

BONUS!
Guide to the
Night Sky 2014

COMET ISON'S
FINAL STAB AT GLORY p.56

CURIOSITY'S
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JANUARY 2014

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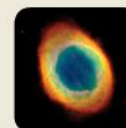
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Where comets live

Comet ISON has been much on the minds of astronomy-lovers, and Senior Editor Rich Talcott brings you up to date with his article on page 56. With the comet at its peak about the time you see this issue, I thought I'd offer some information about the behavior and origins of comets.

The beginning of a modern division of cometary orbits originated with Irish astronomer and science writer Dionysius Lardner (1793–1859), compiler of the 133-volume *Cabinet Cyclopaedia*, who wrote in 1853: “We are in possession of the elements of the motions of 207 comets. ... It appears that 40 move in ellipses, 7 in hyperbolas, and 160 in parabolas.”

Lardner's analysis suggested three classes with elliptical orbits — Jupiter-family comets, Halley-type comets, and long-period comets. Hyperbolic and parabolic orbits are new long-period comets whose orbits have not yet evolved into huge ellipses. He also looked at the direction of cometary motions, noting that — not counting the Jupiter-family comets — roughly equal numbers exist of comets that orbit in the same direction as the planets and those that orbit in the opposite direction.

The murky origins of comets received further study by American astronomer Hubert A. Newton (1830–1896) and Dutch astronomer Adrianus J. J. van Woerkom (1915–1991). In 1948, van Woerkom studied the orbits of comets and demonstrated that their energies were not consistent with an interstellar origin.

Two years later, Dutch astronomer Jan H. Oort (1900–1992) wrote his game-changing paper that tied the questions of cometary origins together. “There is no reasonable escape, I believe, from the conclusion that the comets have always belonged to the solar system,” he penned. “They must then form a huge cloud, extending ... to distances of at least 150,000 [astronomical units], and possibly still further.”

So astronomers came to hold up the Oort Cloud, the distant, enormous shell of comets surrounding the solar system, as the principal storehouse of comets in our vicinity. This is the home of long-period comets, where these objects in their huge orbits flutter out to incredible distances and with orbits that remain stable over billions of years. Just exactly why do astronomers believe this to be so? And how do long-period comets behave?

The young solar system contained a large number of so-called planetesimals, small icy and rocky bodies between the planets and on the solar system's outer edges. The region of about 4 to 40 astronomical units from the Sun, where ices would be able to be vaporized, had countless planetesimals.

It was Oort himself who recognized that long-period comets must originate from a huge spherical cloud at 10,000 or more astronomical units from the Sun. He suggested that most new comets reach the most distant points in their orbits at about 100,000 to 150,000 astronomical units. Recent work suggests figures that may be as small as half these values. And the issue of nongravitational forces muddies the water in trying to determine precise orbital values because they make cometary orbits look more eccentric than they really are.

In ISON's case, we'll take murky origins and eccentricity — as long as it's bright!

Yours truly,

David J. Eicher
Editor

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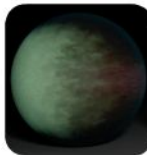
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TRENDING TO THE TOP



GASTRONOMY

Astronomers mapped red clump stars to better constrain the shape of the Milky Way's inner region: its central bulge is peanut-shell-shaped.



CLOUDY WORLD

Exoplanet Kepler-7b has high clouds in the west and clear skies in the east, say scientists after a three-year campaign to map the world's atmosphere.



DARK DENSITY

Advanced computer simulations show that the density of mysterious dark matter is greatest at a galaxy's center and decreases toward the outskirts.

SNAPSHOT

Comets and human beings

Did the stuff of life arrive on Earth from comets?

As early as the fifth century B.C., the Greek philosopher Anaxagoras proposed that perhaps life came floating down to Earth from somewhere in the great sky above. More recently, some scientists have proposed so-called panspermia, in which life originated in space and was deposited onto Earth. Since then, scientists have toyed with the notion that perhaps comets, which could be destroyers of life through impacts, might also be the bringers of life that seeded our planet with living organisms.

There's no evidence for that. But plenty of evidence does exist that comets are loaded with complex organic molecules. They contain abundant CHON particles — short for carbon, hydrogen, oxygen, and nitrogen — the stuff of organic chemistry. They contain polycyclic aromatic hydrocarbons, very large molecules rich in organics. And most amazingly, in 2009 researchers announced the discovery of glycine in material returned from Comet 81P/Wild 2, visited in 2004 by the Stardust spacecraft.

Glycine is an amino acid, one of the building blocks of proteins and an important chemical in living beings. Other complex organics include RNA and DNA, the regulatory molecules of life. When you gaze at Comet ISON this month, think about the 2 trillion comets that float majestically out in the Oort Cloud and how these frozen blocks contain the stuff of life. — **David J. Eicher**



17P/Holmes, a rather ordinary periodic comet, underwent an outburst in October 2007, temporarily brightening by a factor of half a million, with its coma inflating to a diameter greater than that of the Sun.

NASA/ESA/ALAN DYER (COMET 17P/HOLMES); ESO/NASA/JPL-CALTECH/M. KORNMESSER/R. HURT (GASTRONOMY); NASA/JPL-CALTECH/MIT (CLOUDY WORLD); ESO/DSS2 (DARK DENSITY)

Devious duo in Dorado

The Milky Way's largest satellite galaxy, the Large Magellanic Cloud, lies 160,000 light-years from Earth in the constellations Dorado and Mensa. It produces new stars at a fierce rate, most notably in the naked-eye Tarantula Nebula (NGC 2070). Some 2° north of it lies the pair of smaller emission nebulae — NGC 2014 (right) and NGC 2020 (left) — seen in this image taken through the Very Large Telescope in Chile. The cluster of hot young stars at NGC 2014's center ionizes the surrounding hydrogen gas, which glows with a characteristic reddish color. The bluish hue of NGC 2020 arises from oxygen atoms ionized by a single hot star at its center. ESO





STRANGEUNIVERSE

BY BOB BERMAN

Rhythms of the sky

Preview the key celestial motions of 2014.

Jim Metzner's *Pulse of the Planet* is a syndicated radio show that explores nature's various rhythms. Like beating hearts, fluttering wings, or chirping crickets, the night sky also displays a cadence — many of them actually.

Olden observers noted how stars faithfully rise four minutes earlier per night and how the Sun's midday height — now so low — follows an annual cycle that doesn't vary by even a single second. Serious sky-observing cultures like the Maya took it further, basing calendars on beloved patterns like the reliable motions of Venus.

These days, we mostly notice mundane pulses like the daily recurrences of traffic jams. While such earthly repetitions grab the bulk of our attention, the celestial ones continue with all their ancient glory for everyone who cares to notice.

The start of a new year marks the most appropriate time to preview 2014's greatest sky-rhythms.

The Moon's oval path carries it closer and farther while that orbit itself changes shape. Once yearly, it must arrive at its nearest point to Earth. But in 2014, this essentially happens twice. The first is on the year's opening day! This is the same day the Moon is New and hence invisible. Expect extraordinary tides. The Moon's second 2014 close approach is even more interesting. This one, on August 10, happens the exact same hour the Moon is Full. And since this perigee is 17 miles (27 kilometers) closer than the January 1 event

— about a quarter the width of some lunar craters — it too will create dramatic tides. This is the year's biggest Moon.

And that's *still* not the best thing the Moon does in 2014. On U.S. tax day, April 15, and again October 8, it plunges fully into Earth's shadow to create total lunar eclipses. Both are visible from virtually all of the United States and Canada. When does most of our continent get two total eclipses in a single year? Never!

Well, almost: This is the first since 2003. The Maya would have flipped. Imagine: *Two* chances to sacrifice their most annoying tribal members.

No total solar eclipses occur in 2014, but the eastern half of

THE RED PLANET BOASTS A BIENNIAL PATTERN WITH GOOD YEARS ALTERNATING WITH BAD. THIS IS A GOOD ONE.

the United States gets a partial eclipse at sunset October 23. Use #14 welder's goggles.

The Maya's favorite entity would have disappointed them this year, a bummer ranking only slightly lower than having their ruler kidnapped by the Spanish. Their beloved Venus, whose importance was equivalent to our own Philly cheesesteak, has a dreadful year. January opens with the "evening star" very low; then it promptly vanishes into the solar glare. After its January 11 inferior conjunction, the planet soon reappears as a morning star. But a Venus springtime morning apparition is always a miserably

low pattern except for those in far-southern states. And the rest of the year finds it pathetically horizon-hugging until it wimps its way behind the Sun around Halloween, putting our sister planet out of its misery.

Mars is a different story. The Red Planet boasts a biennial pattern with good years alternating with bad. This is a good one. At opposition, nearly a week before its closest approach April 14, Mars shines at a brilliant magnitude -1.5 , its best since 2007. Floating in Virgo, it

dramatically hovers near the Moon on the 13th and 14th. You simply can't miss it. True, its 15-arcsecond width remains pretty small: It'll swell to 24.5 arcseconds four years from now. But then it'll be super-low, so you can't have everything.

When the gossip turns to celestial patterns, nothing beats Jupiter. It comes closest to Earth a month later each year, which means it advances approximately one zodiacal constellation annually. Jupiter is astronomy made simple. This year it hits the ground running. It's already dazzling, reaches its nearest and brightest January 5, and remains striking through

the spring. Jupiter stands above Orion in the constellation Gemini all night long. Nothing except the Moon can shine more brightly at midnight, when Jove hovers high overhead.

Saturn's rhythm has its near point two weeks later each year. Its 2014 opposition is excellent. The rings now slant in a wonderfully "open" orientation, as the outer edge extends clear around the planet, virtually unblocked. Their high reflectivity makes this Saturn's brightest opposition since 2007. (That year keeps popping up here. My vote for 2007's most memorable news story: Australia's storefront Santas were ordered to stop saying "ho ho ho" and instead told to chant "ha ha ha." I'm not making this up.)

Saturn's closest night is May 10. But it's great all spring as it hovers in Libra, which resembles a "scale" only to portly skywatchers craving a midnight coconut cream pie. Locate the ringed world near Libra's Alpha star, Zubenelgenubi. If for some strange reason you want to mention this fact at parties, that Arabic name has its own cadence whose accent is on the second syllable.

But the rhythms of celestial words — ah, that's a topic for another time. ☿

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

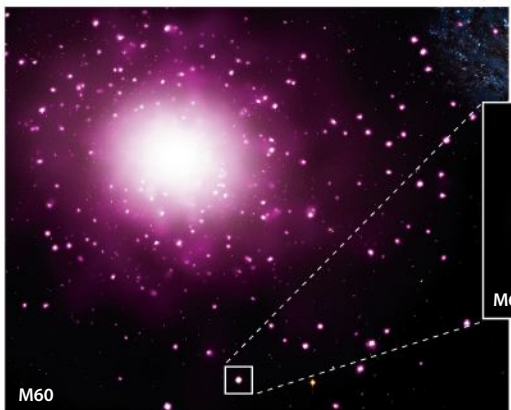
FROM OUR INBOX

The philosophy of science

As I was enjoying your August 2013 issue, I was surprised while reading the "40 greatest astronomical discoveries" article. I have always thought of Pierre-Simon Laplace in conjunction with the Prussian philosopher Immanuel Kant. Like Laplace did in 1796, Kant advanced the hypothesis that the solar system began as a larger gas cloud that collapsed into a spinning disk. Kant, however, did so in a book printed in 1755 but released much later because of the publisher's economic woes. I think the independent discovery of this hypothesis should be credited to both great thinkers. Kant's name would fit well in your magazine, given that he once said that the two things that filled him with awe were "the starry heavens above [him] and the moral law within [him]."

— Scott Stroud, Austin, Texas

DENSEST GALAXY PROVIDES ORIGIN CLUES



M60-UCD1

DENSE DWARF.

Astronomers using the Hubble Space Telescope, with follow-up observations by NASA's Chandra X-Ray Observatory, have discovered what likely is the densest galaxy known.

Called M60-UCD1, it lies near the massive elliptical galaxy M60 in Virgo.

X-RAY: NASA/CXC/MSU/J. STRADER, ET AL.; OPTICAL: NASA/STScI

A little more than a decade ago, astronomers stumbled upon conglomerations of stars that didn't quite fit any mold. They were smaller than typical dwarf galaxies but larger than the largest known globular clusters. Scientists gave this new group the name "ultra-compact dwarf galaxies" (UCDs), and the search began to determine whether these star systems were born as jam-packed star clusters or are the remnants of once massive galaxies. Astronomers announced in the September 20 issue of *The Astrophysical Journal Letters* the discovery of a UCD that likely is the densest known galaxy and could provide clues to these objects' origins.

Using the Hubble Space Telescope, a team of astronomers came across a UCD near the large elliptical galaxy M60 in

Virgo. Follow-up observations of the galaxy, formally called M60-UCD1, showed that this object is remarkable: About half of the UCD's 200 million solar masses is found near the core, making the density of stars about 15,000 times greater than found in the Sun's neighborhood.

X-ray observations also revealed the possible presence of a central black hole weighing some 10 million times the mass of the Sun, something not possible if M60-UCD1 was born a star cluster. Such a characteristic hints at the UCD's origins. "We think nearly all of the stars have been pulled away from the exterior of what was once a much bigger galaxy," says co-author Duncan Forbes of Swinburne University in Australia. "This leaves behind just the very dense nucleus of the former galaxy and an overly massive black hole." — **Karri Ferron**

BRIEFCASE

SHOCKED ICE CREATES LIFE PRECURSORS

A team of scientists fired projectiles into an ice mixture commonly found in comets. The energy produced during the collision created several amino acids, which are the building blocks of proteins and therefore important to life. The study, published in *Nature Geoscience* online September 15, provides more evidence that comets bombarding an early Earth could have initiated life.

MORPHING GALAXIES

Astronomers used supercomputers to show how spiral galaxies can evolve into look-alike disk galaxies; their findings appeared in the October 1 issue of *The Astrophysical Journal Letters*. The scientists incorporated only the gravity of the clumps of stars within spiral arms and modeled what would happen after billions of years. The clumps essentially erased themselves over time to create a steady disk with brightness fading smoothly from the center to the galaxy's edge.

SATURNIAN ATMOSPHERE

Scientists report in the September-October *Icarus* their analysis of images of Saturn's major storm lasting from 2010 to 2011. The light signatures, called spectra, from the planet point to a composition of ammonia ice, a significant amount of water ice, and a third component — likely ammonium hydrosulfide. The team says this is the first spectroscopic evidence of water ice in Saturn's atmosphere. — **Liz Kruesi**



25 years ago in Astronomy

In the January 1989 issue of *Astronomy*, Stephen Cole wrote about two planetary missions that launched that year — Galileo to Jupiter and Magellan to Venus — in "Rediscovering Venus and Jupiter." While Galileo had problems, both spacecraft completed their missions, shooting the United States into planetary science prominence.

Cole praised the probes and presaged their success, saying, "The last time the United States sent a spacecraft to explore the solar system, you had not used a word processor. ... In a matter of months, the long drought in U.S. planetary exploration will be over."

10 years ago in Astronomy

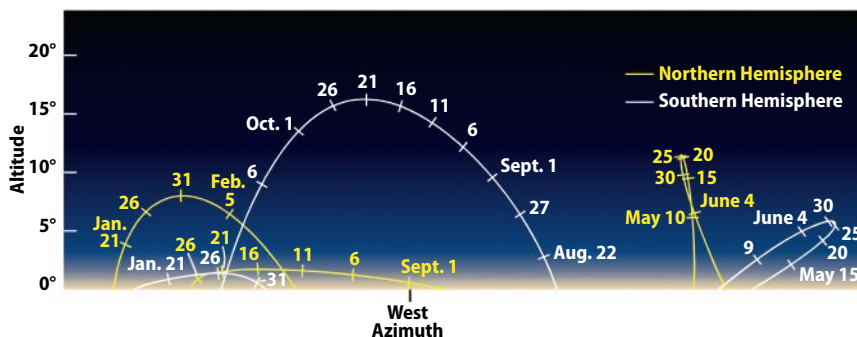
The January 2004 issue of *Astronomy* similarly previewed a planetary mission. The Cassini-Huygens probe, launched in 1997, was to arrive in July 2004. "Journey to Saturn," an article by Alfred S. McEwen, described the pre-launch trials and preparations and forecasted the probe's overall highlights.

"If Cassini makes it to the end of its planned mission," McEwen said, "it should have fuel and power for an extended mission of a year or more." In February 2010, the agency prolonged Cassini's functional lifetime until 2017. — **Sarah Scoles**

MERCURY IN THE EVENING

From 35° north latitude, Mercury peaks at an altitude of 11.3° May 23; from 35° south, the planet climbs 16.2° high September 21.

FAST FACT



THE ELUSIVE INNER PLANET. Mercury has a reputation for being difficult to see. That's because the innermost planet typically hugs the horizon during twilight either after sunset or before sunrise. This chart plots Mercury's positions 45 minutes after sunset for observers at both 35° north and south latitudes throughout the planet's three evening elongations in 2014. The best conditions for northerners come in May's second half, while those south of the equator have their best views in mid- to late September. *ASTRONOMY*: RICHARD TALCOTT AND ROEN KELLY



UNWANTED VACATION. While missions like that of the Mars Curiosity rover continued through the United States government shutdown, nearly all federally employed astronomers were furloughed for 16 days beginning in early October 2013. NASA/JPL-CALTECH

U.S. government shuts down astronomy

When Congress failed to pass a budget for fiscal year 2014 by October 1, 2013, the United States government shut down. More than 800,000 federal employees were furloughed, and government-funded work deemed non-essential was suspended. Scientific — and specifically astronomical — facilities were hard hit.

During the political holdup, 98 percent of NASA employees — more than 17,700 people — were prohibited from working. The space agency's websites were inaccessible, its television channel was not broadcasting, work on missions in progress was suspended, and all public programs were canceled. Those satellites and probes already outside Earth's atmosphere, as well as the Mars Atmosphere and Volatile Evolution (MAVEN) mission scheduled to launch in November, were permitted to continue using minimal staffing.

The National Science Foundation (NSF) was forced to furlough 99 percent of its employees. Outside scientists could not submit grant proposals or receive money for previously accepted proposals. National observatories, which are independent organizations run on behalf of the NSF, were able to continue operations for several days with reserve funds. However, in the shutdown's second week, the National Radio Astronomy Observatory shuttered its facilities, shut down its telescopes, and sent its workers home.

During the shutdown, which ended October 17, federal employees were not allowed to conduct business or research, including travel to conferences. Scientists who had applied for and received time on federally funded telescopes — a process that takes months and sometimes boasts less than a 10 percent acceptance rate — missed their scheduled observations. — S. S.

330–375 KELVINS (134–215° Fahrenheit)

The temperature of the coldest known brown dwarf, WD 0806–661B, a transitional object between planets and stars, according to a September 27 *Science* paper.

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Beautiful Endymion

Look closely at the crescent Moon to see shadow play on a crater floor.

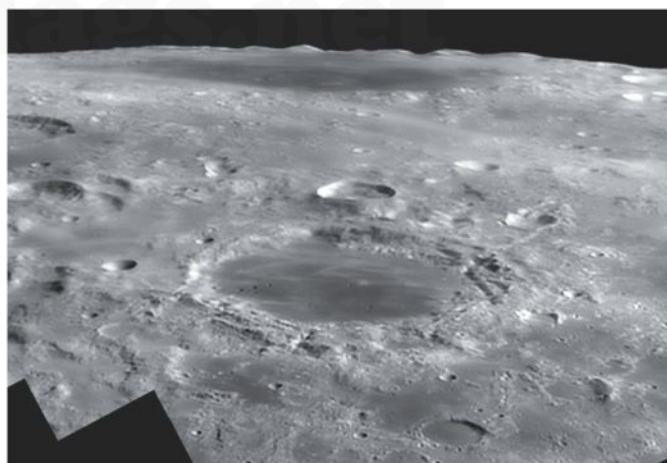
There's a lovely crater on the young crescent Moon befitting its name: Endymion. In one version of the eponymous Greek legend, Endymion was an attractive youth whom the Moon goddess Selene (often depicted wearing a crescent Moon on her head) laid to eternal sleep so she could forever enjoy his beauty.

As seen through a telescope, the crater Endymion mirrors Selene's mythical handiwork. It is one of the crescent's most elegant examples of a large flat-floored crater — an impact feature subsequently flooded by fluid lava to the point of stately elegance. In Endymion's case, this liquid basalt rose into the crater's interior and created a smooth flood plain 15,000 feet (4,570 meters) below the

slumped shoulders of its walls. Even at high powers through a telescope, the crater floor is a smooth, alluring beauty — a tranquil attraction that evokes a sense of visual silence.

Look northeast

You'll find Endymion in the far northeast quadrant of the Moon. It's the most prominent feature northeast of the crater pair Hercules and Atlas, midway between the northeastern shoulder of Mare Frigoris (Sea of Cold) and the western side of Mare Humboldtianum (Sea of Humboldt), located on the Moon's northeastern limb. Endymion's dark floor stands out in the bright, battered terrain that surrounds it and is best explored when the Moon has been in its waxing crescent phase for three days.



The lunar crater Endymion, a noticeable feature on the Moon's northeastern limb, resulted from an impact. Later, lava flooded the depression, creating a flat flood plain 15,000 feet (4,570 meters) below the crater's rim. ANTONIO LASALA GARCÍA

When I observed Endymion on July 11, 2012, with my 3-inch refractor, the 78-mile-wide (125 kilometers) crater appeared as a nearly circular ring (it appears out-of-round due to foreshortening) with long jagged shadows splashed across its eastern floor. I could not detect a single craterlet within its worn, undulating walls or a stitch of the ejected material — called a ray system — that gently dusts the floor from the Thales impact to the north-northwest. Admittedly, I was looking at a moderately low Sun angle, but these features are sometimes difficult to see even when looking through larger scopes.



When the Moon is a young crescent, as it is above, the crater Endymion is visible. Through a small telescope, its ray system and craterlets cannot be seen. However, penumbral effects appear in crater shadows. THINKSTOCK/ISTOCKPHOTO

Shadow world

The most fascinating features I did notice on this particular night were related to shadow play. With imagination, I could see the long shadows radiating from Endymion's scalloped western wall. It looked like a "lake" within the crater's floor was draining through cracks in the depression's wall and flowing into the terminator.

What I found most astounding, however, was the fuzzy grayish penumbral effect of the jagged crater shadows, which were projected on the flat floor from the east. Every shadow — from your shadow to that of Earth — has an umbra (the darkest part) and a penumbra (a diffuse gray margin around the

umbra). The penumbral shadow is less noticeable close to the base of the shadow source and greatest the farther you look from it. So the best time to see the penumbral effects on lunar crater shadows is when the Sun angle is low.

The phenomenon I saw was that the tips of the toothy points in the projected shadow had a general gray fuzziness. The floor's polished surface seemed to enhance the effect's visibility. You'll have to catch the shadows at just the right time, though, to see the penumbrae well. If you look too early, the crater shadows will mingle with the terminator and ruin the view. Look too late, and the shadows will be too short for the fuzzy penumbrae to stand out well.

As always, send your observations of this crater to me at sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Sarah Scoles**

Cold as space			Supernova hot
Yee haw	Dead reckoning	Outdated equipment	Stuff of legend
NASA releases images detailing how it plans to lasso an asteroid and tow it to Earth. The artists, however, forgot to strap the cowboy hats atop the astronauts' helmets.	After two wheels on Kepler fail, NASA says the scope can't hunt for planets. "Reports of my death have been greatly exaggerated," responds Kepler, who will continue work on topics TBA.	A 16th-century astrolabe, used to measure star positions, was stolen 15 years ago from Skokloster Castle. An Italian collector returns it, claiming that there's an app for that now.	NASA issues a press release about centaurs — half-comet-half-asteroid objects — which includes a sketch of a man-horse floating in space, inspiring tattoo artists everywhere.

NASA (YEE HAW); NASA (DEAD RECKONING); WIKIMEDIA COMMONS (OUTDATED EQUIPMENT); NASA/JPL-CALTECH (STUFF OF LEGEND)



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Photograph by: Enrique Perez Garcia

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ASTRONOMY

GAS BILL. The Senate approved the Helium Stewardship Act on September 26. The bill keeps the Federal Helium Program open, averting the "helium cliff."

SPACE SCIENCE UPDATE

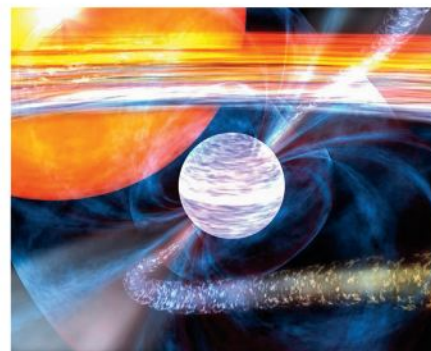
AN EVOLUTIONARY LINK FOR PULSARS

A fleet of X-ray space observatories and ground-based radio telescopes has witnessed a pulsar with a dual personality. Such objects are the highly magnetic and dense remnants of the cores of once massive stars, also known as neutron stars. One emits radiation from its magnetic axis, and as that beam sweeps past Earth, telescopes see a pulse — similar to the flashing of a lighthouse.

Millisecond pulsars have incredibly fast rotation rates of hundreds of revolutions per second; other types take up to five or seven seconds to complete one rotation. Determining why these rates vary, and how one type of pulsar evolves into another, is a major area of research. The dual-personality pulsar described in the September 26 issue of *Nature* helps astronomers bridge the gap.

The European Space Agency's (ESA) International Gamma-Ray Astrophysics Laboratory (INTEGRAL) spied a varying X-ray source March 28 within the globular cluster M28. NASA's Swift spacecraft also observed an X-ray burst at the location. Then on April 4, ESA's XMM-Newton viewed an oscillating X-ray signal with a period of 3.93 milliseconds. On April 29, NASA's Chandra pinpointed the source's location, and it matched up with a previously observed radio millisecond pulsar, PSR J1824–2452L.

In April and May, Alessandro Papitto of the Institute of Space Sciences in Barcelona, Spain, and colleagues looked for the pulsar with four radio telescopes: the Australia Telescope Compact Array, the Green Bank Telescope, the Parkes radio telescope, and the Westerbork Synthesis Radio Telescope. While



TRANSFORMING STAR. A companion star (the orange sun in the background of this illustration) feeds material onto a rapidly rotating pulsar, thus speeding it up to millisecond spin rates. NASA

they didn't see a signal from PSR J1824–2452L in April, it revealed itself in May.

"These observations show that the radio pulsar mechanics were active no more than a few weeks after the peak of the X-ray outburst," the international team writes in *Nature*. Scientists didn't think pulsars could swing between these two phases so quickly, but this object shows that they can.

The team analyzed the X-ray signals to deduce that the pulsar has a companion weighing about one-fifth of the Sun. The scientists think the companion is feeding material onto the neutron star, and as it does, the gas heats up and glows in X-rays. If material thickly coats the pulsar, it can initiate a runaway thermonuclear reaction and explode — thus the intense X-ray bursts that Swift saw. When the companion is feeding little mass to PSR J1824–2452L, the pulsar's magnetic field can deter the extra material, leaving the area relatively gas-free and allowing the radio emission to get through.

As the companion star gives material to the pulsar, it also speeds up the pulsar's rotation. Scientists believe PSR J1824–2452L represents an evolutionary link between a low-mass X-ray binary and a millisecond pulsar. — L. K.



Now accepting submissions for annual \$2,500 award

Astronomy magazine will present its 2013 Out-of-this-world Award to a club or organization anywhere across the globe that has demonstrated excellence in astronomy outreach activities. The annual \$2,500 award focuses on ongoing programs by a nonprofit educational or civic organization and recognizes a group's sustained and successful efforts to involve its local community in the science and hobby of astronomy. The prize money is to be used for future astronomy outreach activities. *Astronomy's* editors will review each entry and select a winner.

The 2012 award went to the New Hampshire Astronomical Society, whose prolific outreach included the Library Telescope Program, dedicated to placing telescopes in libraries throughout the state to encourage people to try astronomical observing.

The official rules and entry form for *Astronomy's* 2013 Out-of-this-world Award are available for download at www.Astronomy.com/award. Applications and material must be postmarked by January 17, 2014. The winner will be announced March 3.

Logged: the interstellar wind's 40-year change

The Sun's wind and magnetic field create a heliosphere that protects the solar system from most interstellar material. Our planetary system, however, is traveling through a galactic cloud, and some interstellar particles still penetrate the heliosphere. That interstellar wind has changed direction substantially over the past four decades, say researchers after analyzing data from 11 spacecraft. They published their findings in the September 6 issue of *Science*.

The astronomers pursued this study after learning of a recent Interstellar Boundary Explorer (IBEX) discovery. IBEX samples neutral particles from the interstellar wind that interact with the heliosphere. In January 2012, the IBEX team showed that the interstellar wind enters the heliosphere from a different direction from what the Ulysses craft measured in the 1990s. That prompted Priscilla Frisch of the University of Chicago and colleagues to look at archived data as far back as 1972. They found that the wind had shifted direction by about 6.8°.

The researchers aren't sure what is causing the direction change, but they think it might be related to the fact that the solar system is near the edge of the local interstellar cloud, and at that position the heliosphere is more exposed to different winds. — L. K.

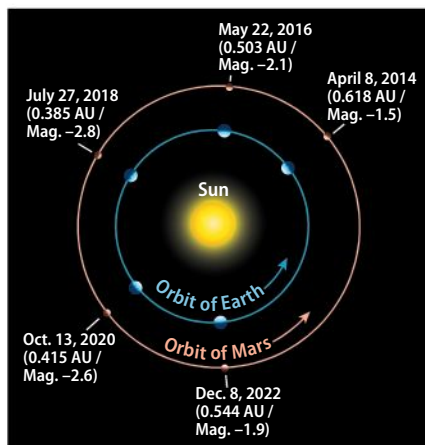


WINDY MOVEMENT. The Sun is near the edge of the local interstellar cloud, which might explain why the interstellar wind has been changing direction over the past four decades. NASA/GODDARD/ADLER/U. CHICAGO/WESLEYAN

After 2018, Mars won't come closer to Earth until September 11, 2035, when it stands 0.380 AU away.

FAST FACT

FUTURE OPPOSITIONS OF MARS



BRIGHT RED PLANET. When the Sun, Earth, and Mars line up, astronomers call it an opposition. But not all oppositions are the same. The numbers in parentheses show the planets' closest approaches (in astronomical units [AU]) around the next five oppositions along with Mars' magnitudes. One AU is the average Earth-Sun distance. ASTRONOMY: MICHAEL E. BAKICH AND ROEN KELLY

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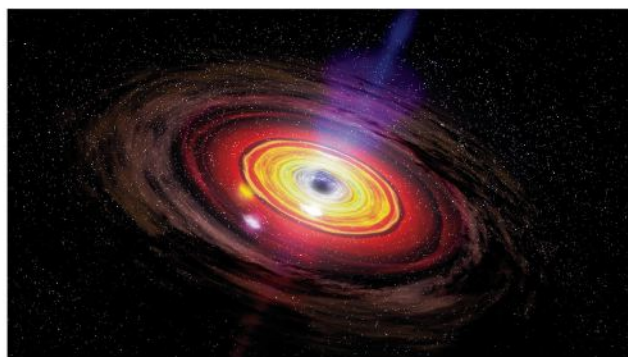
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ASTRONNEWS

DELIVERY. On September 18, Orbital Sciences launched 1,500 pounds of cargo — including chocolate — to the International Space Station.



GROWTH CHART. When material approaches a black hole, its speed increases, and friction between particles increases its temperature. Its newfound energy and the black hole's magnetism cause it to emit radiation. Scientists have discovered that 2 million years ago, our galaxy's black hole, normally dormant, went through a violent version of this process. NASA/DANA BERRY/SKYWORKS DIGITAL

Milky Way's black hole flared 2 million years ago

The Milky Way's black hole, known to astronomers as Sagittarius A* (Sgr A*), is surprisingly calm and quiet these days. While many stars orbit near the center of the galaxy, the black hole there has not devoured a significant amount of gas in recent memory.

Mounting evidence suggests, however, that Sgr A* had a violent outburst some 2 million years ago. The latest argument in favor of a flare-up relates to the Magellanic Stream, a filament of gas streaking from the Large and Small Magellanic Clouds.

"For 20 years, we've seen this odd glow from the Magellanic Stream," says Joss Bland-Hawthorn of the Australian Astronomical Observatory in Marsfield. "We didn't understand the cause. Then, suddenly, we realized it must be the mark, the fossil record, of a huge outburst of energy."

Bland-Hawthorn's team believes that Sgr A*'s explosion rammed into the Magellanic Stream, causing it to light up. Their work has been accepted for publication in *The Astrophysical Journal*.

The Magellanic Stream's mysterious radiation is not the only energy attesting to an outburst. Infrared and X-ray observatories see jets of material coming from the area around the black hole, and gamma-ray and radio telescopes can see bipolar burps known as the "Fermi bubbles" bursting from the center of the galaxy. A flare-up 2 million years ago could have produced all of these still visible effects.

Sgr A* may again wake up a bit as a gas cloud called G2 comes close to its event horizon this year. "It's small," says Bland-Hawthorn, "but we're looking forward to the fireworks!" — S. S.

QUICK TAKES

GALACTIC GEMS

Astronomers hunted for "red nugget" galaxies, the potential seeds of ellipticals. In a forthcoming paper in *The Astrophysical Journal Letters*, they report more than 600 discoveries.

LIVABLE SATELLITES?

The magnetic fields of gas giant planets affect the habitability of their moons, according to a paper accepted to *The Astrophysical Journal*.

ORBITAL MECHANICS

The Massachusetts Institute of Technology announced September 6 that researchers have designed inflatable antennas to boost tiny satellites' signals without adding bulk.

DUST BUSTER

The asteroid Phaethon formed a tail as it approached the Sun, making it a "rock comet," according to a presentation September 10 at the European Planetary Science Congress in London.

CHEMICAL BONDING

The Sutter's Mill meteorite contains organic molecules never seen in primitive space rocks, scientists announced October 10 in *Proceedings of the National Academy of Sciences*.

SUCCESSFUL SHIP

The Japan Aerospace Exploration Agency's Epsilon-1 rocket made its maiden voyage September 14.

TITAN'S TUPPERWARE

NASA announced September 30 that Cassini has found propylene — used in food containers and car bumpers (on Earth) — on Saturn's Titan. — S. S.

Jet shows how planetary nebulae get their shape

Stars like the Sun have beauty written all over their futures: Toward the ends of their lives, they'll transform into dense cores surrounded by stunning clouds of gas called planetary nebulae. For years, scientists have been searching to understand what sculpts these objects' stunning shapes, and astronomers reported online September 15 in *Monthly Notices of the Royal Astronomical Society Letters* a key to unlocking the mystery: magnetic jets.

