How astronomers are searching for comets disguised as asteroids p. 28

APRIL 2017

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## Hunting for Earth's cousins

Exoplanets larger than our world harbor some surprisingly Earth-like traits p. 22

## Percival Lowell's visions of Mars and Pluto p. 44

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AND MORE!

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How weather affects observing p. 52

BONUS ONLINE CONTENT CODE p. 4

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

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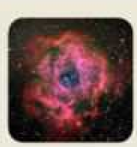
**Picture of the Day**
Gorgeous photos from our readers


**Our brand-new 2017 eclipse page**
All the news you can use!

BY DAVID J. EICHER

# America's observatory

Few stories typify the rise of American astronomy like the tale of Percival Lowell. Born into a wealthy Boston family several years before the Civil War, Lowell was encouraged early on by his parents to study science and mathematics. Armed with an impressive supply of available cash, he became particularly interested in the planet Mars after reading French astronomer Camille Flammarion's book *La planète Mars*, published in 1892.

By the time he turned fully toward science in the 1890s — he had traveled extensively in the Far East and studied culture there the previous decade — he was obsessed with the Red Planet and the burgeoning idea that perhaps life could exist there.

In 1894, Lowell chose a spot to build an observatory dedicated to researching Mars and other celestial wonders. He settled on the frontier town of Flagstaff in Arizona Territory, on a spot that became known as "Mars Hill" in later years, at an elevation of 7,250 feet, providing a platform for telescopes that overlooked the town.

In this issue you can read Lowell Observatory historian Kevin Schindler's fascinating story on the life and times of Percival Lowell. Other historic observatories are scattered across America: Mount Wilson, Palomar Observatory, Lick Observatory, and Yerkes Observatory, to name a few. But none quite has the all-American, go-for-it-all story of Lowell and his obsession with Mars.

Lowell studied Mars furiously with the 24-inch Clark refractor at the observatory for years, famously obsessed with "canals" that he believed could represent irrigation systems of a civilization on the Red Planet.

He also believed that another planet, Planet X, should lie in the outer solar system, and commenced the search that would ultimately employ young astronomer Clyde Tombaugh to discover Pluto. The 13-inch "Pluto camera" still stands on Mars Hill, too.

Other incredible discoveries took place on Mars Hill, as well, not the least of which was Vesto M. Slipher's use of a spectroscope to discover galaxy redshifts — the expanding universe — rotation in what turned out to be spiral galaxies, and the first evidence of the interstellar medium.

Last November, I was privileged to give a public talk at Lowell and stay at the observatory for a few days, in the very apartment where Clyde lived when he discovered Pluto. I strongly encourage you to visit the observatory and to support its important programs of science and education. The staff there — Director Jeff Hall, Deputy Director for Science Michael West, my old friend Brian Skiff, and the whole gang — is absolutely first class, the nicest group of people you could meet.

Lowell Observatory has much to offer. It tells a unique story of astronomy in this country. And it is powering on into a new era with the fantastic 4.3-meter Discovery Channel Telescope located outside the city.

For more, see Lowell.edu. You'll be glad you got to know America's observatory.

Yours truly,

David J. Eicher
Editor

DAVID J. EICHER

David Eicher stands beside the 24-inch Clark refractor used by Percival Lowell for his Mars research at Lowell Observatory in Arizona.

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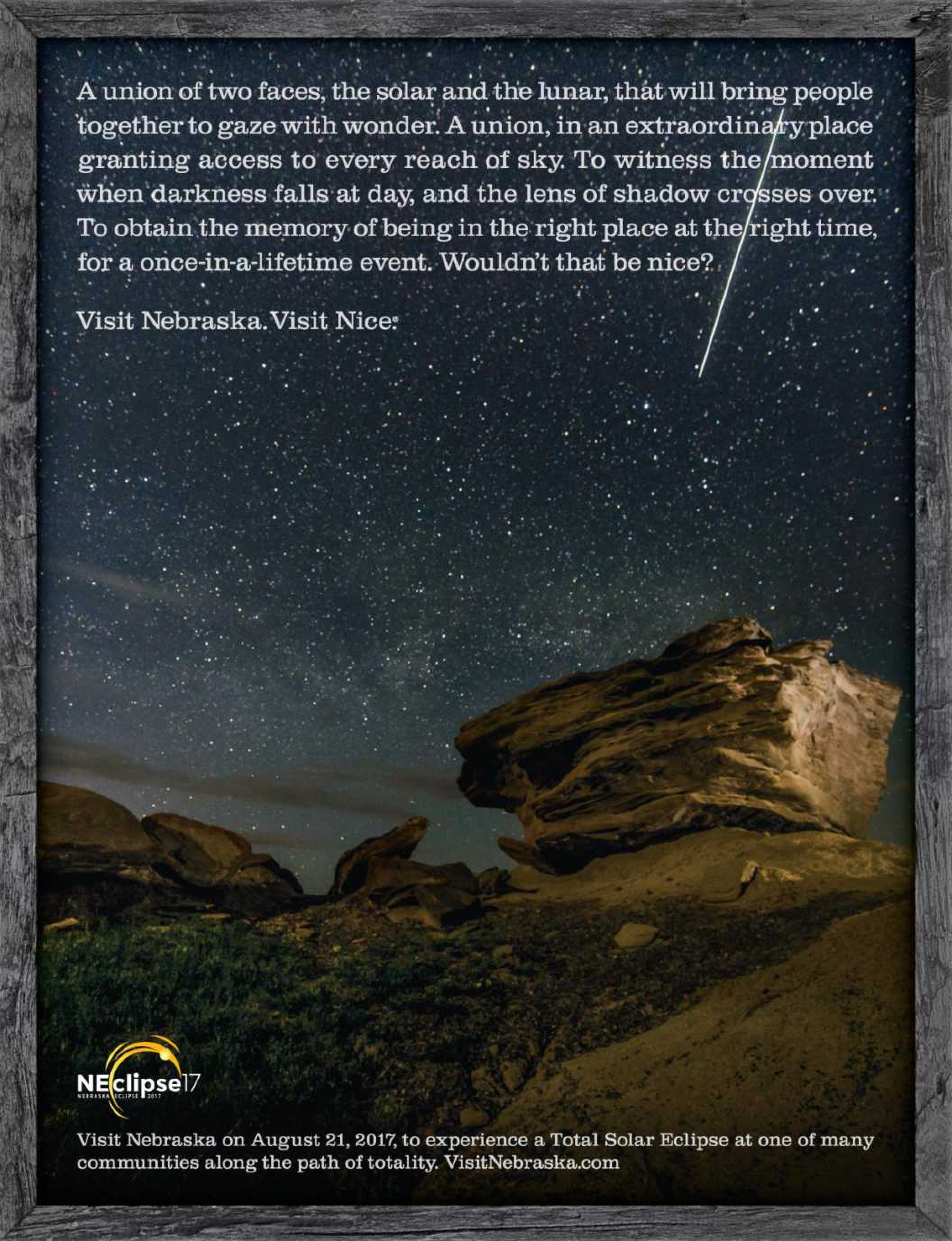
A union of two faces, the solar and the lunar, that will bring people together to gaze with wonder. A union, in an extraordinary place granting access to every reach of sky. To witness the moment when darkness falls at day, and the lens of shadow crosses over. To obtain the memory of being in the right place at the right time, for a once-in-a-lifetime event. Wouldn't that be nice?
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# QG QUANTUM GRAVITY

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

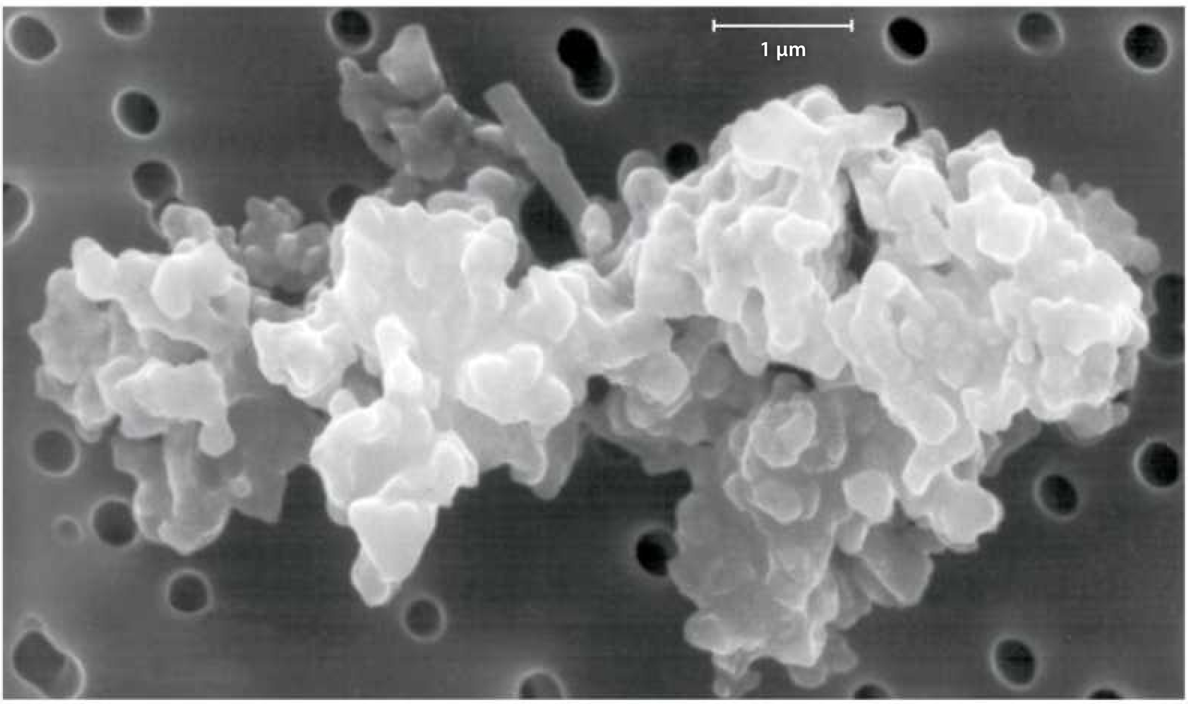
## HOT BYTES>>

**TRENDING TO THE TOP**

**THE BIG HUNT**
A new chip built by Australian National University could make directly imaging exoplanets easier by reducing starlight.

**DOUBLE TROUBLE**
A double pulsar was discovered with Einstein@Home, an analysis tool that relies on using computer processors of amateur participants.

**DUSTY SKIES**
UCLA studies of galaxy II Zw 40 showed heavy elements are often produced in star clusters.




Cosmic dust particles can make their way to Earth's surface — and into your home. This grain, shown through a scanning electron microscope, is about 8 micrometers across — a micrometer is 1/50 the width of a human hair. DONALD E. BROWNLEE, UNIVERSITY OF WASHINGTON, SEATTLE, AND ELMAR JESSBERGER, INSTITUT FÜR PLANETOLOGIE, MÜNSTER, GERMANY/WIKIMEDIA CREATIVE COMMONS
TOP RAIL, L TO R: AUSTRALIAN NATIONAL UNIVERSITY; NASA/FERMI/CRUZ DE WILDE; S. M. CONSIGLIO ET AL., ASTROPHYSICAL JOURNAL LETTERS, 2016

**SNAPSHOT**

## Collecting cosmic dust

Some of the dust in your living room arrived from outer space.

OK, I'm going to tell you something that's pretty gross. The dust in your house — the soot you wipe off in the never-ending quest to keep things clean — consists of pollen, dead skin cells, human and animal hairs, mineral particles from outdoor soil, animal dander, insect waste, and textile and paper fibers. But you probably knew that.

You might not have known that a small percentage of it is extraterrestrial. Some small fraction of 1 percent of the dust consists of interplanetary dust particles, grains of material less than 100 micrometers across that have "floated" down gently through Earth's atmosphere without burning up. (One micrometer, a millionth of a meter, is about the width of an ordinary bacterium, or 1/50 the width of a human hair.)

In 1951, the great astronomer Fred Whipple first proposed this mechanism as a way to deliver cosmic dust to Earth's surface. Planetary scientists have since found abundant examples of this dust, which originates from asteroids and comets — particularly collisions between small bodies in the inner solar system and in the Kuiper Belt — and from grains originating in the interstellar medium.

No one knows exactly how much cosmic matter falls to Earth's surface. Planetary scientists estimate the number lies within the range of dozens of tons per day. The estimate arises from studying the abundances of rare metals believed to be extraterrestrial in origin found in polar ice cores.

So remember the next time you empty that Dyson bin into the trash: You're undoubtedly tossing out a few very tiny particles from far beyond your house. Astronomy really is an interest you can never quite fully escape. **— David J. Eicher**

# ASTRO**LETTERS**

### Creating a non-violent universe

Concerning Michael West's article "When galaxies become cannibals" (p. 20, December issue), am I the only one tired of seeing natural cosmic processes described with the same terms used on the evening news about murder and mayhem?

Large galaxies pulling in smaller ones are not "violent." Violence implies intent, anger, hatred, and racial and ethnic bigotry. What we're talking about is gravity. The individual stars and planets involved go about their business mostly as if nothing happened.

I'm not picking on West individually because this sort of sensationalist vocabulary is present in most popular-level astronomy articles on cosmology. Please, let's stop projecting humankind's greatest shortcoming — violence — onto the universe. It barely knows we're here. "The fault … is not in our stars, but in ourselves." — **Roger Kern**, Richmond, VA

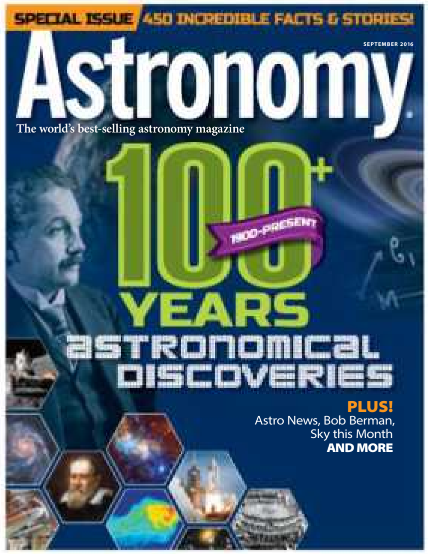
### A sizable correction

I often like to show images of asteroids or comets juxtaposed with objects on Earth when I give public talks about these types of solar system bodies. Thus, it's not surprising that I enjoyed Michael Carroll's article "Sizing up space rocks" (p. 30, November issue). However, there is one item in the article that needs correcting.

It stated that the samples brought back from asteroid Itokawa by the Hayabusa spacecraft "bear similarities to those of common carbonaceous chondrite meteorites." This is not correct. Both the returned samples and infrared spectra taken by the spacecraft demonstrate that the material in this asteroid is most similar to LL ordinary chondrites.

