. The Bubble lies roughly 7,000 light-years from Earth and spans some 7 light-years; SAO 20575 is the brightest point of light inside it. Scientists captured the four images that make up this mosaic with the Hubble Space Telescope's Wide Field Camera 3. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

ONE VERSATILE PACKAGE. INFINITE POSSIBILITIES.

The 2017 total solar eclipse is just around the corner, and Sky-Watcher USA wants to make sure you're prepared for this once-in-a-lifetime event. The Sky-Watcher Virtuoso comes equipped with a 90mm Mak-Cassegrain optical tube and a white-light solar filter, giving aspiring astronomers the opportunity to view everything from planets to the sun. Thousands of astronomers will be traveling from all over the country to view the eclipse, making this lightweight, carry-on ready motorized telescope a must-have for anyone traveling to view the Eclipse.

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

December 2016: Evening planet lineup

The first half of December finds three bright planets strung out nicely in the western evening sky. **Mercury** hangs closest to the horizon and never really escapes the twilight glow. The innermost planet reaches greatest elongation on December 11, when it lies 21° east of the Sun and appears 9° high in the west-southwest 45 minutes after sunset. Mercury shines at magnitude –0.5 and is quite easy to spy with the naked eye once you know where to look. If you don't see it right away, use binoculars to home in on the world.

When viewed through a telescope, Mercury grows more interesting after December 15. It then shows a lovely crescent phase on a disk that measures 8" across. The planet draws closer to the Sun after midmonth and disappears around the 22nd. It passes between the Sun and Earth at inferior conjunction on the 28th.

Next along the line is brilliant **Venus**. Gleaming at magnitude –4.3, it is by far the brightest point of light in the sky and dominates the western scene after sunset. The planet spends December's first week in eastern Sagittarius before crossing into Capricornus on the 7th. It then traverses most of that constellation, ending the year on the doorstep of Aquarius.

A telescope reveals Venus as a modestly sized gibbous disk. The planet appears 17" across and two-thirds lit on December 1; by the 31st, its disk spans 21" and the Sun illuminates 57 percent of it.

December's third evening planet is **Mars**. Although it appears just 1 percent as bright as Venus (shining at magnitude 0.8 at midmonth), it nevertheless is quite easy to spot. The planet still ranks among the 10 brightest objects in the evening sky and stands out for its distinctive orange-red color. Mars begins December in central Capricornus and crosses into Aquarius around midmonth.

Unfortunately, the planet doesn't offer much for telescope users. Little, if any, surface detail will show up on its 6"-diameter disk.

A beautiful crescent Moon adds to the evening scene during December's first week. On the 1st, Luna passes 7° north of Mercury. You'll likely need binoculars to see the 3-percent-lit crescent low in evening twilight. You won't have any such problems two nights later, when the waxing crescent perches 6° north of Venus. The Moon then appears 13 percent illuminated and should show plenty of earthshine on its unlit portion. And two nights after that (on the 5th), a 30-percent-lit Luna stands 3° north of Mars.

Jupiter becomes a prominent morning object in December. It rises more than two hours before the Sun at the beginning of the month and gains another 30 minutes or so with each passing week. Jupiter lies in central Virgo, roughly 5° northwest (to the left) of that constellation's brightest star, 1st-magnitude Spica. The giant planet shines at magnitude –1.8, so it appears more than 10 times brighter than the star.

The increasing altitude of Jupiter before dawn makes it an attractive target for those with telescopes. Watch for intricate atmospheric details on a disk that spans 34" at midmonth. Also keep an eye on the planet's four large moons as they change positions from night to night.

Saturn passes behind the Sun from our viewpoint on December 10. You might spot it low in the east-southeast on December's final few mornings, but much better views await observers in January.

The Moon occults Regulus on the morning of December 19 for observers in far southern and western Australia. From Perth, the 1st-magnitude star disappears behind the waning gibbous Moon's bright limb at 1:07 A.M. AWST and reappears from behind the dark limb 30 minutes later.

The starry sky

Southern Hemisphere observers don't have a lot of time to savor December's sky. The summer solstice takes place this month (at 10h44m UT on December 21), which means we experience the shortest nights of the year. And many locations keep daylight saving or summer time, so the sky does not grow completely dark until late in the evening.

Although the summer Milky Way does not inspire as much awe as the view in winter, scanning along the spine of our galaxy this month reveals a number of interesting objects. The best and brightest make fine targets through both binoculars and telescopes.

Two of my favorites are the open star clusters M46 and M47 in the constellation Puppis, the Stern of the great ship Argo. The pair lies about 13° east and 2° north of brilliant Sirius. They are, as their names suggest, objects from 18th-century French astronomer Charles Messier's famous list of objects that look like comets but are not. Messier first saw them in February 1771, although Italian astronomer Giovanni Hodierna (1597–1660) discovered M47 in the 17th century while observing from Sicily.