Using the Australia Telescope Compact Array, the team has for the first time found a high-speed magnetic jet emanating from a dying star. "What we're seeing is a powerful jet of particles spiraling through a strong magnetic field" around the star IRAS 15445-5499, says co-author Wouter Vlemmings of the Chalmers University of Technology in Sweden. "Its brightness indicates that it's in the process of creating a symmetric nebula around the star."

The scientists expect the jet may only last a few decades and could fully shape the planetary nebula in a few hundred years. — K. F.



STELLAR TRANSFORMATION

Scientists have discovered a jet of energetic particles (shown in magenta) shaping the environment around the star IRAS 15445-5449. Such jets could explain how planetary nebulae get their shapes.

E. LAGADEC/ESO/A. PÉREZ SÁNCHEZ

WHAT ARE WE LEARNING ABOUT THE TRUE IDENTITY OF CENTAURS?

Generally, centaurs are asteroidal bodies whose orbits mostly reside in the region between the giant planets. Like the mythical creatures, these objects have dual natures, with about a tenth of them showing cometary activity. Their great distance and smaller size also make them a challenging population to characterize, adding to their enigmatic natures. Without infrared missions like the Wide Field Survey Explorer (WISE), even basic properties like their diameters and surface reflectance would remain elusive for statistically large samples.

Throughout the 1990s and early 2000s, planetary scientists were hunting for centaurs and trying to find out what we could about them from their colors

and, for the brightest, spectra. We discovered water ice and evidence of other volatiles on some of them, while others seem devoid of unique chemical signatures. Astronomers also found that about two-thirds have a gray or blue color, while the remaining have quite a red color, with none really in between. The WISE mission sample of centaurs, the largest infrared survey of these objects to date, showed that the gray centaurs look a lot like comets — they reflect only a few percent of the light and distribute the heat from the solar radiation over their surface in a similar fashion.

We are anxious to see how the WISE sample of comets, over 150 total, presently being analyzed will compare with the centaur results

James Bauer

Research scientist at the Jet Propulsion Laboratory, California Institute of Technology



COURTESY JAMES BAUER

and with other targeted comet surveys. The planetary-funded component of the WISE mission, NEOWISE, has been a remarkably

successful mission for small-body science, and we are looking forward to continuing the work in the NEOWISE restart mission.

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OBSERVING BASICS

BY GLENN CHAPLE

Astro-freebies

The Web provides tons of free tools to help you better enjoy the night sky.

I love freebies. A food sample served up at the supermarket, a fishing guide handed out at an outdoor expo, even the toothbrush my dental hygienist gives me after cleaning my teeth — if it's gratis, I'll take it!

Needless to say, I'm always on the lookout for astronomy-related freebies. On rare occasions, I'll hit the jackpot — a telescope rescued from a local recycling facility or an eyepiece donated by a friend who upgraded his set. More realistically, free astronomical goodies come my way in the form of printouts and downloads gleaned from the Internet. Here are a few of my favorites.

The Big Dipper Star Clock. Did you know it's possible to determine the time of night by noting the position of the Big Dipper relative to Polaris? All you need is a simple device called the Big Dipper Star Clock. While it won't provide the accuracy of a high-tech timepiece, it's fun to use and (pay attention, parents, teachers, and Scout leaders) makes a nifty cut-and-paste project for youngsters ages 9 and up. Get instructions and a printable copy at www.pbs.org/seeinginthedark/for-teachers.

Uncle Al's Star Wheel. A star wheel, or planisphere, is an essential planning tool for the backyard astronomer. If you don't have a planisphere or you've misplaced yours and need one in a pinch, look into Uncle Al's Star Wheel.

Like the Big Dipper Star Clock, Uncle Al's Star Wheel is available in printout form at the PBS "Seeing in the Dark" website. Parent, teacher, and Scout leader alert: Uncle Al's Star Wheel is another fun-to-assemble project for junior astronomers and, once completed, an engaging way for them to learn about the night sky.

The Mag-7 Star Atlas. You can't navigate the night sky without a star atlas, although

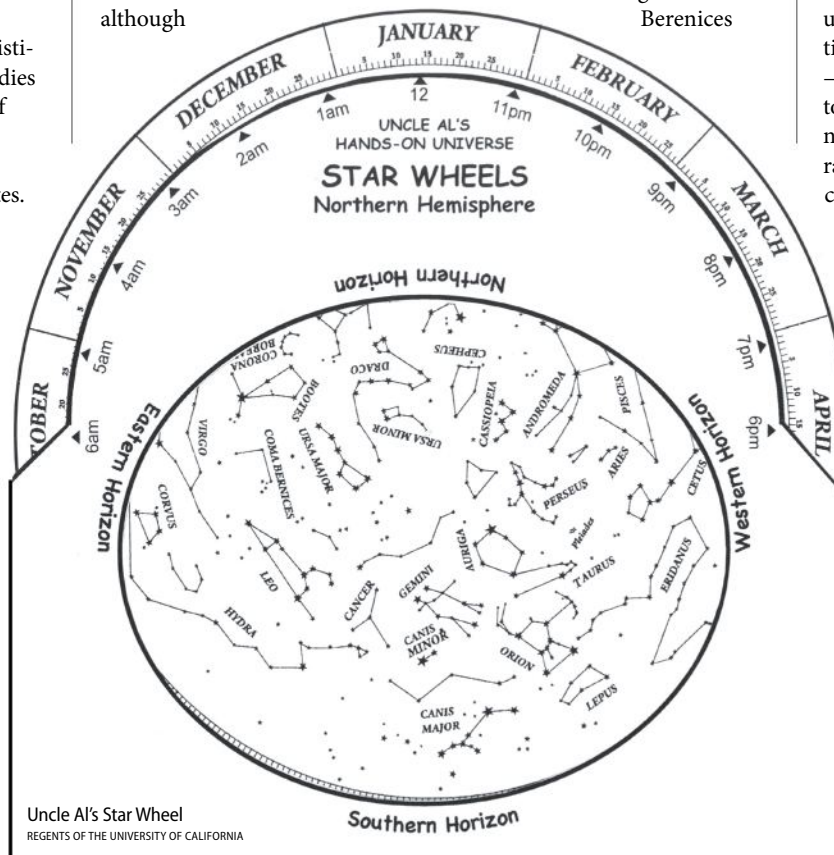
objects on the Messier list, the Royal Astronomical Society of Canada's NGC list, and the Herschel 400 list. Andrew L. Johnson's Mag-7 Star Atlas (<http://tinyurl.com/mag7star>) is composed of 20 primary charts and one supplemental chart for the Virgo-Coma Berenices

take you to the general neighborhood of a sky object; a finder chart puts you right at the doorstep. Among the Web sources that offer free finder charts is the aptly named freestarcharts.com. What differentiates this site from the others is that it's a work in progress with frequent updates and additions. Its selection of Messier and NGC charts — each augmented with a photographic image, descriptive notes, and pertinent data — is rapidly growing. [Freestarcharts.com](http://freestarcharts.com) also plots currently observable bright comets and provides monthly updates on the planets.

Astronomy's "Sky

Guide 2014." Now that 2014 has arrived, you'll want a concise guide to the year's astronomical events. *Astronomy's "Sky Guide 2014"* keeps you in the astronomical loop with month-by-month sky calendars — each supplemented by a brief narrative that focuses on a key event that month. You'll even find a preview of coming celestial happenings for 2015. *Astronomy's "Sky Guide 2014"* comes free to subscribers if they simply log on to www.Astronomy.com/skyguide.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: astro-shopping in the strangest places. Clear skies! ☺



most cost anywhere from about \$10 to well over \$100. A cyber-visit to the Cloudy Nights website, however, will get you a free atlas that plots stars down to magnitude 7.25 and includes all

region. It comes in either a field edition (standard black stars on white background) or colored "desk" version.

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FROM OUR INBOX

Cannon in the canon

In the August 2013 issue, you included the enjoyable article "The 40 greatest astronomical discoveries" about the history of astronomy. You mentioned the work of Ejnar Hertzsprung and Henry Norris Russell (p. 26); however, you failed to mention Annie Jump Cannon, who discovered the spectral classifications of stars that are still in use today. If it weren't for her insightful research, the Hertzsprung-Russell diagram — which shows the categories, characteristics, and evolution of stars — may not have come to fruition. Cannon was never awarded a Ph.D. from Harvard even though she deserved it. I feel she should have been included in your article. — **Harold Kozak**, Staten Island, New York

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Featured video



"Tour the solar system: Jupiter"

Jupiter, the king of the planets, reaches opposition in January, making now the best time to view and photograph it. But what do scientists know about this gas giant world with a speedy rotation? Senior Editor Richard Talcott provides an overview in "Tour the solar system: Jupiter."

A planet with a significant mass and dozens of moons, Jupiter, along with its satellites, is like a solar system in miniature. In the video, Talcott provides the basic physical and orbital



parameters of the world; explains the processes behind its striped appearance and Great Red Spot; explores the unusual characteristics of its four largest moons; and much more.

"Tour the solar system: Jupiter" and the rest of the *Tour the solar system* series are available to registered members of Astronomy.com. Registration is easy, so sign up today and head to www.Astronomy.com/solarsystem to learn more about this fascinating world.

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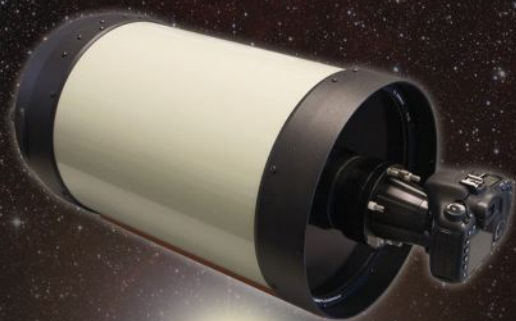
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Taking HyperStar Imaging to New Heights

- Sep 7, 2013 Discovery of Comet Lovejoy (C/2013 R1) by Terry Lovejoy with a HyperStar C8
- Jul 20, 2012 HyperStar C9.25 telescope launches to the International Space Station
- Feb 10, 2012 Discovery of Comet Bruenjes (C/2012 C2) by Fred Bruenjes with a HyperStar M14
- Nov 27, 2011 Discovery of Comet Lovejoy (C/2011 W3) by Terry Lovejoy with a HyperStar C8
- Oct 7, 2009 HyperStar C11 goes to the first White House Star Party in Washington, DC



The ISS-based HyperStar C9.25 is part of the ISERV system, which uses a downward viewpoint to obtain near-real-time data about Earth-based environmental disasters, humanitarian crises and environmental threats, transmitting that data within hours to scientists back on Earth.

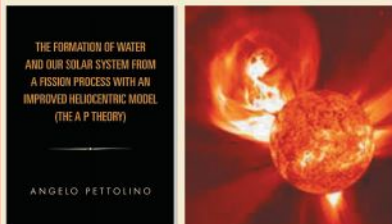
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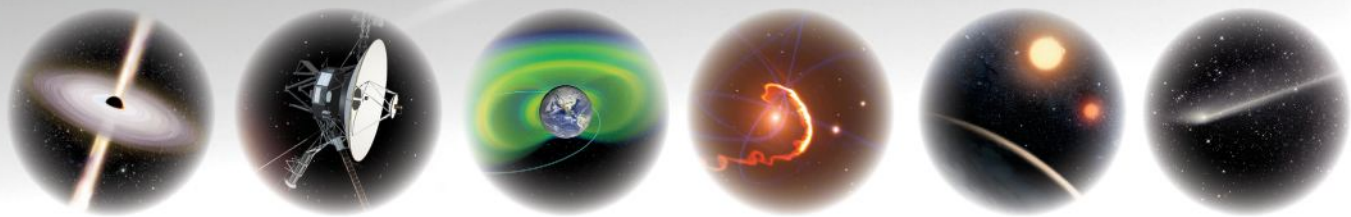
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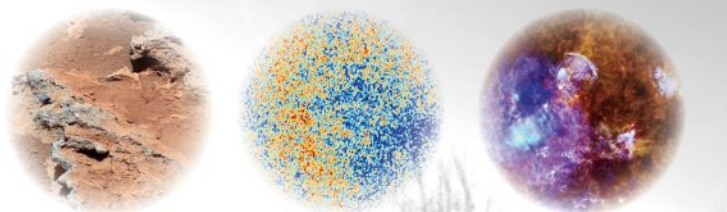
TOP



SPACE STORIES

A meteoroid explosion over Chelyabinsk, Russia, in February and the subsequent push from NASA for improved technology for near-Earth-asteroid missions tops *Astronomy's* list of the biggest space stories from 2013. MARAT AKHMETVALEYEV

10



OF 2013

Astronomers refined the composition and age of the universe, our galaxy's biggest black hole unraveled a gas cloud, and a massive meteoroid exploded above Russia. **by Liz Kruesi**

As scientists create advanced detectors and bigger telescopes, they learn more about the universe and the objects within. This past year certainly gave many examples of this correlation, which made the job of pinning down the 10 biggest space stories even harder for *Astronomy* magazine's editors. And we couldn't forget two bright comets or a once-in-a-century meteoroid explosion — 2013 was clearly a big year for space science.

Over the past year, most of the astronomical headlines went to news about the universe's most extreme objects and events — like black holes, high-energy cosmic rays, and the cosmic beginning. But solar system science also had its share of discoveries in 2013.

After you read about the past year's important astronomical findings — both near and far from Earth — and the science they pushed forward, you'll see why we included them in our top 10.

Liz Kruesi is an associate editor of *Astronomy* magazine.

A black hole's chaotic surroundings and entwined magnetic fields can launch jets of radiation and particles moving at nearly light-speed. ASTRONOMY: ROEN KELLY

10 Black holes launch jets similarly

Black holes represent the extremes of gravity and density, and their nearby environments provide scientists with natural physics laboratories. These compact objects come in a wide range of masses: Stellar-mass black holes weigh in at a few to tens of times that of the Sun while supermassive black holes at the centers of galaxies hold millions to billions of solar masses. The chaotic environment around black holes, including disks of hot gas and entwined magnetic fields, can launch beams of particles moving near light-speed perpendicular to the disk — these are called relativistic jets. Although astronomers don't know exactly what process makes and powers these beams, research published December 14, 2012, in *Science* shows that the jets distribute an amount of energy into their nearby environments proportional to the black hole's mass.

Astronomers have witnessed hundreds of jets launched as massive stars collapse into stellar-mass black holes — visible as blasts of the highest-energy radiation, called gamma-ray bursts (GRBs) — and hundreds from the supermassive black holes at the centers of large galaxies — seen as active galactic nuclei (AGNs). They've modeled the jet behavior

in computers, too, to try to understand them. The information gleaned from the new study will help scientists figure out the mechanism responsible for launching relativistic jets.

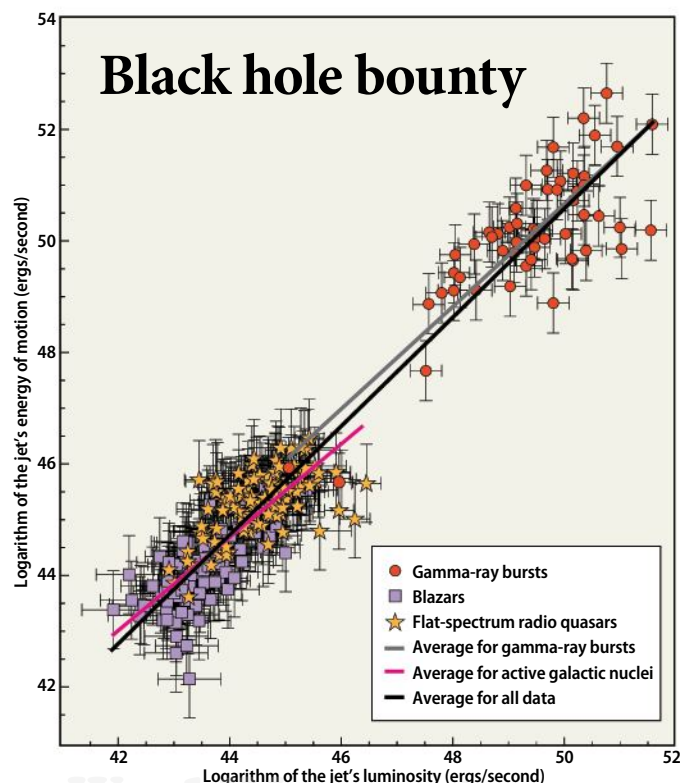
A NASA-led team of astronomers scoured archived data of black-hole-powered jets that point to Earth: 54 GRBs and 234 AGNs. The scientists measured the luminosities of these 288 jets, which tell them “how much energy in the form of photons is emitted by the beam itself as it is moving away from the black hole,” says lead author Rodrigo Nemmen of NASA's Goddard Space Flight Center in Greenbelt, Maryland. They then estimated how much energy, in the form of motion, the high-speed particles in the jet carried and how much of this “kinetic energy” the jet deposited into its environment.

Nemmen's team analyzed how these two properties — the luminosity and the energy of motion — relate among the 288 stellar-mass and supermassive black holes and found that both populations show the same relationship. The jets emit between 3 and 15 percent of their power as radiation. “It's a bit like a poor man and a billionaire spending the same percentage of their incomes on their heating bills,” says

co-author Markos Georganopoulos of the University of Maryland, Baltimore County.

So while scientists don't yet know what physical process launches these beams from black holes' surroundings, it must be a single fundamental mechanism that does so over a huge range of black hole sizes.

Scientists analyzed the high-speed particle and radiation jets emitted from 54 stellar-mass black holes and 234 supermassive ones to find that they deposit a similar percentage of energy into their nearby environment. ASTRONOMY: ROEN KELLY, AFTER RODRIGO NEMMEN, ET AL.



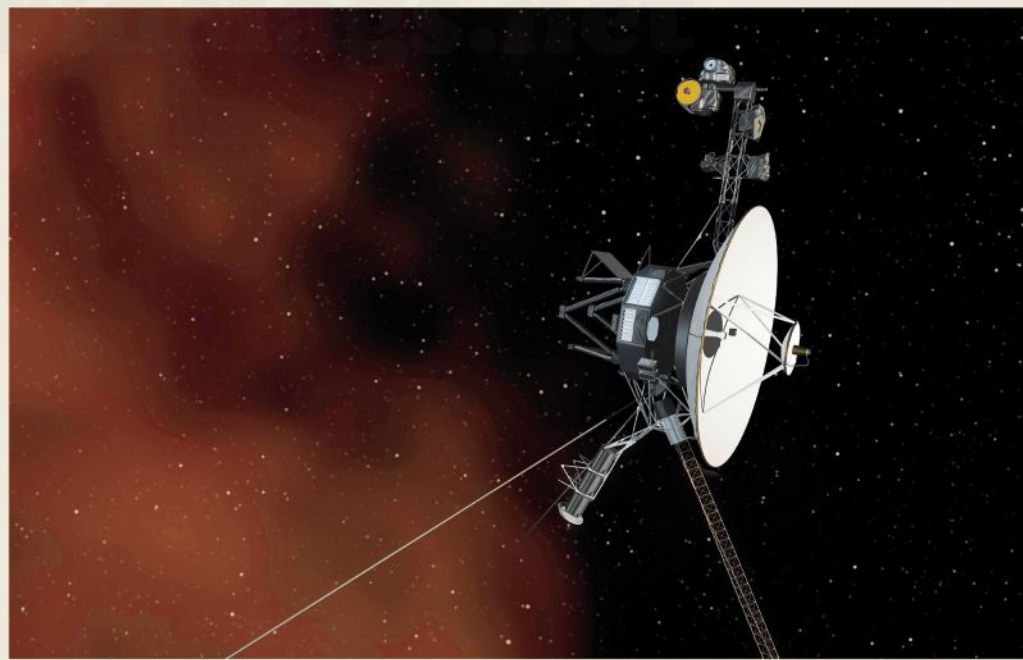
9 Voyager 1 is in interstellar space

After a year of back and forth about whether Voyager 1 had crossed out of the Sun's heliosphere, the spacecraft's team announced September 12 that Voyager 1, at 126 astronomical units (1 AU is the average Earth-Sun distance), is now in interstellar space. Not just that, but the craft had passed the boundary August 25, 2012.

The Sun's magnetic field and wind of particles and radiation create a protective bubble from interstellar material within the galaxy. The outer area of this heliosphere is made up of the "termination shock" and the "heliopause." Voyager 1 crossed the termination shock in 2004 (Voyager 2 crossed it in 2007).

In July to August 2012, scientists reported that Voyager 1 detected more high-energy cosmic rays coming from the galaxy and also observed fewer particles from the Sun. However, the craft didn't detect a change in the magnetic field's direction — which scientists believed would be the smoking gun evidence that Voyager 1 had crossed out of the heliopause and into interstellar space. Thus, the team agreed that the craft was in a transitional "magnetic highway" region.

The Plasma Science (PLS) instrument that could have answered the question concisely in 2012 had stopped working in 1980. The Plasma Wave Subsystem (PWS) instrument, however, collected the clinching evidence April 9, 2013. It detected strong oscillations in the plasma around Voyager 1



Data obtained in 2013 show that Voyager 1 passed into interstellar space August 25, 2012. NASA/JPL-CALTECH

from that date to May 22; plasma is like an extremely hot gas with charged particles freely moving about.

Donald Gurnett of the University of Iowa in Iowa City and colleagues used the PWS observations to determine the density of electrons in the spacecraft's environment and found that Voyager 1 was clearly outside the heliosphere during the April/May detection; the density was some 80 times greater than that expected in the heliopause. They looked at archived data and found weaker oscillations from October 23 to November 27. Comparing the two time periods, Gurnett's team could calculate how the plasma

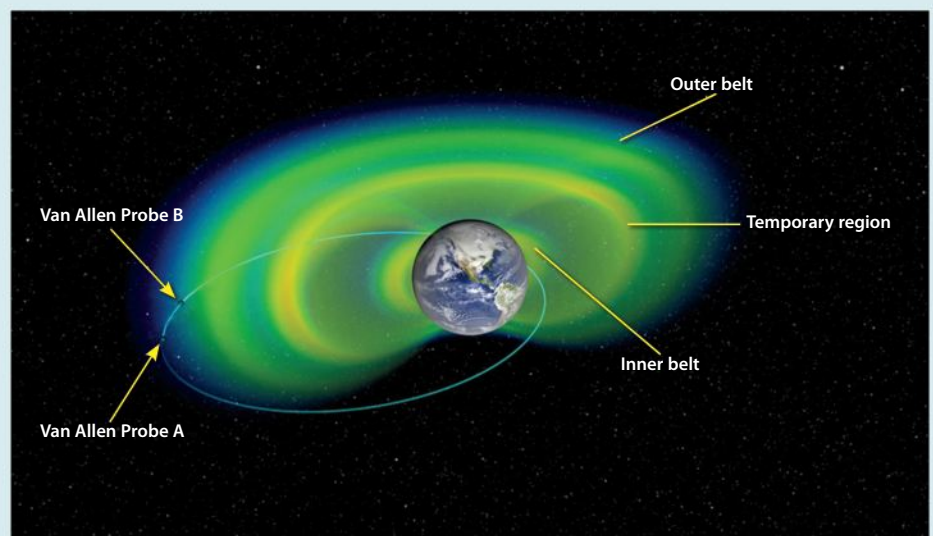
environment changes at different distances from the Sun. The scientists also know that Voyager 1 travels at about 3.58 AU per year. Both pieces of information led them to conclude that the spacecraft passed into interstellar space August 25, 2012.

The Voyager team is careful to say that the craft has passed into interstellar space, not that it has left the solar system. This distinction is important: The Sun's gravity actually extends much farther and holds comets that are nearly 100,000 AU from our star (in what's called the Oort Cloud). At its current speed, it would take Voyager 1 some 28,000 years to leave the solar system.

8 Scientists solve radiation belt mysteries

Earth's magnetic field corrals high-energy particles from the Sun and space into two doughnut-shaped regions surrounding our planet. The inner "belt" ranges from about 370 to 4,000 miles (600 to 6,400 kilometers) above Earth's surface and holds its form over time. The outer region starts some 8,000 miles (13,000km) from the planet's surface and can extend out to 40,000 miles (64,000km); its shape and intensity vary on timescales of hours to days. These areas, the Van Allen Belts, were named for the space scientist integral to their 1958 discovery.

— Continued on next page



NASA's Van Allen Probes observed a third belt of radiation around Earth for a month in the fall of 2012. This was the first time scientists detected a temporary ring in addition to the two permanent ones.

NASA/GODDARD SPACE FLIGHT CENTER

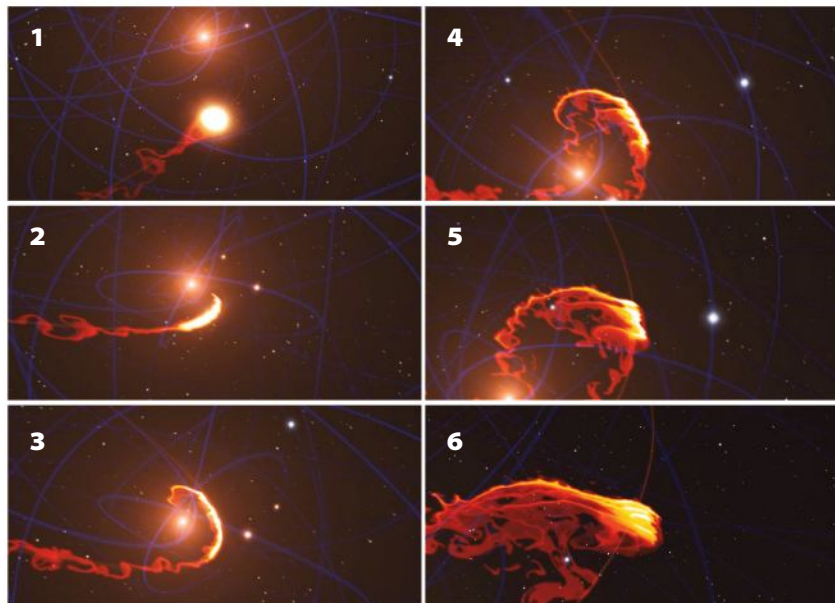
NASA launched two spacecraft in August 2012 — now called the Van Allen Probes — to study the belts and learn why the particles trapped in the regions have such high energies. These identical crafts follow each other in orbits around Earth, where they pass through different regions of the belts to compare and measure radiation changes. At their closest distance to our planet, they fly just 370 miles (600km) above the surface; at their farthest, they reach 23,000 miles (37,000km).

A few days after opening their eyes, the probes measured a third radiation ring forming between the two main belts. This new ring — the first time scientists had witnessed a third radiation belt — lasted from September 3 to October 1. They think that as a filament of solar material and radiation broke loose from the Sun, it hurled a shock wave through the solar system. When that wave hit Earth's magnetic field, it disrupted the outer Van Allen Belt and moved particles inward to form the temporary third belt. They remained in the new region because they were too high-energy to be thrown out, or scattered, by naturally occurring plasma waves within the belts, scientists concluded in a September 22, 2013, *Nature Physics* article. When the Sun let out another storm four weeks later, it destroyed the temporary belt.

The Van Allen Probes also witnessed an energy surge within the radiation rings, which helped scientists solve a long-standing question about the radiation belts: Does a process outside Earth's magnetic field accelerate the belts' electrons and protons to near light-speed, or is the source of acceleration from within the belts? Engineers designed the probes to distinguish between those two possibilities. On October 8 and 9, 2012, the crafts measured the highest energies in the middle of the radiation belts, while the energy decreased as the probes investigated nearer the inner and outer edges of the belts. These observations, reported in the August 30, 2013, issue of *Science*, follow exactly what scientists would expect if the source of the energy comes from the belts themselves.

The Van Allen Probes can't determine what specifically accelerates the particles to those energies, but researchers think radiation waves coursing through the belts might be responsible. Such energy increases can cause significant damage to the electronics aboard satellites orbiting Earth — which is why they're placed in orbits that avoid the Van Allen Belts. Understanding what accelerates particles to more than 99 percent light-speed helps scientists predict when such surges will occur and thus enables more protection for Earth-orbiting satellites.

7 Milky Way's central black hole distorts a gas cloud



ESO/S. GILL/LESSEN/MP/EP/MARC SCHARTMANN/L. CALÇADA

A cold cloud of gas and dust, called G2, is making a close approach to our galaxy's central supermassive black hole, and this computer simulation shows what scientists think is happening. Astronomers have an observational campaign in place to watch this rare event.

In late 2011, astronomers with the Max Planck Institute for Extraterrestrial Physics in Germany announced that they had discovered an odd object with just three times Earth's mass approaching the Milky Way's central supermassive black hole. The object appeared to be moving in the direction opposite Earth and toward the black hole, called Sagittarius A*.

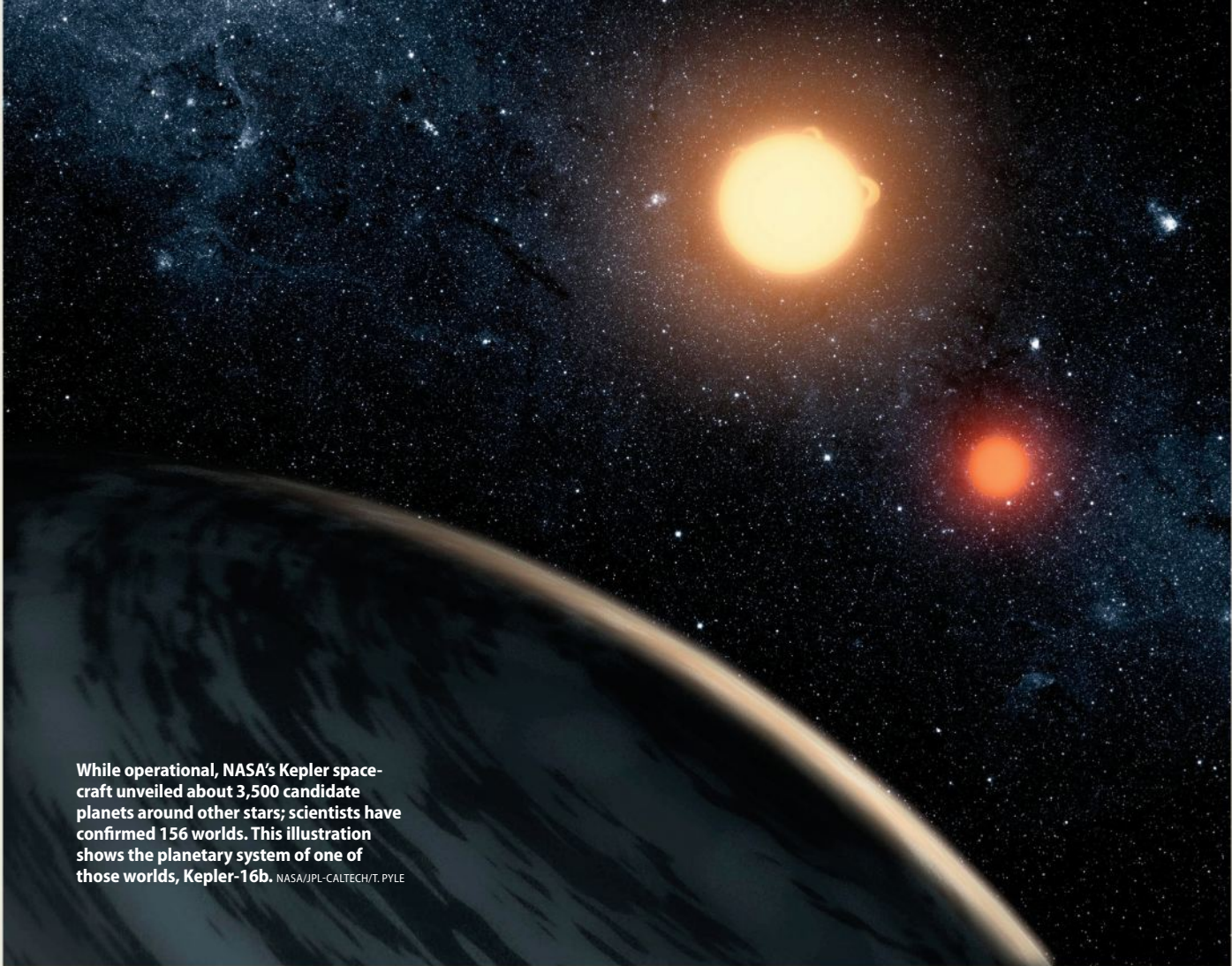
After measuring its temperature of 550 kelvins (530° Fahrenheit), they determined that the object, called G2, is a cloud of gas and dust instead of a star. (A star's surface would be at least triple the newly discovered object's temperature due to the nuclear fusion that powers it.) The German-led team calculated that G2 would reach its closest approach to Sgr A* starting in the summer of 2013.

Sgr A* holds some 4.3 million times the Sun's mass in a region about 18 times as wide as the Sun. Cramming so much mass into such a small area creates extreme warping in the fabric of space-time, and anything that passes near the black hole will feel a mammoth gravitational force. G2 is passing about 130 times the average Earth-Sun distance from the black hole, but Sgr A*'s gravity will stretch it even at that distance. If the object were instead a star,

it would have enough gravity to remain mostly intact during the passage.

Astronomers began seeing effects of the black hole's intense gravity on the small cloud in April 2013. Their observations show that G2's leading edge has rounded the far side of the black hole and is now moving toward Earth. Researchers can tell this movement by analyzing the cloud's light. As it moved away from telescopes, the light appeared redder; as it now moves toward telescopes, the light appears bluer. Simulations show Sgr A*'s gravity will stretch the cloud over about a year before it is too diffuse to see.

Researchers rarely have the opportunity to watch a supermassive black hole interact with passing material and thus are training many observations on the center of our galaxy to view G2's close approach. Because other enormous black holes lie far away — the next closest to Earth sits at the Andromeda Galaxy's center some 2.5 million light-years distant — telescopes don't have the resolution to see the details as material passes close to those black holes. These types of interactions can tell astronomers about the physical processes of the black hole's immediate environment, a location where extreme physics occurs.

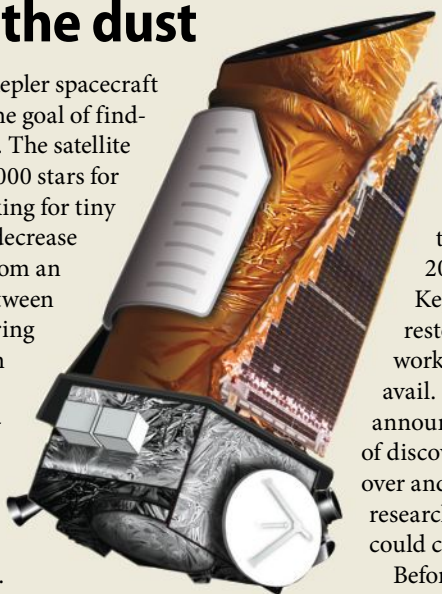


While operational, NASA's Kepler spacecraft unveiled about 3,500 candidate planets around other stars; scientists have confirmed 156 worlds. This illustration shows the planetary system of one of those worlds, Kepler-16b. NASA/JPL-CALTECH/T. PYLE

6 Planet-hunting machine bites the dust

NASA launched the Kepler spacecraft March 6, 2009, with the goal of finding Earth-like planets. The satellite stared at roughly 160,000 stars for nearly four years, looking for tiny dips in brightness. A decrease in light could result from an exoplanet crossing between its star and Kepler during the planet's orbit — an event called a transit. Scientists have discovered some 3,500 candidate planets in the Kepler data so far analyzed and confirmed 156 worlds.