However, the samples expected back from the targets of the Hayabusa2 and OSIRIS-REx mission are expected to be similar to the material in carbonaceous chondrites. — **Scott Sandford**, NASA-Ames Research Center, Moffett Field, CA

*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.*




### An extra discovery

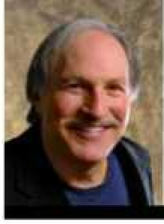
I'm a bit late in this response, but your September "100+ years of astronomical discoveries" issue needs one more item. August 1966 marks the first high-resolution photos of the Moon ever taken returned by the Boeing Lunar Orbiter. All five LO missions were successful and returned detailed mapping information and better gravity maps to assist the Apollo program in selecting landing sites. LO 1 also took a fantastic photo of Earth with the Moon in the foreground.
— **Dennis Wood**, Sunriver, OR

### Reclassifying Phobos

Joel Davis' article "How Moon dust will put a ring around Mars" (p. 46, December issue) says, "Because Phobos has an orbital period faster than the martian day …" referencing the anomalously rapid prograde orbit.

Since the discovery of Phobos, retrograde moons have been discovered around Jupiter, Saturn, and Neptune, but no more anomalously rapid prograde moons. Therefore, it makes sense simply to reclassify Phobos as a retrograde-orbiting moon, all else being equal. Then, with two theories in contention, Karl Popper's falsifiability method, which defines the testability of scientific hypotheses, will detect the correct model. — **John Roach**, Yellville, AR

*Correction: The Astrobabble column in the January 2017 issue calls Mercury a gas giant when the column was supposed to say Uranus.*



# STRANGE**UNIVERSE**

**BY BOB BERMAN**

# Lessons of Mir

The Russian space station was a legend …
and a bit of a death trap.

We picture astronauts performing routine orbital experiments. We are also aware of tragedies like *Challenger* and *Columbia*. But life beyond Earth is often much stranger than those extremes of normalcy versus terror.

Let's focus on the Russian space station Mir, since this is the 20th anniversary of when U.S. astronauts inhabited it as a prelude to the ISS.

Astronauts are more than smart and physically buff; they're incredibly brave. Their courage goes far beyond dealing with scary mishaps. They sometimes suffer prolonged situations that would make normal people panic. Even in the days of Mercury, how many of us could be OK in a capsule the size of a phone booth?

U.S. astronauts each spent four to six months on Mir. Some, like Shannon Lucid, had no problems. Others, like John Blaha, endured hard times. In his case, it was a tense relationship with the Mir commander, Valeri Korzun, with Blaha accusing Korzun of micromanaging him. Often, the Russian cosmonauts themselves had very strained relationships with their own mission controllers, with complaints about genuine problems easily getting black evaluation marks from their ground commanders, with significant pay cuts following — contributing to Korzun's demanding leadership style.

U.S. astronaut and medical doctor Jerry Linenger spent the first five months of 1997 on Mir. He arrived to a cramped and cluttered station filled with equipment and cables spilling out from every available space. Corroded pipes leaked in the cooling system, spreading drops of antifreeze and other debris in the air. Sleeping was usually difficult because when the air had too much junk — including leaking propylene glycol aerosoling into living quarters — everyone had to wear breathing masks.

The oxygen system was taxed to its limits so that the astronauts were often not permitted to exercise, lest they breathe too deeply. The climate control routinely was messed up for weeks at a time, putting the temperature around 90° F with no relief, day or night. The humidity was excessive, too, which promoted the growth of mold and bacteria all over the station. By the end of the station's lifetime, 140 species of microorganisms were found to be "passengers" on board.

**AFTER ONE AND A HALF MINUTES, THE FIRE BURNED ITSELF OUT, LEAVING TOXIC, SMOKY AIR.**

Microbes weren't the only hazards they faced. On February 23, 1997, an oxygen-generating canister accidentally ignited, blasting out a 3-foot geyser of flame. The crew frantically tried to put out the fire, using three out of 10 fire extinguishers on the station. They busted out respirators in case they became necessary, with Linenger examining his fellow space farers afterward.

The intense flame blocked access to a Soyuz escape craft. Even if they had reached it, they wouldn't have been able to flee because the instructions for reentry first needed to be printed from the station's computer.

After one and a half minutes, the fire burned itself out, leaving toxic, smoky air. Of course, cosmonaut Korzun downplayed the incident to his mission control. But a worse event soon unfolded.

Russian controllers ordered the crew to dock with an uncrewed Progress 234 cargo ship on June 25, 1997. They weren't allowed to use their radar because its signals interfered with other electronics. Russian Mir commander Vasily Tsibliyev tried to bring in the Progress module remotely, using nothing more than a blurry TV screen. With no radar, he had to judge its distance and speed solely from Mir's changing angular size and position on the monitor.

It became apparent that the cargo ship was approaching too fast. When it was a minute away, he frantically applied continuous braking, trying to avoid a collision. It didn't work.

With a loud crunch, the cargo ship plowed into the station's solar arrays at a speed of 10 feet per second, tearing a gash in the hull of the science section. The air pressure rapidly dropped. Occupants heard air hissing into the vacuum of space as alarms clanged.

The crew tried to seal off the science module, but hoses and cables snaked through the doorways. Russian flight engineer Aleksandr Lazutkin grabbed a knife and started severing the live wires, producing fireworks of electrical sparks. The pressure dropped so low that they were close to abandoning the station. Time was running out. Finally freed of the cables, they still couldn't get the connecting hatch closed because of the pressure difference as it was hinged in the wrong direction. The collision had also sent the entire station tumbling. Its solar panels no longer pointed toward the Sun. Electrical power was waning.

Ultimately, they heroically saved everything, although all the previous problems remained.

That was exactly 20 years ago. Mir was eventually deorbited in 2001 shortly after the International Space Station came into full-time service, but Mir's tale is one of extended courage that deserves to be told.

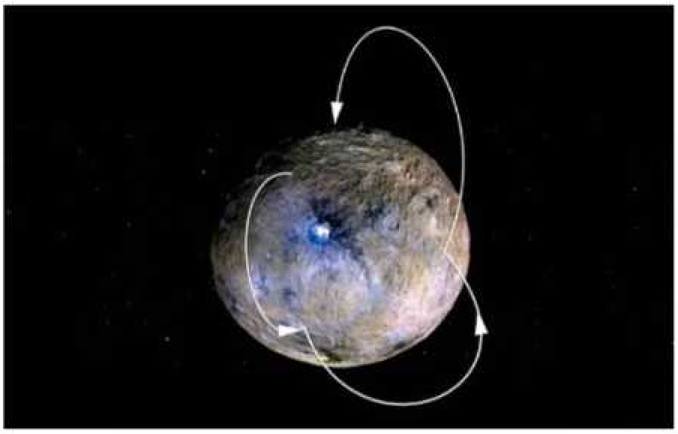
*Contact me about my strange universe by visiting* **http://skymanbob.com.**

Mir was the first long-duration space station, paving the way for the International Space Station. The first module launched in 1986, with subsequent modules following up until 1996. By the end of its mission in 1999, Mir had its share of problems. It was deorbited in 2001 once the ISS was ready for human habitation. NASA/STS-91 CREW

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

**ASTRONEWS**

**GALAXY DISRUPTION.** Astronomers have shown that too many supernovae can cause the matter in a galaxy to move outward, creating galaxies as faint as a dwarf galaxy but as large as the Milky Way.



**VAPING IN SPACE.** Water "flows" on Ceres, at least when water vapor sweeps across the dwarf planet and into cold traps that convert it to ice. The cold spots can hold that ice for over a billion years in relative darkness, thanks to being in shadow much of the time. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

# CERES HAS AN ABUNDANCE OF ICE

Of all the water worlds in the solar system, perhaps the most surprising is Ceres. For years the tiny dwarf planet, located in the asteroid belt, was thought of as a rocky body akin to other asteroids. But NASA's Dawn orbiter confirmed evidence first suggested by Hubble observations: Ceres is abundant in water. We just weren't sure in what form.

Underneath a dusty coating, Ceres seems to be more like some of Saturn's small, icy moons. In fact, it's just a hair smaller than Saturn's moon Tethys, another small, icy body. Ceres' ice thus far seems to be inert, though Dawn scientists are now researching whether it might have had liquid water in the past — or even, bizarrely, life.

"By finding bodies that were water-rich in the distant past, we can discover clues as to where life may have existed in the early solar system," Dawn scientist Carol Raymond said in a news release.

Evidence suggests that the ice works its way between a loose assemblage of rocks on Ceres' surface. So far, there's no evidence for long-term bodies of liquid water. Bright spots on Ceres, first detected by Dawn, may indicate that collisions in the past heated up parts of the ice at crater basins. From there, the liquid water could have turned into a gas, leaving behind briny spires.

There still may be intermittent activity, with ice subliming and falling back to the surface in so-called "cold traps," areas away from the Sun's light that trap water in its solid state. Unlike other areas of the world, ice is unlikely to leave the cold traps on Ceres.

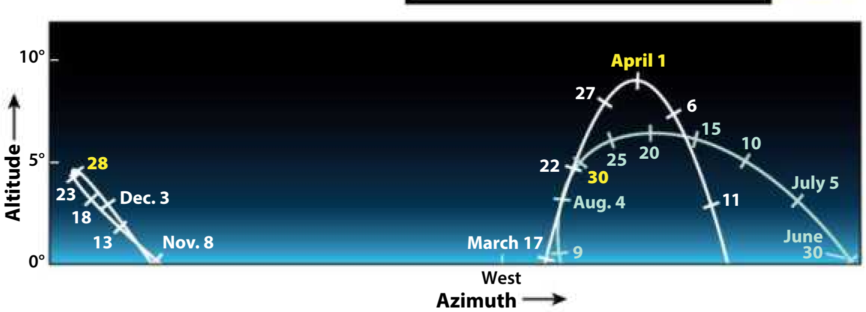
Cold traps like this exist in the polar regions of other worlds, including Mercury and the Moon, where deposits of ice can live undisturbed for millions of years.

**— John Wenz**

# MERCURY AT DUSK

**Mercury's best evening appearance of 2017 comes in early April; it reaches a peak altitude of 9.0° on the 1st.**

**FAST FACT**




ASTRONOMY: ROEN KELLY

**ELUSIVE WORLD.** Mercury has a reputation for being hard to see because it hugs the horizon during twilight either after sunset or before sunrise. This chart plots the innermost planet's positions 45 minutes after sunset for observers at 35° north latitude for the planet's three evening elongations during 2017. Notice that Mercury's peak altitude often doesn't necessarily coincide with its greatest solar elongation (dates highlighted in yellow). **— Richard Talcott**

## BRIEFCASE

### GEMSTONE CLOUDS

It's pouring on HAT-P-7b, but don't expect to go singin' in the rain. Researchers at the University of Warwick detected weather patterns on the planet, which features clouds made of corundum. Normally in a solid state when found on Earth, corundum is in a vapor state on HAT-P-7b, thanks to the planet's scorching temperatures. The mineral condenses and falls back to the surface on HAT-P-7b's night side. Corundum forms sapphires and rubies on Earth, meaning it's raining similar materials on that weird, weird planet.

•

### SIGNAL BOOST

In planetary science, finding an exoplanet can sometimes be difficult because of noise affecting the strength of the signal. Yale University has a possible workaround. In research published December 20, 2017, in *The Astronomical Journal*, lead author John Wettlaufer and his colleagues laid out the possibility of using fractal patterns to determine what the noise appears as in the data. By looking for data bunching associated with other detections, the team can find planets in otherwise noisy data.

•

### SMOOTH OPERATOR

While researchers have looked for chunks of dark matter in galaxies, they may be looking for it in all the wrong places. A study of 15 million galaxies published in *Monthly Notices of the Royal Astronomical Society* suggests that dark matter is so smooth that it remains in a cold state. This may make the elusive dark matter — the "missing mass" necessary for the universe to function as expected — even harder to find. The data contrasts with other data from missions, like the European Space Agency's Planck spacecraft, that suggested the clumpier structure. **— J. W.**

# Will Earth exist in 5 billion years?

An international team of astronomers used the ALMA radio telescope to study L2 Puppis, a star about 208 light-years away from Earth, to see what kind of future we have in store. The research was reported December 8, 2016, in *Astronomy and Astrophysics*.

L2 Puppis is about 10 billion years old and has a lot in common with our Sun, according to Ward Homan of the KU Leuven Institute of Astronomy. "Five billion years ago, the star was an almost perfect twin of our Sun as it is today, with the same mass," he says.

In a few billion years, the Sun will become a red giant star, according to Leen Decin, a professor also at the KU Leuven Institute. It will grow to be 100 times bigger than it is right now, lose a large amount of mass through a strong stellar wind, and, 7 billion years from now, end up as a tiny white dwarf star.

Not only will this change impact Earth, but it will also affect the rest of the solar system. Although Mercury and Venus will be engulfed and destroyed, Earth's fate remains up in the air.

No one is sure yet if Earth will survive the Sun or lose the battle, but studying L2 Puppis may show us Earth's fate. **— Nicole Kiefert**

# ASTRONEWS

**UNIVERSAL MAP.** The Pan-STARRS project has publicly released the largest digital sky survey to date. Pan-STARRS' catalog contains 3 billion separate sources, including stars and galaxies.

## Could life lurk within Pluto's ocean?

One of Pluto's most remarkable features is its "heart." Sputnik Planitia (originally called Sputnik Planum) comprises the western half of this feature, a likely impact basin measuring roughly 800 by 560 miles (1,300 by 900 kilometers). The region is filled with nitrogen ice estimated to range from 1.8 to 6 miles (3 to 10km) thick. Recent computer models have determined that, beneath that ice, Pluto could maintain a liquid ocean.

On Earth, where there's water, there's life. So the presence of an ocean on Pluto raises an important question: Could there be life on Pluto as well?

William McKinnon, a professor of Earth and planetary sciences at Washington University and co-author of several recent Pluto studies published in *Nature*, argues that Pluto's ocean could not support life-forms such as sea creatures found on Earth. "But," he points out, "who knows what tricks nature has up her sleeve?"

What makes Pluto's ocean different, and why is it so unlikely to harbor life? Using New Horizons data, McKinnon's team has studied both the nitrogen ice and the ocean believed to lie beneath it. Detections of ammonia on two of Pluto's moons lead McKinnon to believe ammonia is likely inside Pluto, too. If it's there, the compound would act as antifreeze, keeping the subsurface ocean liquid, even at temperatures well below the freezing point of pure water.

This ocean would likely be cold, salty, and viscous, not to mention more rich in ammonia than any life-form on Earth could tolerate. But in this "syrupy" ocean, as McKinnon describes it, pre-cellular life tolerant of these conditions could exist.

Pluto's potential ocean has been the subject of several additional *Nature* papers in recent months. James Keane of the Lunar and Planetary Laboratory at the University of Arizona found that surface fissures support the existence of a subsurface ocean, though it could be frozen solid. Other studies, such as one published by Douglas Hamilton of the University of Maryland, have questioned the ocean's existence, stating results from computer models that don't require an ocean to re-create Pluto's current orientation and behavior.