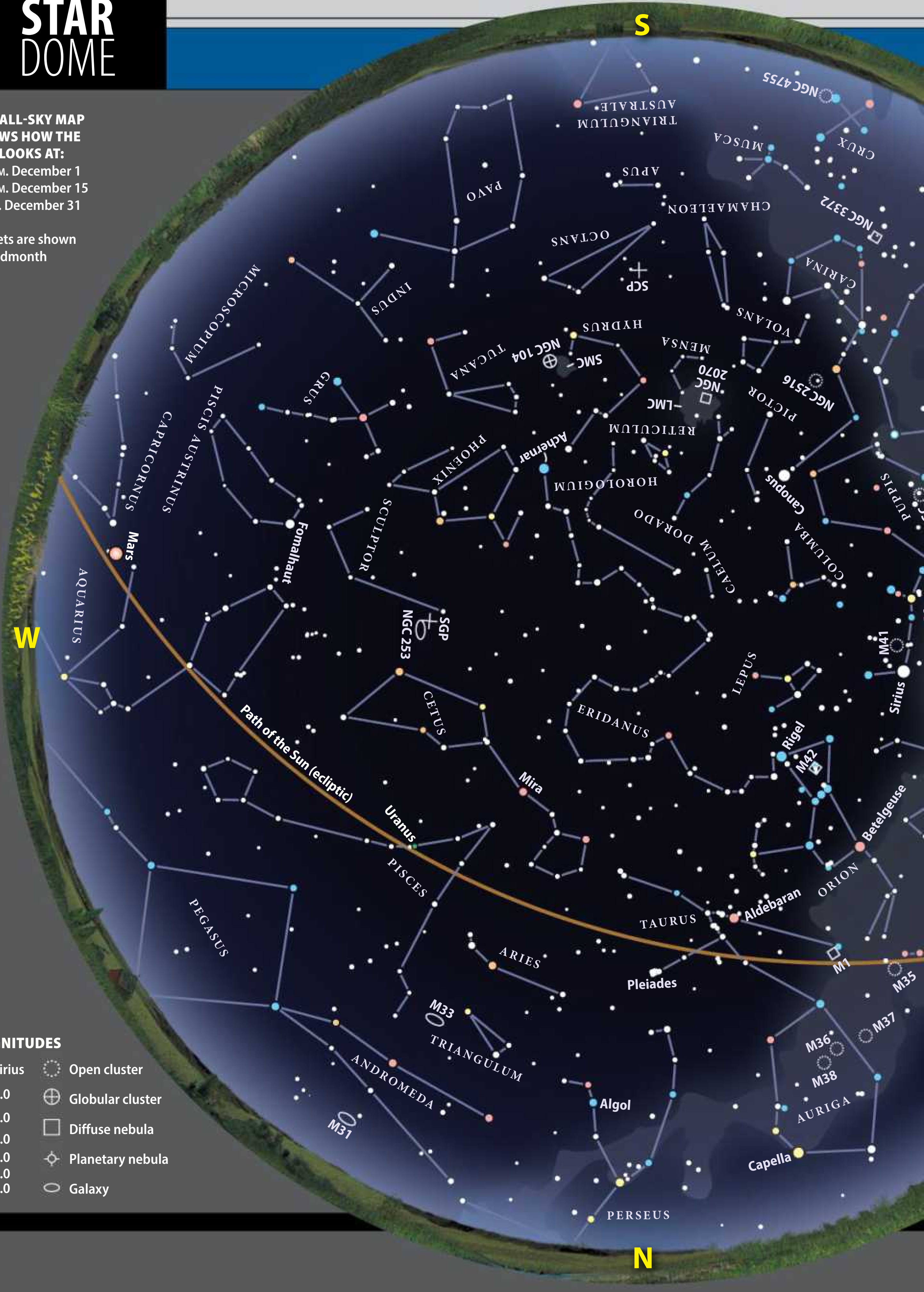
M47 is a couple of magnitudes brighter than its neighbor, so it's not really surprising that Hodierna did not notice M46. Still, M46 lies a scant 1.5° east of M47, and finding the brighter cluster will help you track down the fainter one. Despite their proximity in the sky, they are not really close together in space. M47 lies about 1,600 light-years from Earth while M46 is around 5,400 light-years away. That's the main reason M47 appears brighter and is much easier to resolve.

M46 and M47 are also known as NGC 2437 and NGC 2422, respectively. The identification of the latter with the 47th entry in Messier's list has not always been clear, however. This happened because Messier recorded the position of number 47 at a spot where no obvious deep-sky object exists — a point just over 0.5° southeast of the star 10 Puppis. It appears that Messier made a simple sign error when calculating M47's position, and astronomers now assume that NGC 2422 is indeed his M47.

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 2016

Calendar of events

1 The Moon passes 7° north of Mercury, 4h UT

3 Asteroid Vesta is stationary, 4h UT

The Moon passes 6° north of Venus, 13h UT

5 The Moon passes 3° north of Mars, 11h UT

6 The Moon passes 0.7° north of Neptune, 22h UT

7 First Quarter Moon occurs at 9h03m UT

9 The Moon passes 3° south of Uranus, 20h UT

10 Saturn is in conjunction with the Sun, 12h UT

11 Mercury is at greatest eastern elongation (21°), 5h UT

12 The Moon is at perigee (358,461 kilometers from Earth), 23h29m UT

13 The Moon passes 0.5° north of Aldebaran, 5h UT

14 Full Moon occurs at 0h06m UT

Geminid meteor shower peaks

15 Asteroid Ceres is stationary, 7h UT

18 The Moon passes 1.0° south of Regulus, 19h UT

19 Mercury is stationary, 7h UT

21 Last Quarter Moon occurs at 1h56m UT

Summer solstice occurs at 10h44m UT

22 The Moon passes 2° north of Jupiter, 17h UT

25 The Moon is at apogee (405,870 kilometers from Earth), 5h55m UT

27 The Moon passes 4° north of Saturn, 21h UT

28 Mercury is in inferior conjunction, 19h UT

29 New Moon occurs at 6h53m UT

Uranus is stationary, 16h UT

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