Sadly, Kepler can't collect additional data with the sensitivity to dig out exoworld signatures. In July 2012, one of its four gyroscope-like wheels failed; these are crucial to the craft because they, in conjunction with the craft's star tracker,



precisely point Kepler. The satellite was still able to observe the same field of view properly with three wheels, but in May 2013, another failed.

Kepler scientists tried to restore one of the non-working wheels — to no avail. On August 15, they announced that the craft's days of discovering exoplanets were over and they'd look into other research the disabled spacecraft could carry out.

Before the craft went kaput, astronomers had found multiple-planet systems and Earth-sized worlds within the Kepler data. They've also learned a great deal about the observed stars. Changes in stellar brightness don't necessarily result from a planet blocking

The Kepler spacecraft, NASA's planet-finding machine, lost the use of its second of four gyroscope-like wheels in July 2013. Without three such wheels, the satellite lacks the precision to point Kepler accurately to monitor about 160,000 stars for brightness changes. NASA/KEPLER MISSION

some of its host star's light. Star spots, stellar flares, and interior pulsations can cause a change in light output. Using the Kepler data, scientists have determined the ages and sizes of thousands of stars by studying such oscillations.

Researchers need at least three "dips" to catalog a source as a possible planet-hosting star — each "dip" represents one orbit. So, if an Earth-sized world orbits a Sun-like star at the distance where liquid water could exist on the surface — essentially just like our planet — it would take at least three Earth years of data to see three transits. Kepler scientists say they have yet to analyze about half of the telescope's data, and smaller planets farther out from their stars — those with fainter signals and longer orbital periods — are probably still hiding within the unanalyzed observations. So, while the spacecraft can no longer collect data about exoplanets, that doesn't mean the discoveries from the Kepler team have ceased.



Comet PANSTARRS (C/2011 L4) passed near the Sun on March 10, 2013. This astrophotographer captured the comet and its dust and ion tails some three months later. DAMIAN PEACH



Once Comet ISON (C/2012 S1) came within about 280 million miles (450 million kilometers) of the Sun, our star's heat began turning the comet's ices directly to gas. DAMIAN PEACH

5 Dusty snowballs brighten the sky

People love a bright comet. It creates a fantastic spectacle in the sky, leaves the world outside in awe, and offers another laboratory for researchers to study the early solar system. Comets can turn the public on to astronomy more than any other celestial object, and having two bright comets in 2013 — Comet PANSTARRS (C/2011 L4) and Comet ISON (C/2012 S1) — has thus provided a fabulous opportunity to excite people across the globe.

Even though Comet ISON was touted as *the* comet to watch for in 2013, another inner solar system interloper made headlines in the spring. That was Comet PANSTARRS, named for the telescope that spied it overnight June 5/6, 2011 — the Panoramic Survey Telescope and Rapid Response System. This dusty snowball passed some 28 million miles (45 million kilometers) from the Sun on March 10, 2013, when observers in the Southern Hemisphere

had a better view of the comet than those in the Northern Hemisphere. Comet PANSTARRS peaked at magnitude 0.6, a nice sight but still some 2,300 times fainter than ISON was expected to be.

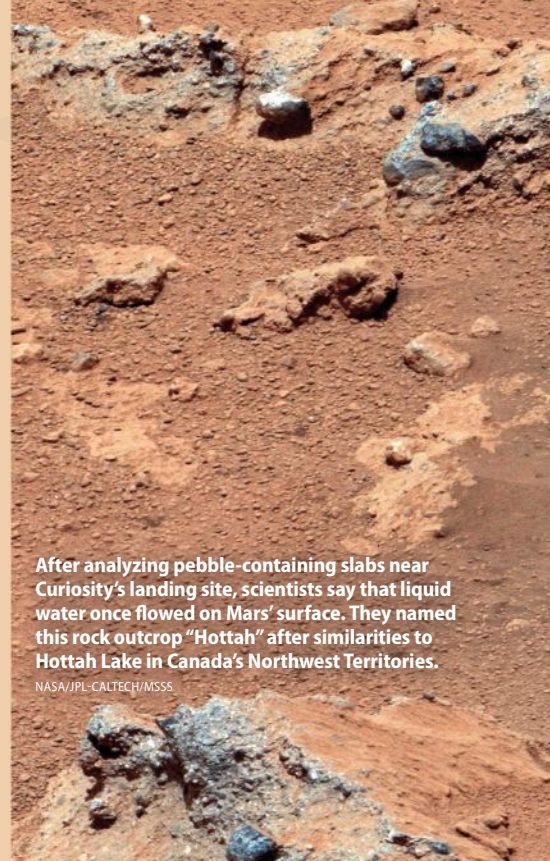
Observers Vitali Nevski from Vitebsk, Belarus, and Artyom Novichonok from Kondopoga, Russia, discovered a faint blob on images they recorded with the International Scientific Optical Network's (ISON) 40-centimeter telescope September 21, 2012. Scientists further analyzed the object, determined it was a comet, and predicted it would pass within 1.1 million miles (1.8 million km) of the Sun's surface — just 1.3 times our star's diameter — November 28, 2013.

Most comets originate from the Oort Cloud, a hypothesized region filled with trillions of dirty snowballs some 20,000 to 100,000 times the Earth-Sun distance from our star. As one of those clumps enters the inner solar system, the Sun's radiation warms the

comet, and its ices turn directly to gas. The comet brightens as its surrounding gas cloud — the coma — expands.

Reports that Comet ISON could reach a peak brightness equivalent to the Moon quickly swirled. One month prior to opposition, though, predictions suggested the icy conglomerate would be closer to magnitude -7.8 — still a spectacle in a twilight sky. The comet has never approached the Sun, so no one at press time in late October yet knew how ISON will behave. It could break apart due to the pull of the Sun's gravity as it passes and perhaps put on a more impressive show. Recent analysis suggests that one side of the cometary nucleus has faced the Sun, which means the other side is still frozen, pristine material that could put on a fabulous show as it nears our star.

No matter what happens, Comet ISON still has infiltrated the media, scientists' discussions, and the general public's minds.



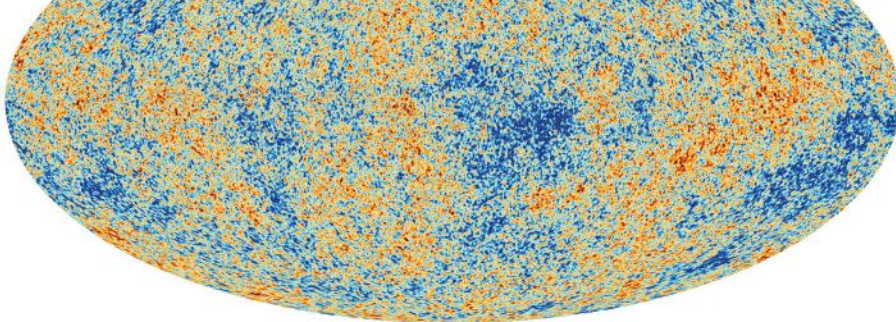
After analyzing pebble-containing slabs near Curiosity's landing site, scientists say that liquid water once flowed on Mars' surface. They named this rock outcrop "Hottah" after similarities to Hottah Lake in Canada's Northwest Territories.

NASA/JPL-CALTECH/MSSS

4 Curiosity finds a once-habitable environment on Mars

A complex string of engineering put the Curiosity rover on the martian surface August 6, 2012. Landing on the Red Planet was itself an impressive feat, but what followed was even better: Curiosity drilled 2.5 inches (6.4 centimeters) deep into its first rock February 8, 2013, collected that material, and analyzed it with its onboard Chemistry and Mineralogy and Sample Analysis at Mars instruments. "Mineral analysis of the powder drilled from that rock found smectite clay that testifies to an ancient environment with liquid water that was not too acidic, too alkaline, or too salty," says Curiosity Project Scientist John Grotzinger of the California Institute of Technology in Pasadena. "Chemical analysis identified all of the main elemental ingredients for life: sulfur, nitrogen, oxygen, phosphorus, and carbon." So, with its first drilled sample, Curiosity showed that Mars once harbored a habitable environment.

The rover also found other evidence that liquid water once flowed on Mars. In a May *Science* article, scientists described Curiosity's observations of pebbles and sand conglomerates, much like slabs in riverbeds on Earth. They calculated the depth and speed water



The cosmic microwave background (CMB) holds a plethora of information about the early universe. After observing the microwave sky for 15.5 months with the Planck spacecraft and analyzing the data for another two years, the Planck team released this map of the CMB. ESA/PLANCK COLLABORATION

3 Advanced instruments observe the early universe

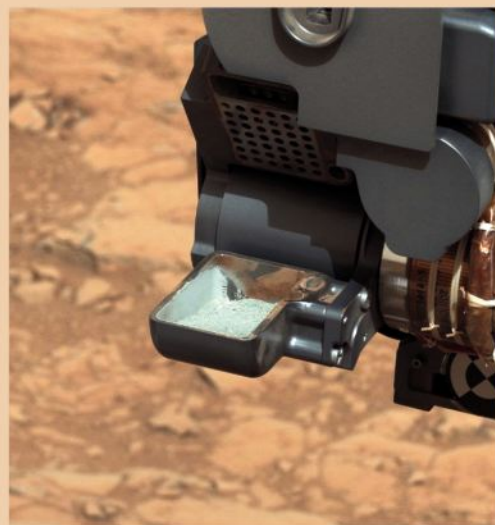
The universe began in a hot, cramped state about 13.8 billion years ago and has since expanded and cooled. In the early cosmos, electrons, protons, and radiation (called photons) bounced off one another constantly. About 370,000 years later, once the universe cooled to some 3000 kelvins (4940° Fahrenheit), electrons and protons could combine, letting photons travel unimpeded. The distribution of matter at this “time of last scattering” left a pattern on the radiation that now fills the sky. Astronomers can study this cosmic microwave background (CMB) radiation to learn about the universe as it was when light and matter separated and about all the material that radiation has traveled through since then.

The CMB is a treasure-trove that scientists have been analyzing for decades, and each new telescope tells them more details about the cosmos. The European Space Agency’s Planck satellite is the most recent space probe to map the CMB and learn about the universe’s properties. Planck launched in May 2009, and the team released its first all-sky CMB results in March 2013. According to the newest map of the CMB, the universe comprises 4.9 percent normal matter (like stars, gas, and planets), 26.8 percent dark matter (an invisible mass), and 68.3 percent dark energy (a mysterious force that seems to be speeding up the universe’s expansion).

Astronomers also used the Planck data to map the largest scales in the universe. “The CMB is traveling to us over billions of years, and the gravity of basically everything it goes past bends that light ever so slightly,” says Joanna Dunkley of the University of Oxford in England. Analyzing this “gravitational lensing” of the CMB gives the distribution of all the matter in the universe — normal and dark matter, from the time of last scattering to the present day.

The Planck team hopes to release its next data set in mid-2014 and incorporate another aspect of the CMB that’s much more difficult to get to — the polarization of that radiation. The CMB light waves do not vibrate in random directions. Instead, they can follow two types of patterns: E-mode or B-mode. As CMB photons collide with electrons in the universe, they scatter with a specific direction, seen as E-mode. B-mode polarization, however, is a smaller signal and thus much harder to see. One type of B-mode polarization comes from gravitational disturbances produced during a period of hyperacceleration in the universe’s first fraction of a second, called inflation.

The South Pole Telescope (SPT), which has been operating for nearly seven years from — you guessed it — the South Pole, is also looking for polarization signals. The SPT team announced July 22 that it had detected B-mode polarization within the gravitational lensing of the CMB. While this isn’t the inflation signature astronomers have been searching for, it is still an important milestone in research, as it shows that scientists are digging deeper into what the CMB holds.



The Curiosity rover drilled a 0.63-inch-wide (1.6 centimeters) and 2.5-inch-deep (6.4cm) hole in martian bedrock and collected its first sample February 8. It then analyzed the powder — shown here in the rover’s scoop — using the Chemistry and Mineralogy instrument and Sample Analysis at Mars instrument.

would have moved to make the shapes of the gravels embedded in the conglomerates. “The stream was flowing at a speed equivalent to a walking pace — a meter, or 3 feet, per second — and it was ankle-deep to hip-deep,” says Rebecca Williams of the Planetary Science Institute in Tucson, Arizona.

The rover is now on its 4.4-mile (7.1 kilometers) drive to Mount Sharp. What it finds there will continue to excite planetary scientists and the public alike.



The South Pole Telescope studies the cosmic microwave background (CMB) from Antarctica. In late 2013, scientists with this project published their observation of a specific direction to the CMB radiation. DANIEL LUONG-VAN, NATIONAL SCIENCE FOUNDATION

2 Supernovae accelerate cosmic rays

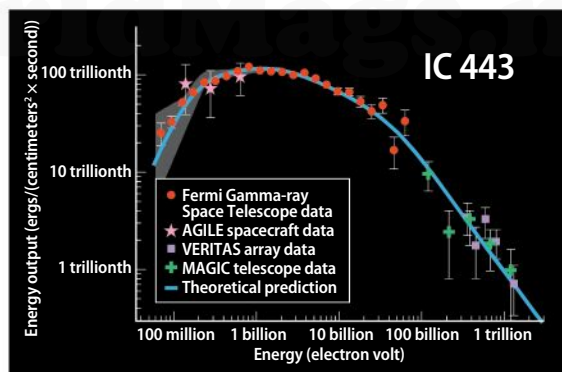
In 1912, Austrian-American physicist Victor Hess flew aboard a hot air balloon to 17,600 feet (5,350 meters) and found a fourfold increase in radiation above 9,840 feet (3,000m). This cosmic radiation came from all directions. As the decades passed, researchers learned that these cosmic rays constitute 90 percent of high-energy protons, while electrons and atomic nuclei make up the other 10 percent. But finding the source of these particles, and what gives them their incredible energies, has been difficult.

Our Milky Way Galaxy has a magnetic field, and cosmic-ray particles have electric charge — protons and nuclei are positive while electrons are negative. Charged particles like cosmic rays change their directions when moving through a magnetic field, and thus their original trajectories can't be traced.

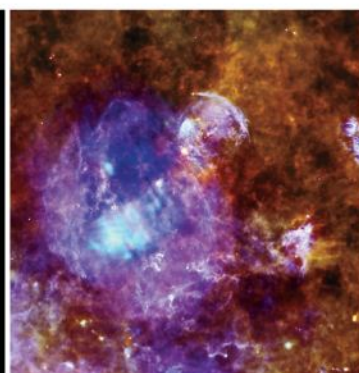
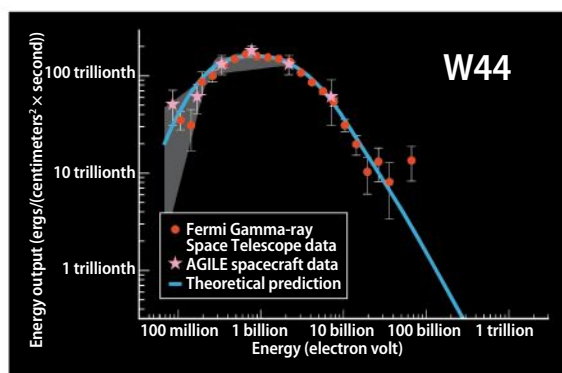
But astronomers have another way to find out where cosmic rays come from. They know that a fast-moving proton (like a cosmic ray) that collides with a proton sitting in interstellar gas will produce an elementary particle called the neutral pion. This particle then decays into two gamma rays, each with a specific energy signature centered at 67.5 million electron volts (MeV; for comparison, visible light has energy between 1.5 and 3 electron volts). A gamma ray has a neutral electric charge, and thus magnetic fields don't affect it. If you can find gamma rays with that specific energy signature, then you've found cosmic rays.

NEWS STORIES TO WATCH IN 2014

- The European Space Agency's Rosetta spacecraft will arrive at Comet 67P/Churyumov-Gerasimenko in May and touch down on its surface in November.
- NASA reactivated its Wide-field Infrared Survey Explorer in August 2013 to hunt near-Earth asteroids. See how this mission progresses in 2014.
- The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission, which was scheduled to launch in November 2013, will reach the Red Planet in September 2014.
- The Curiosity rover will arrive at Mars' Mount Sharp in early 2014.



Astronomers collected gamma rays from IC 443, the remnant of an exploded star. The collected energy signature below about 200 million electron volts — at the left edge of the diagram — provided “smoking gun” proof that supernova remnants accelerate cosmic rays to their extreme speeds. ASTRONOMY: ROEN KELLY, AFTER M. ACKERMANN, ET AL. (DIAGRAM); ECHO/DSS/VLA (IC 443)



After studying the highest form of radiation, gamma rays, from supernova remnant (SNR) W44 and combining that data with observations of SNR IC 443, scientists say that the shock fronts of these exploded stars can trap charged particles, push them to extreme energies, and create what are known as cosmic rays. ASTRONOMY: ROEN KELLY, AFTER M. ACKERMANN, ET AL. (DIAGRAM); ESA HERSCHEL/XMM-NEWTON (W44)

Astronomers have looked for the energy signature in the remnant radiation from an exploded star, or supernova. In such an explosion, a star's outer shells of material fly away from its core and compress and heat — or “shock” — nearby gas. Scientists have long hypothesized that these shocked-material sites are regions of frequent proton-proton collisions and thus that supernovae are the culprit behind cosmic-ray acceleration. But direct evidence — the specific energy signature — didn't exist.

In February 2013, scientists reported in the journal *Science* that they had discovered that energy signature — thus proving supernovae are a source of cosmic rays. NASA's Fermi Gamma-ray Space Telescope observed the supernova remnants IC 443 and W44 sporadically from August 4, 2008, to July 16, 2012, down to energies of 60 MeV. The team then compared their observations to the energy spectrum expected if neutral pion particles decayed into the gamma rays, and they matched remarkably well.

So how does a supernova remnant energize particles to such high speeds?

The shock front has entangled magnetic fields. “Charged particles can get trapped in the vicinity of the shock by these magnetic fields, such that they travel back and forth across the shock itself,” explains Scott Wakely, a University of Chicago particle astrophysicist not involved with the Fermi telescope study. “Each time they pass across, they gain a little energy, and so after a while — thousands of years! — they become quite energetic and can escape, at which point they propagate into the galaxy, becoming cosmic rays.”

A century after Hess' discovery, scientists have proven what creates these high-energy cosmic rays. But that doesn't mean they've figured out all there is to know about pervading cosmic radiation. The next step is to determine the details of the acceleration technique and also the maximum energy a cosmic-ray proton can attain. Physicists have discovered gamma rays with energies up to a million times that of the gamma rays discussed in the February *Science* study. How much more energetic can the particles get?



TO FIND OUT THE NEXT 10 TOP SPACE STORIES OF 2013, VISIT www.Astronomy.com/toc.

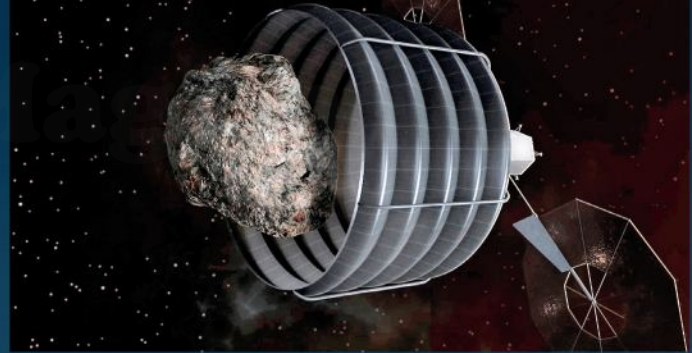
1 Once-in-a-century fireball explodes over Russia

At 9:22 on February 15, the morning in Chelyabinsk, Russia, was rudely interrupted. That's when a meteoroid some 55 to 59 feet (17 to 18 meters) wide entered Earth's atmosphere. Friction from our planet's atmosphere slowed and heated the boulder, causing it to glow as a fireball. Some 35 seconds later, when it was 14 miles (23 kilometers) above sea level, the rock exploded. When the resulting shock wave reached the surface, it broke windows, set off car alarms, and surprised hundreds of thousands of people on the ground. The produced debris injured about 1,000 people, luckily none fatally.

The meteoroid entered Earth's atmosphere at a shallow 14° angle and came from the Sun's direction — thus it was impossible to see much before it was too late. The blast released the equivalent energy of about 440 kilotons of TNT and scattered meteorite fragments over an area a few dozen kilometers squared. Scientists have analyzed fragments to determine that the space rock was a chondrite — the most common type of meteorite that falls to Earth.

While the February 15 event was of great interest, that's not the reason we picked it as the number one story of the past year. What this meteoroid explosion did was remind people that Earth is not isolated from other objects and events in space. Rocky objects collide with our planet all the time, and sometimes — like in 2013 — a house-sized one has Earth in its crosshairs and causes significant damage. Large ones would be even more destructive.

This fact is why NASA has a near-Earth object (NEO) program to catalog 90 percent of the NEOs larger than 460 feet (140m) wide. But the Sun's light blinds us to objects near it — including space



NASA has pushed forward plans to launch a mission in 2020 that will capture a 23- to 33-foot-wide (7 to 10 meters) asteroid and move it to lunar orbit. NASA

rocks coming from that direction. The Chelyabinsk meteoroid event proved why humans need better ways to find and catalog NEOs, and have plans in place if a city-sized one were discovered. NASA and private companies are aggressively addressing this concern.

NASA has moved forward with its 2016 OSIRIS-Rex mission to reach an asteroid, collect a sample, and return that sample to Earth in 2023. On April 10, the space agency also announced a concept to follow in OSIRIS-Rex's footsteps — an asteroid-capture mission. Asteroids, after all, are the big brothers of meteoroids and would cause far more damage to Earth than the Russian one did.

The purpose of the new mission is to launch a craft by 2020 that would capture a small asteroid (23 to 33 feet [7m to 10m]) and move it to lunar orbit. There, astronauts could explore it, grab samples, and bring them back to Earth. Not only would this project encourage new technology for manned spaceflight, but it also would give scientists a way to redirect an NEO set to cross Earth's path, as long as astronomers discovered it in time. NASA opened up a call for ideas for this asteroid-capture mission in June, and they received more than 400. From September 30 to October 2, the space agency heard from those who contributed 96 of the most promising ideas. ▶

A meteoroid entered Earth's atmosphere and exploded over Chelyabinsk, Russia, at 9:22 A.M. local time February 15. Scientists now know the space rock was between 55 and 59 feet (17 and 18 meters) wide. MARAT AKHMETVALEYEV



ATMOSPHERE ACTIVITY

Q: CAN EARTH-LIKE LIGHTNING AND THUNDER OCCUR ON A PLANET OR MOON THAT EXHIBITS STORMS IN ITS ATMOSPHERE?

John Carlson, Colon, Michigan

A: Yes! The cameras on both the Voyager and Galileo spacecraft detected lightning in Jupiter's atmosphere. In 2011, the Cassini probe cameras detected a faint flash of lightning on Saturn, as well. The flashes on both gas giants were associated with recognizable storm systems.

A reliable way to detect lightning turns out to be searching for radio waves emitted during the flash. This method doesn't depend on lighting conditions or whether a camera is pointed at the "right" storm.

Lightning forms as a discharge from one region that has mostly one type of charge (i.e., negative) to a different area that has another type of charge (positive). This often occurs in water clouds because water has polarity — an uneven distribution of electric charge — and can therefore form charge more easily than other molecules that are non-polar. The lightning on both Jupiter and Saturn occurs in the water clouds of the gas giants, and those clouds form at several times Earth's surface atmospheric pressure.

Although Titan, Saturn's largest satellite, has storms in an atmosphere thicker than Earth's, Cassini hasn't detected any evidence of lightning flashes or lightning-generated radio waves on the moon. Titan's atmosphere, however, does not contain much water. Venus has a thick atmosphere and little water, but the Venus Express mission has detected convincing evidence for

radio waves associated with lightning. In fact, scientists estimate that the planet has cloud-to-cloud lightning in its atmosphere about 25 percent of the time, although no flashes have been seen so far. Venus' atmosphere is 90 times thicker than Earth's and contains clouds of sulfuric acid, so its lightning may have a different origin from our planet's.

Glenn Orton

Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Q: DO ORBITAL MOTIONS BETWEEN GALAXIES AFFECT CALCULATIONS OF THE COSMOLOGICAL REDSHIFT?

Steve Davis

Greenacres, Washington

A: Yes, they do. The observed redshift, or wavelength shift due to motion, of a galaxy's characteristic light spectrum is a combination of the galaxy's motion with respect to its neighbors ("peculiar velocity") and the expansion of the universe ("cosmological redshift"). The latter only corresponds to objects moving away from us — their light shifts to the red end of the electromagnetic spectrum.

In less crowded regions (where there are few galaxies), peculiar velocities can be about 60 miles per second (100 kilometers/second), while in clusters of galaxies — which are much more densely packed — they can be more than

600 miles/s (1,000 km/s). A peculiar velocity of 600 miles/s (1,000 km/s) will lengthen or shorten the wavelength of light by a factor of 1.0033.

A cosmological redshift will lengthen the wavelength by a factor that depends on the distance between the telescope and the galaxy. A redshift of 0.01 means a lengthening factor of 1.01.

For galaxies at large distances from us, the cosmological redshift's effect is much larger, which means the peculiar velocities are small in comparison. Galaxies within about 150 million light-years (a small distance for cosmologists), however, correspond to cosmological redshifts less than 0.01, so peculiar velocities at these distances are significant. For example, the Virgo cluster holds galaxies showing wavelength shifts corresponding to factors of 1 (i.e., no shift) to 1.008, yet we know that most of them are in the cluster and have a similar cosmological redshift of 0.004. The range results because galaxies in the cluster can have peculiar velocities up to 750 miles/s (1,200 km/s): either toward us, which can cancel out the effect of the cosmological redshift, or away from us, which increases the observed redshift.

We separate the two effects by estimating the distance to selected galaxies and comparing with their measured redshifts. From this information, we can develop models that predict the peculiar velocities of galaxies

within a volume. We can then use these models to correct measured redshifts to cosmological redshifts. This is an active area of research, and separating peculiar velocities is an important method of measuring the content of an invisible type of mass in the universe, called dark matter.

Ivan Baldry

Liverpool John Moores University, United Kingdom

Q: HOW CAN THE SUN'S AND EARTH'S GRAVITIES PROVIDE A LAGRANGIAN POINT ON THE SIDE OF EARTH OPPOSITE THE SUN? DON'T THEIR COMBINED GRAVITIES EQUAL EACH OTHER ONLY AT LOCATIONS BETWEEN THE OBJECTS?

Stephen Smith

Charlotte, North Carolina

A: You often hear about Lagrangian points because they can be handy places to "park" a spacecraft where it doesn't need much fuel to stay in the same position relative to Earth. If gravity were the only force in the equation that defines these points, you would indeed expect there to be only one such point — between the planet and the Sun, where the gravities from these objects balance. But it's a bit more complicated: The Lagrangian points also involve centrifugal force.

This is the force you feel on your arm when you swing a heavy object around in circles.



In 2011, NASA's Cassini spacecraft imaged lightning within a huge storm that circled Saturn's northern hemisphere. Scientists enhanced these photographs to make the lightning flash more visible; the left image shows the tiny blue flash (arrow), while the image on the right — taken 30 minutes later — shows no electric activity. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

Scientists sometimes call it a “fictional” force to distinguish it from a fundamental force like gravity. But to a craft orbiting in the solar system, it is very real.

In an ordinary Keplerian orbit like the path of Earth around the Sun, the centrifugal force simply balances the gravitational force from our star. But for a satellite orbiting near one of Earth’s Lagrangian points, the centrifugal force approximately balances the sum of the gravitational forces from the Sun and Earth. That situation can occur in five different places in the solar system. For example, on the side of Earth opposite the Sun, the gravitational forces from both objects pull together in the same direction. So a body orbiting with slightly more centrifugal force than an ordinary Keplerian orbit will find its centrifugal force balanced by the combined gravity of the Sun and Earth — at the second Lagrangian point.

Marc Kuchner

*NASA’s Goddard Space Flight Center,
Greenbelt, Maryland*

Q: HOW DO CCDS WORK?

Robert Morstadt

Brigham City, Utah

A: While most people had little experience with charged coupled devices (CCDs) as recently as 10 years ago, digital cameras containing one are much more common today. Astronomers

jumped on the CCD bandwagon early on — in 1979.

A CCD is an array of capacitors. These capacitors, which are referred to as pixels (short for picture elements), are just devices that can store electric charge. The pixels are arranged in rows and columns on a “chip,” and the chip sits at the focus of the camera. A 4-megapixel chip, for example, has 4 million pixels, arranged in 2,000 rows by 2,000 columns.

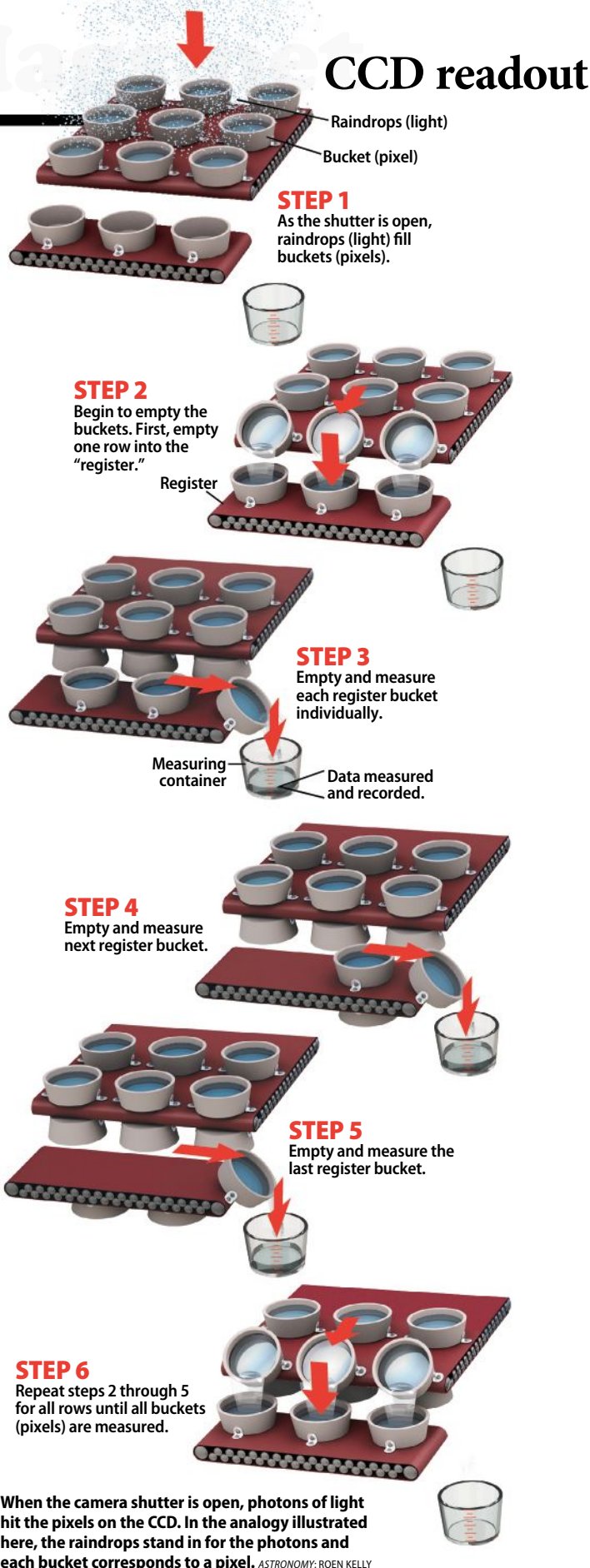
When the camera shutter is open, the camera’s (or telescope’s) optics focus an image on the chip. Each capacitor reacts to light, or photons, that falls on it by ejecting electrons from constituent atoms, causing the capacitor to accumulate a charge. When the shutter is closed, each pixel retains its charge, which is proportional to the amount of light that struck it.

A computer program must then measure the charge pixel by pixel and in the correct order. First, it reads out the bottom row of pixels one at a time, by electronically manipulating the voltage between each pixel. Then, it shifts the next row down one row to read out that one. This process is repeated until every pixel has been measured. The result is an array of numbers, and each number is a measure of the brightness in a pixel.

Software can transform this array of numbers into a black and white image, but how do we get color? For most astronomical pictures, we take multiple exposures of an object through a series of different colored filters placed in front of the camera — for example, red, green, and blue. The red-filter image is read out, then the green-filter one, and so forth. We then assign colors to each picture and combine them, which explains why color can vary dramatically depending on how a user processed an image.

Katy Garmany

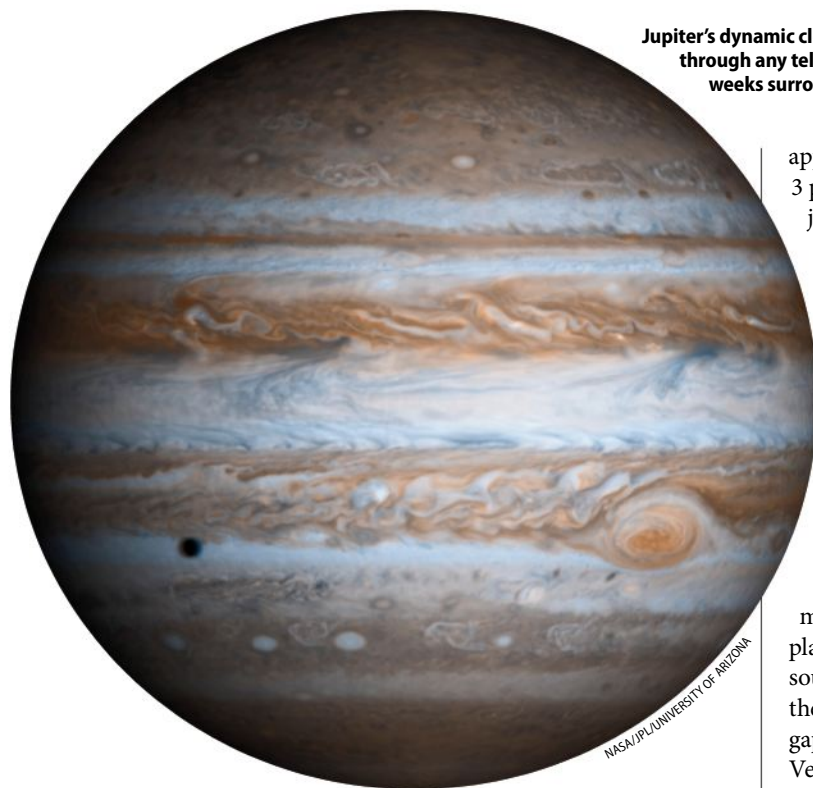
*National Optical Astronomy
Observatory, Tucson, Arizona*



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.