Regardless of their findings, scientists such as McKinnon, Keane, and Hamilton all appear to agree on one point: If Pluto does have an ocean, the processes that allowed it to form could be at play throughout the outer solar system, challenging our current ideas about the existence of water and even life at such great distances from the Sun. — **Alison Klesman**

**PLUTO'S FROZEN HEART.** Sputnik Planitia makes up the left side of the heart-shaped Tombaugh Regio. Some computer models indicate that the smooth, icy surface of the ancient impact basin may hide a subsurface ocean. NASA/JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY/SOUTHWEST RESEARCH INSTITUTE

## The Small Magellanic Cloud is positively glowing

NASA, ESA, STScI, K. SANDSTROM (UNIVERSITY OF CALIFORNIA, SAN DIEGO), AND THE SMIDGE TEAM

**PARTY ON.** The Hubble Space Telescope captured photos of two emission nebulae in the Small Magellanic Cloud in September 2015. The nebulae, which joined together and now look like one, emit a pinkish glow due to radiation from the central stars ionizing the hydrogen atoms in the nebula. NGC 248, about 60 light-years long and 20 light-years wide, is one of several emission nebulae in the Small Magellanic Cloud. — **N. K.**

## QUICK TAKES

### SPINNING STAR
Orion's famous red supergiant Betelgeuse is spinning 150 times faster than expected. Researchers speculate Betelgeuse may have "spun up" by swallowing a nearby companion star.

### GRAVITATIONAL RADIATION
Researchers say that slower-than-expected observed spin rates of neutron stars are explained if the stars lose energy by continuously emitting gravitational waves.

### OUTLIERS EXPLAINED
A new theory explains "outlier" observations of low-mass galaxies undergoing intensive star formation as galaxies in the earliest stages of growth.

### EARTH'S TROJANS
OSIRIS-REx has been given a secondary mission on its way to the asteroid Bennu. It will search for Earth's Trojan asteroids, which share our planet's orbit around the Sun.

### SOLAR BRAKING
The outermost 5 percent of the Sun spins more slowly than its interior. Researchers have recently determined that this is due to the radiation of energy and angular momentum as it rotates.

### SUBZERO SCIENCE
The remote Dome A, Antarctica's highest point, is under consideration as the site of a new observatory. Dome A's elevation and weather could make it an ideal home for telescopes.

### PLANETARY SIGNATURES
Observations with ALMA have revealed a pair of Saturn-sized planets around HD 163296. Each planet has carved out a gap in the disk of dust and gas around the young star.

### GAMMA-RAY SOURCES
Two different source classes have been identified as contributors to the gamma-ray background in the most precise analysis to date — but no signal from dark matter has been found.

### LIGO BACK ONLINE
Following recent upgrades, LIGO is back online and searching for gravitational waves. The upgrades improved the sensitivity and stability of the detectors. — **A. K.**

 **ADOLESCENT GALAXIES.** A team led by Texas A&M astronomers has found evidence that disk-like galaxies, such as the Milky Way, were once disorganized, gas-rich beds of rapid star formation.

# The biggest spiderweb in the universe

**COLD COMFORT.** While this may look like one big galaxy about to swallow dozens of smaller galaxies, the Spiderweb Galaxy is actually a protogalaxy about to spring to life. Like stars or planets, galaxies gain mass over time in order to merge into their more familiar state. M. KORNMESSER/ESO

A galaxy called the "Spiderweb Galaxy" seems to be weaving itself beyond the embryonic states into a full-bore galaxy. As seen in the artist's depiction above, cold gas permeates the area around the galaxy, and a supermassive black hole is drawing it slowly in.

The Spiderweb Galaxy is actually a protogalaxy, a stage of galactic formation during which other protogalaxies (of smaller types than the Spiderweb) have begun to accrete and orbit around a supermassive black hole. Eventually the structure will become more uniform, much like other galaxies in the universe.

The galaxy itself is coming together by feeding on cold gas around it, causing it to gain more mass. This makes for a slower accretion of matter than when galaxies merge by colliding and combining gas. It may also lead to the Spiderweb Galaxy becoming a massive, massive galaxy.

The galaxy earned its name because of the way it slowly entraps other galaxies before feasting on them, much like our eight-legged friends on Earth.

The Spiderweb Galaxy is about 10 billion light-years away. This, of course, means these events are taking place long ago, and we don't know actually what the Spiderweb looks like today, or when it will emerge fully formed as a supermassive galaxy. But by monitoring it, we may find clues to the puzzle. — **J. W.**

NASA/JPL-CALTECH

**COLONIZING MARS.** These silica structures on Mars resemble bacterial colonies on Earth, and they could be an indication of past life in martian seas.

## Mars cauliflower

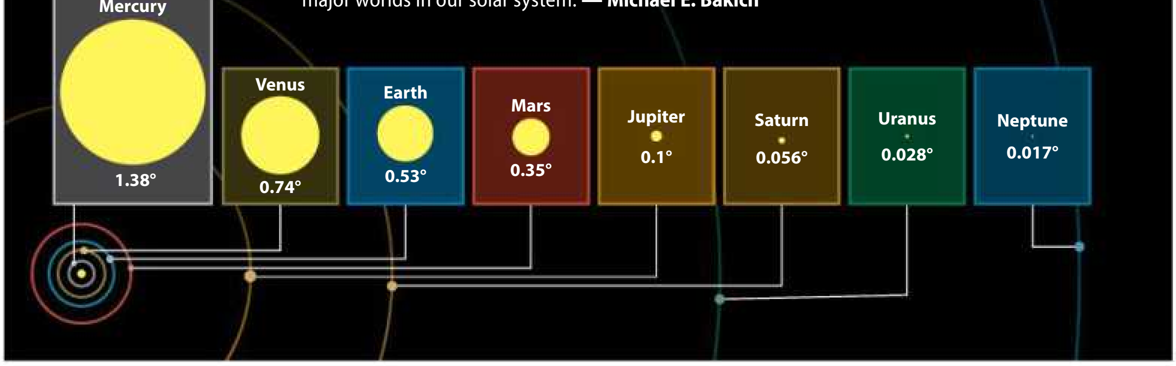
A cauliflower-shaped structure on Mars has some researchers scratching their heads — and others wondering if it could have been created by martian microbes. In 2007, the Spirit rover discovered pieces of a mineral called opaline silica in the Gusev Crater. The silica is commonly found in cauliflower-shaped nodules sprouting on Mars' surface. A recent study in the Atacama Desert in Chile suggests that the silica might have come from microbes depositing the mineral over time as their colonies grew. Because microbes created similar silica deposits in other areas, there's a chance that they also formed the ones in Chile, and possibly on Mars as well, making them a helpful tool in finding evidence for previous life on the Red Planet. — **N. K.**

## 2,903 cubic miles

**The Mars Reconnaissance Orbiter found ice on Utopia Planitia equivalent to the 2,903 cubic miles of water in Lake Superior.**

## How big does the Sun look from each planet?

**SUNSPOTTING.** Here's a guide scaled to our star's apparent size from each of the major worlds in our solar system. — **Michael E. Bakich**




ASTRONOMY: ROEN KELLY

**FAST FACT**

**Even at Neptune, the Sun provides 1,000 times as much light as the Full Moon gives to Earth.**

**PLANET SEEDS.** Researchers have used ALMA's sensitivity for detecting polarized radio emission to precisely measure dust particles around a young star. This dust is the precursor to asteroids, comets, and planets.

# Superluminous event caused by spinning black hole swallowing star

**WAY DOWN IN A HOLE.** What was thought by astronomers to be a supernova may have instead been a star getting violently ripped apart by a black hole. The star's destruction created the brightest flash of light ever seen. This led researchers to believe that it was a superluminous supernova — a massive star undergoing core collapse and blasting its outer layers into space. ESO, ESA/HUBBLE, M. KORNMESSER

New observations from several observatories show that what was thought to be the brightest supernova ever might have been an optical illusion of sorts.

ASASSN-15lh was first detected by the All Sky Automated Survey for Supernova (ASASSN) and was declared a superluminous supernova. It was 20 times brighter than the total light output of the entire Milky Way, giving it the title of brightest supernova.

However, a team of scientists led by Giorgos Leloudas from the Weizmann Institute of Science and the Dark Cosmology Centre has proposed an alternative explanation for the brightness.

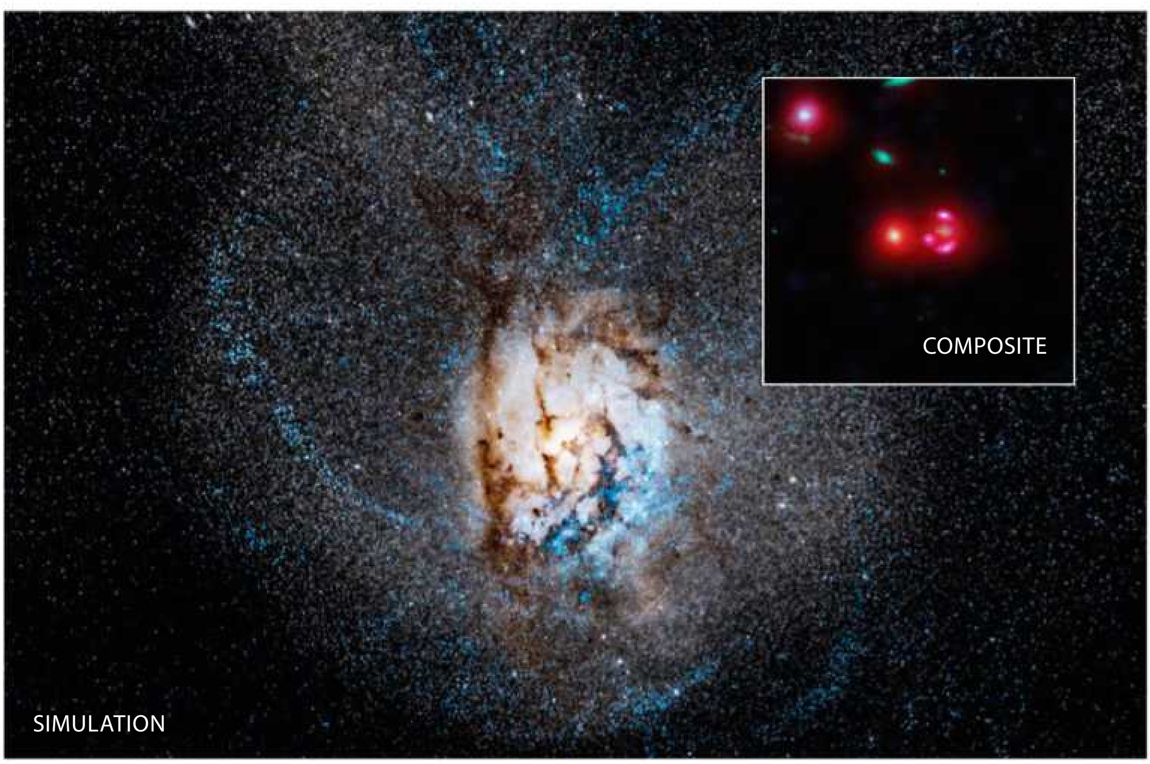
Research from observatories including ESO's Paranal Observatory, the New Technology Telescope at ESO's La Silla Observatory, and the NASA/ESA Hubble Space Telescope has led the team of astronomers to believe that the bright light didn't come from ASASSN-15lh, but from a rapidly spinning black hole that was destroying a nearby star.

"We observed the source for 10 months following the event and have concluded that the explanation is unlikely to lie with an extraordinary bright supernova," Leloudas said in a news release. "Our results indicate that the event was probably caused by a rapidly spinning supermassive black hole as it destroyed a low-mass star."

The researchers believe the Sun-like star got too close to a supermassive black hole, and the gravitational forces stretched the star vertically and compressed it horizontally until it was destroyed. Then the colliding debris and the heat generated from the destruction caused the bright burst of light.

The team says this is a rare event and can occur only with a very specific type of black hole. — **N. K.**

# Distant galaxy setting star-formation record



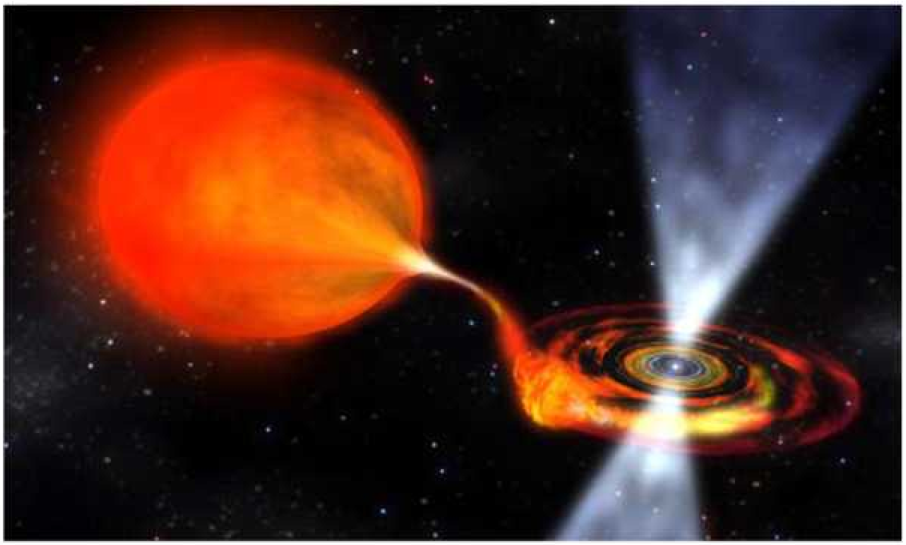

NASA/JPL-CALTECH/CXC/STSCI/ESO/NAOJ/NRAO/ALMA/UNIVERSITY OF FLORIDA

**BABY BOOM.** SPT0346-52 is so distant that it had to be spotted through gravitational microlensing. Studies in X-ray showed no black hole activity despite the bright flashes of light, and similar radio wave searches yielded no results either. This lead astronomers to believe that the brightness is likely caused by stellar formation at a rapid rate. — **A. K.**

**FAST FACT**

**The microlensing event that led to the discovery of SPT0346-52 caused it to look like it was in three different places in the sky.**

 **TRACING TODAY'S STARS.** Astronomers combined VLA and ALMA radio data to study star formation in galaxies 10 billion years ago. Star formation during this epoch produced most of the stars we see today.



**UNHEALTHY RELATIONSHIP.** This artist's impression shows a black widow pulsar feeding on its binary companion. Over time, the pulsar alternates between siphoning and blasting material away from its companion, eventually destroying the star. NASA/DANA BERRY

# Amateur astronomer sheds light on pulsar companion's odd behavior

Pulsars are a class of neutron star identifiable by the radio signals they beam into space as they revolve. Even as these exotic objects continue to intrigue professional astronomers, amateur astronomer André van Staden proved that you don't need a Ph.D. to make unprecedented discoveries.

Millisecond pulsars, or MSPs, have a period between 1 and 10 milliseconds. Many MSPs are found in binary systems; one such MSP is J1723-2837, perfectly visible from van Staden's backyard in Western Cape, South Africa.

In 2014, van Staden turned his backyard 30cm reflector on the source, eventually compiling a 15-month light curve for the pulsar's visible companion star. Unlike the expected light curve for such a companion, J1723-2837's partner exhibited brightness changes that lagged behind the system's 15-hour orbital period. Perplexed, van Staden forwarded his data to University of Toronto astronomer John Antoniadis, but expected his query to go unanswered.

Instead, Antoniadis replied, and the two collaborated to solve the mystery of van Staden's light curve. Their findings, published in *The Astrophysical Journal* in December, revealed a companion star that contains massive starspots (like sunspots on our Sun). Such starspots are indicative of a strong stellar magnetic field, which may be responsible for much of the strange behavior observed in this system, and possibly others like it.

This work sets the stage for future studies of how magnetic fields affect such binary systems, and also highlights the immense value of the contributions that amateur astronomers can make to even the most cutting-edge science. **— A. K.**

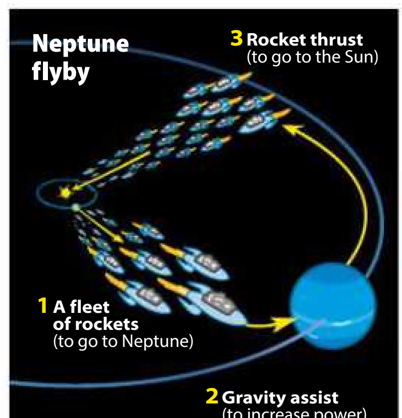
JPL-CALTECH/MSSS/LANL/CNES-IRAP/WILLIAM RAPIN

# First detection of boron on Mars' surface

**BORON FIESTA.** The chemical camera aboard NASA's Curiosity Rover has discovered boron on the surface of Mars. Boron is typically found in areas where water has evaporated. The temperature, pH, and mineral content means the body of water it arose from was once potentially habitable. The boron has two potential sources. It could have been a result of part of Gale Crater Lake drying out, leaving behind a boron deposit. The other scenario is that a chemical change in clay-bearing deposits affected how boron was created. **— N. K.**

## UTTER GARBAGE


Want to send all of Earth's garbage into the Sun? You may have a few problems — and not just because you'd need 168,000,000 Ariane V rockets to do it. Earth is heavily affected by our star's gravity, moving around the Sun at 18.6 miles (30 kilometers) per second. To get close to the Sun, we'd have to go that fast in the opposite direction. Unfortunately, the fastest rocket launch to date only went 10 miles (16km) per second.




In the outer solar system, the effect of the Sun's gravity is less — that's why NASA's Ulysses probe swung by Jupiter to get near the Sun. Distant Neptune moves at 4.2 miles (6.8km) per second. It would be easier to use Neptune as a way to get to the Sun: First, swing around the planet, and then shoot back into our star. But the trip would take 12 years just to get to Neptune — by which point we'd have created even more garbage. **— J. W.**

*ASTRONOMY:* ROEN KELLY

**FAST FACT**

**The Saturn V, the largest rocket ever built, had a maximum payload of 310,000 pounds (140,000 kilograms).**

# ASTRO**NEWS**

**POPULAR NEPTUNE.** A new study suggests that Neptune-sized planets are the most common occupants of stars' outer solar systems.

**IN MEMORIAM.** Vera Rubin, a physicist who confirmed the existence of dark matter, passed away in December. Rubin was the subject of a June 2016 *Astronomy* feature regarding her work. ARCHIVES & SPECIAL COLLECTIONS, VASSAR COLLEGE LIBRARY

## Vera Rubin was a pioneer in dark matter research

Vera Rubin, a physicist who confirmed the existence of dark matter, died December 25, 2016. She was 88.

After receiving her bachelor's degree from Vassar College in 1954, Rubin attempted to enroll in Princeton University despite bans on female Ph.D. candidates in astronomy. Eventually she attended Cornell University, where she earned a master's degree before completing her studies at Georgetown University.

After joining the staff of the Carnegie Institution, Rubin and colleague Kent Ford watched the rotation of nearby galaxies, studying the curves as they moved. Eventually, discrepancies between predictions of angular momentum and the actual angular momentum seemed to confirm dark matter.

Dark matter was the "missing mass" of the universe necessary to explain how the universe expanded, so called because it wasn't accounted for by known stars, galaxies, and other objects.

While it had been discussed decades earlier (Jacobus Kapteyn first suggested it in the 1920s, and Fritz Zwicky coined the term *dark matter* while studying galactic motion in galaxy clusters in the 1930s), Rubin's work helped solidify the emerging field of dark matter research in the present day. Rubin confirmed the work of Zwicky, Kapteyn, and others by nailing down precise measurements of dark matter to support galactic-scale observations. In essence, galaxies were moving faster than they should have been based on the estimated number of stars and other material in spiral galaxies, something that had to be accounted for by unseen forces.

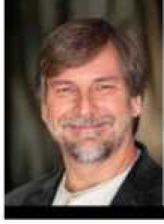
Rubin's work ushered in the modern age of dark matter research. While she won numerous awards for her work, calls for Rubin to win a Nobel Prize in Physics went unheeded.

Still, she helped carve a path for other women in astronomy and other science disciplines. She was a tireless advocate for women in STEM fields, saying, "We all need permission to do science, but, for reasons that are deeply ingrained in history, this permission is more often given to men than to women." **— J. W.**

ESA/HUBBLE, A. FABIAN

## Disorderly

**WEIRD GALAXY.** Most galaxies are bound in fairly orderly groupings, but NGC 4696 is not like most galaxies. It's a member of the Centaurus galaxy group, about 150 million light-years from Earth. Dark "tendril" structures worm their way through brighter dust. These tendrils are 200 light-years across and far more dense than the surrounding gas. Few new stars form in the galaxy. Instead, the supermassive black hole at the center pushes gas into the filaments, leaving few stars to bound the structure. **— J. W.**



FOR**YOUR**CONSIDERATION

BY JEFF HESTER

# A Saguaro's universe

Building a cactus starts with the Big Bang.

I live in the desert near the Superstition Mountains, east of Phoenix, Arizona. Not far from my house is a gorgeous Saguaro cactus that I drive by daily. I'll be honest: I had no clue how big those things were until I stood beside one and looked up! This particular monster has eight arms growing from its 60-foot-tall body.

A Saguaro doesn't even get its first arm until it's at least 75 years old, and it can live for 200 years or longer. Judging by its splendor, this guy has been around long enough to see European settlement in the Valley of the Sun grow from a few buildings along the Salt River into a sprawling metropolis of 4.6 million people spanning 9,000 square miles.

The Sonoran Desert is the only place on Earth where Saguaros grow. That's because the cactus and the desert grew up together. As the climate around here became what it is today, plants that fared better survived, reproduced, and passed along their genes. Less successful plants didn't. Generation after generation, as the climate changed, the Saguaro evolved to keep up.

But wait a minute! Why is this a desert at all? That has a lot to do with the physics of water and convection. Sunlight heats the tropics, driving planetwide convection that carries much of that thermal energy toward the poles. As warm, moist tropical air rises, it also cools, dumping much of its moisture as rain. As water vapor condenses, it releases heat. By the time that once-moist tropical air completes its upward path, it is both dry and a lot warmer than it might have been.

What goes up must come down. As convection carries that air back to lower altitudes, it compresses, turning already relatively warm, dry air into a veritable blast furnace. Welcome to the horse latitudes, latitudes around 30° along which many of the planet's deserts are located.

Now we have to worry about Earth's rotation. As convection carries air north and south, the Coriolis effect diverts that air into strong bands of easterly and westerly winds and the powerful jet streams that carry weather systems west to east around the planet.

Earth's rotation is ultimately a consequence of the rotation of the interstellar cloud from which the Sun and solar system formed. We might not think about it very often, but weather patterns on Earth bear the fingerprints of how gas swirled about in interstellar space 4.5 billion years ago.

And then there's the star that formed at the center of that rotating, collapsing interstellar cloud. Nuclear reactions in the Sun's core power the whole show of climate and life.

Anyway, there is a nice jet stream drawing moist air from the Pacific eastward toward the Sonoran Desert. So why is it still dry? The culprits this time are the mountains that surround it. When moist air flows into the side of a mountain, it moves upward. And just like what happens in the tropics, rising air loses its moisture as precipitation and is heated by condensation. When that now dry and relatively warm air comes flowing down the backside of the mountain, well, there's that blast furnace again!

A towering Saguaro cactus stands tall during sunset near Tucson, Arizona. SAGUARO PICTURES/WIKIMEDIA CREATIVE COMMONS

If you want to know about that cactus I smile at when I drive by, you have to know about mountains. That gets us into the forces that shape Earth's surface. Convection of hot, viscous rock in our planet's interior carries heat outward from the center toward the surface. The scum floating on top, otherwise known as the crust, gets shoved around by those convection currents. Tectonic plates crash together, forcing mountains skyward. Friction near plate boundaries heats rock that ultimately reaches the surface, building towering volcanoes.

By the way, the energy powering that convection comes from the radioactive decay of atomic nuclei that were synthesized in the hearts of stars that lived and died long before the Sun and Earth formed. The same can be said for the carbon, nitrogen, and every other chemical element apart from hydrogen that makes up my friend the Saguaro.

And so the story goes. If you really want to know about that cactus, ask biologists studying evolution. Ask oceanographers or climate scientists. Ask geologists or planetary scientists. Ask astrophysicists studying the life cycles of stars. Ask cosmologists studying the origin and evolution of the universe. Ask particle physicists who are grappling with the nature of the dark matter, without which our galaxy would have never formed.

There is a gorgeous Saguaro cactus near my house. If you really want to know about it, you kind of have to talk to everybody. To really understand that cactus is to understand the universe.

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

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**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**Scientists aren't sure what to make of Kepler-452b. The planet's properties suggest it lies on the border between being a rocky super-Earth and a gaseous sub-Neptune. If terrestrial in nature, it likely has a thick atmosphere and lots of active volcanoes.**

# The hunt for Earth's BIGGER COUSINS

Larger than Earth but smaller than Neptune, these in-between worlds harbor some surprisingly terrestrial environments.

**Text and illustrations by Michael Carroll**

Somewhere between the gas giants and the terrestrial Earth-like worlds that populate our galaxy lies a twilight zone, a region where planets defy easy classification. It is a dimension between gaseous and rocky, a territory where planet size straddles Earth and Neptune.

Several of these recently discovered hybrid planets offer the most exciting possibilities for Earth-like conditions on other worlds. And wherever such environments exist, the chance that life might gain a foothold can't be ruled out.

## In search of Earth 2.0

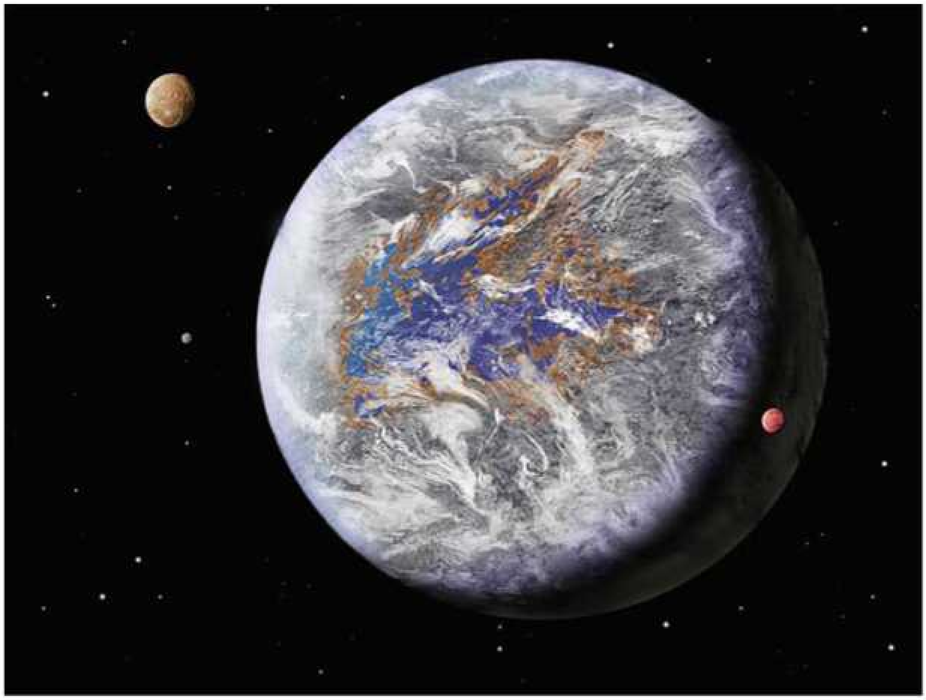
Finding exoplanets isn't easy. It's exceedingly difficult to directly image a planet at interstellar distances because it gets lost in the glow of its host star. But astronomers are adept at teasing out planets by closely examining the light from distant suns. When a world passes directly in front of its star from our perspective (a transit), the star dims, and the amount of dimming depends on the planet's physical size. The Kepler planet-hunting spacecraft used this technique to find thousands of exoworlds.

A second method, called radial velocity, measures a star's movement as an orbiting body pulls on it. The planet's gravity causes its sun to wobble. When the planet tugs the star away from us, the light becomes redder; on the opposite side of the orbit, the star gets yanked toward us, and its light becomes bluer. Astronomers can detect this so-called Doppler shift in a star's light. And the bigger the shift, the more massive the planet must be.

By combining these two techniques, scientists gain insights into the nature of exoplanets. If a planet has twice the mass of Earth but the same volume, for example, it must be very dense and thus rocky. But if a planet with Earth's mass has 10 times our planet's volume, it must be a low-density, fluffy world like a small gas or ice giant.

Astronomers have charted a wide range of planets orbiting in their host star's habitable zone — the region where liquid water could exist on a world's surface — from small terrestrials akin to Mercury to rocky or gaseous worlds the size of Neptune. Of the worlds with sizes comparable to our home planet, our galaxy may hold upward of 10 billion. Among the exoplanets

*Frequent contributor* **Michael Carroll** *is a science writer and astronomical artist. His latest book is* Earths of Distant Suns *(Springer, 2017).*



**Gliese 581g could be one of the more Earth-like worlds in our galaxy. Its tightly wound orbit around a red dwarf sun places the exoplanet within the star's habitable zone. Models indicate that under the right conditions, a large ocean would spread across this super-Earth's star-facing hemisphere.**

discovered so far, however, the Neptune- and sub-Neptune-sized worlds are the most common. Many of these relatively small giants qualify as super-Earths.

## Super-Earths and sub-Neptunes

Broadly speaking, the term *super-Earth* applies to planets that are larger than Earth but still have a rocky surface and a thin atmosphere. The term *sub-Neptune* refers to a small gaseous giant. But uncertainties in the data mean that the boundary between these two classes is more blurry than clear-cut.

Super-Earths seem to be the most common type of exoplanet. Roughly three out of every 10 worlds now known fall into this category. These worlds have no analog in our solar system. Scientists classify super-Earths strictly by mass without considering their composition, nature, or distance from their host star. Most of those discovered so far orbit close to their suns — simply because those that orbit close to their suns are the easiest to detect. The masses of these worlds range from a low of about 1.5 to 2 Earth masses up to a high of 10 Earths.