January 2014: Jupiter's all-night show



Jupiter's dynamic cloud tops are a treat to view through any telescope, particularly in the weeks surrounding its January 5 opposition.

There's lots of action in the planetary arena this month. At the top of the list is Jupiter, which appears better than it has in 13 months and remains on display all night. Venus, the only planet that outshines Jupiter, hangs low in evening twilight in early January and then reappears in the morning sky after midmonth. Once Venus exits the evening stage, Mercury arrives with a fine performance of its own late in the month. Not to be outdone, both Mars and Saturn improve noticeably as they climb high before dawn.

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

Let's begin our tour of the sky shortly after the Sun sets January 1. **Venus** shines at magnitude -4.4 , a brilliant jewel nearly 10° above the southwestern horizon 30 minutes after sunset. Use Venus as a guide for finding an exceptionally young Moon. From mid-northern latitudes, our satellite sets just 45 minutes after the Sun. And from North America's Central time zone, the Moon is then just 15 hours past its New phase and only 0.6 percent lit. With binoculars, scan the area to the lower right of Venus and just above the horizon. You'll need a crystal-clear sky and an unobstructed western horizon to spot the difficult crescent.

A view of Venus through a telescope shows a disk not much more illuminated than the Moon's. On the 1st, it

appears $60''$ across and only 3 percent lit. By January 5, just six days before Venus passes between the Sun and Earth, the inner planet stands 4° high a half-hour after sunset. A scope reveals Venus' $62''$ -diameter disk, which appears a mere 1 percent lit.

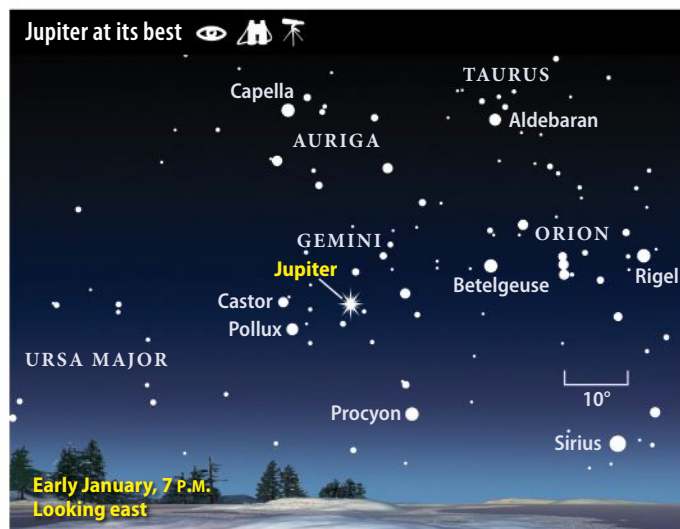
After passing 5° north of the Sun at inferior conjunction January 11, Venus switches to the morning sky. By the 17th, the planet comes up in the east-southeast a full hour before the Sun, and by the 31st, this gap stretches to two hours. Venus crosses from northern Sagittarius to southern Scutum and back during January's final week. Look for the waning crescent Moon near the planet both January 28 and 29. On the month's final morning, Venus shines at

magnitude -4.8 and a telescope shows a disk that spans $52''$ and appears 12 percent lit.

Mercury doesn't come into view until mid-January, when it starts what will be one of its two best evening appearances of 2014. As it initially climbs into view after sunset, the innermost planet shines at magnitude -1.0 ; through a telescope, it shows a nearly full disk that spans $5''$.

Mercury reaches greatest elongation January 31, when it lies 18° east of the Sun. It then appears 11° high in the west-southwest 30 minutes after sunset and, at magnitude -0.7 , stands out through binoculars to anyone with a clear and unobstructed horizon. A telescope reveals the planet's $7''$ -diameter disk, which appears slightly over half-lit.

Earth's Moon takes 29.5 days to complete its cycle of phases, so it shouldn't come as a surprise that a young Moon returns to the evening sky at the end of January. You can find our satellite 5° to



Look for Jupiter in the eastern sky during the early evening. The giant planet resides in the constellation Gemini the Twins. ASTRONOMY: ROEN KELLY

RISINGMOON

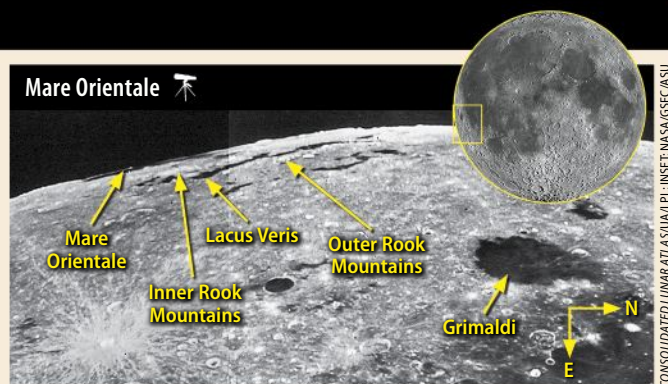
Get a glimpse of the Orient

The Moon's most striking impact basin is arguably Mare Orientale, a sea of lava surrounded by a huge, well-defined double ring of rugged mountains that spans nearly 600 miles. Don't fret if you haven't heard of it — it's tucked against the western limb of the Moon. Only its eastern ramparts and lava lakes show up, and these only when the lunar spin and elliptical orbit align. Such a favorable tilt (or "libration") occurs from January 20 to 27.

Orientale is all about observing at the edge. Before the 20th, the raised rim of the Cordillera Mountains appears in profile as a pair of ears poking above the

western limb. Use the dark crater Grimaldi to orient yourself. The rim edges separate night to night until the 19th, when the long dark line of Lacus Veris tilts into view. You're now looking beyond the tall ring of the outer Rook Mountains, first into the shallows where lava welled up from below and then to the light colors of the lunar crust that push up into the inner Rook Mountains.

To spy Mare Orientale's dark central floor, try the mornings of January 23 to 25 when the libration maxes out. Astronomers deduce that when Orientale formed, the denser mantle underneath bulged upward.



The giant basin known as Mare Orientale lies mostly on the lunar farside, but you can glimpse its eastern edge this month.

This created a mass concentration, and the extra gravitational force produced by this so-called mascon slightly alters the orbits of spacecraft.

The angle of incoming sunlight makes all the difference when it comes to lunar observing. The picture here shows the

back inner wall of Orientale as a thin white line on the limb under a late morning Sun's illumination. If it were late afternoon, when the Moon appears to us as a thin crescent, that wall would be in shadow and provide no help in tracing the outline of this giant impact feature.

Mercury's lower right on the 31st. The Sun then illuminates 2 percent of the Moon, so it still will be a challenge to spot without binoculars.

A much fainter planet also lurks in Mercury's vicinity January 31. Distant **Neptune** lies 4° east of the inner planet. (Mercury lies near the center of a line joining the Moon and Neptune.) Spotting Neptune during twilight is tricky, and the sky doesn't darken completely until the planet is on the verge of setting.

The outer world is much easier to find in early January, when it appears 25° high after twilight has faded away. You can locate the 8th-magnitude world through binoculars among the background stars of Aquarius the Water-bearer. January 4 offers a good opportunity. The waxing crescent Moon then lies 1.9° north of 4th-magnitude Theta (θ) Aquarii while Neptune resides 3.4° south-southeast of the same star. The planet looks

— Continued on page 42

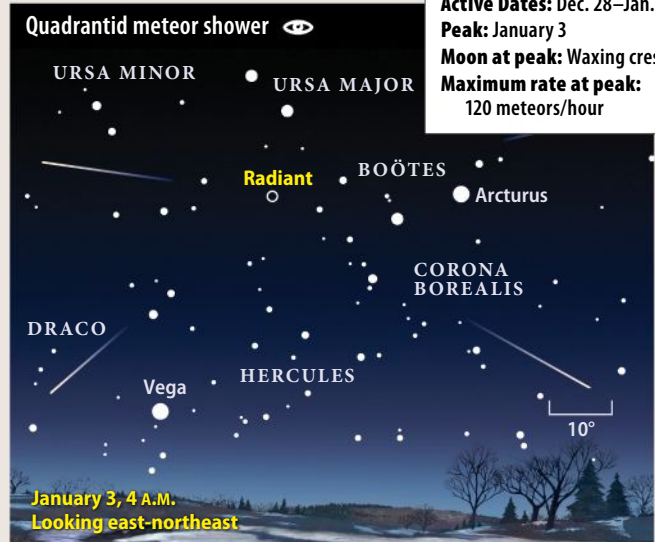
METEORWATCH

Perfect conditions for the 2014 Quadrantids

January's claim to meteor fame is the annual Quadrantid shower. Although activity varies from year to year, the rate usually peaks above 60 meteors per hour under ideal conditions and often goes twice that high. The meteors appear to radiate from a point in northern Boötes.

The Quadrantids reach a sharp peak in the predawn hours January 3. With New Moon arriving January 1, conditions should be excellent, assuming January's often fickle weather cooperates. For the best views, find an observing location far from city lights.

For a time in 2013, the Internet was abuzz with the idea that Earth might get a new meteor shower this month. In mid-January, our planet comes close to where



Quadrantid meteors

Active Dates: Dec. 28–Jan. 12
Peak: January 3
Moon at peak: Waxing crescent
Maximum rate at peak: 120 meteors/hour

A rush of "shooting stars" will populate the predawn sky January 3 in what promises to be 2014's finest meteor shower. *ASTRONOMY: ROEN KELLY*

Comet ISON (C/2012 S1) was during November. Some people thought we'd get a show when Earth forged through the comet's dusty debris. Astronomers

are skeptical, however, that the passage will deliver any meteors. Still, observers are keeping their fingers crossed and plan to see what develops.

OBSERVING HIGHLIGHT Comet ISON (C/2012 S1) should display a bright anti-tail in mid-January when Earth passes through the comet's orbital plane.



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:

9 P.M. January 1
8 P.M. January 15
7 P.M. January 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





JANUARY 2014

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.
						
						
						
						
						
						

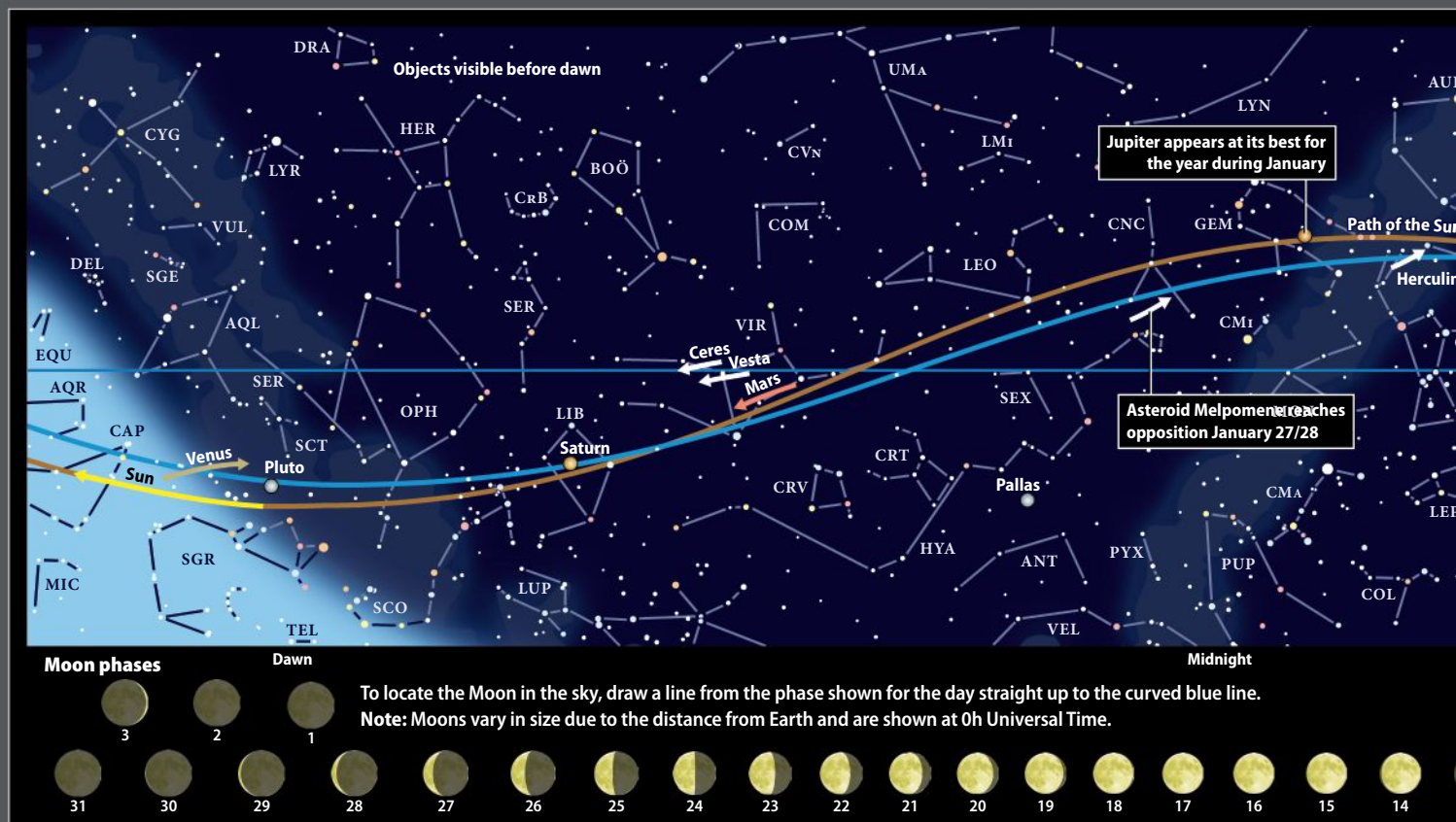
Calendar of events

-  New Moon occurs at 6:14 A.M. EST
Pluto is in conjunction with the Sun, 2 P.M. EST
The Moon is at perigee (221,781 miles from Earth), 3:59 P.M. EST
- Mars is at aphelion (154.9 million miles from the Sun), 7 P.M. EST
- Quadrantid meteor shower peaks
- Earth is at perihelion (91.4 million miles from the Sun), 7 A.M. EST
The Moon passes 5° north of Neptune, 9 P.M. EST
- Jupiter is at opposition, 4 P.M. EST
-  Venus is in inferior conjunction, 7 A.M. EST
- The Moon passes 5° south of Jupiter, 1 A.M. EST
The Moon is at apogee (252,607 miles from Earth), 8:53 P.M. EST
-  Full Moon occurs at 11:52 P.M. EST
- The Moon passes 4° south of Mars, 1 A.M. EST
-  Last Quarter Moon occurs at 12:19 A.M. EST
- The Moon passes 0.6° south of Saturn, 9 A.M. EST
- Asteroid Melpomene is at opposition, 3 A.M. EST
Mars passes 5° north of Spica, 3 P.M. EST
- Jupiter reaches its 2014 peak today, shining at magnitude -2.7 and appearing 46.8" across through a telescope.
- The Moon passes 2° south of Venus, 10 P.M. EST
- The Moon is at perigee (221,879 miles from Earth), 4:59 A.M. EST
-  New Moon occurs at 4:39 P.M. EST
-  First Quarter Moon occurs at 10:39 P.M. EST
- Mercury is at greatest eastern elongation (18°), 5 A.M. EST
- Asteroid Pallas is stationary, 4 A.M. EST
- Venus is stationary, 2 P.M. EST

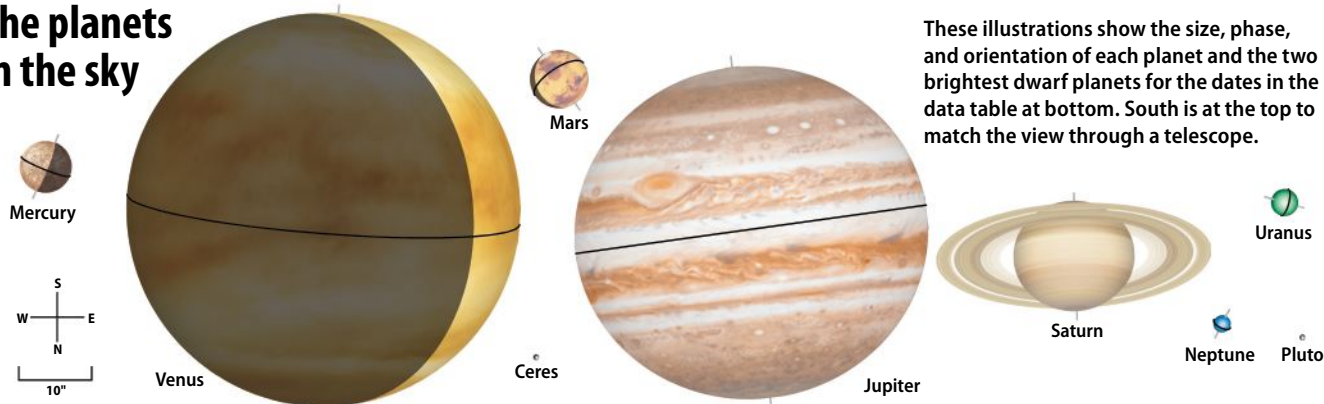
SPECIAL OBSERVING DATE



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



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.

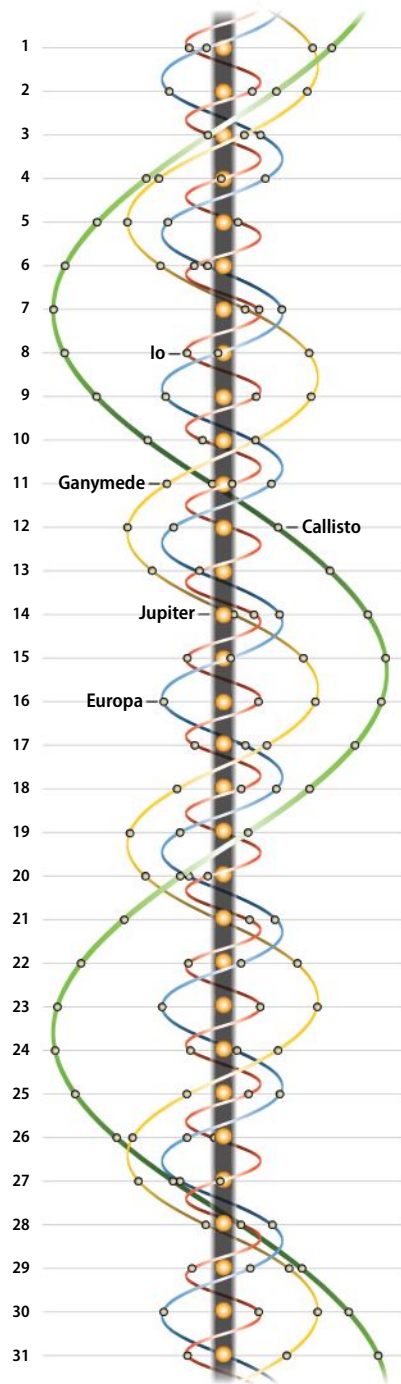
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Jan. 31	Jan. 31	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15	Jan. 15
Magnitude	-0.7	-4.7	0.6	8.4	-2.7	0.6	5.9	8.0	14.2
Angular size	6.9"	51.9"	7.6"	0.6"	46.6"	16.2"	3.5"	2.2"	0.1"
Illumination	56%	12%	91%	96%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.972	0.321	1.225	2.407	4.227	10.287	20.279	30.738	33.537
Distance (AU) from Sun	0.312	0.719	1.665	2.582	5.197	9.884	20.033	29.979	32.580
Right ascension (2000.0)	22h05.0m	18h55.2m	13h07.2m	13h51.5m	7h01.0m	15h18.0m	0h33.2m	22h22.4m	18h49.2m
Declination (2000.0)	-11°36'	-15°51'	-4°37'	0°25'	22°51'	-15°58'	2°50'	-10°52'	-20°13'

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.



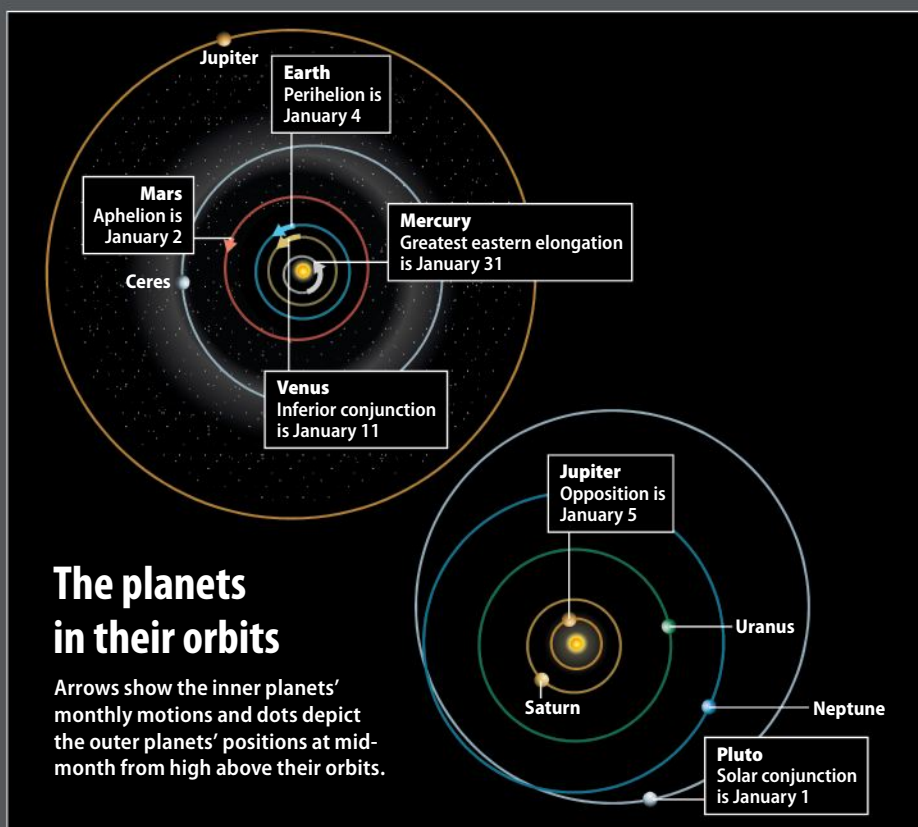
Jupiter's moons

Dots display positions of Galilean satellites at 11 P.M. EST 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.



WHEN TO VIEW THE PLANETS

EVENING SKY

Mercury (west)
Venus (southwest)
Jupiter (east)
Uranus (southwest)
Neptune (southwest)

MIDNIGHT

Mars (east)
Jupiter (southwest)

MORNING SKY

Venus (southeast)
Mars (south)
Jupiter (northwest)
Saturn (south)

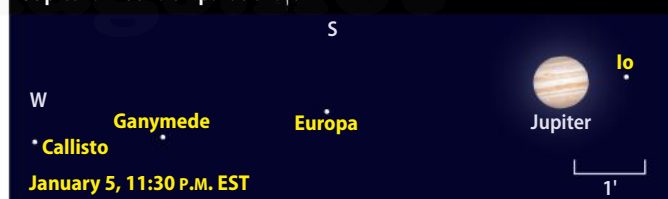
like a double star through binoculars from January 10 to 15 when it passes within 5' of a magnitude 7.7 background sun. Neptune slides 2.8' due south of this star January 12.

Neptune's sister world, **Uranus**, stands much higher in the evening sky. It sets near midnight local time in early January and around 10 P.M. at month's end, providing several hours for binocular observers

to track it down. The magnitude 5.9 planet wanders slowly to the east-northeast in southern Pisces, some 6° southwest of 4th-magnitude Delta (δ) Piscium. A telescope at medium magnification reveals the planet's 3.5"-diameter disk and blue-green color.

As twilight descends these cold winter nights, you easily can spot **Jupiter** climbing in the east. The giant planet

Jupiter's moons on parade



On the night of opposition, Jupiter's four big moons line up in order of their distances from the giant planet. ASTRONOMY: ROEN KELLY

reaches opposition and peak visibility January 5 among the background stars of central Gemini. It then rises at sunset and passes nearly overhead around midnight local time for observers at mid-northern latitudes. Jupiter shines brilliantly at magnitude -2.7 , which makes it the brightest point of light in the sky whenever Venus is out of sight.

Around opposition, Jupiter remains above the horizon for at least 12 hours — two hours

longer than its own rotation period. This provides a perfect opportunity to view the entire dynamic planet in a single night. An alternating series of bright zones and dark belts stands out on its 47"-diameter disk. If you don't see the Great Red Spot right away, it simply may be on the planet's far side. Wait a few hours, and it should rotate into view.

Jupiter's four bright moons provide plenty of action to fill these chilly nights. On the

COMETSEARCH

ISON bids a fond farewell

Assuming Comet ISON (C/2012 S1) survived its close pass by the Sun in late November, it should be set to deliver a lovely encore in January's sky. ISON's broad fan tail will transform quickly into a sharp sword as Earth swings through the comet's orbital path in mid-January, treating us to a bright anti-tail.

ISON belongs to both the evening and morning skies this month because it passes close to Polaris. Because the North Star never sets for observers north of the equator, the comet remains visible all night. To see ISON best, find a dark observing site and sidestep moonlight. In early January, dark skies come in mid- to late evening after the Moon sets. During the month's second week, the waxing Moon demands a switch to predawn hours. Once past its Full phase, our satellite rises later, so you can return to evening viewing.

As January begins, we see ISON almost broadside, with its

tail spread into a wide fan. This happens because most of the ejected dust lies along a sheet matching the comet's orbit around the Sun. But our viewing angle changes quickly. By the night of January 15/16, Earth passes through this sheet. We get an edge-on perspective, and the fan sharpens into a long blade. Watch the night-to-night transformation during the month's second week.

Despite the inescapable Full Moon, try hard to observe during these edge-on nights. In a trick of perspective, ISON should sport a bright anti-tail, one that points toward the Sun and not away. If ISON continues to produce a significant amount of gas, a blue or green ribbon of light should overlay the "normal" tail that points away from our star. Don't let city skies stop you from checking out the show. A 4-inch or larger scope should let you witness the dust tail's transformation into an anti-tail.

Comet ISON (C/2012 S1)



Comet ISON glowed at 10th magnitude when the Hubble Space Telescope captured it October 9. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

ISON will test your star-hopping skills later in the month as it glides from the barrens of northern Cepheus into the confusing constellation Camelopardalis (the nearly invisible Giraffe). On January 18 and 19, the dirty snowball should glow around 8th magnitude as it passes the large, low-surface-brightness spiral galaxy IC 342. And enjoy the delightful treat

on the 24th when ISON crosses Kemble's Cascade, a pretty star chain that flows into the sparkling star cluster NGC 1502. Finally, the comet's tail likely will wipe out the well-defined planetary nebula NGC 1501 the night of January 26/27. For more information on observing this celestial visitor during January, see "Comet ISON's final stab at glory" on p. 56.

Mercury brightens late-January evenings



The Moon slides past Mercury on January 31, the same evening that the inner planet reaches the peak of an impressive apparition. ASTRONOMY: ROEN KELLY

night of opposition, all four appear as points of light arrayed on either side of the planet. As a bonus, they appear in order of their distance from Jupiter, with Io closest, followed by Europa, Ganymede, and Callisto.

Many observers enjoy watching the moons and their shadows cross Jupiter's face. Several such transits occur in January. For North Americans, Europa puts on a fine show after sunset January 8. The moon first touches the planet's disk at 6:48 P.M. EST, followed by the shadow 10 minutes later. The moon clears the jovian disk at 9:29 P.M. EST, and the shadow leaves at 9:40 P.M. EST. Io performs a similar maneuver January 13, with the innermost moon crossing between 6:22 P.M. and 8:38 P.M. EST and its shadow between 6:35 P.M. and 8:50 P.M. EST.

The geometry between Earth, Jupiter, and the Sun constantly changes as the planets orbit our star, and this shows up in the timing of satellite events. For example, when Io transits January 27, the moon starts crossing at 9:51 P.M. EST and the shadow follows 33 minutes later.

Not long after the fireworks die down on New Year's Eve, Mars pops above the eastern

horizon. The Red Planet rises just 10 minutes or so after midnight January 1 and nearly two hours earlier by month's end. On the 1st, it glows at magnitude 0.8 some 1.4° southeast of 3rd-magnitude Gamma (γ) Virginis. The planet moves eastward during January and closes the month 5° north of 1st-magnitude Spica, the Maiden's leading star. During January's 31 days, the Red Planet brightens by half a magnitude, so it noticeably outshines the star.

By the end of January, Mars' apparent diameter reaches 9", big enough to show modest detail through 8-inch and larger telescopes. The best views of the planet will come in the two hours before twilight starts to paint the sky, when it appears at least 40° above the horizon. The higher altitude lessens the blurring effects of Earth's atmosphere.

The hour or so before twilight begins is also the best time to view Saturn. The ringed world stands out in the southeast against the backdrop of Libra the Balance. Saturn shines at magnitude 0.6, two magnitudes brighter than any of Libra's stars. The planet measures 16" across its equator at midmonth while

LOCATING ASTEROIDS

Iris keeps an eye on Pisces' Circlet

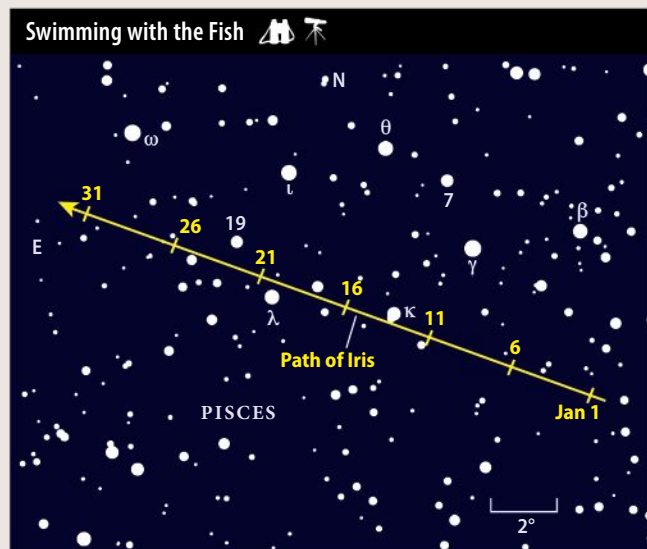
Asteroid 7 Iris threads a celestial ring this month when it pierces the Circlet asterism in Pisces the Fish. This region lies in the southwest after darkness falls, below the conspicuous Great Square of Pegasus. The surest way to confirm a sighting of this 10th-magnitude object is to detect its motion relative to the background stars. From the suburbs, a 4-inch scope will do the trick.

To differentiate Iris from the look-alike stars along its path, first sketch a framework of three or four dots representing the surrounding star field. Identify the western edge of the sketch by watching which side the stars disappear out of the field of view. Return with your drawing on another night to see which mark changed position. If you want to see Iris move in a single evening,

January 14, 15, 17, 19, and 21 provide excellent patterns that are easy to get to from either Kappa (κ) or Lambda (λ) Piscium.

While you're in the neighborhood on the 23rd, stop off at the guide star 1° north of Iris. Soak in the lovely peach to pale-orange color of 19 Piscium, an irregular variable star that also carries the designation TX Psc. Although trained eyes can detect its half-magnitude wavering, we're here just to admire its beautiful hue.

English observer John Hind discovered Iris in 1847 almost 50 years after Italian astronomer Giuseppe Piazzi found 1 Ceres. Astronomers named Iris after the Greek goddess of the rainbow. This was the first of Hind's 10 asteroid discoveries, all of which he found by searching for objects that moved against the background of "fixed" stars.



Asteroid 7 Iris glows at 10th magnitude when it splits the Circlet asterism in the constellation Pisces this month. ASTRONOMY: ROEN KELLY

the rings span 37" and tilt 22° to our line of sight.

As January draws to a close, take note of all three bright morning planets. They offer a wide variety of wonder

for planetary viewers — the changing phases of Venus, the stunning rings of Saturn, and the ruddy desert plains of Mars. It marks a great start to a new year of observing. ☿



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WorldMags.net

Inside Gale Crater



Curiosity's latest findings from Mars

More people tuned in to see the Curiosity rover land on Mars than watch CNN during Sunday prime time. When NASA's most sophisticated, mobile, and outfitted robot touched down August 6, 2012, half a million viewers sat on the edges of their seats. A sky crane lowered Curiosity to a soft arrival on a planet it had traveled 352 million miles (567 million kilometers) to study. In the months since, the rover and the scientists who control it have been working hard to determine what Mars is like now, what it was like in the past, and what its past and present might mean for the past, present, and future of Earth.

A wild descent

Curiosity touched down in Gale Crater, a depression 96 miles (154km) across, near an alluvial fan that is called Peace Vallis — a

there. Sharp is 5 miles (8km) from the rover's landing site, and Curiosity's longest day of driving has thus far been 464 feet (142 meters). The mound will be worth the wait, though, according to scientists. "Orbiting spacecraft suggest that the lower layers of this mound contain minerals formed in the presence of ancient water," says Nadine Barlow, a Mars expert and professor at Northern Arizona University in Flagstaff, "while the upper layers appear drier and may contain evidence of more recent, but still distant, volcanic activity."

The mound will surely prove to be a gold mine. After spending 11 months investigating Gale's depths, Curiosity set out for Mount Sharp on July 4.

But what, exactly, did researchers hope to learn when they set metal feet on this planet? Which questions has the rover answered already, and which new questions has it brought up? As Grotzinger said at the

what happened on Mars, how that happened differently on Earth, and how that allowed life on Earth to thrive."

Red biology

Curiosity has been busy helping scientists piece the planet's timeline together. During the rover's first year at work, it collected 190 gigabits of data; took more than 36,700 full images and 35,000 thumbnail images; fired lasers at targets more than 75,000 times; fully characterized rock samples; and drove more than 1 mile (1.6km).

The data are yielding serious results. The first came March 7, when NASA announced that Curiosity had discovered a streambed in which life could have survived.

"We have found a habitable environment that is so benign and supportive of life," Grotzinger said at the time, "that, probably, if this water was around and you had been there, you would have been able to drink it."

In August 2012, NASA's newest rover landed in Mars' Gale Crater. From finding ancient streambeds to analyzing hundreds of samples, the rover has kept busy helping scientists learn about the Red Planet's habitability. **by Sarah Scoles**

cone-shaped buildup of debris from, presumably, once-flowing water.