Astronomers sort super-Earths into four categories. Low-density planets contain large amounts of hydrogen and helium and are referred to as dwarf or sub-Neptunes. Medium-density super-Earths probably are ocean worlds where water is a major component. A third type has a denser core than a sub-Neptune but still possesses a sub-Neptune's extended atmosphere. The extent of that atmosphere depends on the planet's distance from its star — the farther away it orbits, the cooler it will be, and the more atmosphere it will retain. Finally, larger, high-density super-Earths, sometimes called mega-Earths, probably include major components of rock and/or metal.

## Not quite like Neptune

The ubiquitous sub-Neptunes join the exoplanet menagerie with masses ranging up to slightly less than our system's Uranus and Neptune. (Uranus contains 14.5 Earth masses; Neptune holds 17.1.) These worlds likely come with a wide variety of personalities.

Research scientist Mark Marley models exoplanet atmospheres at NASA's Ames Research Center in Moffett Field, California. He believes that sub-Neptunes may turn out to be the most varied of any size worlds. "You get bigger than a Saturn or so, and [planets] all tend to be about the same size because they are dominated by their hydrogen-helium atmospheres. When you get down closer to 1 Earth mass, they're probably all rocky worlds with a little bit of atmosphere. But [in this region between Neptune and Earth], there's probably a huge range of what these planets could be like. Every one is going to be unique," he says. Their natures depend on a host of factors, including their mass, the amount of water they possess, and the size of their core.

Like Neptune, most sub-Neptunes are gaseous. Unlike Neptune, however, many of these worlds orbit near their primary star. This provides astronomers with a mystery: How did sub-Neptunes end up close to their star when they had to form in the outer regions of their planetary system? Such worlds can be born only beyond the so-called snow line, where cool temperatures enable them to collect large quantities of ices and gases.

Planets, it seems, are slippery things, capable of forming in one place and shuffling off to another. Our solar system's arrangement of gas and ice giants outside of smaller terrestrial worlds apparently is not the norm across the galaxy. Astronomers developed the Grand Tack model to explain the solar system's early evolution. The theory proposes that Jupiter and Saturn marched toward the Sun, but Saturn was able to pull

**Kepler-22b likely is a rocky planet with a radius about 2.4 times that of Earth. It orbits its host star near the inner edge of the habitable zone, so it may resemble Venus more closely than Earth.**

Jupiter back from the brink of death. Similar migrations may be common in other systems, where sub-Neptunes could form at a large distance and drift starward later. An Earth-like world that develops close to its sun would have a much higher density because it lacks the water content of a planet originating in a system's cooler outer region.

Elisa Quintana of NASA's Ames Research Center has been working with a team trying to figure out when a planet transitions from being Earth-like to being a gaseous sub-Neptune. "Before we knew of any exoplanets, we had a basic mass-radius relationship based on our solar system. Now, we've had to throw that away," she says. "Theoretical models tell us that the transition from rocky super-Earth to gaseous sub-Neptune is about 1.5 or 1.6 Earth radii. Once a planet reaches 2 Earth radii, it will be more like a sub-Neptune." Researchers hope to pin down the transition point as they study more super-Earths.

## How much like home?

Although the discovery of planets with terrestrial dimensions is exciting, it takes more than size to make an Earth. Even among worlds close to Earth's size and mass, the "Earth-like" pickings appear to be slim. Most orbit outside the host star's habitable zone.

Typical of these is the nasty Earth-sized planet circling the star Gliese 1132. Astronomers calculate that Gliese 1132b spans 1.2 times the radius of Earth and has a mass about 1.6 times as large as our planet, putting it on the border between being rocky or sub-Neptunian. As Earth-like planets go, so far, so good. But scientists estimate that its surface broils at the temperature of an oven, around 460° F (225° C).

Just how Earth-like is a super-Earth? Features that contribute to our own world's uniqueness offer a good yardstick. First, Earth orbits in the Sun's habitable zone. Although some super-Earths orbit within the habitable zone of their own star, studies show this may not be enough to beget Earth-like environments. Plate tectonics is another critical attribute of our home world because it recirculates the minerals that wash into the seas and recycles elements of the atmosphere that have been chemically locked into rocks.

But recent models contend that super-Earths may not enjoy the benefits of plate tectonics. First, it takes the right mineral smorgasbord to create the planetary jigsaw pattern of shifting plates. On Earth, as one plate slides under another, increasing pressure rearranges the atoms within it, making the rock denser. Without this alteration, plates would stall out and cease sliding past each other. The change in density depends on the plate's makeup. Planets with mineralogically different crusts may not be able to maintain a conveyor belt of plates.

Second, a super-Earth's crust may be too thick to carry on tectonics. Simulations of the pressures within giant Earths reveal that thick crusts likely surround most of these worlds, putting up a physical barrier to plate tectonics. Still, some researchers suggest that the increased heat within a super-Earth might be enough to drive plate tectonics.

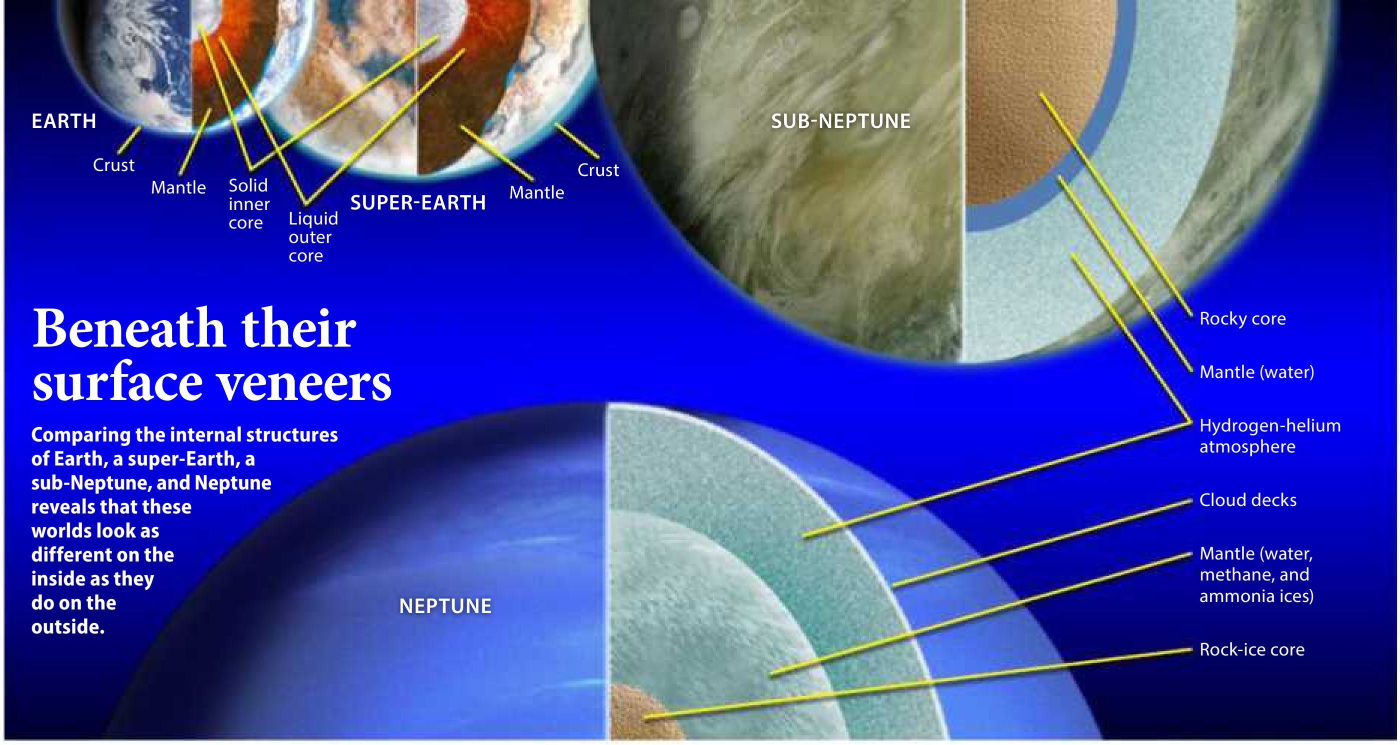
Another factor that would contribute to a super-Earth's earthiness is a magnetic field. Earth's rotating molten core generates a field that protects us from energetic charged particles. To be Earth-like, a super-Earth needs to have such a field.

## A survey of super-Earths

Out of the thousands of exoplanets known, astronomers have found only a few super-Earths with the right characteristics to be potentially Earth-like. One of the closest matches appears to be Kepler-452b.

The first roughly Earth-sized planet found in the habitable zone of a star similar

**Two super-Earths orbit Kepler-62. Both worlds likely have deep oceans of water, though Kepler-62f (bottom) orbits farther from its star than Kepler-62e (top) and thus may be covered with ice.**




# Beneath their surface veneers

**Comparing the internal structures of Earth, a super-Earth, a sub-Neptune, and Neptune reveals that these worlds look as different on the inside as they do on the outside.**

to the Sun, Kepler-452b is roughly 1.5 times larger than Earth. Although it lies slightly farther from its star than Earth does from the Sun, its star (Kepler-452) shines slightly brighter than ours, so the planet gets just a bit more energy than Earth does. Any terrestrial vegetation transported there likely would thrive in similar lighting conditions and temperatures.

That is, *if* Kepler-452b has a solid surface. The planet's size hovers right on the edge between a rocky super-Earth and a gaseous sub-Neptune. Columbia University astronomers Jingjing Chen and David Kipping published a study in *The Astrophysical Journal* in late 2016 that gives the planet only a 13 percent chance of being terrestrial rather than gaseous. Models suggest that if Kepler-452b is rocky, it probably has a thicker atmosphere than Earth's and likely would be volcanically active.

Kepler-452b takes 385 days to orbit its sun, a year quite similar to Earth's. But all may not be well on this world. Its star is 1.5 billion years older than the Sun and radiates more light and heat than it used to. The planet once was in the center of the habitable zone, but as the aging parent star has warmed, its habitable zone has migrated outward, stranding the planet on the inner edge. Any oceans it once had likely are evaporating into a thick atmosphere.

Other possible matches may circle Gliese 581, a red dwarf star that lies 20 light-years from Earth. Up to five planets may orbit this star, and three of them may be super-Earths in the star's habitable zone. Gliese 581c orbits near the zone's inner edge. It may circle close enough to the star that it suffers from a runaway greenhouse effect like that found on Venus.

The other two planets — Gliese 581d and Gliese 581g — may be more Earth-like, but astronomers aren't even sure they exist. Both worlds have been detected by multiple teams, but other researchers have failed to confirm them. If real, they would be on the shortlist for most Earth-like planets.

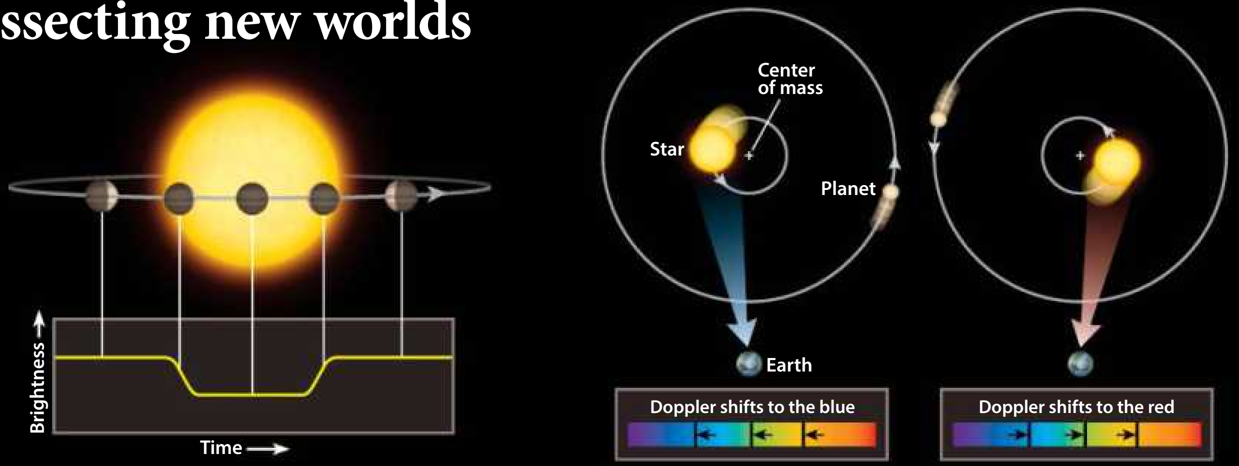
Gliese 581g appears to orbit just 0.13 astronomical unit (AU; 1 AU is the average Earth-Sun distance) from the star. But because the red dwarf is dim, the planet receives roughly the same amount of energy as Earth does from the Sun. Its mass may be no larger than 2.2 Earths, barely qualifying it for super-Earth status. The planet orbits close enough to its sun that it should be tidally locked, always keeping the same face toward the star. Depending on its atmospheric composition and surface, it might be a barren, Venus-like world, or one with an abundance of water.

If it has an atmospheric pressure similar to Earth's, the globe might be blanketed in a thick ice crust. But if the air contains enough greenhouse gases like carbon dioxide, temperatures could be substantially warmer. The tidally locked world could develop a permanent ocean on the hemisphere facing the star, where temperatures would be similar to those in Earth's tropics.

Another possible world in this system, Gliese 581d, appears to be much heavier,

**Seen from the surface of a hypothetical nearby moon, super-Earth Gliese 667Cc may be a sub-Neptune, with windy cloudscapes rather than rocky vistas. The planet lies so close to its red dwarf host that it probably is tidally locked, a situation that may wreak havoc with its banded cloud formations.**

# Dissecting new worlds




**Astronomers know the most about exoplanets observed with both the transit and radial velocity methods. When a planet passes in front of (transits) its parent star (left), it causes a slight dip in the star's light. The wobbles induced by a planet's gravity alter the host star's radial velocity and show up as shifts in the stellar spectrum (right). In the rare cases when scientists can view a planet with both methods, they get valuable information on the world's size, mass, and density.** *ASTRONOMY:* ROEN KELLY

perhaps as much as 7 Earth masses. This purported planet's size caused astronomers to add a new class to exoplanets: the mega-Earth. The world apparently orbits its star with a period of 67 days, placing it near the outer edge of the habitable zone.

## Kepler's reign of glory

At a distance of 620 light-years, the Sun-like star Kepler-22 hosts Kepler-22b. The planet has the distinction of being the first habitable-zone world discovered by the Kepler spacecraft.

With a diameter about 2.4 times that of Earth, it has a density similar to rock, which means that it may be terrestrial. Kepler-22b also might have a fairly dense atmosphere and, because it orbits in the inner region of its star's habitable zone, the climate may resemble Venus more closely than Earth. But the planet's rotation and cloud cover could moderate conditions there. Some recent models point to a surface temperature hovering around a comfortable 72° F (22° C).

Farther out in the galaxy, at a distance of about 1,200 light-years, Kepler-62 boasts five confirmed planets. Two of these reside in the habitable zone of the host orange dwarf star. Both are roughly 1.5 times larger than Earth, putting them at the border between Earth-like and super-Earth.

Studies indicate that water likely covers Kepler-62e in a deep global ocean. And although sibling Kepler-62f also may have a large component of water, it lies far enough out in the habitable zone that the surface might be frozen, at least at the poles. The latter world may have an atmosphere denser than Earth's, perhaps similar to — but cooler than — that of Venus.

Some 22 light-years from Earth lies the triple-star system Gliese 667. Two of the members are K-type orange dwarfs somewhat cooler than the Sun, while the third is an even cooler red dwarf. The two K-type stars orbit each other; the red dwarf, Gliese 667C, circles them both at a distant 230 AU. Gliese 667C appears to have at least three planets in the vicinity of its habitable zone.

Perhaps the most intriguing of these is Gliese 667Cc, which has a mass less than four times that of Earth. This alien planet may be a rocky terrestrial, though some researchers think it may be a sub-Neptune. The world circles its sun at breakneck speed, completing a circuit in just 28 days. But because Gliese 667C is a red dwarf, the world lies far enough out that liquid water could exist on its surface. Gliese 667Cc collects about 90 percent of the light that Earth receives from the Sun. And as with any large planet in a habitable zone, it may have moons with quite Earth-like environments.

One of the most Earth-like planets yet discovered is a world with a radius 12 percent larger than our own. Kepler-438b orbits within the habitable zone of a red dwarf, making a circuit every 35 days. If Kepler-438b is terrestrial in nature, its mass would be about 1.4 times Earth's. Surface temperatures on this world likely would range from 32° to 140° F (0° to 60° C). The planet suffers from the disadvantage of orbiting close enough to its parent star to feel the fallout from the stellar flares common to red dwarfs. In fact, observers have seen Kepler-438 unleashing radiation and plasma every few hundred days. But if Kepler-438b has a strong magnetic field, its surface still might be hospitable.

**A red dwarf sets behind clouds on Kepler-438b. The planet lies close enough to its active star to be exposed to massive stellar flares. If it does not have a magnetic field, the world likely experiences deadly levels of radiation.**

Astronomers have discovered a variety of exoplanets within their host star's habitable zone. The field seems ripe for the discovery of worlds with thriving biomes beyond our own. The search for life-forms on Earths of distant suns will be a difficult one, but the detection of a new living world would forever change our views of biology, planetary development, and the frequency of life in the universe.

# Impostors in the asteroid belt

Astronomers are on the hunt for comets disguising themselves as asteroids.

by Nola Taylor Redd

The asteroid belt is home to a few "main belt comets" — icy objects throwing off tails associated with comets. These objects can be hard to detect, and even harder to understand. RON MILLER FOR *ASTRONOMY*

O

**ON A SUMMER EVENING IN 2002,** then Ph.D. student Henry Hsieh peered through a telescope on the summit of Hawaii's Mauna Kea. He was hunting for 133P/Elst-Pizarro. Half a dozen years earlier, scientists had identified a comet-like tail behind this asteroid belt resident that lasted two months before it disappeared from view. Working with his adviser David Jewitt, Hsieh (pronounced SHAY) hoped to find signs that the tail had returned.

Their timing was impeccable. "We noticed it right away," Hsieh says. He quickly spotted a faint tail trailing from the tiny body during their very first observing session. "We happened to be in the right place at the right time."

**An illustration of asteroid P/2012 F5, which displayed a "tail" in observations. The tail may have been formed by either a rupture inside the asteroid or a collision with another object.** SINC

The pair continued to monitor the comet-like creature in the asteroid belt for the rest of the year, following its path until it went behind the Sun in December. When it emerged in fall 2003, it was once again just another rocky asteroid.

The original appearance of 133P's tail grabbed a lot of attention, but Hsieh said there wasn't a lot of follow-up. "People knew at the time that Elst-Pizarro was a kind of unusual object because it was active and it was in the asteroid belt, but it was sort of like a one-off freak object," he says.

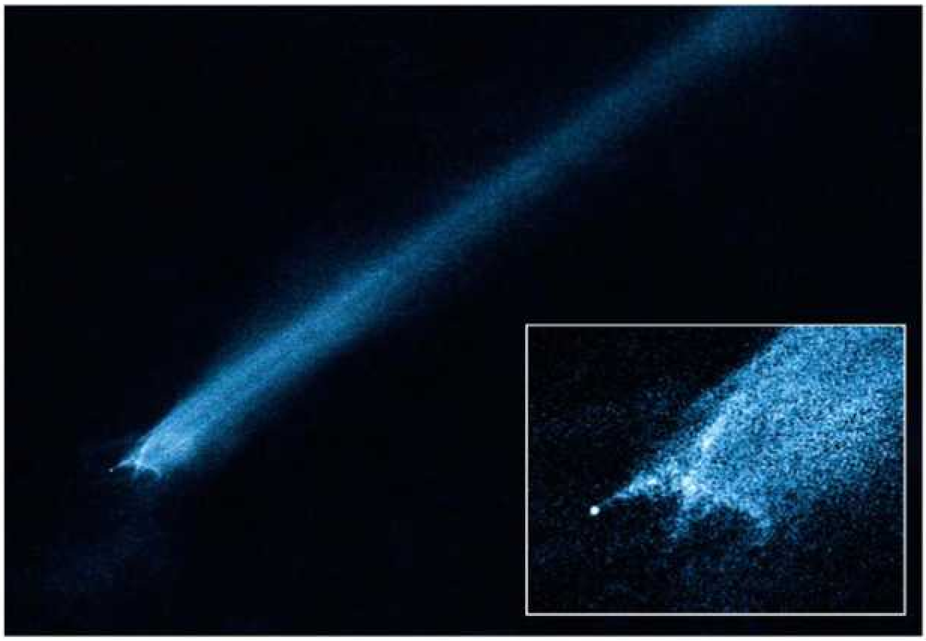
That changed with the 2002 observations. While a random impact from debris in the belt could have briefly created a tail, Hsieh said such impacts are unlikely to occur twice in six years.

"Suddenly, we had this thing that definitely seemed to be a comet that was in the asteroid belt," he says.

Traditional comets are balls of dust and ice that swoop in from the outskirts of the solar system, where icy bodies can survive far from the Sun's warming rays. While traveling through colder regions, the chunks of ice bear a strong resemblance to the rockier asteroids. But as comets draw close to the Sun, heat transforms the ice directly into a gas, creating their signature streaming tails.

Unlike comets, asteroids in the main belt spend their life relatively close to the Sun, orbiting between Mars and Jupiter. Any water ice on their surface boiled away long ago, leaving behind only rock. But rocks don't create long, streaming tails as they draw closer to the Sun. Somehow, 133P had managed to hold onto its ice.

Hsieh and Jewitt predicted that their oddball asteroid would resume its comet-like activity in 2007. While they waited, they began hunting for similar objects in the asteroid belt. Along the way, they tried to figure out why some asteroids suddenly resemble comets, and how these objects could help answer questions about the origin of Earth's water.



**When Hubble snapped this image of P/2010 A2, many remarked on the plume's resemblance to a Romulan bird of prey from *Star Trek*. The plume of gasless dust may have resulted from two objects smashing into each other at 9,321 mph (4.2 km/s).** NASA, ESA, D. JEWITT (UCLA)

## A new population

By the time 133P developed the predicted tail again in 2007, astronomers had spotted three more objects with comet-like activity. Almost immediately after each discovery, Hsieh and Jewitt began follow-up observations. Two active asteroids were spotted with 1-meter instruments, but astronomers discovered most of the faint tails by scrutinizing a larger survey of the asteroid belt for unusual objects. By 2016, nearly 20 tailed objects had been spotted. According to Jewitt, the known population has risen because more people are looking for them today. Enormous surveys, many of them automated, produce a wealth of data, and computers make it easier to pull out the most intriguing objects. While some surveys searched the skies in the 1950s, no one was watching for tailed asteroids because they weren't expecting to see them. That's not unusual in astronomy — both Neptune and Pluto were observed as "stars" long before they were identified as planets.

With millions of pieces of rubble orbiting between Mars and Jupiter, searching individual asteroids in the belt for these faint tails is challenging. Whereas traditional comets in the outer solar system are often spotted by amateur astronomers, main belt comets shine even dimmer than Pluto's moon Charon, Hsieh says, and their tails are even harder to detect and can't be seen without extremely precise professional-grade instruments.

Hsieh and Jewitt initially referred to the newly spotted tailed asteroids as "main belt comets" and thought they had perhaps been captured in the wealth of material between Mars and Jupiter, but it soon became clear that these objects weren't all acting like traditional comets. As they travel closer to the Sun, icy comets from the outer solar system form a tail through sublimation, with water leaping from solid ice to gas. In contrast, many of the discoveries appear active when farther from the star, and some have trails of material that may not have developed as water shifts phase.

Instead, some of the new objects may have been born of collision. In 2010, scientists noticed that the 71-mile-wide (115 kilometers) asteroid Scheila suddenly had developed an enormous tail. Since its discovery just over a hundred years ago, Scheila had remained relatively stable. Later simulations revealed that a 98-foot-wide (30m) rock could have created the startling plume. That same year, scientists found another object with a tail, the 62-mile-wide (100km) 2010 A2. Eventually they determined that it would take an object only 3.3 to 6.6 feet wide (1 to 2 meters across) — not much larger than a chair — moving at 3.1 miles (5km) per second to blow off the cloud of material. Radiation pressure sweeps away the smaller debris, leaving a husk of an object in its wake.

Despite Hollywood's portrayal of daring flights through close-lying material, the asteroid belt contains mostly empty space. The average distance between asteroids is about 600,000 miles (965,606km). Missions to the outer solar system all pass through the belt without a hitch. At this point in the solar system's 4.6 billion-year life, collisions are rare; a kilometer-sized body may crash into something once every 100 million to 1 billion years, Jewitt says.


**Asteroid P/2013 P5 displayed not just one, but six tails in this Hubble image from September 2013. After initial detection by the Pan-STARRS survey of asteroids, Hubble observations indicated that the object had begun rotating out of control, throwing up more dust and debris, which appeared as a tail.** ESA/HUBBLE

That makes collisions for an individual object rare, but the asteroid belt hosts about 800,000 large rocky bodies. So while one asteroid has a low chance of colliding with something, those same odds multiplied over the entire belt means a handful of objects are probably smashing into each other somewhere in the belt right now.

A dying asteroid can also produce a tail without any outside help. A fast rotation can occasionally split the rocky body apart, creating a trail of rocky dust as it disintegrates. Hsieh, who today is based in Hawaii and affiliated with the Planetary Science Institute, estimated that one or two of the identified objects could have been produced by disintegration. As the asteroid falls apart, it reveals any subsurface ice, which allows sublimation to take hold and produce an icy tail.

With evidence that not all of the objects act like comets, and that even the most comet-like are probably more rocky than icy, scientists began to refer to any tailed asteroid as an "active asteroid." Those with regular, predictable tails that appear seasonally are often referred to as main belt comets, a subset of active asteroids.

Of the 20 tailed objects in the asteroid belt, only a few have had their tails vanish and reappear. That doesn't mean other active asteroids aren't functioning as comets; it simply means scientists haven't seen them producing their tails again. The hunt can be a challenge, since asteroid belt objects can disappear behind the Sun for months at a time, making it difficult to observe them at the same point in their orbit over consecutive years.

Where did they come from? Although they could have been captured from the outer solar system, Jewitt said that it is improbable. Most likely, they formed in the asteroid belt. When the Sun was young, the asteroid belt was cooler, and water and other gases could have survived as ice on

## WHAT'S IN A NAME?

Almost immediately after Hsieh and Jewitt dubbed the newfound objects "main belt comets," the name became a source of contention.

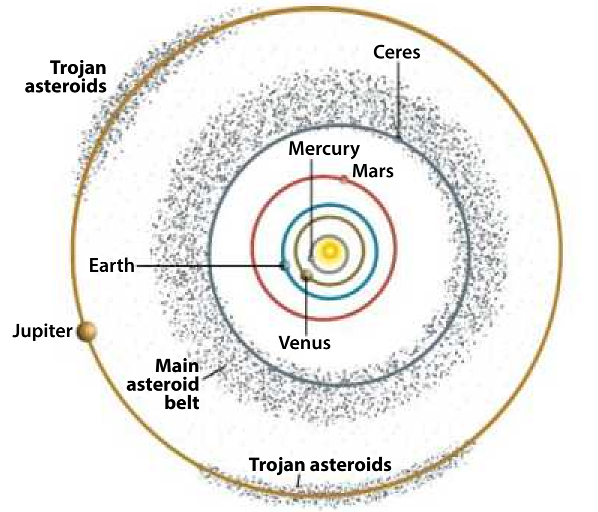
"At meetings, we found that when we gave a talk about main belt comets, instead of focusing on the science part of the talk, people focused on the name," Jewitt says, sounding disgusted. "It just messed up the whole subject."

To help clear up the confusion, the entire class of tailed objects in the asteroid belt was relabeled as "active asteroids." For Jewitt, that's where it ends.

But Hsieh and others continue to use the term *main belt comet* as a subclass of active asteroids that they think sublimate like comets. Without sending a mission to the asteroid, the best way to tell if sublimation drives the tail is if it reappears when the object draws near the Sun, like Elst-Pizarro. Since collisions are rare, if an asteroid has a tail, loses it, and then later regains it, the chances are high that sublimation drives the process.

Asteroid 596 Scheila displays its comet-like tail, as recorded by a backyard imager using a 24-inch telescope. KEVIN HEIDER @ LIGHTBUCKETS

## Belt-tightening




The space between the inner and outer solar system is riddled with asteroids. Many are shepherded by Jupiter into an orbiting group known as the main asteroid belt, while others follow ahead of and behind the gas giant. Those objects are known as Trojan asteroids. NASA; *ASTRONOMY*: ROEN KELLY

the surface of the rocky bodies. When the region heated up, the surface ice sublimated, leaving behind a thin layer of dirt and rock that would protect the ice beneath. That ice can form a tail when another object knocks away the rocky material in a collision (an active asteroid) or when the parent body draws near the Sun (an active asteroid and a main belt comet).

## A source for Earth's water?

Whatever you call them, active asteroids or main belt comets could have played a role in making Earth habitable. Our planet's habitability is linked with its liquid water, so understanding how the planet holds on to water is key to knowing how life originated here, and how it could develop on planets around other stars.

Most scientists think conditions around the Sun were too hot for Earth to form with the vital liquid. Instead, they look for ways water might have been delivered to the planet. For a long time, comets from the frigid edge of the solar system were considered prime candidates. But simulations of the Sun's early neighborhood revealed that the icy leftovers were evicted from their orbit around the Sun more often than they were hurled in toward the inner planets, leaving too few surviving to deliver water to the planet.