"We didn't just stumble into this area," said John Grotzinger, Curiosity's project scientist, in a press conference March 7, 2013. Scientists chose Gale Crater after much debate about balancing safety and science. After all, it doesn't matter if interesting geology lies at the top of a boulder-strewn outcrop if your rover drives off a cliff. Gale Crater presented few such physical obstacles and appeared to offer diverse geology within a small area. Proximity is important: While the rover can move, engineers expect it to drive only 12 miles (20km) in its lifetime, making targets separated by 15 miles (24km) undesirable.

Gale Crater is also home to Mount Sharp, a 18,000-foot-tall (5.5km) mountain toward which Curiosity currently is traveling. But it's going to take a while to get

March press conference, "When you land on Mars, strange things can happen."

While some of Curiosity's discoveries have not been surprising, others have changed the public conception of Mars from a dead, dusty place to one that has been evolving for billions of years and continues, even now, to do so.

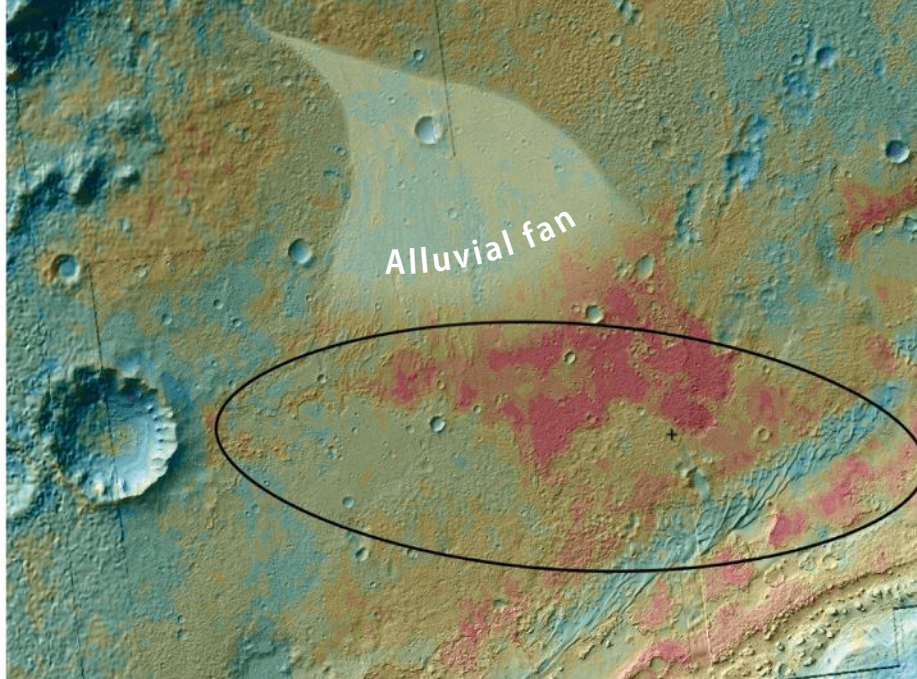
When NASA launched Curiosity, it had biological, geological, and chemical goals. But the mission's umbrella objective is to determine whether Mars was ever habitable. Grotzinger was quick to point out, though, that the rover is not there to determine whether metabolizing microbes actually were on Mars. "We are not a life-detection mission," he said in March. Curiosity instead will determine whether life could have arisen and survived there. And the answer is directly applicable to us mammals and microbes: If Curiosity discovers that Mars used to be hospitable and has turned barren, what does that mean for our planet?

Christopher Edwards, a postdoctoral fellow at the California Institute of Technology and a member of the Curiosity science team, confirms, "[We're] going to look for

The location, Yellowknife Bay, was not just wet — it had Goldilocks conditions: salty but not too salty, not too acidic, not too basic, and full of porridge-like chemical energy for metabolism. These results came from the first rock Curiosity drilled, February 8. The fine-grained rock, called John Klein, sits where streams appear to have descended from the crater's rim, perhaps leaving standing water, and is covered in nodules and veins. The rover bored a 2.5-inch (6.4 centimeters) hole into it, sending samples to its Sample Analysis at Mars (SAM) and Chemistry and Mineralogy (CheMin) instruments, which investigate chemical makeup.

A month passed before NASA announced that the sample suggested a water-wet, life-friendly spot. When Curiosity ran John Klein through its spectrometers and X-ray diffractors, the agency said, it found sulfur, nitrogen, hydrogen, oxygen, phosphorus, and carbon. Sulfates (sulfur plus oxygen) signal the presence of water. Ancient, hardy bacteria on Earth use sulfides (compounds containing sulfur minus two electrons) as fuel. DNA, meanwhile, is

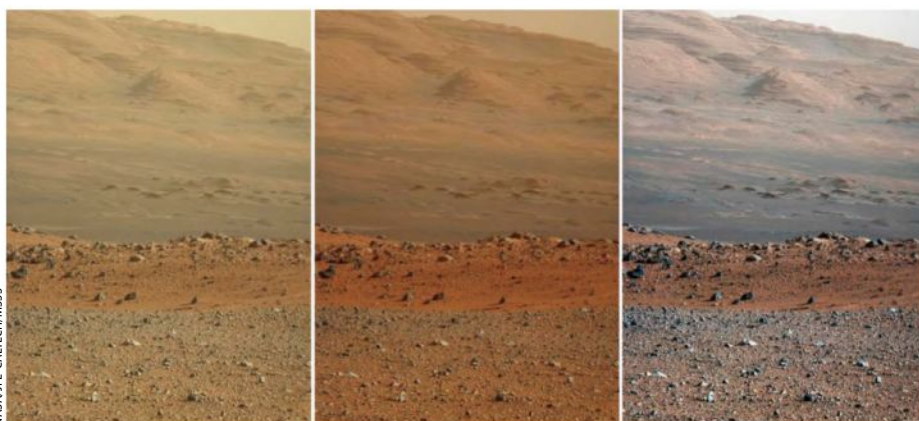
► **During Curiosity's 177th day on the Red Planet — February 3, 2013 — it took the dozens of images that, combined, make this full self-portrait. Soon after, the rover drilled into its first rock, becoming the first machine to sample the interior of another planet.** NASA/JPL-CALTECH/MSSS



This map shows Gale Crater, where Curiosity touched down in August 2012. The colors represent the terrain's ability to hold heat. Red loses thermal radiation slowly, suggesting the material in the soil is cemented tightly together. The topography, including a fan-shaped deposit of debris called Peace Vallis, suggests water once flowed through this area on Mars. Curiosity, which landed inside the black ellipse, has seen rounded pebbles cemented to rocks, material that may have been carried and polished by a moving river. NASA/JPL-CALTECH/UNIV. OF ARIZONA



Two different Mars rovers — Opportunity and Curiosity — have seen concretions (the small spheres pictured here) and cemented rocks, geological features that form in the presence of water. Opportunity's Wompay rock (top) appears to have formed in an acidic, inhospitable environment. Curiosity's Sheepbed rock, however, formed in a neutral, non-salty environment with plenty of chemical energy. NASA/JPL-CALTECH/CORNELL/MSSS



Scientists receive images directly from Curiosity — the raw files (left) — but from there, they have two options. They can process the pictures to show the view as it would look if you were standing on Mars (middle), or they can white-balance the photos so the scene looks as it would under Earth-lighting (right).

made of phosphates (phosphorus plus oxygen), carbohydrates (carbon, hydrogen, and oxygen), and nitrogen groups. In short, John Klein contains the ingredients necessary to whip up a batch of life. And the pH-balanced, fresh(ish) conditions would have been favorable to that life's survival.

"A fundamental question for this mission is whether Mars could have supported a habitable environment," says Michael Meyer, the lead astronomer for NASA's Mars Exploration Program located in Washington, D.C. "From what we know now, the answer is yes." Mission accomplished, but far from over.

Sarah Scoles is an associate editor at *Astronomy magazine*.

Water, water

So now we know Mars was, at some point, wet. But how long was the water there? How deep and extensive was it? Initial results from a third Curiosity instrument — the Mast Camera (MastCam), which uses near-infrared vision to detect iron- and water-bearing minerals — suggest the planet's wet habitability was not limited to the resting place of a single rock but extended at least up to Mount Sharp.

Scientists have long had solid evidence that water used to flow across the surface of the Red Planet. Data dating back to the Viking landers of the 1970s provided proof of the H₂O molecule's existence, but Curiosity is doing its part to show that the H₂O came in the form of rivers, streams, and

lakes. In addition to drilling rocks toward that end, the rover also has scooped soil. At a sandbox called Rocknest, its SAM instrument heated the dirt to 932° Fahrenheit (500° Celsius), and evidence of water, sulfur, and chlorine compounds popped out.

But the most satisfying answer came from close-up pictures the MastCam took of three rocks. The images are from the first 40 days of the mission, but analysis did not come right away. In June, scientists determined that "Goulburn," "Link," and "Hottah" — as the rocks are affectionately known — are glued-together pebbles. On Earth — and so, presumably, on Mars — sediments stick together like this when they are immersed in flowing water. To create deposits the size of Goulburn's, Link's, and Hottah's, the martian stream would have been ankle- to hip-deep and flowing about 3 feet per second (1 m/s).

Although scientists speak of the streams in the past tense, Mars retains some of its water in frozen form. Curiosity found out just how much is there, searching for ice on-the-go as it traveled from Yellowknife Bay to its next big landmark: a three-terrain

intersection called Glenelg. Its Dynamic Albedo of Neutrons (DAN) detector searched for slow neutrons, which indicate the presence of water. Cosmic rays constantly strike the planet's surface, kicking neutrons out of their atoms. If the ejected neutrons interact with hydrogen atoms on their way out of the ground, they slow down. DAN looks for low-energy neutrons and, based on their abundance, can tell how full of water molecules the ground is. On its travels, Curiosity sometimes saw water merely on the surface, but other times the chemistry extended more than 15 inches (40cm) underground, making up between 1.3 and 3 percent of the total material.

Remarkable Mars

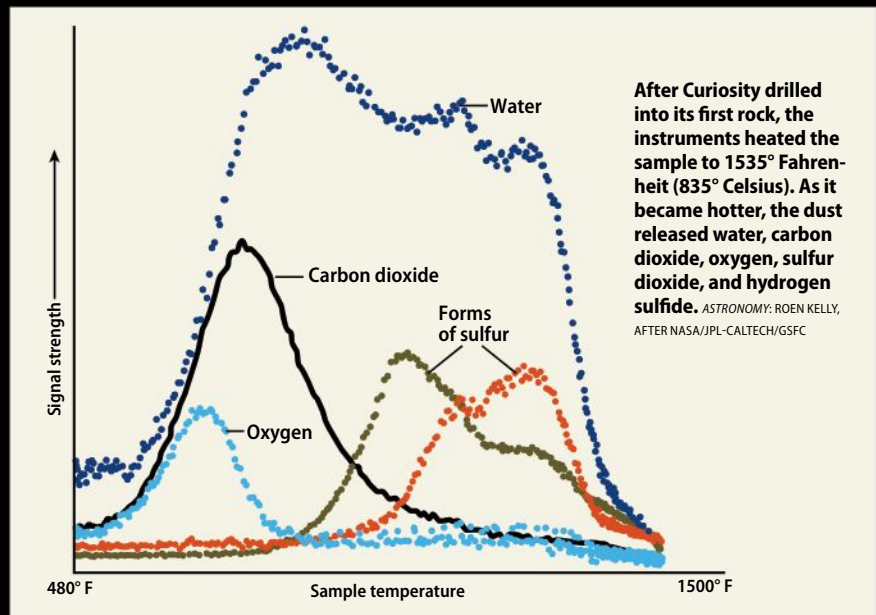
As temperatures on Mars changed, it was unable to hold on to its liquid water. Its water-friendly warmth was due solely to its atmosphere, which is now an inhospitable 95.95 percent carbon dioxide and 0.146 percent oxygen, according to Curiosity's latest readings. Long ago, though, Mars' atmosphere was different. Its many giant volcanoes were active, and they now act as road maps. "Even though they might not be as exciting as life," says Joshua Bandfield, a Mars expert who was on the team that characterized Curiosity's landing site, "volcanoes can point you to both where the liquid water and energy sources were in the martian past." At one point in Mars' history, they also spewed plumes of methane, a powerful greenhouse gas, into the air. The gas trapped the Sun's heat, and the heat re-radiated from the martian ground — a combination that potentially warmed Mars enough for liquid water to exist despite its distance from the Sun.

But Mars' atmosphere is depleted now, too thin to keep the planet warm, and Curiosity discovered how, exactly, the once-thick blanket became so threadbare. Its SAM instrument analyzed the abundances of isotopes, which are versions of the same



Curiosity's 1.6-inch-wide (4 centimeters) scoop created these divots in the sand at Rocknest. At this location, the sand consists of a crust of coarse grains atop finer dust. NASA/JPL-CALTECH/MSSS

Drilling into John Klein



Curiosity collected the first drilled sample from another planet. The next day, its Chemistry Camera sent laser pulses into the rock, creating the smaller holes. The larger hole has a diameter of 0.6 inch (1.6 centimeters) and is 2.5 inches (6.4cm) deep. NASA/JPL-CALTECH/LANL/IRAP/CNRS/LPGNANTES/IAS/CNRS/MSSS

element with different numbers of neutrons. The more neutrons an isotope has, the "heavier" it is. Scientists can compare the light-to-heavy isotope ratio in today's martian atmosphere to that of the early solar system. If Mars were not letting atoms escape, the two would be the same.

But SAM found that heavy isotopes of hydrogen, carbon, oxygen, and argon are more prevalent on Mars than they were in the solar system's early years. In other words, the planet, which has low gravity and no significant magnetic field, can't hang on to its lighter isotopes. It has evolved since its early years, losing lighter atoms. It actively continues to lose its less substantive substances today. And the more scientists learn about the planet, the more they see it

as a generally dynamic place, rather than a Pompeii-style preservation of a bygone era.

Mars' surface is lively, a fact Curiosity must contend with to reach its next destination. Simone Silvestro, a postdoctoral researcher at the SETI Institute in Mountain View, California, demonstrated that the martian wind is, as you read this sentence, reshaping the planet's dunes. He compared results from ground-level wind sensors to satellite images and saw that the wind pushed the dunes surrounding Mount Sharp some 1.3 feet (0.4m) each year. "The action of the wind is the most active process in shaping the planet," Silvestro says.

Silvestro works with research scientist Lori Fenton, who is excited by this proof that Mars isn't a "dead" planet. "You can



At the Rocknest site in November 2012, Curiosity's Mast Camera took this panoramic mosaic. NASA/JPL-CALTECH/MSSS

actually see how wind and water have played a role in martian history," she says. "To me that's living, breathing." The rover will have to travel up and over this lively surface in the coming months to continue its scientific work.

A time machine

Mars was more violent between 3.5 and 4.5 billion years ago. This time period, known as the Noachian Era, saw the formation of large impact craters, such as Gale, which are ready-to-use tools for scientists. Barlow phrases it more aggressively: "I like to refer to impact craters as 'nature's drills.'"

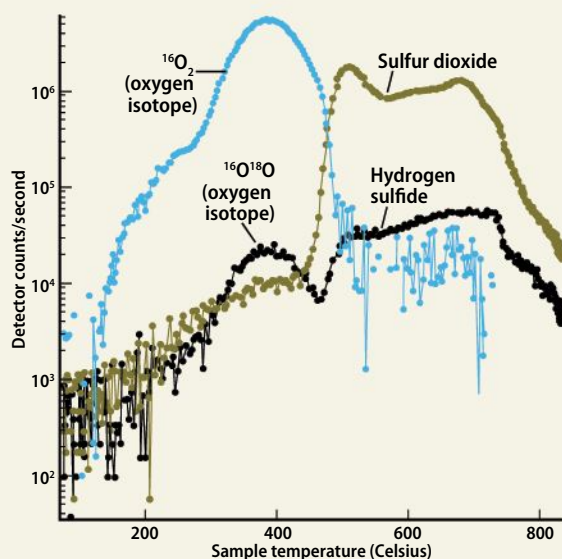
Because of their low-lying bottoms, crater floors collect material that flowed from higher elevations. If they were once wet, for instance, they retain sediments and deposits. Some rocks in Gale formed when flowing water cemented material together, while some rocks formed from volcanic activity. Curiosity can investigate both types.

Gale Crater showcases parts of Mars that are below the surface but used to *be* the surface. "The layers exposed in craters provide insights into past environments quite different from what we see on the planet today," says Barlow. If Curiosity looks at the different strata — just like a scientist in the Grand Canyon might sample different elevations along the rock walls — it can help scientists learn more about the planet's past.



Curiosity's Mast Camera snapped this portrait of the rover's Alpha Particle X-Ray Spectrometer (APXS). Scientists directed the camera to take the image to determine whether APXS had been covered in dust during the rover's landing.

What's inside martian sand?



The sand that Curiosity scooped at Rocknest contains sulfur, chlorine, and oxygen compounds. To determine the material's composition, the Sample Analysis at Mars instrument heated it and analyzed the resulting emissions. Perchlorates — compounds containing chlorine and oxygen — in the sample could indicate the presence of accompanying organic molecules.

ASTRONOMY: ROEN KELLY, AFTER NASA/JPL-CALTECH/GSFC

Mount Sharp, where the rover is headed, also has rocky strata compacted together like a book of pressed flowers, if a book of pressed flowers contained flora from geological eras separated by millions of years.

It's no Earth

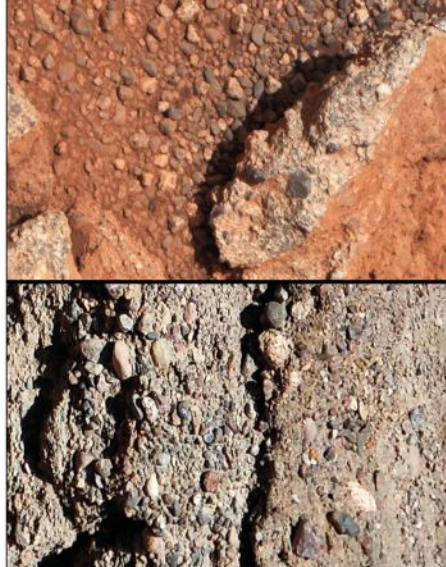
While it's unlikely that Mars ever had mammals, it was habitable, at least in spots. But like on Earth, conditions there vary from region to region, just as Earth is home to both the Badlands and the bayou. For instance, Curiosity has found that the planet's relative humidity changes based on its location. The Rover Environmental Monitoring Station (REMS) saw the humidity drop from 60 percent to about 5 percent in the 0.25 mile (400m) between the landing site and the sandy area where the rover spent its 55th to 101st days on Mars.

The surface temperature, though, did not depend on the rover's location, at least not on small scales. The average daily high has been a still-freezing 32° F (0° C), while the low averages -94° F (-70° C). On Earth, the average temperature is a comfortable

61° F (16° C), while Mars is only a frigid -31° F (-35° C).

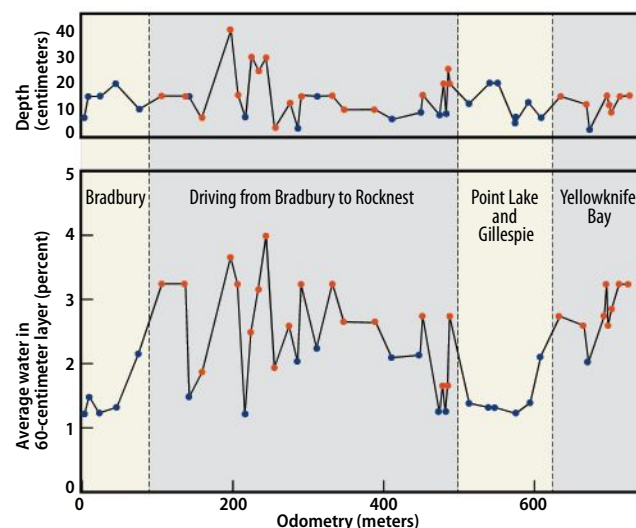
Curiosity, so mindful of its own condition that it is almost self-aware, also uses REMS to determine how strongly the atmosphere is pressing down. The pressure between mid-August 2012 and late February 2013 — about a quarter of a martian year — slid upward by 0.029 pound per square inch. This seasonal change occurs because the spring sunlight causes carbon dioxide (CO₂) to sublime from the southern polar cap. The CO₂ becomes part of the planet's atmosphere, increasing its mass by 30 percent each time the season rolls around. But even the highest pressure is 0.0095 atmosphere, not even a hundredth the pressure we experience on Earth.

So although the planet resembles Utah, remember Earth and Mars are still quite different. For one, everything Curiosity sees is gigantic. "The scale of features on Mars is massive," says Edwards. "When I look at a crater, I always have to tell myself, 'That crater is bigger than the entire Los Angeles Basin.'" Secondly, everything Curiosity sees



Some martian geology is remarkably similar to that of Earth. The Link outcrop on Mars (top) has small gravel pieces called clasts embedded in the larger rock. Erosion can release clasts, which fall to the ground and create piles of pebbles. A similar sedimentary formation on Earth is on the bottom.

Surface water on Mars



Curiosity's Dynamic Albedo of Neutrons instrument detects the presence of hydrogen, and thus water. On Mars, most of this water is bound to minerals, which are then called "hydrated." The amount of water near the surface of Yellowknife Bay is an average of 3 percent of the total material.

ASTRONOMY: ROEN KELLY, AFTER NASA/JPL-CALTECH/RUSSIAN SPACE RESEARCH INSTITUTE

is old. "Look at a typical rock in your backyard," Edwards continues. "It probably formed 100 million years ago. On Mars, rocks have been sitting on the surface for billions of years. You have an unadulterated record of rocks that often formed 3 billion years ago, a period that has been largely erased on Earth."

Sending a rover to Mars is like going back in time. When Curiosity samples a streambed, it peers into a period in the solar system's history that we — earthlings who build structures on top of our wetter, more volcanic, more pressurized, and more tectonic planet — cannot easily access.

Where to next?

Curiosity is continuing its long trek toward Mount Sharp, and it will stop along the way whenever scientists see something interesting. So far, their plans have encountered only minor blips: Curiosity's computer had a memory glitch February 28; it flipped into

"safe mode" after a software malfunction March 16; and the rover popped a wheelie for a while in June. But the system generally works. In fact, it works so well that Curiosity sometimes operates without a baby sitter, reacting to obstacles without checking in with ground control.

The rover's first year of results will help space agencies put astronauts' boots on the ground — eventually. Astronomers need to thoroughly understand this desert planet if the United States is going to send humans there in 2020, as President Obama plans. Curiosity is pushing that agenda forward by learning where meltwater-ice supplies are and measuring how much radiation reaches the surface each day. With current technology, the level of radiation — about a CT scan's worth every five days — is too high. But as long as scientists know that, they can work to innovate new protections.

Aside from the logistical investigations into whether humans can hack it on Mars,

Curiosity is making inquiries into Earth's prehistory. In September, scientists announced that they had found a rock, which they called Jake Matijevic, that was nearly indistinguishable from a certain kind of volcanic rock on Earth. The similarities suggest Mars' interior may be more similar to Earth's than anyone thought.

"You can think of planets as giant laboratory experiments set up 4.5 billion years ago," says Bandfield. "Each has slightly different proportions of rock, water, etc." How did those slightly different proportions lead to such radically different results? Specifically, how did they produce Mars — a planet that may have been habitable, but not inhabited, in the distant past — and Earth, a geologically similar planet now teeming with everything from upright mammals to archaeobacteria?

"We study these other planets to reflect on ourselves," says Edwards. "It's a system, right? Our solar system." 🌌



In this 360° image, taken during Curiosity's 59th Earth day on Mars, the Navigation Camera recorded Rocknest in the foreground and Aeolis Mons (Mount Sharp) in the background. The mountain rises some 18,000 feet (5.5 kilometers) from the floor of Gale Crater. The rover currently is on its way to Mount Sharp, leaving more tracks like those in the right portion of the image. NASA/JPL-CALTECH



VIEW AN INTERACTIVE MAP OF CURIOSITY'S TRAVELS AT www.Astronomy.com/toc.

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How much water is on the MOON?

If frozen water fills some of the Moon's shadowed craters, as some scientists think, the supply could quench future colonists' thirst. But reality might be a bit more complicated. **by Robert Zimmerman**

If humans are to explore the solar system, they will need to have the basic necessities of life, and after breathable air, the most important of those is water. We now know that water lurks frozen in asteroids, comets, planets, and moons — specifically, our Moon. But questions remain: How much water, and how difficult is it to extract?

Scientists currently are on a quest to determine whether the Moon has a reservoir of water ice locked in its permanently shadowed polar craters. If many are home to frozen water, creating a lunar colony would be a less daunting prospect. Evidence of large deposits, however, is inconclusive, and data are piling up in favor of a different

scenario. The hydrogen scientists had hoped was in larger water deposits may actually exist in a thin layer, mixed with soil across the lunar surface. In the first setup, the plentiful water ice would have come from impacts. In the second, the skimpy supply would have come from the solar wind, which is made of hydrogen ions that spread across the satellite's exterior.

But telling the difference between these scenarios is not simple — not from 238,900 miles (384,400 kilometers) away. Plus, an intriguing third possibility — that the Moon's water came from Earth — could help explain the conflicting and mixed results scientists have gathered so far.

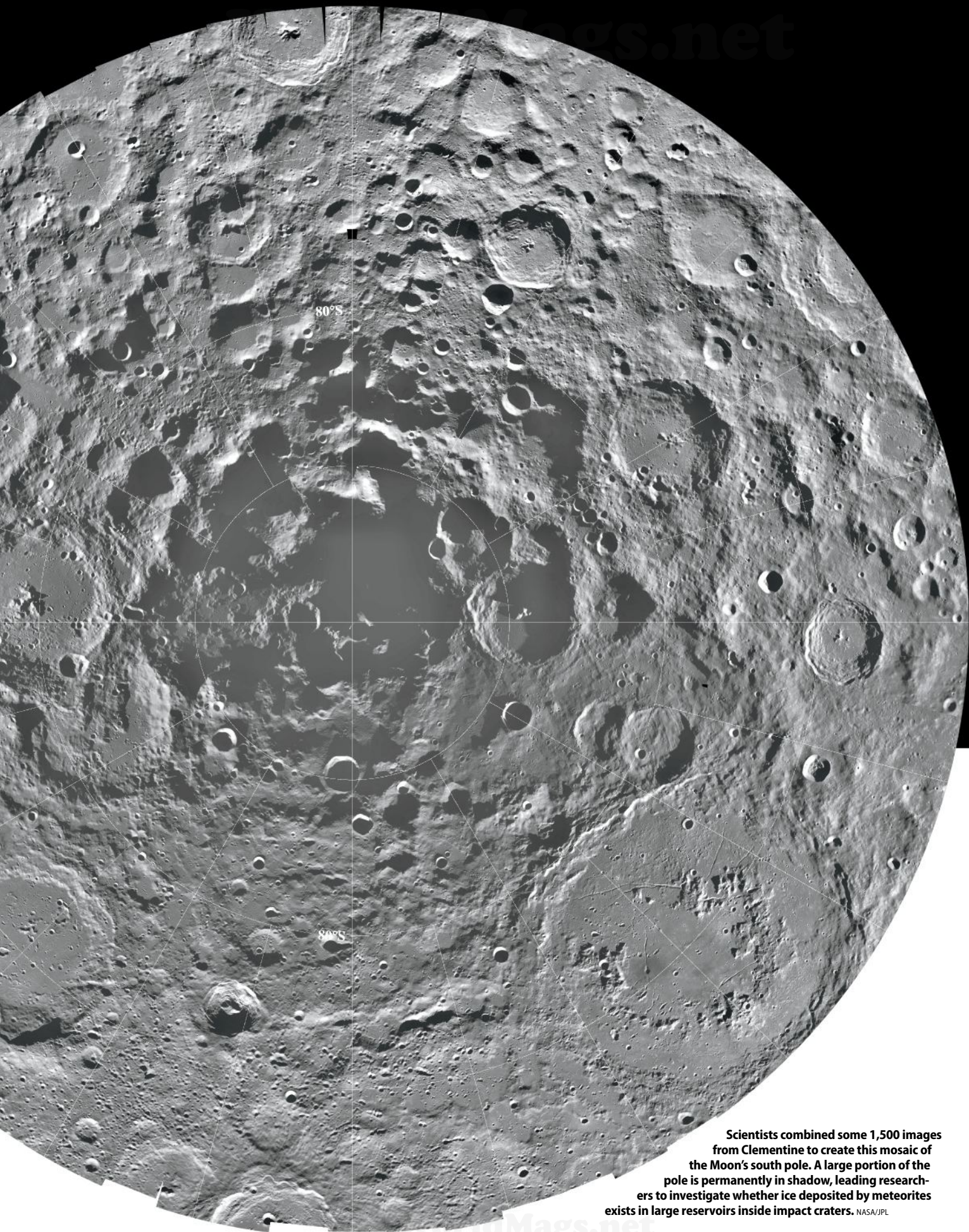
Water, water everywhere?

The first evidence of polar ice on the Moon came in 1994 from Clementine, a NASA probe. Five years later, the Lunar Prospector appeared to confirm Clementine's results,

as did 2009 data from the Indian Space Research Organization's lunar orbiter, Chandrayaan-1. But still scientists were not sure it was there. That same year, NASA sent the upper stage of the Lunar Crater Observation and Sensing Satellite (LCROSS) rocket crashing into the floor of Cabeus Crater. Water ice (among other things) came flying up. With this concrete evidence, the question appeared to be settled.

But another spacecraft has brought conclusions from LCROSS into question. The Lunar Reconnaissance Orbiter (LRO) suggests there might be less water on the

Robert Zimmerman, a frequent contributor to *Astronomy*, recently released a digital edition of his book *Genesis: The Story of Apollo 8* (Mountain Lake Press, 2012).

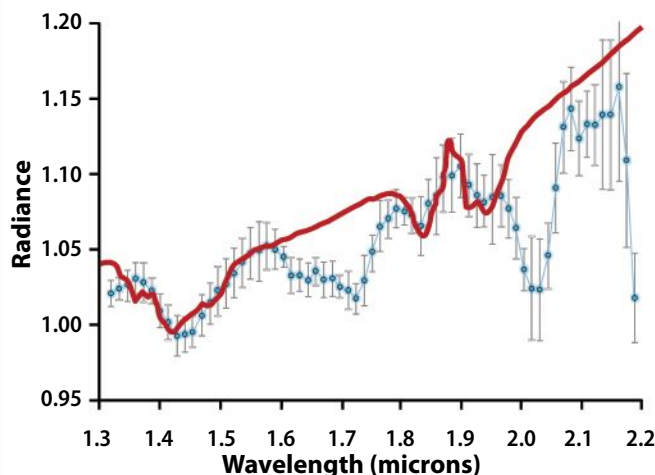


Scientists combined some 1,500 images from Clementine to create this mosaic of the Moon's south pole. A large portion of the pole is permanently in shadow, leading researchers to investigate whether ice deposited by meteorites exists in large reservoirs inside impact craters. NASA/JPL



The Lunar Reconnaissance Orbiter (LRO) sent its Lunar Crater Observation and Sensing Satellite (LCROSS) crashing into Cabeus Crater so that the ejected material could be analyzed. One-fifth of the plume was composed of volatile elements like hydrogen (implying water) and methane. LRO took this picture of the impact site. NASA/GSFC/ARIZONA STATE UNIVERSITY

Spectroscopic signature



Results from the Lunar Crater Observation and Sensing Satellite (LCROSS) show that Cabeus Crater, into which LCROSS crashed, contains water. The red line indicates a hypothetical crater filled with water alone. The blue points are observations and match water's key features.

ASTRONOMY: JAY SMITH, AFTER LCROSS/NASA ARCA/COLAPRETE

Moon's surface than previously hoped and that the existing water is so scattered that colonists would have difficulty mining it.

"The problem is that there's not a lot there," explains William Boynton of the Lunar and Planetary Laboratory in Tucson, Arizona, who works as operations support for LRO. "We're talking about a few hundred parts per million." In other words, for every 10,000 molecules of lunar soil, there may be only one molecule of water — not good odds. These new results have sparked a vigorous debate within the planetary science community. While some researchers consider the new data reliable and significant, others are dubious of LRO's water-seeking workhorse: the Lunar Exploration Neutron Detector (LEND).

Dowsing the Moon

The trouble with finding out how much water is on the Moon — and where — is that most detections are indirect. Clementine, for instance, found water as part of an impromptu project devised after the probe had set sail. It sent radio signals toward the Moon's poles, and the surface reflected them back to Deep Space Network stations on Earth. By the strength and direction of the signals echoing back, scientists knew that highly reflective frozen volatiles — chemicals with the tendency to vaporize — lie on the lunar surface. They inferred that these compounds included water, but because of the indirect nature of the result, not all were convinced.

Four years later, in 1998, NASA launched the Lunar Prospector. On board was an instrument called the Neutron Spectrometer. Like Clementine, it did not actually detect water specifically — merely hydrogen. The presence of large quantities of hydrogen is strong evidence — but not absolute proof — that H_2O is around, and the Neutron Spectrometer searched for hydrogen by looking at neutrons escaping the Moon. Energetic particles called cosmic rays constantly bombard the Moon's surface and knock neutrons loose from their atoms' nuclei. These free neutrons travel through the soil. The soil re-absorbs some; some shoot straight into space; some, however, bounce around in the lunar soil for a while and then escape. If, while in the soil, they hit small atoms like hydrogen, they lose energy. Then, when they finally leave, they travel more slowly. The amount by which the soil slows and absorbs the neutrons tells astronomers what that soil is made of — specifically, what portion of it is hydrogen.

Scientists used data from the Neutron Spectrometer to make a map of where the hydrogen-slowed neutrons came from and saw a steady increase going from the north and south poles to the equator. The spectrometer's resolution was not good enough to pinpoint exactly where that hydrogen was located — whether it was inside craters or spread out just below the Moon's surface. If the hydrogen was from the solar wind, scientists would expect the map to look exactly as it did: Incoming hydrogen ions from the

Sun hit the equator directly, but as you go up in latitude, exposure becomes less and less direct, meaning less sticks to the surface. Then again, if the hydrogen was in water ice frozen inside craters, it would also appear most prevalent at the poles, where the Moon is coldest and most shadowy. But when scientists sent the Lunar Prospector crashing to the lunar surface and watched to see what compounds it kicked up, they did not see water's signature.

Eleven years later, though, LRO did. It watched as LCROSS crashed into the polar Cabeus Crater and took spectroscopic observations — information about the energy emitted and absorbed — on the plume of ejected material. Some 20 percent of the crater's material appeared to be methane, carbon dioxide, hydrogen gas, ammonia, carbon monoxide, and water.

International effort

If shadowy craters generally contain ice, like Cabeus does, future lunar colonists would have an accessible, centralized source of water. A robot bulldozer sent to these dark craters would be able to break off chunks of ice, providing water to drink as well as hydrogen and oxygen for fuel.

In the case of spread-out sheets, however, water will be like low-grade ore: Once the solar wind hits the lunar surface, they join with soil to create hydrated materials. Any resulting water would require extraction and probably exists in quantities too small and too widely distributed to be useful.