Another hole in the comets-for-water idea comes from studies of the deuterium-to-hydrogen ratio, often called D/H. Also known as "heavy water," deuterium exists as a percentage of water in comets and Earth's oceans. But missions that have studied the D/H ratio of comets reveal a fingerprint different from the oceans back home.

With comets as a dead end, scientists turned to asteroids as a potential water source. Space rocks that crash-land on Earth carry traces of minerals that include water. Water wasn't present as puddles on early asteroids; they simply had some of it locked into their mineral composition. If the materials were plentiful throughout the asteroid belt, and enough hydrated material collided with Earth — and studies show that it could have — they could have delivered Earth's oceans.

Active asteroids provide another path for water to have landed on Earth. Instead of carrying the liquid locked up in rocks as hydrated minerals, they suggest that at least some asteroids have ice beneath their rocky exterior. When debris is knocked off, perhaps by tiny micrometeorites scraping various spots on the surface, the exposed ice begins to sublimate, creating the tail.

While water is expected to make up about 5 percent of the mass of rocky asteroids, that's not enough to power main belt comets. New models suggest that the comets instead carry at least 20 percent of their weight as ice. That could provide a wealth of water crashing toward the terrestrial planets early in the life of the solar system.

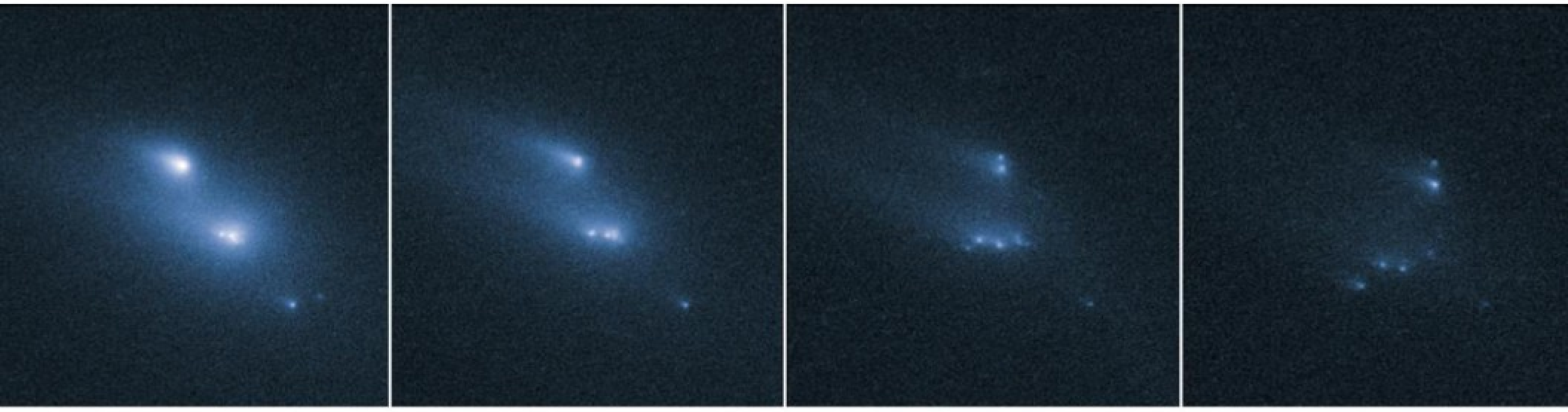
But that doesn't mean Earth was pelted by a storm of tiny objects. It's far more likely that larger, Ceres-sized objects reigned in the inner solar system. Instead of billions of kilometer-sized objects, only a few hundred bodies between the size of Ceres and Mars crashing into the planet could have delivered Earth's water.

During the first few hundred million years, the solar system was populated by thousands of such bodies, protoplanets hoping to grow up to full-size worlds. The Grand Tack theory proposes that Jupiter and Saturn journeyed into the inner solar system before turning around, or tacking, back to the outer regions. Their dance could have sent these objects flying out of previously stable orbits, hurtling toward the Sun or out of the solar system.

As the baby planets collided with one another, simulations suggest that their water could have traveled from one to the next in a domino effect. Water could have jumped from one protoplanet to another until one crashed down on Earth, carrying the precious liquid. Others could have fallen to Venus or Mars, delivering oceans to their surfaces, as well.

"It's a matter of efficiency," says Nader Haghighipour of the University of Hawaii, who modeled the amount of water active asteroids would need to maintain their observed activity. "Main belt comets show you a pathway. Indirectly, they are telling you that the bigger parent bodies contained ice."

Main belt comets, and potentially other active asteroids, could provide insight into the water of the early solar system.



**This series of images taken by the Hubble Space Telescope shows the destruction of P/2013 R3, in a progression from 2013 to 2014. Each fragment created a tail of its own.** NASA, ESA, D. JEWITT (UCLA)

"They represent an extreme case in which the ice that was incorporated in the body where it formed survived 4.5 billion years in the inner solar system without melting," Jewitt says. "Active asteroids hold the promise of being able to deliver to us samples of this primordial ice."

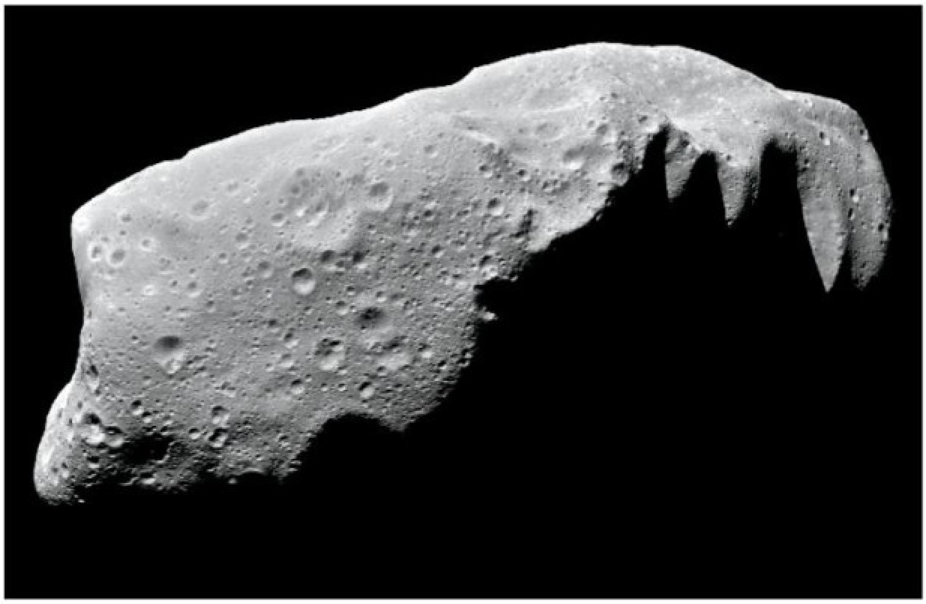
## Visiting a main belt comet

Not everyone is content to wait for active asteroids to reveal their secrets. The University of Hawaii's Karen Meech led the team that proposed the Proteus mission in 2015 to NASA. Proteus was planned to launch in 2021 and rendezvous with MBC 238P/Read before it reached perihelion in 2028, when it would reactivate. Mission investigators hoped to map the surface of the asteroid, observe its physical properties, and determine how outgassing occurred on the tiny object. It would also measure the D/H ratio of the tiny main belt comet.

Proteus wasn't selected in 2015, but Meech and her team plan to resubmit. "It's a compelling spacecraft project because it's a new type of object that we've never explored in the solar system," she says.

NASA isn't the only space agency investigating a main belt comet visit. The European Space Agency (ESA) is examining the Castalia mission to visit the first identified main belt comet, Comet 133P/Elst-Pizarro, arriving in time to view its activity in 2035 after a 2028 to 2030 launch.

"Castalia is in some ways a mini-Rosetta," says Colin Snodgrass of Open University in England, Castalia's principal investigator. ESA's Rosetta mission visited the full-fledged comet 67P/Churyumov-Gerasimenko. Since main belt comets are less active, they are easier to orbit. Advances in technology, reducing the number of instruments, and the lower activity combine to make Castalia a lower-cost mission.



**This image of asteroid 243 Ida taken by the Galileo probe in 1993 shows the surface features common to most asteroids.** NASA/JPL-CALTECH

"Rosetta has been a very successful mission and has told us a lot about comets like 67P," Snodgrass says. "Being able to make direct comparisons of a main belt comet would be the ideal way to understand these bodies better."

By June, ESA will have selected two to three mission concepts for an in-depth study. The final decision should be made in 2021.

By the time decisions are made about Castalia and Proteus, scientists may have already sampled an active asteroid. The OSIRIS-REx mission should arrive at the asteroid Bennu in 2018. Christina Richey, deputy program scientist for the mission, pointed out that Bennu is the same type of asteroid as Elst-Pizarro and the suspected main belt comet 176P/LINEAR. Bennu doesn't currently show signs of activity, but that could change in the future.

"Observations of the 'real life' nature of Bennu's activity, if it has any, will be enormously instructive in interpreting past and future observations of other active asteroids," Hsieh says. If Bennu grows active, OSIRIS-REx could help reveal the cause. On the other hand, if Bennu remains silent, Hsieh said the mission could still provide clues as to why, perhaps revealing a lack of fresh craters or signs that water is scarce or vanished long ago. Since Bennu is a near-Earth asteroid, circling the warmer region near our planet rather than out in the cooler asteroid belt, the Sun may have baked away any ice it once contained.

"OSIRIS-REx will certainly give us far more detail to work with than we've ever had before for this type of asteroid," Hsieh says.

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

# PLANETARY WEIGHT LOSS

The imager captured this composite of Perseid meteors August 11/12, 2016, from Joshua Tree National Park in California. Because the particles creating meteors are tiny, they don't add much to Earth's mass. MICHAEL KRYPEL

## Q: WE SEE ESTIMATES OF THE TONNAGE OF METEORITES THAT LAND ON EARTH EVERY YEAR AND ARTICLES ABOUT SOLAR WIND ABLATION OF ATMOSPHERIC MOLECULES. HAS IT EVER BEEN DECIDED WHETHER EARTH IS, OVERALL, GAINING OR LOSING MASS?

***Barry McElmurry,*** *Vista, California*

**A:** To answer this, we have to compare loss of atmosphere to gain by meteoritic material. Atmospheric gas escapes from a planet in two main ways. First, the motion of the molecules themselves at a certain temperature may cause their speed to exceed the planet's escape velocity. The higher the mass of the molecule is, however, the lower its speed. So, hydrogen, the lightest element, is more likely to escape than helium, etc.

Two other factors weigh in here as well: the mass of the planet (more gravity) and its distance from the Sun (a warmer, more energetic environment). When we compare Earth to Jupiter, for example, our planet is closer to the Sun and much less massive. That's why Jupiter has retained much of its hydrogen while Earth has not.

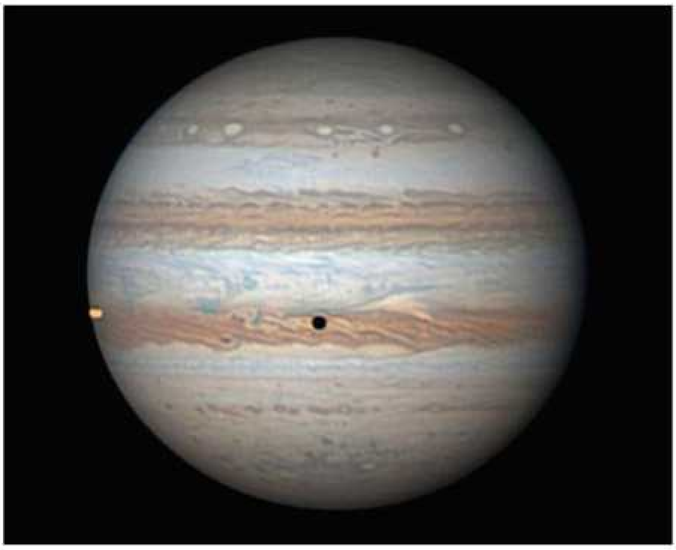
The second major way a planet can lose atmosphere is through interaction with the solar wind. In this case, the energy of that stream of charged particles can increase the velocity of gas molecules to more than a planet's escape velocity.

In Earth's case, however, we have a natural defense mechanism that guards our atmosphere from the solar wind: a strong magnetic field. It deflects nearly all particles in the solar wind as far as 40,000 miles (65,000 kilometers) from Earth.

Current estimates place the loss of hydrogen and helium at 6.6 pounds (3 kilograms) per second. That works out to just a tad more than 100,000 tons (90,700 metric tons) per year. When you compare that to the estimated mass of meteoric material that falls to Earth each year (approximately 50,000 tons), indeed, our planet does seem to be on a weight-loss program.

Don't worry, though. If that diet remained constant over a billion years, our planet would have lost only eight-billionths of its total mass.

***Michael E. Bakich***
*Senior Editor*



Both Io and its shadow were transiting Jupiter on June 16, 2016, at 22h38m48s UT. At the time, Jupiter's phase was 99.2 percent, though at this image scale, it's impossible to see it as less than full. DAMIAN PEACH

## Q: DOES JUPITER'S ILLUMINATION (AS SHOWN ON THE MONTHLY PLANETARY TABLE) EVER DROP BELOW 100 PERCENT? IS THERE AN EQUATION THAT GOVERNS HOW FAR OUT A PLANET NEEDS TO BE TO NEVER HAVE ITS ILLUMINATION DROP BELOW 100 PERCENT?

***Andrew Hadley***
*Colorado Springs, Colorado*

**A:** Yes, Jupiter's illumination occasionally dips below 100 percent, although the giant planet never appears less than 99 percent lit. Unfortunately, this phase effect is hardly noticeable through amateur telescopes except under exceptional observing conditions. Even then, the most you can hope to see is a slight softening along the planet's eastern or western limb.

Every outer planet shows its minimum phase (when it deviates most from 100 percent) when it reaches quadrature. This is the point in its orbit when the Sun-Earth-planet angle equals 90°, and the planet-Sun-Earth angle, or phase angle, reaches a maximum. The maximum phase angle depends on the object's orbital radius.

To pursue this, we need a bit of simple math. If theta ($\theta$) is this maximum angle and r is the orbital radius measured in astronomical units (AU, where 1 AU is the average Earth-Sun distance), then $\theta=\arcsin(1/r)$. Jupiter's average orbital radius is 5.204 AU while Saturn's is 9.582 AU, so their maximum phase angles are 11.1° and 6.0°, respectively.

The minimum phase of an outer planet occurs at its maximum phase angle and equals

**This spectacular image of the Andromeda Galaxy (M31) required 19 hours of exposure through luminance and RGB filters. The imager combined shots taken with 14.5- and 6-inch telescopes.** TONY HALLAS

$0.5(1+\cos(\theta))$. So, in Jupiter's case, the phase can dip as low as $0.5(1+\cos(11.1°))=99.1$ percent. Similarly, Saturn can fall only to 99.7 percent, which rounds off to 100 percent.