But scientists held out hope that later probes would pin down the location and thus the nature of the hydrogen they knew was there. The Japanese Institute of Space and Astronomical Science's Selenological and Engineering Explorer (SELENE) saw no signs of crater ice in 2009. But 2010 radar data from Chandrayaan-1 showed that at high latitudes the shadowed craters reflected most of the radio waves, indicating that they were full of frozen water ... or that they had fresh, rough surfaces. Results from crater-based ice or non-crater-based ice would have looked the same. If new debris had caused the high reflectivity, though, Chandrayaan-1 should have seen lots of reflection outside and inside the crater. If ice had caused it, the reflection would only come from inside, where shadows keep temperatures low, as Chandrayaan-1 saw.

But spectroscopic data that came from Chandrayaan-1's Moon Mineralogy Mapper (M³) gave a potentially contradictory result: Hydrogen was scattered across the high latitudes, even areas that receive sunlight. As Tim Livengood, a scientist from the University of Maryland who researches lunar hydrogen, said, "Not a lot [of ice]. But there's more than zero, which is the surprising part." Because the hydrogen appeared to be dispersed and found in hotter spots, the evidence from M³ pointed to the solar wind scenario and to soiled water. In other words, the results were the definition of mixed. So is the water frozen in shady craters, or is it locked up with dust grains? Or both?

When taken together, results from LCROSS, Chandrayaan-1, and the Lunar Prospector could paint a picture of abundant water on the Moon's surface, frozen as ice at the bottom of the polar craters where the Sun never shines. Or not.

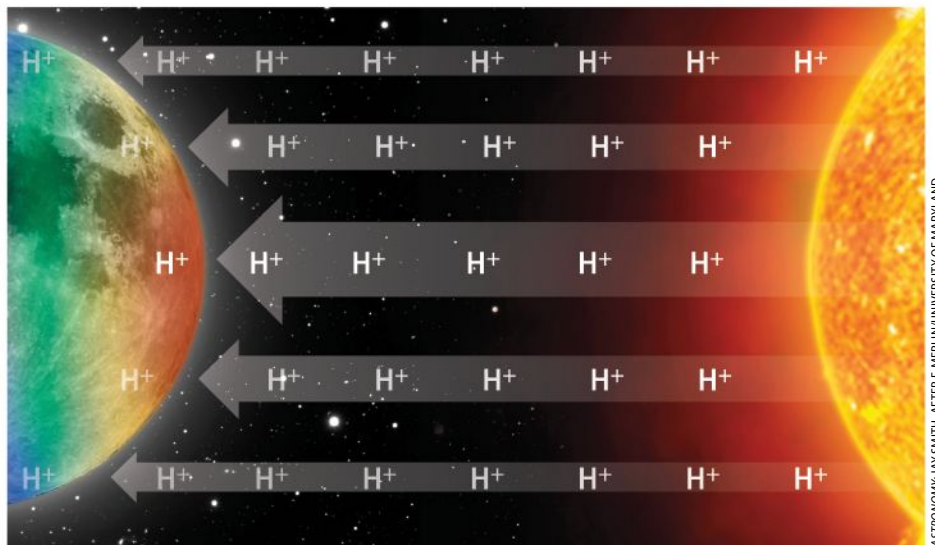
High-time for resolution

LRO's neutron detector, LEND, promised to resolve the debate. LEND looks for hydrogen the same way the Neutron Spectrometer had and has found, as its predecessors had, water stuck near the poles. Unlike its predecessors, it has a resolution high enough to see exactly where that hydrogen is and whether it matches up with cold craters.

To focus LEND's vision, the designers built one set of its detectors at the end of a plastic, boron, and cadmium tube to shield the detector from neutrons coming from the side. By aiming the tube at the lunar surface, scientists hoped that the instrument could map the location of the hydrogen concentrations at a resolution of about 6 miles (10km). With this level of detail, it



The Lunar Reconnaissance Orbiter sat, ready for launch, in a clean room at NASA's Goddard Space Flight Center in Greenbelt, Maryland, in 2009. Its Lunar Exploration Neutron Detector (above) and the Lunar Orbiter Laser Altimeter work together to map the locations of craters and hydrogen. NASA/DEBBIE MCCALLUM



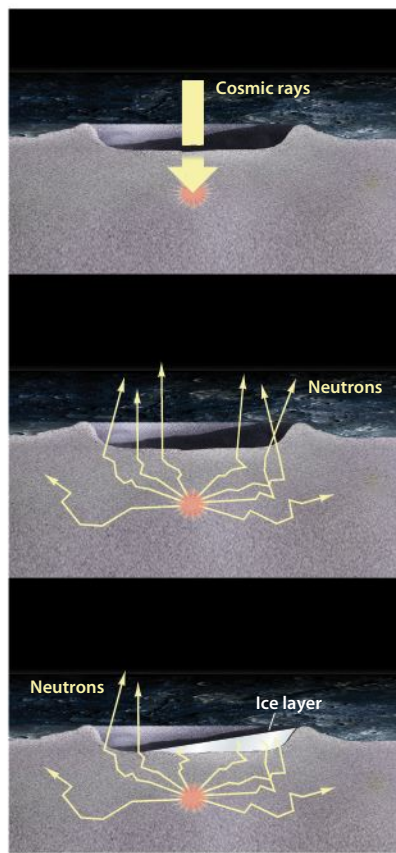
The solar wind sends hydrogen ions streaming into space. Some hit the Moon. The highest concentration is along the equator (red), and the impacts decrease farther north and south. These hydrogen atoms react with oxygen on the surface to create hydrated material. If the Moon's hydrogen comes primarily from this wind, water is not likely to be abundant enough for colonists to harvest large deposits.

could connect the element's appearance to specific regions.

With this setup, LEND has found only three craters — Cabeus and Shoemaker in the south and Rozhdestvensky U in the north — that show significant concentrations of hydrogen. Most of the hydrogen that LEND has found is in random surface

patches. As the LEND team noted in one paper, "The data is enough for [the] definite conclusion that [the permanently shadowed regions] at both poles are not reservoirs of large deposits of water ice." If that is true, and most craters do not contain significant water ice, the LCROSS scientists were merely lucky to have picked Cabeus Crater.

Slow neutrons



When a cosmic ray hits a planetary surface, it knocks neutrons loose from their atoms. These neutrons interact with material before they travel into space. Epithermal neutrons are those whose paths are deflected and moderated by hydrogen, making them “slow.” ASTRONOMY: JAY SMITH, AFTER NASA/JPL

And because of that fortuitous choice, they may have become prematurely hopeful about the contents of other craters.

The baffling secondary part of LEND’s result, however, is that concentrations of hydrogen crop up in lower-latitude areas that receive sunshine — the same thing Chandrayaan-1 found. Water’s survival for even a short time in the Moon’s harsh daylight seems implausible at best. “It is a conundrum that no one can really explain yet,” notes Boynton.

So far, the data do not bode well for future lunar colonists. The accessible water may be only be in a few craters, and even the hard-to-mine water may not be enough to supply a lunar base.

LEND your ears

LEND’s results, if correct, could lead to a definitive conclusion about lunar water, but they have not convinced all scientists. David

Lawrence, a neutron spectroscopy expert at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, for instance, rejects the analysis. “I don’t think their interpretations are correct,” he says.

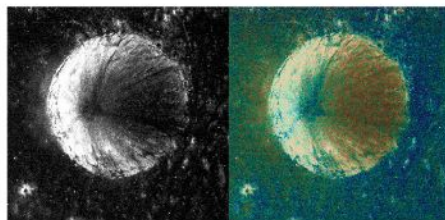
The controversy centers on the instrument’s resolution, which some believe is not as high as its creators claim. In fact, some scientists even think LEND’s maps are no more than noise. As Paul Spudis of the Lunar and Planetary Institute in Houston notes on his website, “The high-resolution neutron data set is a singular observation, and cause has been shown to doubt it as a reflection of reality.”

These doubts come from two places. First, some scientists question whether the size of LEND’s detector is sufficient. To collect as many neutrons as possible, the detector needs to be big. LEND’s detector has an area of about 12 square inches (78 square centimeters). “The amount of area that you actually need to make really good measurements is something like 900 square centimeters,” explains Lawrence.

Second, other scientists question how much background noise LEND’s tubes actually screen out. The neutron flux that leaks through the tube’s sides is some 40 percent of the total. At that level, separating the actual signal from the noise is difficult. LEND’s discoveries could just be variations occurring in the background. “Those detections are getting to the noise limits of their data,” continues Lawrence, who is dubious.

The LEND scientists counter by pointing to the data itself — specifically, the correlations between observations from separate instruments. If LEND’s resolution is so poor, they ask, why did it detect the dimensions of a crater like Shoemaker? As the detector traveled over this crater, it measured a clear decline and then increase in neutrons that matched perfectly with the crater’s dimensions as measured by the Lunar Orbiter Laser Altimeter (LOLA).

“That the hydrogen data agree so incredibly well with the topography means that at least in [Shoemaker’s] case, the



The two images above show two different polarizations — wave directions — Rozhdestvensky U reflected during radar observations of it. The similarity in brightness between the two suggests the crater is either ice-rich or young and fresh.

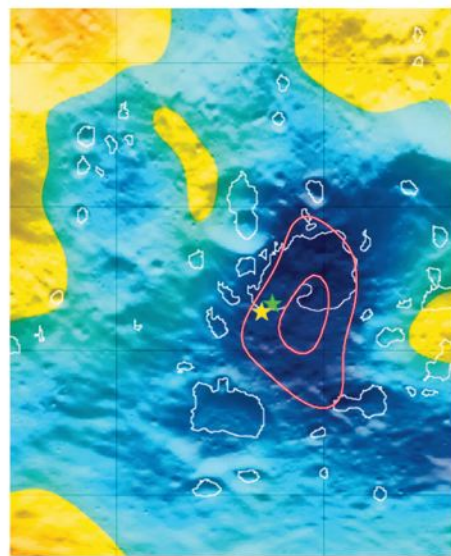
topography is defining what’s going on,” says Boynton.

In addition, the LEND team has been accumulating data for three years, and data from the first 1.5 years look identical to data from the second half. If the results were noise, the areas of “hydrogen concentration” would have shifted randomly over time. Instead, the maps are stable, suggesting that LEND is detecting something real.

But aside from technological concerns, a political consideration also may come into play: LEND was built in Russia, and NASA chose it over an American-designed instrument. Has a turf war over funding contributed to the conflict? “Scientists are human beings,” says Livengood. “We are passionate about our work. And being passionate means people are subject to their feelings.”

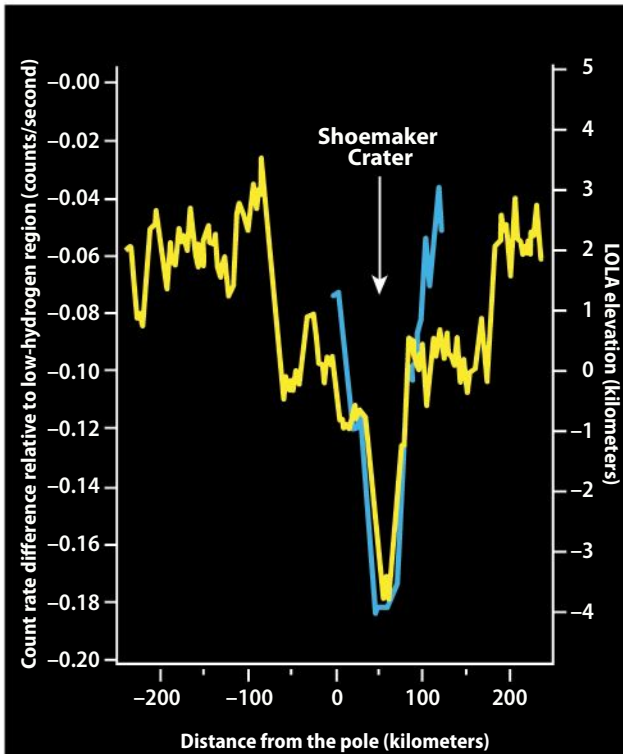
Common origin

In the end, though, scientists may have found answers 238,900 miles (384,400km) closer to home — at home, in fact, in samples that Apollo 11, 15, and 17 astronauts returned to Earth. In 2012, researchers dug into dust that Neil Armstrong had returned from the Moon’s surface, looking for tiny bubbles of glass that had formed when meteorites hit and heated the surface. The water and hydroxyl (OH) embedded within these beads are low in the element deuterium, a “heavy hydrogen” atom (called an isotope) that has one more neutron than regular hydrogen (which has zero neutrons

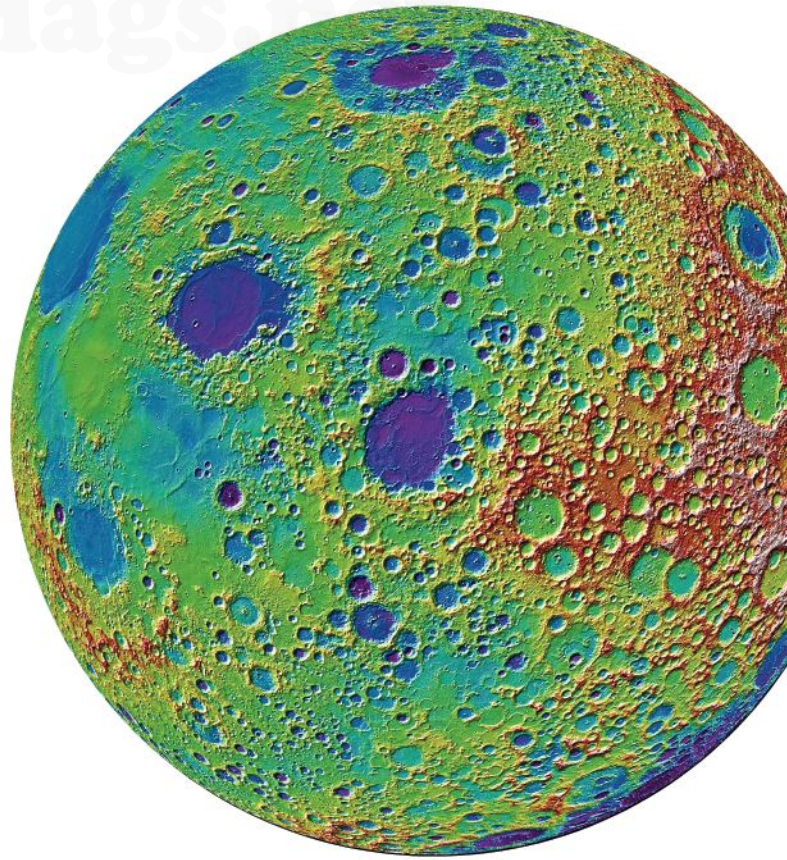


The number of slow neutrons escaping from Cabeus Crater varies from low (dark blue) to high (red). In areas with more hydrogen, the neutrons escape more slowly, so scientists expect a lower flux. In Cabeus, the lowest counts come from the center of the crater. The contours (pink) are from the Lunar Orbiter Laser Altimeter and show that the crater’s elevation matches the neutron flux data. The stars represent the LCROSS impact sites.

Shoemaker's water



In Shoemaker Crater, the elevation change according to the Lunar Orbiter Laser Altimeter (LOLA) (blue) matches the change in number of slow neutrons (yellow), suggesting that the hydrogen detections are real.



The Lunar Reconnaissance Orbiter mapped the Moon's topography, telling the story of the Moon's bombardment history. It found 5,185 craters greater than 12.4 miles (20.0 kilometers) across. NASA/GODDARD/MIT/BROWN/LRO

and only a proton in its nucleus). Hydrogen coming from the Sun is usually of the normal variety, whereas in the rest of the solar system, much of the hydrogen actually comes in the form of deuterium. The scientists took this as evidence that the solar wind supplied the Moon's surface with its hydrogen and, consequently, with its locked-in water.

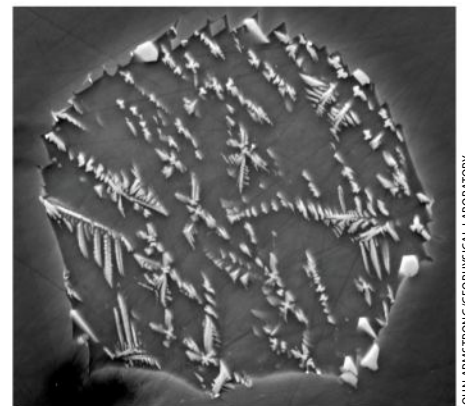
In May 2013, however, another group of astronomers analyzed similar objects called "melt inclusions." Volcanic activity created these glassy rocks, and olivine particles surrounding them kept water trapped inside, providing a pristine sample. The hydrogen in these, too, is low in deuterium. This team, though, found that the ratio of regular hydrogen to its isotope is the same as it is in chondritic meteorites — the oldest type, which formed at the beginning of the solar system. These meteorites delivered water to Earth. So some of the water on the Moon probably came from meteorite impacts and not cometary impacts, as many scientists thought. Or perhaps the meteorites delivered the water to Earth

alone. Then, when a larger impact caused part of Earth to separate and coalesce into the Moon, some of Earth's water remained on the new satellite.

Other answers recently emerged from re-analyzed M³ data. In August, scientists found that Ballialdus Crater contains water bound to "magmatic material," or solidified lava from the Moon's interior. The water, then, traveled to the crater's surface from the lunar interior.

Feet on the ground

While it's clear there's water on the Moon, evidence for its origin — and thus its distribution — points in several different directions. Regardless of where lunar water came from, though, the LEND results do indicate the best places to look for large quantities of it. Future explorers would be foolish to aim their first Moon-mining efforts at places where the spacecraft found nothing. Better to shoot for the three craters that have produced positive results no matter which instrument has pointed at them. To go anywhere else would simply be too much of a



Melt inclusions are blobs of melted material trapped inside magma that eventually will form rock. Astronauts brought some, like the one shown here from the Apollo 17 mission, back from the Moon. The lunar melt inclusions have the same type of water molecules that Earth does. This common chemistry suggests a common origin.

gamble. The only way to settle this scientific debate is to go to the Moon and poke at its surface directly. Remote sensing can provide a lot of information, but in the end, it leaves too many questions. ☾





COMET OF THE CENTURY?

Comet ISON's final stab at glory

This cosmic visitor should remain a fine binocular object as it skims near the North Star during its retreat from the inner solar system.

by Richard Talcott

Comet Hyakutake (C/1996 B2) blazed above Utah's Hellgate Cliffs on March 26, 1996. Hyakutake appeared bright and featured a long tail because it came close to Earth. CHRISTOPHER CLEMENS

WorldMags.net

Few comets have suffered through the trials and tribulations thrown upon Comet ISON (C/2012 S1). Sure, other sungrazing comets have experienced intense heat as they passed close to our star. Some even succumbed to the blistering assault by breaking into pieces or, in a few cases, completely disintegrating.

What sets ISON apart is that the repeated blows came from pessimistic prognosticators on Earth. At first, the claims seemed rather benign: ISON wasn't brightening as quickly as predicted and might fall short of initial forecasts that it could be as bright as the Full Moon. Others then set the bar higher, saying that the comet might not reach naked-eye visibility. The battering reached a crescendo in early October when reports flooded the Internet that ISON would disintegrate well before it made its closest approach to the Sun.

NASA refuted those final claims when it released an image taken with the Hubble Space Telescope on October 9 (see p. 42) that showed ISON still in one piece, with its light spreading out evenly from a bright center. If the comet had split, Hubble would have seen the fragments as pinpricks of light scattered throughout the overall glow.

As we put the finishing touches on this issue in mid-October, ISON continued to barrel toward its late-November rendezvous with the Sun. On the 28th, it swept within 730,000 miles (1.16 million kilometers) of our star's surface. The searing heat and strong tidal forces acting on the comet's nucleus might have broken it into multiple pieces — or ignited some fireworks that produced a spectacular display.

Most astronomers expected ISON to survive its brush with the Sun and produce a sterling show in December. As the calendar turns to the new year, however, will the

comet have anything left? Based on brightness estimates calculated by the Minor Planet Center of the International Astronomical Union (IAU), the answer is "yes."

ISON should glow around 6th magnitude in early January. If all its light were concentrated in a point, that would be bright enough to see without optical aid under a dark sky. A comet's light spreads out, however, making a naked-eye sighting unlikely unless ISON exceeds expectations. Still, binoculars should deliver wonderful views under good conditions. By the end of January, the IAU predicts the comet will hover between 9th and 10th magnitude. You'll need a 4-inch or larger telescope to see much detail at this stage.

Although astronomers often have a tough time predicting how bright a comet will shine, they have no problem calculating precisely where it will appear in the sky. And fortunately for Northern Hemisphere observers, the cosmos provides a convenient star to point the way to ISON in early January. Second-magnitude Polaris, the North Star, lies within 15° or so of the comet's position during the new year's first two weeks. Because Earth's axis points near Polaris, the heavens appear to wheel around this star and its surroundings remain visible all night. As January progresses, however, ISON climbs higher in the evening sky and dips lower after midnight.

As you make plans to observe the comet, remember that its position near Polaris means it always lies toward the north. For the best views, you'll want an observing site located north of any cities or towns to avoid their light pollution. Dress in layers and bring along hot coffee or tea to stay warm.

A date with the Dipper

During January's first week, ISON follows a path that roughly parallels the handle of the Little Dipper. This asterism, or recognizable pattern of stars, forms the main shape of the constellation Ursa Minor the Little Bear. Although the Dipper can be hard to discern from the suburbs, it shows up clearly under a dark sky. Of the seven stars that form the Dipper's shape, the easiest to see is Polaris (which marks the end of the handle) and the toughest is 5th-magnitude Eta (η) Ursae Minoris (at the bowl's southeastern corner).

On the evening of January 1, ISON lies 2.5° southeast of Eta. Two nights later,



Comet PANSTARRS (C/2011 L4) sported an anti-tail 7° long when Earth passed through its orbital plane this past spring. ISON also should grow a striking anti-tail in mid-January. GERALD RHEMANN

the comet passes 2.1° southeast of 4th-magnitude Epsilon (ε) UMi in the Dipper's handle. And two nights after that, the interplanetary wanderer slides 1.7° southeast of 4th-magnitude Delta (δ) UMi. If you examine ISON through binoculars that evening (January 5), you'll see that its tail falls less than 1° from Polaris even though its nucleus lies nearly 5° from this star.

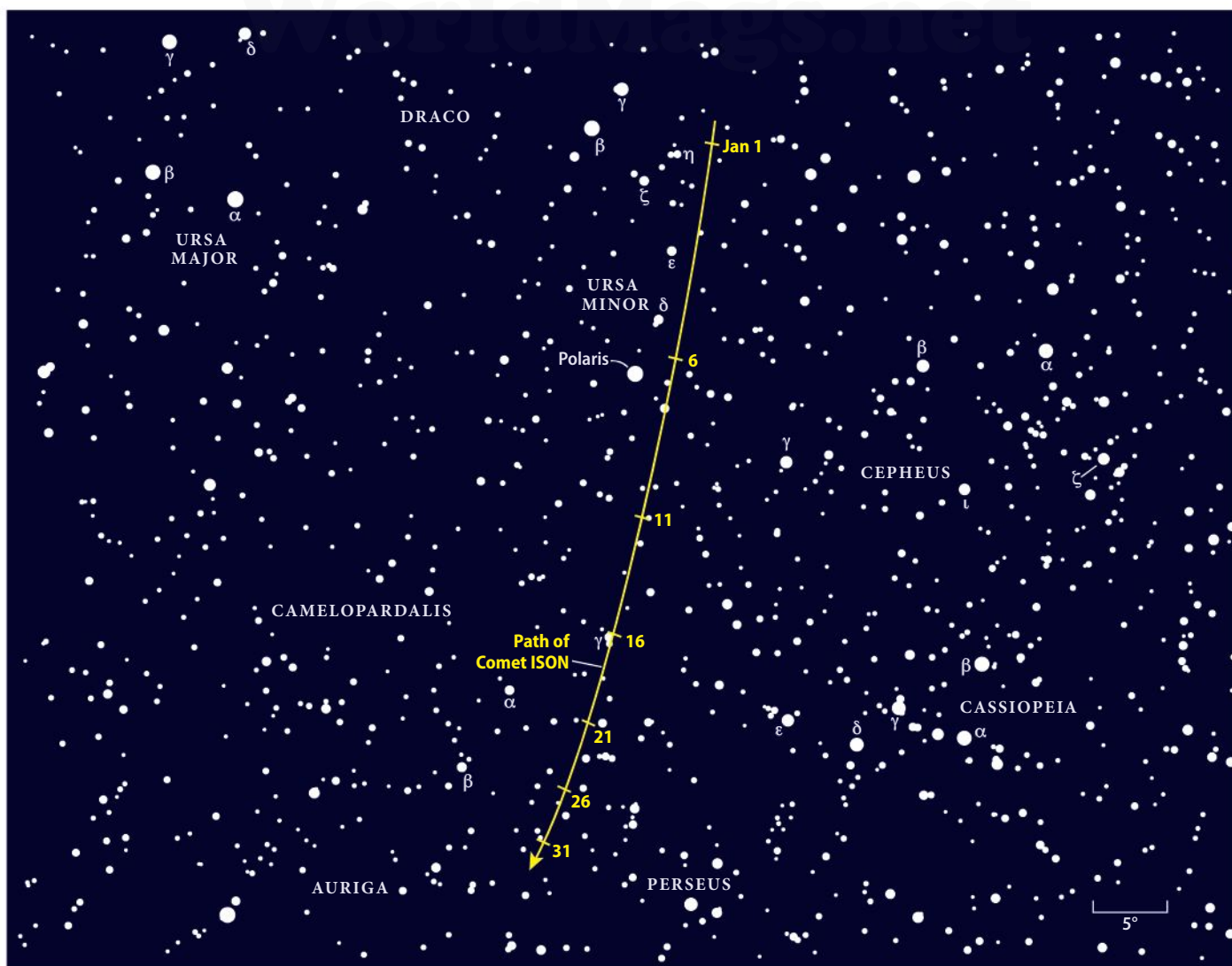
Of course, the nucleus is much too small to show up from Earth. Even Hubble can't resolve this "dirty snowball" of ice and rock that in ISON's case measures only a mile or two (2 or 3km) across. As tiny as it is, the nucleus generates all of the comet's activity. Sunlight warms the surface ices and causes them to sublimate, or turn directly to gas. And as the gases erupt, bits of rock and dust get carried along for the ride.

As the gas and dust particles escape from the nucleus, they form a vast cloud called a "coma" that shrouds the nucleus. Observers who study comets through a telescope often see a bright point of light near the coma's center that they mistake for the nucleus. This so-called false nucleus is simply a spike in the inner coma's brightness. A typical bright comet sports a coma that spans up to 1 million miles (1.6 million km).

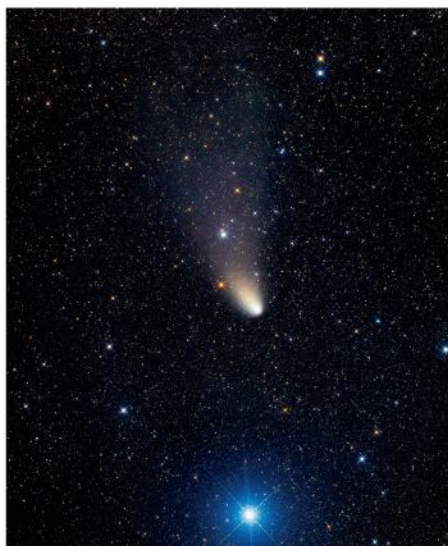


Comet ISON (C/2012 S1) had a nice ion tail in early October when it glowed at 10th magnitude in western Leo. ADAM BLOCK/MOUNT LEMMON SKYCENTER

Richard Talcott is an Astronomy senior editor and author of *Teach Yourself Visually Astronomy* (Wiley Publishing, 2008).



Comet ISON speeds from Ursa Minor through Cepheus and into Camelopardalis during January, when it remains visible all night for Northern Hemisphere observers. This map shows the comet's positions at 11 P.M. EST and includes stars down to magnitude 6.5. *ASTRONOMY: ROEN KELLY*



Comet LINEAR (C/2012 K5) blazed near the 2nd-magnitude star Beta (β) Tauri in early January 2013. The comet put on a good show despite glowing at 9th magnitude, about what ISON should dip to late this month. *GERALD RHEMANN*

The Sun's ultraviolet radiation ionizes the gas molecules by stripping electrons from them. The magnetic fields in the solar wind then drag these ions away from the Sun, creating a long straight tail that emits light with a slightly bluish color.

The Sun affects the dust particles differently. Solar radiation produces a slight pressure that pushes the dust into a gently curving tail that follows the comet's orbit. The dust simply reflects incoming sunlight, so it has a subtle yellowish hue.

Both the ion and dust tails can stretch 100 million miles (160 million km) or more. The Ulysses spacecraft detected the ion tail of Comet Hyakutake (C/1996 B2) 300 million miles (480 million km) from its nucleus. The precise geometry of the Sun, Earth, and comet determines the appearance of the dust tail. During January's first week, we see ISON's orbit nearly broadside, so the dust tail spreads out into a fan shape.

Dance around the Pole Star

A closer look at ISON on January 5 reveals the straight ion tail passing just to the right of Polaris during the evening hours from North America. The dust tail likely will cover Polaris partially and may make it appear slightly dimmer than its normal magnitude 2.0. If ISON continues to produce lots of gas and dust in January, the two tails should extend as far as the North Star, though you likely will need to observe through binoculars or a telescope from a dark site to trace them all the way.

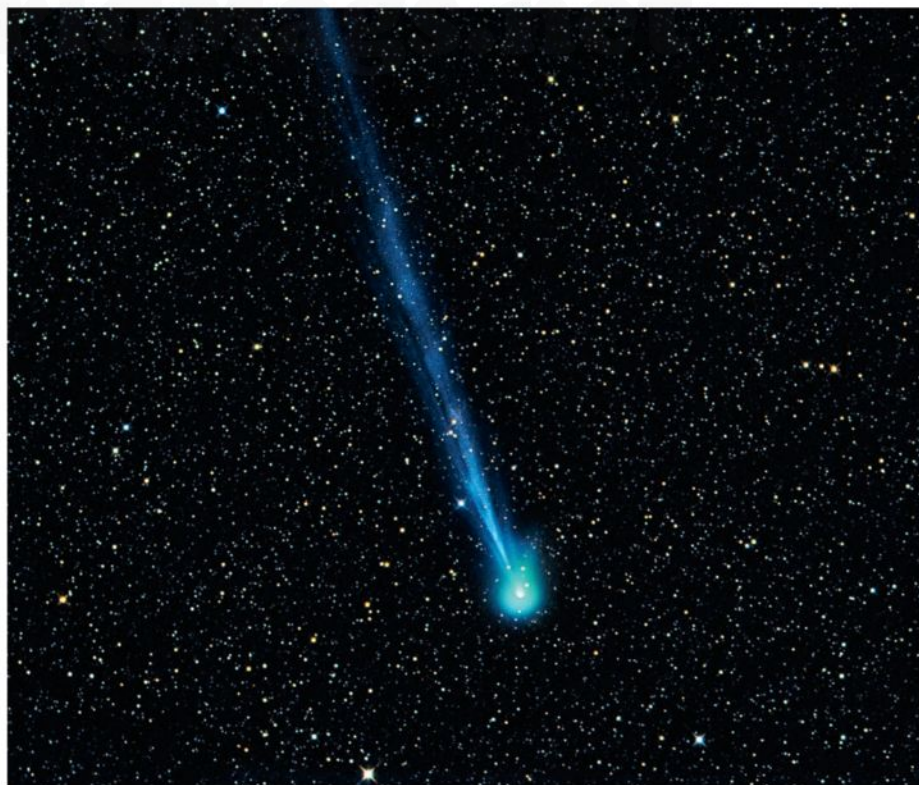
As night falls on the 6th across Europe and Asia, the ion tail points directly at Polaris. North Americans won't see this alignment. By the time evening twilight fades in the Western Hemisphere, the tail has shifted to the star's left. ISON lies just 3° from Polaris on the 6th. The two objects make their closest approach the following evening, when the gap shrinks to 2.7° .

MOON PHASES IN JANUARY

New Moon	Jan. 1
First Quarter	Jan. 7
Full Moon	Jan. 15
Last Quarter	Jan. 24
New Moon	Jan. 30

During the year's first week, the Moon waxes from New to First Quarter phase and sets during the evening hours. The best comet views come after our satellite dips below the horizon in mid- to late evening. With the arrival of First Quarter Moon on January 7, bright moonlight washes across the evening sky during the month's second week. This means the prime viewing hours shift to the morning, slightly before dawn starts to color the sky. At this time of year, twilight begins around 5:30 A.M. local time.

As the best comet viewing switches from the more pleasant evening hours to the morning, ISON moves from the friendly confines of Ursa Minor into the relative emptiness of northern Cepheus the King. Few stars light the way, so tracking down the comet could test your observing skills. ISON crosses from Cepheus into eastern Cassiopeia the Queen on January 13, but the comet lies some 15° from the constellation's familiar W-shaped asterism. To find ISON on either the 13th or 14th, draw an imaginary line between Polaris and 3rd-magnitude Epsilon Cassiopeiae (the W's eastern end), and then scan approximately 5° east of that line's midpoint.



Comet McNaught (C/2009 R1) reached 6th magnitude near its peak in June 2010, similar to the brightness ISON should be in the first week of January. GERALD RHEMANN

The edge of darkness

During January's second week, solar system geometry carries Earth progressively closer to ISON's orbital plane. The comet's broad fan-shaped dust tail narrows significantly with each passing day until the night of January 15/16, when our planet passes through the plane and the dust tail collapses into a sharp spike.

This alignment should create a bright anti-tail — one that points toward the Sun instead of away from it. Because the dust particles that form the anti-tail are larger than those in the normal dust tail, radiation pressure can't drive them away from the Sun as fast as the comet itself moves. These bits of debris remain in the comet's orbit, but they lag behind. The Sun lights up the particles impressively when we view them edge-on. The best views of ISON's anti-tail should come between January 14 and 16. Look at the normal dust tail on one of these nights, and you might see a bluish streak of light from the ion tail superimposed on it.

It's too bad that Full Moon arrives on the same night (January 15/16) that Earth passes through ISON's orbital plane. Scattered light from our satellite brightens the background sky and thus reduces contrast with celestial objects, making fine detail harder to see. Still, the comet should glow at 8th magnitude in mid-January, and the anti-tail should show up nicely through 4-inch scopes even from the suburbs.

Some researchers have speculated that Earth's passage through the comet's orbital plane could trigger a meteor shower. When our planet crosses ISON's orbit, it will be near where the comet was this past November. Unfortunately, it doesn't look like we'll see much effect because ISON likely didn't

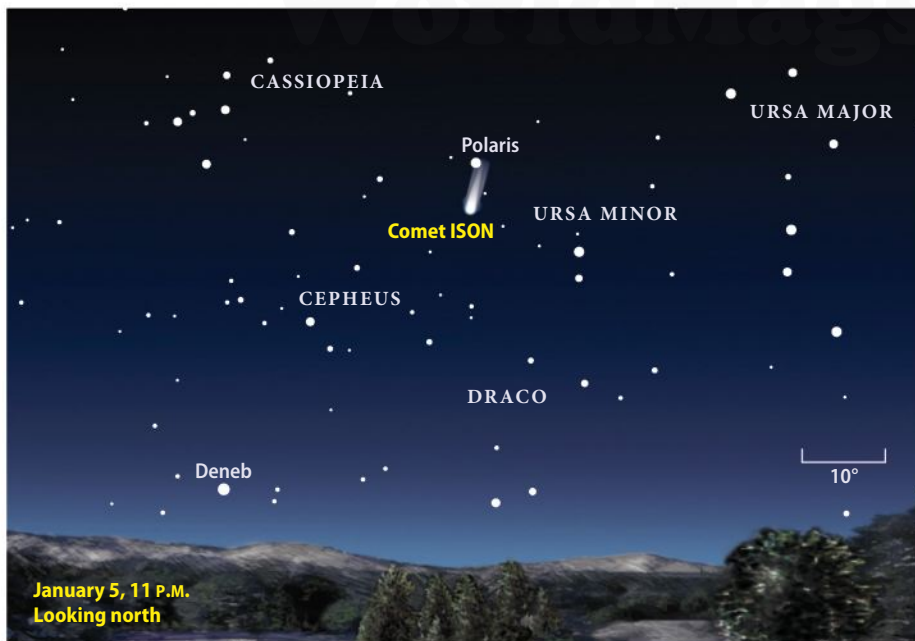


Comet PANSTARRS (C/2011 L4) appeared near Polaris (the bright star at top center) in May 2013. ISON comes even closer to the North Star in January's first week. JOSÉ CHAMBO

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Comet Hyakutake (C/1996 B2) passed near
Polaris in 1996, when its incredibly long tail
stretched all the way back to the Big Dipper in
Ursa Major. ISON makes a similar close pass by
Polaris in early January. DEAN EASTON*

WorldMags.net



Comet ISON's tail points toward Polaris near the end of January's first week. ASTRONOMY: ROEN KELLY

eject bigger particles — the ones that produce impressive meteors — at high enough speeds to get them to Earth.

If any of ISON's dusty debris reaches us, the particles would be too small to create bright flashes. Perhaps the most we can expect is that some fine dust will make its way here and seed the formation of noctilucent clouds, the icy high-altitude clouds people at far northern latitudes occasionally see during twilight. Observers looking for a meteor shower in January should target the prolific Quadrantid shower, which peaks before dawn January 3.

It runs through a river

By January 16, ISON pushes south into the sprawling constellation Camelopardalis the Giraffe. That evening, the comet lies just 0.5° (the width of the Full Moon) west of the magnitude 4.6 double star Gamma (γ) Camelopardalis. Because the ion tail then streams eastward, it passes directly in front of this star.

On the 17th, the waning gibbous Moon doesn't rise until nearly 7 P.M. local time, leaving a Moon-free period right after twilight ends. The number of dark hours grows each evening thereafter. The comet also climbs higher on each succeeding night, so optimal viewing once again reverts to the evening.

Unfortunately, the background sky is nearly devoid of nearby stars bright enough to point the way to ISON. On January 19

and 20, your best chance to locate the comet is to look about one-third of the way between 4th-magnitude Alpha (α) Cam and Epsilon Cas.

The finest sight in the second half of January comes on the evening of the 24th when ISON resides among the background stars of Kemble's Cascade. This beautiful binocular asterism holds about 20 stars; the number you see depends on the size of your binoculars and the transparency of the night. These distant suns range in brightness from 5th to 9th magnitude and run

from northwest to southeast across a span of about 2.5° .

The comet should glow around 9th magnitude when it passes through the group's central region on the 24th. The attractive conjunction will look best through binoculars or a low-power telescope, though you'll have to pan across the asterism to see it all through a scope.

As January winds down, ISON continues its trek southward through Camelopardalis and climbs higher in the early evening sky. It's moving at a slower pace now because it lies farther from both the Sun and Earth. Unfortunately, it passes no bright guides in the sky — the most conspicuous stars in the neighborhood shine at 5th magnitude.

The long journey home

Once we put January in the rearview mirror, most casual skywatchers will abandon ISON. Those with bigger scopes can follow it for several months, however, as it treks from Perseus the Hero into Auriga the Charioteer, where it passes within 3° of brilliant Capella in mid-March.

What will the legacy of ISON be? Will it go down as the "Great Comet of 2013," a benchmark against which future comets will be judged? Or will it become another Comet Kohoutek (C/1973 E1), a disappointment for which rosy expectations never panned out? The best way to find out is by watching the sky diligently this autumn and winter to see what wonders ISON brings our way. ☿



Kemble's Cascade makes a stunning backdrop for ISON and its flowing tail January 24. ASTRONOMY: ROEN KELLY



FOR CONTINUING UPDATES ON ISON'S PROGRESS, VISIT www.Astronomy.com/ISON.

Target 12 kinds of globular clusters

Nearly a century ago, astronomers Harlow Shapley and Helen Sawyer divided globulars into a dozen types. Find out what makes them different. by Rod Pommier

Globular star clusters are among the most beautiful of deep-sky objects. These dazzling spheres of tens to hundreds of thousands of stars are bright and easy to observe, even under moderate light pollution. Showstoppers like the Hercules Cluster (M13) and Omega Centauri (NGC 5139) are regulars at star parties and observatory tours.

They also are popular subjects among deep-sky imagers. Despite all their attributes, however, many amateur astronomers have observed only a handful of the most popular globular clusters. In fact, some amateurs actually have told me, “If you’ve seen one globular, you’ve seen them all.”

This simply isn’t true. While globular clusters may not display the infinite variations of size, shape, and arrangement found

among other deep-sky objects, they do exhibit considerable structural diversity if you know what to look for. What amateurs need to recognize and appreciate this diversity is a good classification system. Luckily, one already exists.

Early work with globulars

The most useful classification system for globular clusters is one devised by American astronomer Harlow Shapley and his assistant Helen Sawyer. Their work with these objects from 1927 to 1929 helped establish our position in the Milky Way.

Shapley used key stars within 93 globular clusters to determine their distances. He found they formed a spherical distribution, then correctly assumed the center was also the Milky Way’s center. Many lie at immense

distances in the general direction of Sagittarius, but only a few relatively close globular clusters appear in the opposite direction.

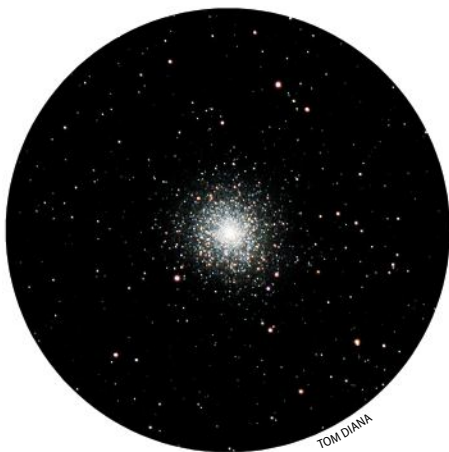
The implication was inescapable: Earth is not at the center of the galaxy, but well toward its outskirts. This produced our biggest demotion of position in the universe since Copernicus correctly placed the Sun in the center of our solar system.

A 12-step program

The classification scheme Shapley and Sawyer came up with rates the degree of concentration of the cluster’s stars. They divided globulars into 12 classes. Class I has the most concentrated stars; class XII has the least. A globular’s “Shapley-Sawyer class” has considerable impact on its visual and photographic appearance, as well as its surface brightness.

Concentrated clusters will have few peripheral stars and cores that are difficult, if not impossible, to resolve. This density gives these objects high surface brightness, rendering them visible across great distances. Any class of globular may exist in any location around the Milky Way, but only the concentrated ones are visible from far away. Because of their vast distances, some of them may appear quite small.

Clusters with less concentration are easier to resolve. Their lower surface brightness, however, means they will be visible



M2 — Class II You’ll find this cluster roughly 4.5° due north of Beta (β) Aquarii. From a dark site, you might even spot it with your naked eyes.



M54 — Class III This magnitude 7.7 object lies 87,000 light-years away, making it the most distant globular in Messier’s catalog.



M75 — Class I Because of its great distance (67,500 light-years), you won't resolve stars in this globular through scopes smaller than 12 inches in aperture. KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF

only if they lie fairly close. For that reason, those classes of globular clusters often appear larger.

The quick tour

We'll begin our tour through the Shapley-Sawyer classification with Class I and work our way down. Because the differences between one class and the next are sometimes subtle, we'll skip some classes and group others together. However, you'll find examples of every class pictured, with their details in the table on p. 65.

As we progress, note the distance to each class example. You'll see that it generally decreases due to the corresponding reduction in the surface brightness that occurs with each successive class.

The best example of a Class I globular cluster is M75 in Sagittarius. Observers commonly consider it one of the most boring objects in Charles Messier's catalog. That's because it appears merely as a small ball of light, only 5' in diameter. The only resemblance it bears to our usual conception of a globular cluster is that it appears slightly ragged around the edges. But the main glowing mass resolutely refuses to be resolved, even through large amateur telescopes.

M75 shines at magnitude 8.6 from a staggering distance of 67,500 light-years. Have you ever wished you could observe deep-sky objects on the opposite side of our galaxy? Well, here's one. When you view M75, you are peering just past the galactic core and seeing this distant globular cluster hovering over the outskirts of the far side of



M15 — Class IV At magnitude 6.2, this globular shines brightly enough for sharp-eyed observers to spot it without optical aid.

the Milky Way's disk. Considering these amazing facts, M75 is a Messier object to be revered rather than neglected.

Our next stop is M2 in Aquarius, a Class II globular. In this object, we can now resolve some scattered stars just around the edges and even a few in front of it. However, the vast majority still appear as a dense ball of unresolved light.

How concentrated is it? Photometric (light intensity) measurements indicate that a 1' by 1' area in the center of this cluster contributes 37 percent of its total light. At 5' from the center, an equal area contributes only 0.02 percent. An interesting visual feature of M2, which is also visible in photographs, is a dark lane curving across the southwest quadrant of the cluster.



M13 — Class V Under a dark sky, you'll spot this magnitude 5.8 object easily as a fuzzy "star" two-thirds of the way from Zeta (ζ) to Eta (η) Hercules.

M2 lies 50,000 light-years from Earth. But this distance is nothing compared to that of another Class II globular, NGC 2419 in Lynx. Astronomers dubbed it the Inter-galactic Wanderer because it lies 300,000 light-years away. The fact that we can see this 4'-wide cluster from such a tremendous distance is due to the combination of its high surface brightness and a lack of intervening galactic dust.

Classes III and IV

We'll combine our next two stops, Class III and IV globular clusters. They feature more noticeable scattering of their outer stars, but they retain a strong central core. You can see this easily in the Class IV globular M15, located in a star-poor field in Pegasus.



M4 — Class IX Point a 6-inch telescope at this globular, and you'll see dozens of stars scattered loosely across its diameter. It lies 1.3° west of magnitude 1.1 Antares (Alpha [α] Scorpii).

A 6-inch telescope will resolve many individual stars strewn about its outer regions. However, it still harbors a small concentrated core that you cannot resolve, regardless of aperture.

In the case of M15, the dense core is intensely brilliant and has a distinctly triangular shape outlined by dark lanes, one of which is remarkably linear. The core enables M15 to shine brightly from a distance of 33,600 light-years.

Classes V through VIII

An important change occurs as we move through Shapley-Sawyer Classes V through VIII: The central concentration of stars decreases enough that the cores become resolvable. This change is responsible for producing the classic “snowball of stars”

appearance that we associate with showpiece globulars like the Hercules Cluster (M13).

M13 in Hercules is a Class V globular that lies 25,000 light-years from Earth. Like M15, it has swarms of outer stars, but its core is distinctly different. Through a large scope, the entire central face of the cluster appears as tightly packed, innumerable individual stars. A curious visual feature in M13 is a Y-shaped dark lane in the southeast part of the cluster. William Parsons, the 3rd Earl of Rosse, saw it in the 1850s. More recently, amateurs have dubbed it “the propeller.”

As we move through the next three classes, the concentration of the central core continues to decrease, as though the center of each globular is progressively expanding outward. You can see this effect

by sequentially viewing a Class VI globular like M3 in Canes Venatici, a Class VII globular like M22 in Sagittarius, and a Class VIII globular like the spectacular Omega Centauri in Centaurus.

The core stars in M3 are almost as tightly packed as those in M13, whereas those in Omega Centauri are more scattered. Omega's stars still give the impression of a cohesive core that is considerably brighter than the outlying regions.

Classes IX through XII

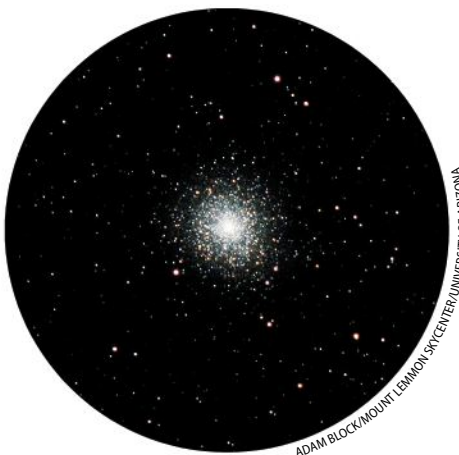
Yet another important structural change occurs as we move through Classes IX through XII: The cores break up! You'll see this as a progression from loosely concentrated centers to almost no central concentration. For the example of a Class IX globular, I've chosen M4 in Scorpius.

The outer regions of M4 show the typical scattering of peripheral stars we expect to see with globular clusters. However, examination of the nuclear region fails to show the expected round core of resolved stars that we saw in Classes V through VIII.

Instead, the only semblance of central concentration is a curious band of glittering resolved stars oriented in a roughly north-south direction. Darker vertical regions composed of fewer stars flank it on either side, particularly toward the east. This lack of concentration significantly decreases M4's intrinsic surface brightness.

Despite this, M4 still shines brightly at magnitude 5.4, surpassing many of the more concentrated globular clusters you can observe. Its brightness, however, is largely due to its proximity. M4 hovers north of our galaxy's central bulge only 7,200 light-years away.

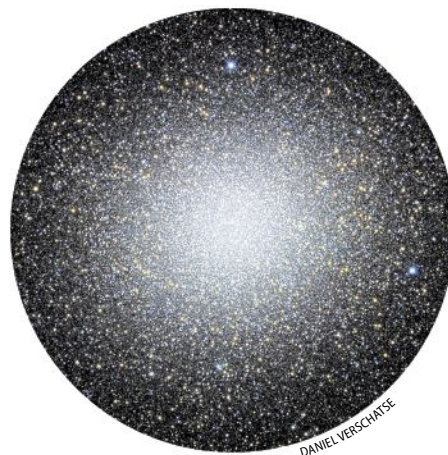
We'll skip next to a Class XI globular, M55 in Sagittarius. The stars in the central



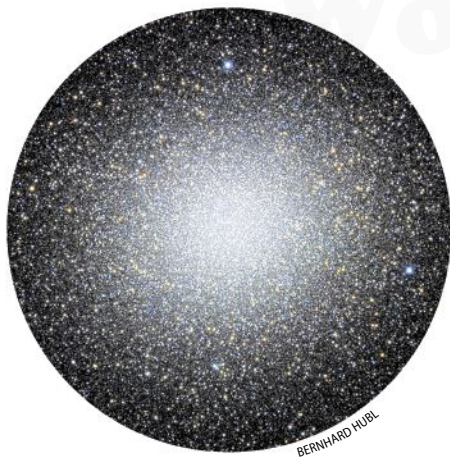
M3 — Class VI This cluster lies on the midpoint of a line between Arcturus (Alpha [α] Boötis) and Cor Caroli (Alpha Canum Venaticorum).



M22 — Class VII This object ranks as the sky's third-brightest globular. You'll find it 2.4° northeast of Kaus Borealis (Lambda [λ] Sagittarii).



Omega Centauri — Class VIII The sky's brightest globular covers more area than the Full Moon and reveals 1,000 stars through an 8-inch telescope.



M56 — Class X To find this fairly small cluster, look 45 percent of the way from Albireo (Beta [β] Cygni) to Gamma (γ) Lyrae.

region of M55 are loosely concentrated. In fact, they are so loose that you can count the individual stars and observe numerous open gaps with no stars at all.

It seems as though we can see completely through this globular cluster and glimpse deep space on its far side. However, this is just an illusion. Deep photographic exposures do show very dim cluster stars within the gaps visible through amateur instruments. M55 lies 17,600 light-years away.

Palomar 12 in Capricornus is an example of a Class XII globular. Unfortunately, it is not close to Earth, so, due to its low surface brightness, it glows feebly at magnitude 11.7.

Palomar 12 is a sparse cluster composed of evenly spaced stars with no discernible central concentration. Even when observing it through the 24- and 32-inch telescopes at Pine Mountain Observatory in central Oregon, I saw only a circular collection of a few

faint stars, which I found indistinguishable from a round open star cluster.

Now set up your scope

I hope this tour of the Shapley-Sawyer classification inspires you to want to observe each type. Learning the 12 classes reveals that globulars exhibit great diversity. I challenge you to apply this as a new observing skill. Use it to discern subtle structural differences among these objects.

Astronomer William E. Harris of McMaster University in Hamilton, Ontario, Canada, maintains a catalog of Milky Way globular clusters. The tally currently stands at 158, 29 of which are members of the Messier catalog. How many have you observed? Why not revisit

your favorites or, better yet, observe some new ones, and see if you can now discern their Shapley-Sawyer classifications.

And challenge yourself with questions. Do you see few or many peripheral stars? How concentrated is the core? Is it resolvable, tightly packed, expanded, or breaking apart? Are there any gaps in the core with no visible stars? Do you see any dark lanes?

If you systematically examine each globular in this manner, you'll see more features and details than you ever thought possible. I also think you'll enjoy viewing them more than ever before. But beyond that, the next time you hear someone say, "If you've seen one globular, you've seen them all," you will certainly be able to tell them otherwise. ☛

EXAMPLES OF THE 12 SHAPLEY-SAWYER CLASSIFICATIONS

Class	Object	R.A.	Dec.	Mag.	Other
I	M75	20h06m	-21°55'	8.6	NGC 7006
II	M2	21h34m	-0°49'	6.6	M80
III	M54	18h55m	-30°29'	7.7	NGC 6541
IV	M15	21h30m	12°10'	6.2	NGC 5634
V	M13	16h42m	36°28'	5.8	M30
VI	M3	13h42m	28°23'	6.3	NGC 6752
VII	M22	18h36m	-23°54'	5.2	M10
VIII	Omega Centauri	13h27m	-47°29'	3.9	M14
IX	M4	16h24m	-26°32'	5.4	M12
X	M56	19h17m	30°11'	8.4	M68
XI	M55	19h40m	-30°58'	6.3	NGC 5053
XII	Palomar 12	21h47m	-21°15'	11.7	NGC 4372

Key: R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude; Other = Another example of a globular cluster in this class.



M55 — Class XI This treat from Charles Messier's catalog is a superb globular you may just spot with your naked eyes from a dark site. Observers describe M55 as "highly resolved," meaning its core doesn't appear packed with stars.



Palomar 12 — Class XII Look 2.8° southeast of magnitude 4.5 Epsilon (ε) Capricorni for this faint globular. It lies more than 60,000 light-years away, and its brightest stars glow around magnitude 15.



Masking the stars

Isolate stars from whatever else is in your image.

Unwanted amplification of the stars is a natural byproduct when we increase the contrast of our astroimages. Brighter stars also result when we apply unsharp masking to an image. In other words, if the whole point is to make a faint nebula appear more detailed, we don't need the added distraction of distended stars. What can you do so this doesn't happen? Follow these eight steps to isolate the stars.

1. First, apply a high-pass filter to a nebula or galaxy. You want to enhance it without affecting the stars. Begin by using *Photoshop* to make a duplicate layer of your image.

2. Go to "Filter," then "Other," then "High Pass Filter." Initially, try a radius of 30 pixels. Adjust this value to suit the degree of enhancement you want.

3. Make sure the duplicate layer you created is active by

clicking on its icon. Go to "Select," then "Color Range," and scroll down to "Highlights." Click "OK." You have just selected all the bright stars.

4. Next, go to "Select," then "Modify," then "Expand," and put in a value of 6 pixels. You want to make sure you have selected even the faint outer glow of the stars. If 6 pixels doesn't capture the area you want, make the amount larger.

5. Go to "Select," then "Modify," then "Feather." Choose a value of 3 pixels. Typically, you want a value for this that's half the amount you expanded.

6. Now go to "Layer," then "Layer Mask," and choose "Hide Selection." This last click is where the magic happens. You just turned a feathered selection into a feathered layer mask.

7. You should still be on your high-pass filter layer. Change the combine method to "Soft Light." You will notice an

increase of contrast and detail, but when you click the "eye" on and off for the high-pass layer, you'll see that the stars did not change. You have successfully masked them out.

8. If you think the amount of high-pass filtering was too much, you can reduce it by lowering the opacity of the high-pass layer. If it wasn't enough,

simply duplicate the layer again, and you will see added high-pass filtering.

Use your imagination, and you'll be able to apply this technique to any process in which you can use a layer to modify your image. At the same time, you will isolate the stars from the effects.

Happy star masking! ☛



In the author's original image of Stephan's Quintet (NGC 7317, NGC 7318a, NGC 7318b, NGC 7319, and NGC 7320), the galaxies show little detail. ALL IMAGES: TONY HALLAS



When the author processed the image to increase the contrast in the galaxies, the stars (and the galaxy cores) became intolerably bright.



By using the process outlined in this column, the author was able to increase the detail visible in the galaxies and keep the star images small.

FROM OUR INBOX

Literary leaders

The Lake County Astronomical Society (LCAS), based in Illinois, has been doing astronomy outreach events at libraries throughout our 30 years of existence. We've always wanted to do a better job at helping kids find the great astronomy resources nearby in their local library. The new Star Reader program is our most concerted effort yet to connect kids and books.

To encourage kids to check out library books about astronomy and space, LCAS is donating special astronomy bookmarks to libraries. The libraries determine how they'll distribute them. Many choose to coordinate the materials with an LCAS viewing event, a schedule of which you can find at <http://tinyurl.com/starreaderprogram>, where you can also find a picture of the bookmark. We will distribute our fall 2013 design of the Star Reader bookmark. It features galaxies M81 and M82 and says, "Galaxies aren't far away. They're as close as your public library." If you're in the area, come by one of our events. If you're far away, consider starting a similar program near you. The books in a library can continue the excitement that starts at the eyepiece of a telescope.

— **Joseph Shuster**, Ingleside, Illinois

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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Diagonal

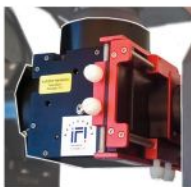
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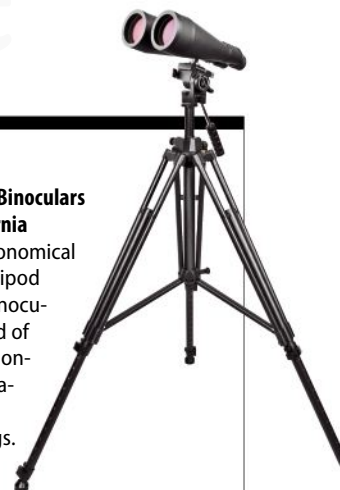
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Very faint nebulae

The trickiest part of sketching large, complex nebulae within a star field is accurate positioning of both the stars and the nebula's structure. Begin by plotting the brightest stars in your sketch as references. Then build up bright nebulae with the tip of a blending stump loaded with graphite. Plot additional stars as needed to help with positioning, and then render dark nebulae with a sharpened vinyl eraser. Let's take a look now at two choice nebulae that make great sketching targets.

The Rosette Nebula

Modest magnification can help you tackle an object notorious for its low surface brightness, such as the Rosette Nebula (NGC 2237–9/46), an emission nebula nestled within the “jowls” of the constellation Monoceros. Spanning 1°, this cloud of gas and dust has a wreath-like shape surrounding open cluster NGC 2244.

Radiation and wind from the cluster's hot young stars contribute to the Rosette's shape

and reddish color. Every part of the nebula benefits from the use of an Oxygen-III or Ultra High Contrast filter, which really help dim the stars.

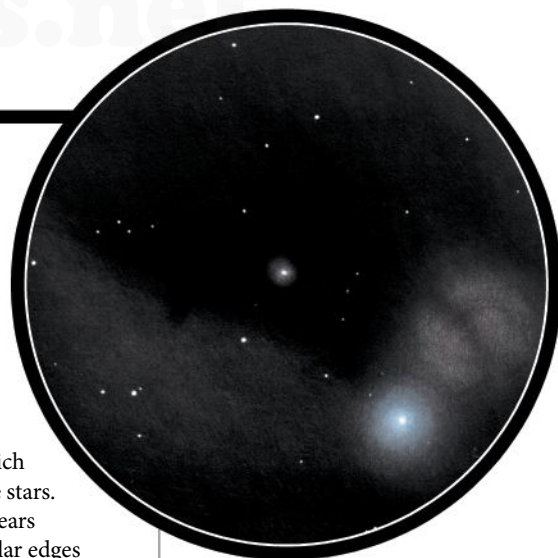
The nebula appears patchy with irregular edges through an 8-inch telescope at a magnification of 50x. The cluster's brightest stars form two parallel chains with yellow-colored 12 Monocerotis shining the brightest at magnitude 5.9. Using the same magnification through a 12-inch scope reveals distinct dark lanes.

The Horsehead Nebula

This famous dark nebula lies silhouetted against the eastern edge of emission nebula IC 434 in the constellation Orion. To locate the Horsehead — also known as Barnard 33 — find Zeta (ζ) Orionis in Orion's Belt, and then follow emission nebula IC 434 to the south. You'll see the soft glow of reflection nebula NGC 2023 and two magnitude 7.5 stars running from the northeast to the southwest.

The Horsehead lies 9' south of the middle star and appears as a dark 5'-wide thumbprint embedded in IC 434 through an 8- to 10-inch telescope. It becomes increasingly pronounced through larger apertures, and it's possible to detect the horse's “snout” protruding north through a 16-inch scope.

This elusive dark nebula responds well to a Hydrogen-beta (H β) filter, and though



The Horsehead Nebula, IC 434, NGC 2023, and the Flame Nebula all appear in this eyepiece drawing. The sketcher viewed through an 8-inch Newtonian reflector and used a 25mm eyepiece (40x) with an Ultra High Contrast filter.

dark, pristine skies are a must when trying to locate it, finding the optimal exit pupil creates the recipe for a successful observation — and sketch.

Filters have specifications listed for the best exit pupil range. For example, the optimal range for my H β filter is 3 to 7 millimeters. So, which of my eyepieces should I use to observe through it?

To find the exit pupil of any eyepiece, divide its focal length by your telescope's focal ratio. My telescope has an f/ratio of 4.5. So, a 20mm eyepiece would give me a $(20/4.5)$ 4.4mm exit pupil, making it a good choice for this object.

A 12mm eyepiece gives an exit pupil 2.7mm across, while a 40mm eyepiece yields a whopping 8.9mm exit pupil. When the exit pupil is too small, the view will be excessively dark; too large an exit pupil means insufficient contrast.

Choosing the right magnification and increasing the contrast between a faint nebula and the background sky are two ways you can improve your odds of recording more detail. As a result, you will produce better sketches of these grand objects. ▀



This sketch shows the Rosette Nebula (NGC 2237–9/46) in the constellation Monoceros as seen through an 8-inch Newtonian reflector with a 31mm eyepiece (which yielded a magnification of 32x) and an Ultra High Contrast filter. The observer created both sketches on this page with graphite on white paper and then scanned and inverted his results using *Photoshop*. ALL ILLUSTRATIONS: MICHAEL VLASOV (WWW.DEEPSKYWATCH.COM)

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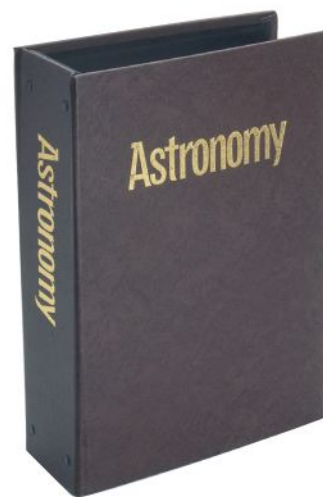
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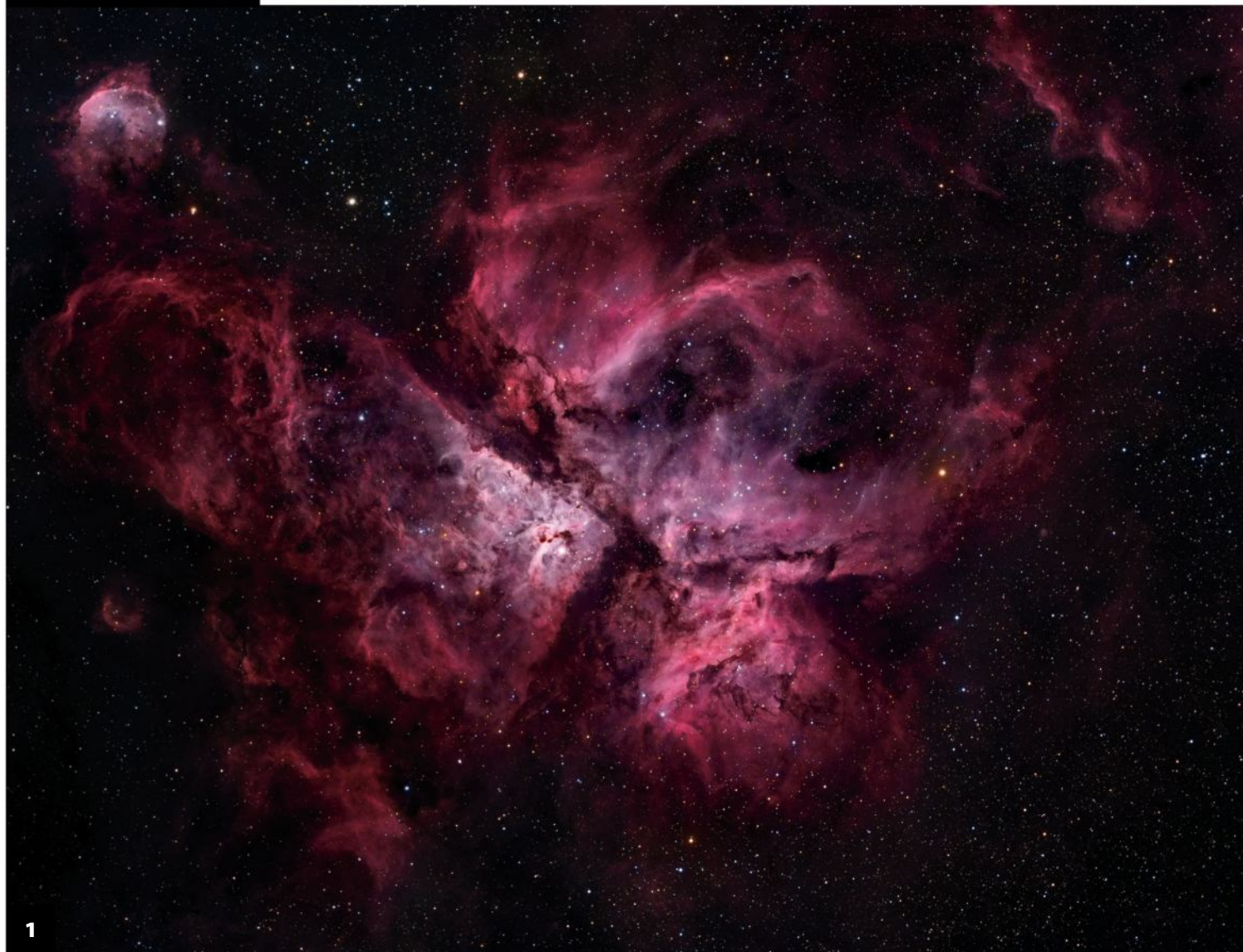


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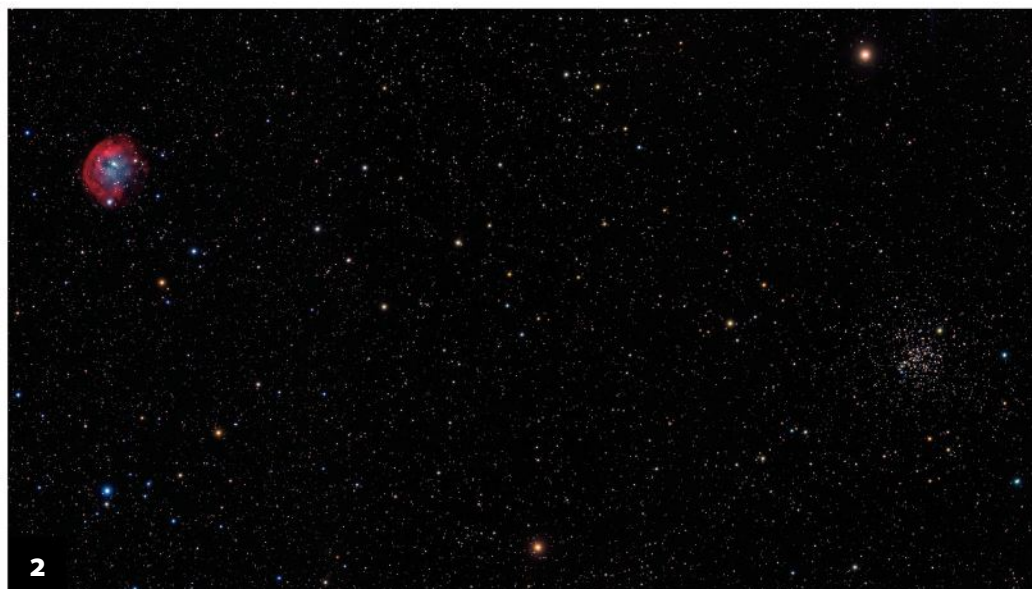


1. THE RED HOOD NEBULA

The Carina Nebula (NGC 3372) is a huge emission nebula. Observers have named regions within NGC 3372 with such evocative names as the Keyhole Nebula and the Homunculus. Now comes the Red Hood — a large section just above center that combines bright and dark areas. (8-inch Officina Stellare Veloce Riccardi-Honders telescope at f/3, SBIG STL-11000M CCD camera, H α RGB image with six 10-minute exposures through each filter, stacked) • *Harel Boren*

2. NEBULA AND CLUSTER

Planetary nebula Sharpless 2-290 (left), also known as Abell 31 and PN G219.1+31.2, contrasts with the old open cluster M67. Both objects lie in the constellation Cancer the Crab. (5.2-inch Takahashi TOA-130 refractor at f/6, SBIG STL-11000M CCD camera, H α LRGB image with exposures of 12, 4, 3.67, 3.67, and 3.67 hours, respectively) • *Alistair Symon*



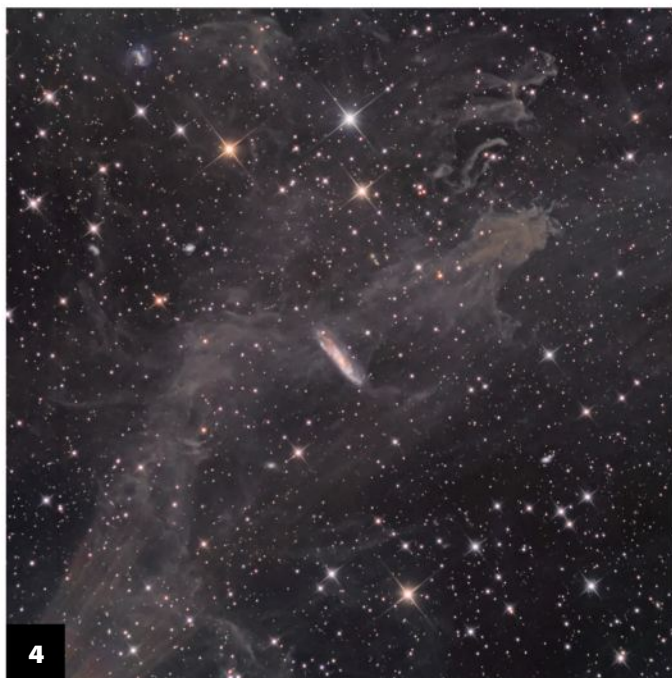


3. GORGEOUS GALAXY FIELD

Spiral NGC 4725 in Coma Berenices shines relatively brightly for a galaxy at magnitude 9.4. But it's not alone. Magnitude 12.5 NGC 4712 lies just to its right, while magnitude 12.2 NGC 4747 lies to its upper left. And for a real challenge, glance toward PGC 86434 to NGC 4725's upper right. It glows at a meager magnitude 17.5. (5.6-inch Telescope Engineering Company TEC-140 refractor at f/7, SBIG ST-8300M CCD camera, LRGB image with exposures of 6, 1.5, 1.5, and 1.5 hours, respectively, taken remotely from the Rancho Hidalgo Astronomy and Equestrian Village near Animas, New Mexico) • **Bernard Miller**

4. IN THE DUST

Spiral galaxy NGC 7497 in Pegasus lies 60 million light-years away. Much closer, yet seeming to swirl around it, is the molecular cloud MBM 54. It is part of the integrated flux nebula, immense faint clouds of dust that lie outside the Milky Way's plane. (12.5-inch RC Optical Systems Ritchey-Chrétien astrograph, FLI PL-16803 CCD camera, LRGB image with exposures of 13, 4.25, 4.75, and 4.25 hours, respectively) • **David Kopacz and Lee Buck**



5. PALOMAR SUNSET

The Sun sets behind the dome that houses the 200-inch Hale Telescope at Palomar Observatory in California. The instrument saw first light January 26, 1949, and it was the largest optical telescope on the planet until late 1975. (Canon EOS 30D DSLR, Canon EF70–300 f/4–5.6 IS USM lens set at 70mm and f/5.6, ISO 100, 1/600-second exposure, taken August 2, 2013, at 7:22 P.M. PDT) • **Behyar Bakhshandeh**

6. IMBRIUM SCULPTURE

This image shows a section of the Moon from Ptolemaeus Crater on the left to Mare Serenitatis on the right. Ejecta from the impact that formed the Imbrium Basin scoured the entire region. (11-inch Celestron Schmidt-Cassegrain telescope, ZWO ASI120MM CMOS video camera, mosaic of three images, each a stack of 1,000 frames, taken August 26, 2013, from Memphis, Tennessee) • **Ross Sackett**



Send your images to:

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NASA/ESA/THE HUBBLE HERITAGE TEAM (STSC/AURA)

Hubble zooms in on Comet ISON

In late July 2013, astronomers released this unusual Hubble Space Telescope shot of Comet ISON (C/2012 S1), taken April 30, 2013. The dim comet (about magnitude 15.5) was floating in a field populated by galaxies in the

constellation Gemini the Twins. Approaching the Sun, ISON was still 3.9 astronomical units (363 million miles) away, and some 4.32 astronomical units (402 million miles) from Earth. That's nearly as far from the Sun as

Jupiter. Although it seems far away, it's actually close to us.

The galaxies, on the other hand, are billions of times more distant. So in this portrait, we have an extraordinary lesson in depth of field. ☿



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March 2014: Venus and Mercury dazzle

Jupiter continues to rule the evening sky during March. As twilight ends, the giant planet appears almost due north and at its highest position of the night. But what sets it apart is its brilliance — in mid-March, Jupiter shines at magnitude -2.3 . It nestles between the two lines of stars that mark the positions of Gemini the Twins. The planet moves slowly westward until March 6, when it comes to a halt before resuming its normal eastward motion. Naked-eye observers will be hard-pressed to detect this sluggish drift against the background stars.

The best time to view Jupiter through a telescope is when it lies highest in the north during the early evening hours. The giant planet spans an impressive $41''$ at midmonth and should show a wealth of atmospheric detail even through small instruments. The most prominent features are two parallel dark equatorial belts, one on either side of a brighter zone. Adding to the display are four bright moons that change positions noticeably from one night to the next.

By mid-evening, two bright points of light adorn the eastern sky. The lower and brighter one is **Mars**, which appears against the backdrop of Virgo the Maiden. The other is Virgo's brightest star, Spica. The planet shines at magnitude -0.9 in mid-March, some two magnitudes brighter than the star. The objects' colors also separate them: Mars glows distinctively

orange-red while Spica has a blue-white hue.

With Mars set to reach opposition and peak visibility in early April, take advantage of clear skies this month to observe the planet through a telescope. Its disk swells 25 percent during March, growing from $11.6''$ to $14.6''$ across. (By opposition, it will be only $0.6''$ larger.) Even small scopes will show the white north polar cap and a few dusky markings on the surface. In moments of good seeing — more common once the planet climbs higher after midnight — larger apertures will reveal plenty more.

The cavalcade of planets continues when **Saturn** rises in late evening. The ringed world pokes above the eastern horizon around 11 P.M. local time in early March and two hours earlier by month's end. It shines at magnitude 0.3 , significantly brighter than the background stars of Libra the Balance.

Your best looks at Saturn through a telescope come when it appears high in the north shortly before dawn. Expect exquisite views of the planet's ring system, which spans $40''$ and tilts 23° to our line of sight in mid-March. The rings wrap around a rather bland and yellowish disk that measures $18''$ across.

Although Mars and Saturn ride high and shine brightly in the predawn darkness, they pale in comparison to **Venus**. The brightest planet reaches greatest elongation March 22, when it lies 47° west of the

Sun. It then rises nearly four hours before our star and climbs 25° high in the east by the time twilight commences. At greatest elongation, Venus shines at magnitude -4.5 , some eight times brighter than its nearest competitor, Jupiter.

Venus continues to be a treat for viewers with telescopes. The planet appears large, though it shrinks from $33''$ to $22''$ across during March, and shows a phase that waxes from 36 to 54 percent lit.

Mercury keeps Venus company in the morning sky all month. The innermost planet reaches its own greatest western elongation March 14, when it lies 28° from the Sun — the farthest it can ever get. Not surprisingly, this is the finest morning appearance of Mercury during 2014. The best views of Mercury through a telescope come early in the month, when it still displays a pleasing crescent shape.

The starry sky

Each of the five bright planets puts on a show during March. But this doesn't mean observers should ignore the background sky. The Milky Way passes through the zenith during the early evening hours and, although it doesn't appear as spectacular as it does during the winter and spring, our galaxy still delivers great views on clear March evenings.

This is a good time to trace the galactic equator, the imaginary line that slices through the center of the Milky Way's disk. Let's start in Gemini,

Jupiter's current home and a conspicuous group in the northern sky on March evenings. The equator clips the western end of Gemini, passing close to the lovely open star cluster M35, which makes a great target through binoculars and small telescopes.

The galactic equator crosses the celestial equator in the rather inconspicuous constellation Monoceros the Unicorn, between the more familiar Orion and the bright star Procyon. After leaving the Unicorn's corral, the galactic equator enters the northeastern corner of Canis Major before reaching Puppis, the Stern of the great ship Argo Navis. It's here, in northwestern Puppis, that the line passes a few degrees from the intriguing open clusters M46 and M47. Ten degrees farther on, the equator passes through the outskirts of the cluster M93. This whole area is great for exploring through 7×50 or larger binoculars.

Continuing through the ship Argo, the line cuts across Vela the Sails and Carina the Keel. In the latter constellation, it passes between the exceptional Carina Nebula (NGC 3372) and NGC 3532, one of my favorite binocular star clusters. The equator then edges past Alpha (α) Crucis and almost bisects the Coal Sack, the sky's most prominent dark nebula. As the galactic equator dips toward the southeastern horizon, it passes between the bright stars Alpha and Beta (β) Centauri. ☛

STAR DOME

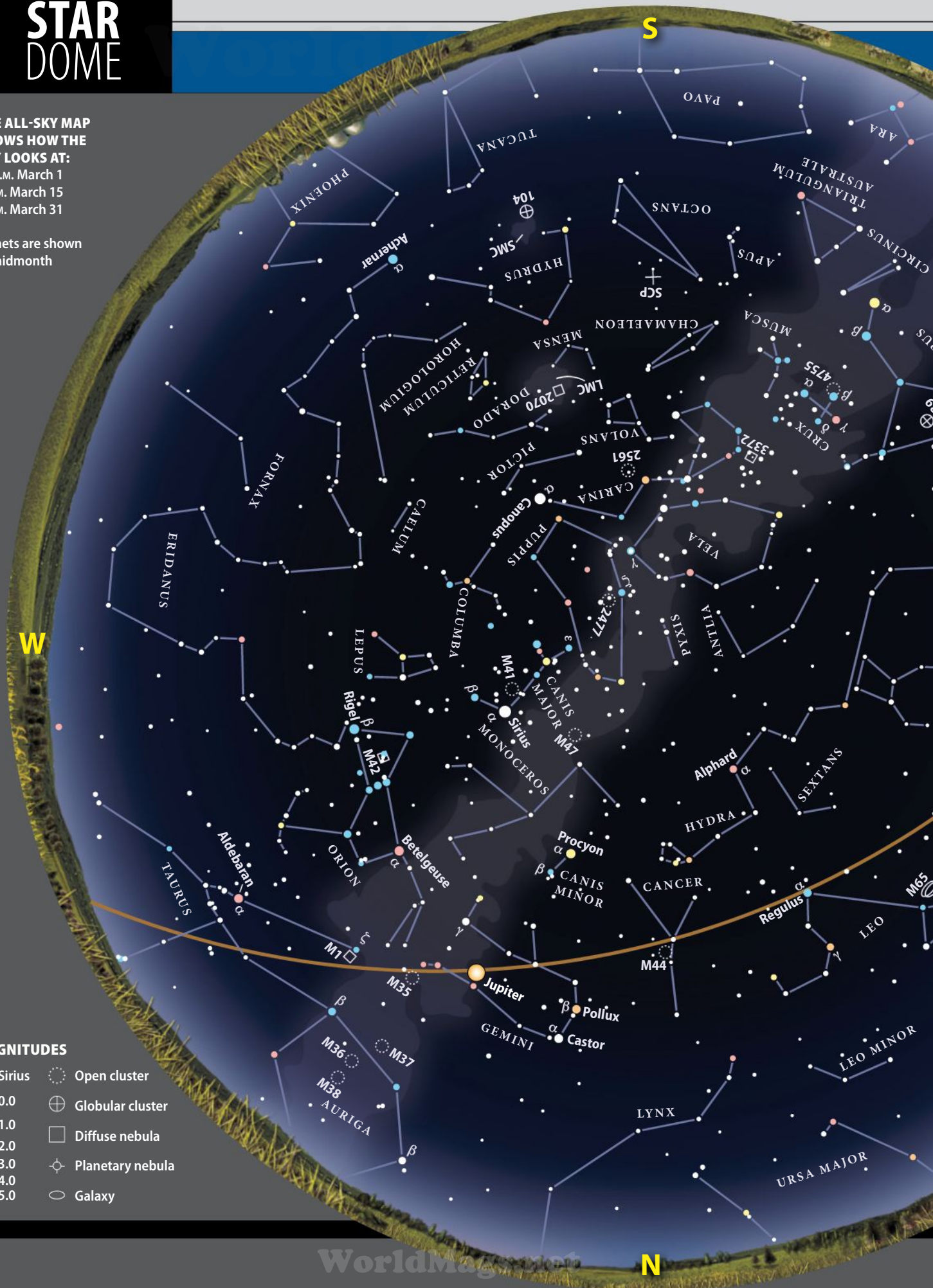
THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:

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

Planets are shown
at midmonth

MAGNITUDES

- Sirius ○ Open cluster
- 0.0 ⊕ Globular cluster
- 1.0 □ Diffuse nebula
- 2.0 ◇ Planetary nebula
- 3.0 ○ Galaxy
- 4.0
- 5.0



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

MARCH 2014

Calendar of events

- 1** New Moon occurs at 8h00m UT
Asteroid Ceres is stationary, 20h UT
Mars is stationary, 21h UT
- 3** Saturn is stationary, 4h UT
The Moon passes 2° north of Uranus, 11h UT
- 5** Asteroid Vesta is stationary, 9h UT
- 6** Jupiter is stationary, 10h UT
- 8** First Quarter Moon occurs at 13h27m UT
- 10** The Moon passes 5° south of Jupiter, 11h UT
- 11** The Moon is at apogee (405,364 kilometers from Earth), 19h47m UT
- 14** Mercury is at greatest western elongation (28°), 7h UT
- 16** Full Moon occurs at 17h08m UT
- 19** The Moon passes 3° south of Mars, 3h UT
- 20** March equinox occurs at 16h57m UT
- 21** The Moon passes 0.2° south of Saturn, 3h UT
- 22** Mercury passes 1.2° south of Neptune, 12h UT
Venus is at greatest western elongation (47°), 20h UT
- 24** Last Quarter Moon occurs at 1h46m UT
Asteroid Pallas is stationary, 21h UT
- 27** The Moon passes 4° north of Venus, 10h UT
The Moon is at perigee (365,703 kilometers from Earth), 18h34m UT
- 28** The Moon passes 5° north of Neptune, 14h UT
- 29** The Moon passes 6° north of Mercury, 5h UT
- 30** New Moon occurs at 18h45m UT
- 31** Mars passes 5° north of Spica, 4h UT



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Astronomy's 2014 Guide to the Night Sky

LUNAR PHASES

New	First	Full	Last
Jan. 1	Jan. 7	Jan. 15	Jan. 24
Jan. 30	Feb. 6	Feb. 14	Feb. 22
March 1	March 8	March 16	March 23
March 30	April 7	April 15	April 22
April 29	May 6	May 14	May 21
May 28	June 5	June 13	June 19
June 27	July 5	July 12	July 18
July 26	Aug. 3	Aug. 10	Aug. 17
Aug. 25	Sept. 2	Sept. 8	Sept. 15
Sept. 24	Oct. 1	Oct. 8	Oct. 15
Oct. 23	Oct. 30	Nov. 6	Nov. 14
Nov. 22	Nov. 29	Dec. 6	Dec. 14
Dec. 21	Dec. 28		

All dates are for the Eastern time zone. A Full Moon rises at sunset and remains visible all night; a New Moon crosses the sky with the Sun and can't be seen.



THE MOON is Earth's nearest neighbor and the only celestial object humans have visited. Because of its changing position relative to the Sun and Earth, the Moon appears to go through phases, from a slender crescent to Full Moon and back. The best time to observe our satellite through a telescope comes a few days on either side of its two quarter phases. For the best detail, look along the terminator — the line separating the sunlit and dark parts. NASA/GSFC/Arizona State University

Mars appears conspicuous from February through June. The Red Planet rises around midnight at the beginning of the year but comes up earlier with each passing day. It peaks at opposition in April, when it shines at magnitude -1.5 and reaches an apparent diameter of $15''$. It also stays on display all night. A telescopic view reveals Mars' icy north polar cap and more subtle features, which show up as contrasting shades of orange and brown. The planet remains visible in the evening sky until year's end. NASA/ESA/STScI



JUPITER always shows a dynamic face. Its atmosphere displays an alternating series of dark belts and bright zones pocked by the Great Red Spot. Even through a small telescope, the planet's four big moons appear conspicuous. You often will see dramatic movement of these moons during the course of a single night. Jupiter reaches its peak in early January, when it shines brightest (magnitude -2.7) and looms largest ($47''$ across), though it's a fine sight through June and again from September until year's end. NASA/JPL/USGS



SATURN and its rings provide a spectacular attraction for telescope owners during most of 2014. The ringed world is on display from January through October and again in December, but it appears best around the time of opposition in mid-May. Saturn then shines at magnitude 0.1 and its disk measures $19''$ across, while the rings span $42''$ and tilt 22° to our line of sight. Even a small telescope reveals the dark, broad Cassini Division that separates the outer A ring from the brighter B ring. NASA/ESA/STScI



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WINTER

The sky

Winter boasts the brightest stars of any season. Orion the Hunter dominates the evening sky this time of year. Its seven brightest stars form a distinctive hourglass pattern. The bright blue star marking Orion's left foot is Rigel, and the ruddy gem at his right shoulder is Betelgeuse. The three stars of the Hunter's belt point down to Sirius, the brightest star in the night sky, and up to Aldebaran, the eye of Taurus the Bull. To Orion's upper left lies the constellation Gemini.

Deep-sky highlights

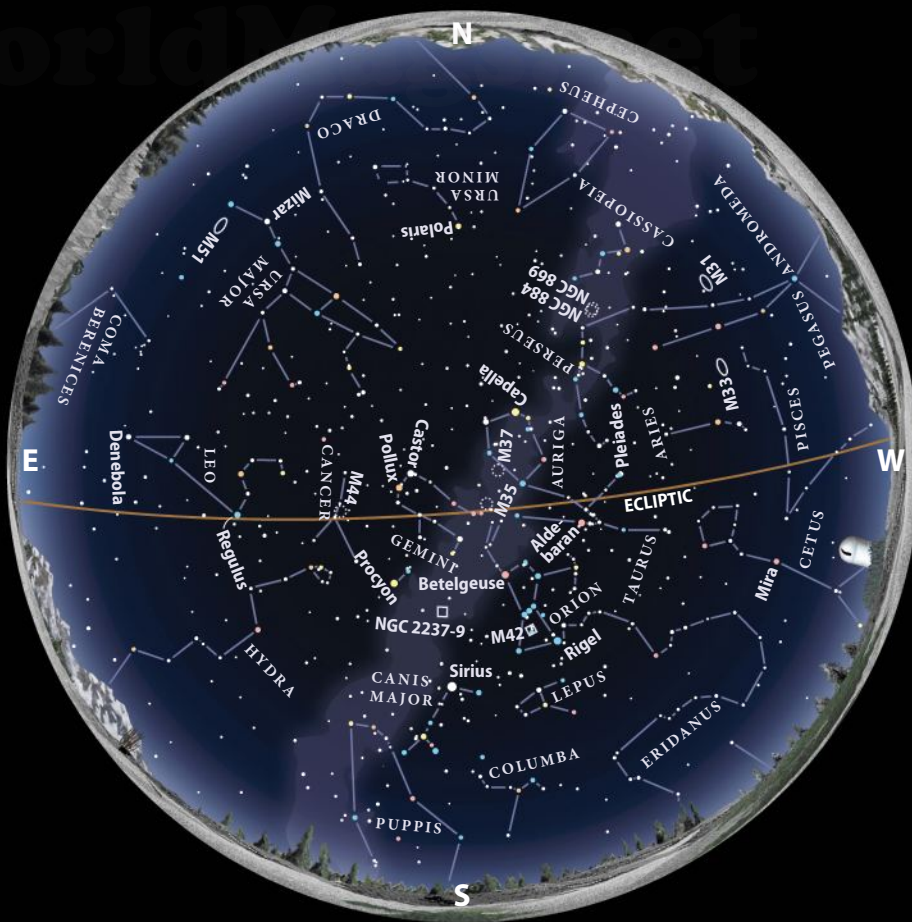
The Pleiades (M45) is the brightest star cluster in the sky. It looks like a small dipper, but it is not the Little Dipper.

The Orion Nebula (M42), a region of active star formation, is a showpiece through telescopes of all sizes.

The Rosette Nebula (NGC 2237–9/46), located 10° east of Betelgeuse, presents an impressive cluster of stars and a nebula.

M35 in Gemini the Twins is a beautiful open cluster best viewed with a telescope.

Castor (Alpha [α] Geminorum) is easy to split into two components with a small telescope, but the system actually consists of six stars.



SPRING

The sky

The Big Dipper, the most conspicuous part of the constellation Ursa Major the Great Bear, now rides high in the sky. Poke a hole in the bottom of the Dipper's bowl, and the water would fall on the back of Leo the Lion. The two stars at the end of the bowl, called the Pointer Stars, lead you directly to Polaris, the North Star. From the bowl's top, simply go five times the distance between the Pointers. Spring is the best time of year to observe a multitude of galaxies. Many of these far-flung island universes, containing hundreds of billions of stars, congregate in northern Virgo and Coma Berenices.

Deep-sky highlights

The Beehive Cluster (M44) was used to forecast weather in antiquity. It is a naked-eye object under a clear, dark sky, but it disappears under less optimal conditions.

M5, a conspicuous globular cluster, lies between the figures of Virgo the Maiden and Serpens Caput the Serpent's Head.

The Whirlpool Galaxy (M51) is a vast spiral about 30 million light-years away.

M81 and **M82** in Ursa Major form a pair of galaxies that you can spot through a telescope at low power.



Jan. 3 Quadrantids meteor shower peaks

Jan. 5 Jupiter is at opposition

Jan. 31 Mercury is at eastern elongation

Feb. 15 Venus is at maximum brilliancy

March 22 Venus is at western elongation

April 8 Mars is at opposition

April 13 Asteroid 1998 QE2 is at opposition

April 15 Asteroid 1998 QE2 is at opposition

April 15 Total lunar eclipse

May 6 Eta Aquarids meteor shower peaks

May 10 Saturn is at opposition

May 25 Mercury is at eastern elongation

July 4 Pluto is at opposition

Aug. 17 Venus is at maximum brilliancy of Jupiter

Aug. 29 Neptune is at opposition

Oct. 7 Uranus is at opposition

Oct. 8 Total lunar eclipse

Oct. 21 Orionid meteor shower peaks

Oct. 23 Partial solar eclipse

Nov. 1 Mercury is at western elongation

Nov. 17 Leonid meteor shower peaks

Dec. 14 Geminiid meteor shower peaks

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

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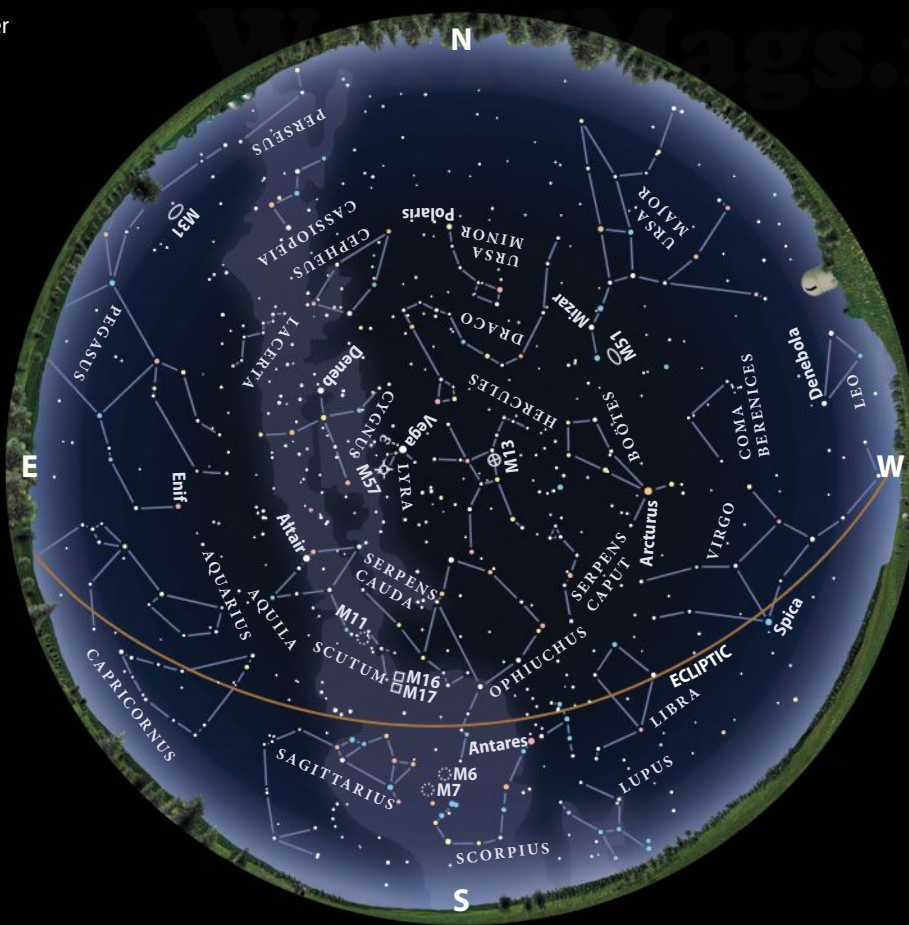
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SUMMER

The sky

High in the sky, the three bright stars known as the Summer Triangle are easy to spot. These luminaries — Vega in Lyra, Deneb in Cygnus, and Altair in Aquila — lie near the starry path of the Milky Way. Following the Milky Way south from Aquila, you'll find the center of our galaxy in the constellation Sagittarius the Archer. Here lie countless star clusters and glowing gas clouds. Just west of Sagittarius lies Scorpius the Scorpion, which contains the red supergiant star Antares as well as M6 and M7, two brilliant clusters that look marvelous at low power.

Deep-sky highlights

The Hercules Cluster (M13) contains nearly a million stars and is the finest globular cluster in the northern sky.

The Ring Nebula (M57) looks like a puff of smoke through a medium-sized telescope.

The Omega Nebula (M17) looks like the Greek letter of its name (Ω) through a telescope at low power. This object also is called the Swan Nebula.

The Wild Duck Cluster (M11) is a glorious open star cluster. On a moonless night, a small scope will show you some 50 stars.

AUTUMN

The sky

The Big Dipper swings low this season, and from parts of the southern United States, it even sets. With the coming of cooler nights, Pegasus the Winged Horse rides high in the sky as the rich summer Milky Way descends in the west. Fomalhaut, a solitary bright star, lies low in the south. The magnificent Andromeda Galaxy reaches its peak nearly overhead on autumn evenings, as does the famous Double Cluster. Both of these objects appear as fuzzy patches to the naked eye under a dark sky.

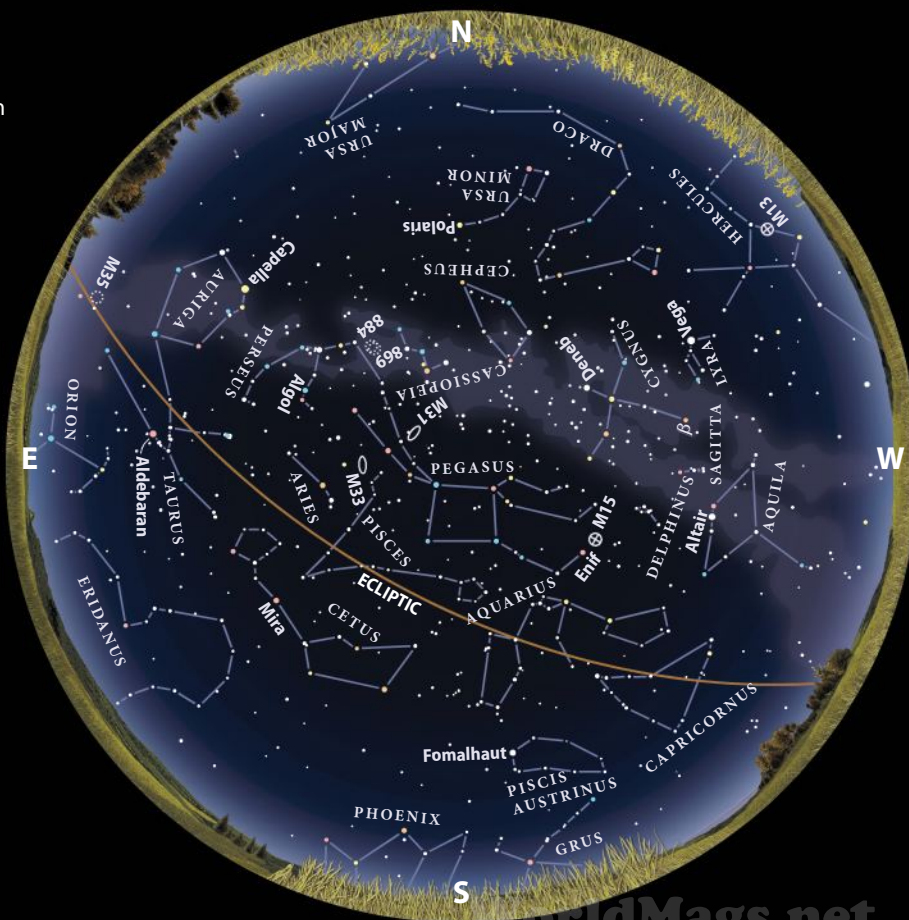
Deep-sky highlights

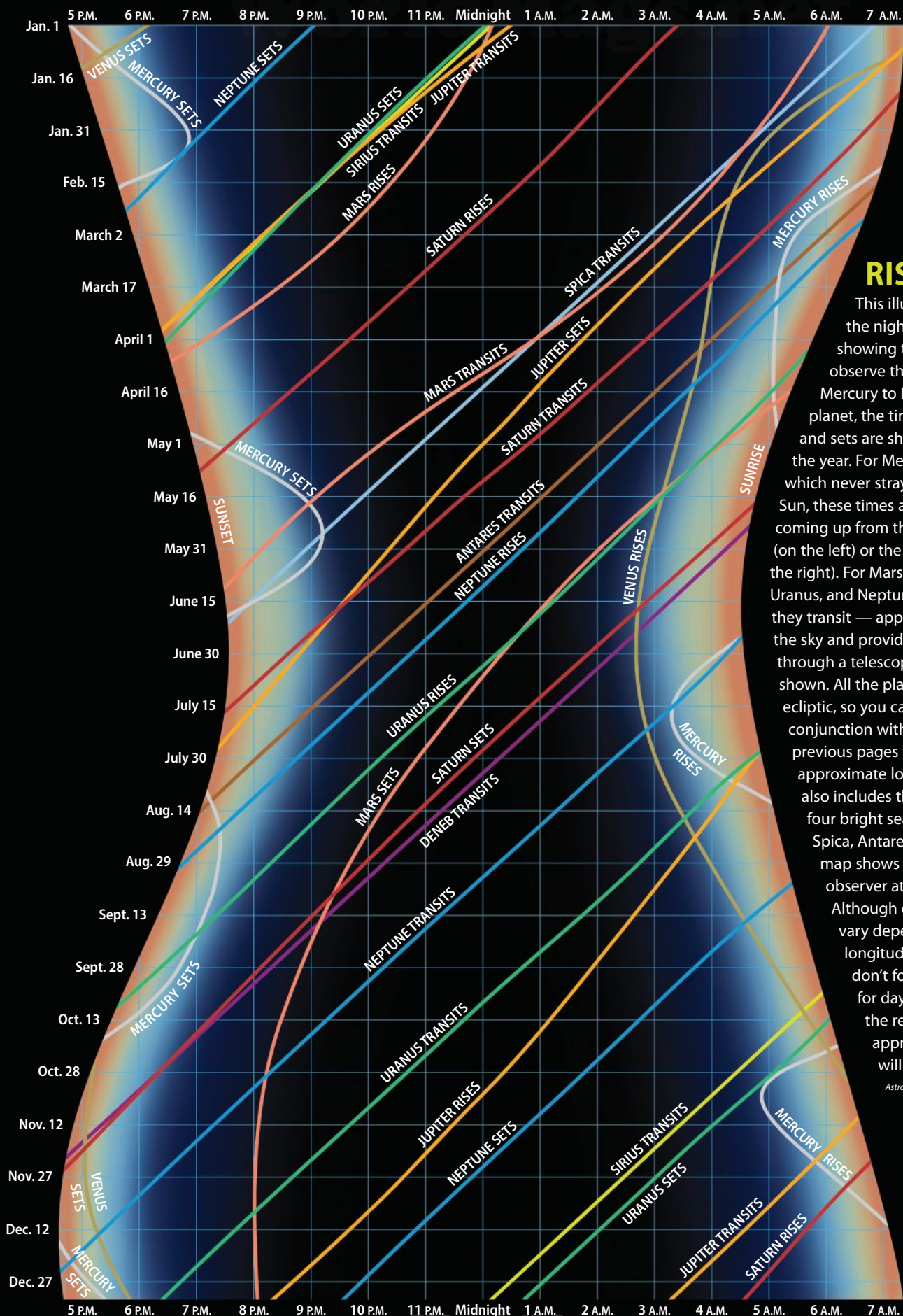
The Andromeda Galaxy (M31) is the brightest naked-eye object outside our galaxy visible in the northern sky.

The Double Cluster (NGC 869 and NGC 884) in Perseus consists of twin open star clusters. It's a great sight through binoculars.

M15 in Pegasus is a globular cluster containing hundreds of thousands of stars, many of which can be glimpsed through a medium-sized telescope.

Albireo (Beta [β] Cygni), the most beautiful double star in the sky, is made up of suns colored sapphire and gold.





RISE & SET

This illustration presents the night sky for 2014, showing the best times to observe the planets from Mercury to Neptune. For each planet, the times when it rises and sets are shown throughout the year. For Mercury and Venus, which never stray too far from the Sun, these times appear as loops coming up from the sunset horizon (on the left) or the sunrise horizon (on the right). For Mars, Jupiter, Saturn, Uranus, and Neptune, the times when they transit — appear highest in the sky and provide the best view through a telescope — also are shown. All the planets lie near the ecliptic, so you can use this chart in conjunction with the maps on the previous pages to find a planet's approximate location. The chart also includes the transit times of four bright seasonal stars: Sirius, Spica, Antares, and Deneb. This map shows local times for an observer at 40° north latitude. Although exact times will vary depending on your longitude and latitude (and don't forget to add an hour for daylight saving time), the relative times and approximate positions will stay the same.

Astronomy: Rick Johnson