To find out how far away a planet would need to be so that its illumination can never drop below 99.5 percent, simply reverse this process. The cosine of its maximum phase angle needs to be $2(0.995)-1=0.99$, so $\theta=8.1°$. And the planet's orbital radius then would have to be $1/\sin(8.1°)=7.097$ AU, which would place it between Jupiter and Saturn.

***Richard Talcott***
*Senior Editor*

## Q: IS THERE A SIMPLE WAY THAT AMATEUR COLLECTORS CAN DETERMINE IF METEORITES FOR SALE ARE AUTHENTIC?

***Joseph Rusz***
*Oak Hill, Virginia*

**A:** First, decide whether you're beginning a collection or just acquiring a few specimens for "show and tell." If the former, you'll want to read all you can about meteorite classification. *Astronomy* devoted its entire August 2006 issue to meteorites. It's still a great reference if you can find a copy. If the latter, read at least a little and select a meteorite of each type that shows the characteristics of its category well.

When buying meteorites, it's always best to examine the specimen firsthand. Learn the basic characteristics that will allow you to distinguish genuine meteorites from "meteorwrongs." For example, most meteorites (even stones) contain some iron and will react to a strong magnet.

If you are shopping online, buy from a well-known dealer. Head to an online forum about meteorites, and see what others are saying about the dealer you're considering. Be careful when buying meteorite samples in online auctions, such as the ones on eBay. Make sure you can return the specimen and get a refund if you have any doubts about its authenticity.

Also, pay attention to the quality and professionalism of the website, which can tell you a lot about the dealer. Does the site provide complete contact information, including a mailing address and telephone number? And how recently was it updated?

The best websites include a good deal of educational material to aid the customer. One example is the Meteorite Market (meteoritemarket.com), which is loaded with useful information.

***Raymond Shubinski***
*Contributing Editor*

## Q: I NOTICE THAT SOME LONG-EXPOSURE PHOTOS ARE TAKEN USING LRGB FILTERS. I UNDERSTAND THE RGB (RED, GREEN, AND BLUE), BUT WHAT DOES THE L FILTER DO?

***Ronald F. Greene***
*Florence, Arizona*

**A:** "L" stands for luminance, and it is a clear filter, which, at first glance, may sound confusing. Do CCD manufacturers insist on putting a clear filter in among the red, green, and blue so that they can charge you more? Think about it: clear glass or air — is there any difference? Read on.

The luminance filter plays an important role in CCD photography. Think of it as the "detail" data that you download out of the sky whereas the color data is just that — color. If skillfully made, the L filter will keep the focus similar between the clear and color filters. Without a filter in the L slot, imagers would have to refocus every time they selected that option.

All color filters block near-infrared wavelengths to keep them from interfering with the signal. The L filter also must block the near-IR so that when you combine the L with the RGB, you don't get unsupported signal. In other words, if your RGB filters block the IR, but the L doesn't, there will be no color data to support the IR, and the IR data the L lets through will show up as an ugly gray in the picture.

Being clear, the luminance filter lets in more light than the color filters, usually twice as much per given time period. Depending on your image scale, it is possible to bin your L exposures 1x1 for maximum detail, and bin your RGB exposures 2x2 to make the camera more sensitive to color. Binning allows you to group pixels on your chip so they collect more light but still act as a single pixel. So, if you bin 1x1, you are using single pixels. If you bin 2x2, however, you're making four pixels act as one, with a four-times gain in light collected. In this way we get the high detail from the luminance combined with the binned color to make a high-quality image. And in many cases you can keep the exposure times identical.

With very fast, short focal length telescopes, binning the color blurs the detail too much. With such instruments, it's better to shoot the RGB binned 1x1 and use image-processing software to create a synthetic luminance out of the color data. By doing this you can treat the L as a separate entity to sharpen it or reduce noise.

Remember, the luminance provides the detail, and the RGB provides the color. It is to your advantage to treat them independently where possible and then combine them for the final image.

***Tony Hallas***
*Contributing Editor*

## Send us your questions

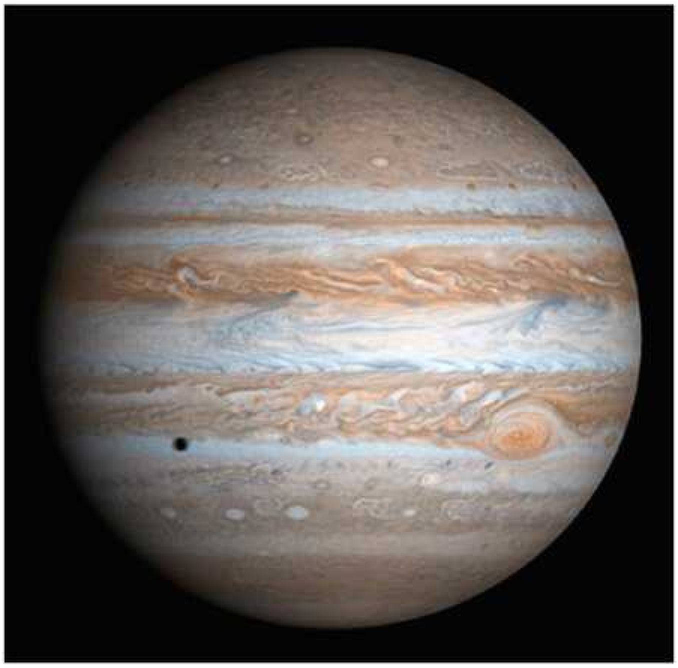
Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

SKY THIS MONTH

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

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

# April 2017: Jupiter rules the night



**Jupiter's dynamic atmosphere displays a wealth of detail through telescopes of all sizes, particularly in the weeks surrounding its early April opposition.** NASA/JPL/UNIVERSITY OF ARIZONA

Mercury, Mars, and the Moon will delight evening observers in early April. The three create a fine prelude for the month's "star" performer, Jupiter. The solar system's largest planet reaches peak visibility in April and remains visible throughout the night. As Jupiter dips low in the west before dawn, early risers can enjoy nice views of ringed Saturn in the south while brilliant Venus dominates the east.

Although **Mercury** has a reputation for being hard to see, novices who head out in evening twilight April 1 might wonder why. The innermost planet stands 12° high in the west a half-hour after sunset and dips to a still-respectable 7° high 30 minutes later. Mercury shines at magnitude –0.1 and shows up easily against the fading twilight. Meanwhile, fainter Mars appears 15° to its upper left and the waxing crescent Moon gleams some 30° to the Red Planet's upper left.

April 1 marks the peak of Mercury's best evening appearance of 2017. Point a telescope at the planet and you'll see its 8"-diameter disk and 39-percent-lit phase. A week later, Mercury appears 9" across and the Sun illuminates just 16 percent of its Earth-facing hemisphere. Unfortunately, the planet has dimmed to magnitude 1.6 and hangs lower in the twilight sky. The Sun's glare swallows the fading world just a few days later.

**Mars** glows at magnitude 1.5 for most of April. It's a conspicuous point of light above the western horizon as darkness falls and doesn't set until shortly after 10 P.M. local daylight time. A telescope won't help you enjoy the ruddy world — even the best instruments show only a featureless disk 4" across. Instead, Mars shines this month by the company it keeps.

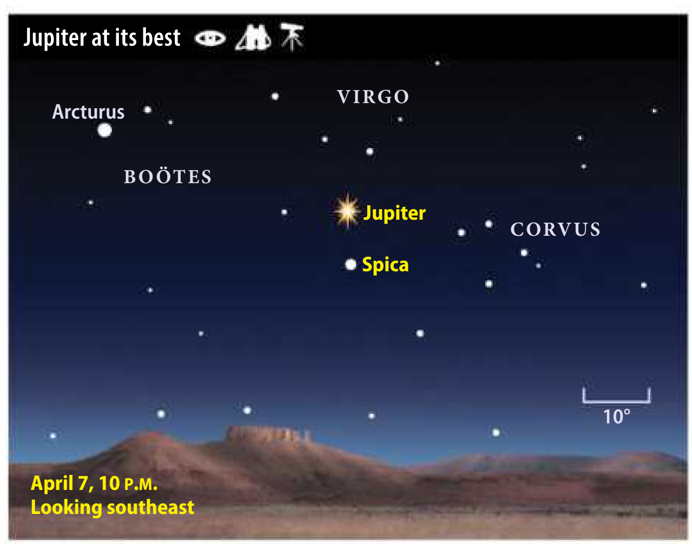
The Red Planet moves from Aries into Taurus on April 12, setting up a string of pretty binocular conjunctions. Mars passes less than 4° south of the Pleiades star cluster (M45) on the 19th and 20th, but the pair appears in a single field of view for more than 10 days. And during the month's final week, the planet stands between the Pleiades and Hyades clusters.

A waxing crescent Moon punctuates this scene April 27 and 28. On the 27th, the slender crescent lies 9° south of the Pleiades and 11° west of 1st-magnitude Aldebaran, the luminary that marks one tip of the V-shaped Hyades. The following evening, a slightly fatter crescent Moon stands 4° east of Aldebaran. With Mars entrenched between the two clusters, the star-studded gathering creates a stunning scene in the deepening twilight.

If you shift your gaze from west to east as darkness falls, **Jupiter** immediately grabs your attention. The giant planet reaches opposition April 7, when it lies opposite the Sun in our sky and thus stays on view all night. Opposition also brings the planet closest to Earth, so it shines brightest and appears largest through a telescope.

You won't mistake Jupiter for any other object. Blazing at magnitude –2.5, it shines 25 times brighter than Spica, the 1st-magnitude luminary of its host constellation, Virgo. The gap between planet and star grows from 6° to 9° as Jupiter moves westward during April. The giant world has a closer encounter when it slides 10' south of 4th-magnitude Theta (θ) Virginis on April 5.

Jupiter pulls within 414 million miles of Earth at




**The solar system's biggest planet lies in Virgo at its April 7 peak, not far from that constellation's brightest star, Spica.** ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

# RISINGMOON

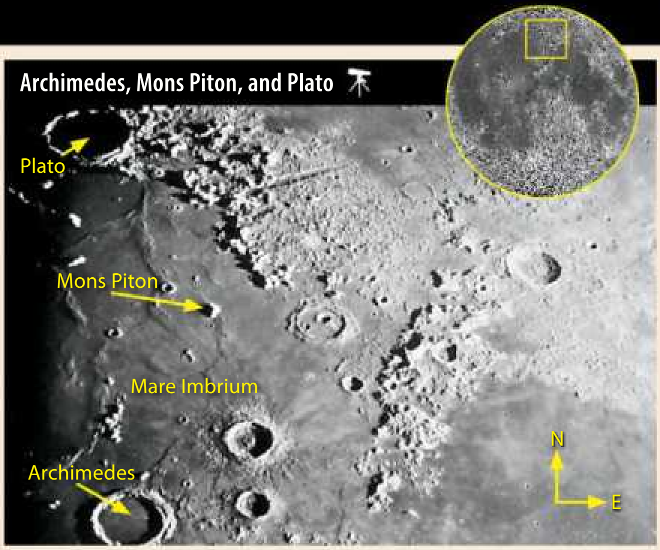
## On the shoals of a rainy sea

Chances are pretty good that your first memorable view of the Moon through a telescope revealed a landscape packed with dramatic craters arrayed along the dividing line between lunar day and night known as the terminator.

You can rekindle those memories on the evening of April 4, a day after First Quarter phase. Notice the perfectly circular crater Archimedes, which rests on the terminator halfway from the lunar equator to the north pole. The ragged eastern rim of this 52-mile-wide crater projects sharp shadows onto its smooth, lava-filled floor, while the western rim throws even longer spikes to the west. Galileo Galilei realized in 1610 that even the gentlest lunar hill would cast a long shadow under a low Sun angle.

To the north and a little east of Archimedes, the solitary Mons Piton rises from the wrinkled floor of Mare Imbrium (Sea of Rains). The large elliptical crater Plato to its northwest appears as a broken outline early on the evening of the 4th. Watch it become whole during the next couple of hours.

Over the next few nights, the Sun gradually illuminates Mare Imbrium and reveals its true extent. No one recognized this circular feature as an enormous impact basin until the early 1960s, when planetary scientists noticed a pattern of multiple rings centered on Mare Orientale at the Moon's western limb. Researchers quickly noticed similarities to many other large maria, and connected these features to giant impacts. Mons Piton and some other nearby isolated peaks suddenly fit into a broader picture as the tallest mountains in a ring largely submerged under lava that welled up long after the basin formed.




**The eastern edge of Mare Imbrium features giant craters and isolated mountain peaks.** *CONSOLIDATED LUNAR ATLAS*/UA/LPL;INSET: NASA/GSFC/ASU

opposition. The gas giant thus looms large and shows dramatic detail when viewed through a telescope. Great views come when it's higher as midnight approaches.

At opposition, Jupiter spans 44.3" across its equator. If you look carefully, you'll notice that its polar diameter comes up short, measuring just 41.4". This polar flattening — obvious even through small scopes once you know to look for it — arises from Jupiter's gaseous nature and rapid spin.

The top of Jupiter's atmosphere breaks into a series of bright zones and darker belts. Two belts stand out in particular, one of either side of a zone that coincides with the planet's equator. During moments of good seeing, you'll likely see several more belts and zones. Also keep an eye out for the Great Red Spot. If you don't see it on first look, wait a few hours for the planet's spin to bring it into view.

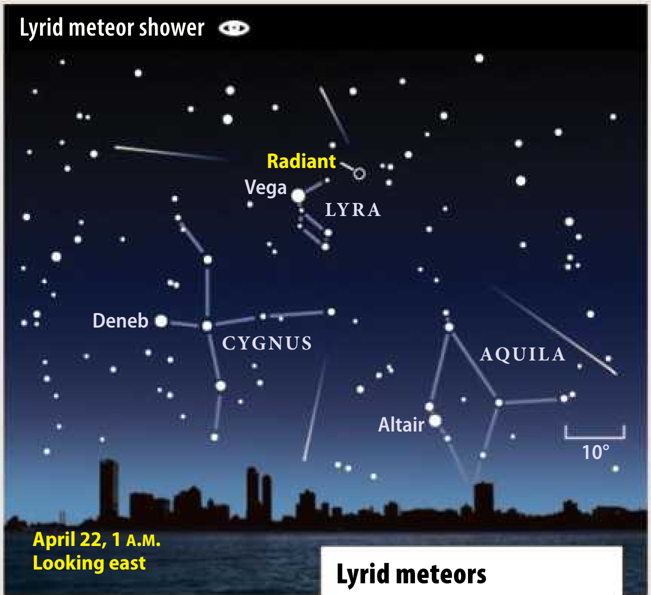
— *Continued on page 42*

# METEORWATCH

## The Lyre plays a sweet song

Although the Lyrid meteor shower often rates as an afterthought on the calendar of annual showers, this year should be different. Peaking under a waning crescent Moon the morning of April 22, the Lyrid shower promises the best viewing conditions of any spring or summer shower this year. Observers who seek out dark skies should see up to 18 meteors per hour before dawn.

The "shooting stars" appear to radiate from the constellation Lyra the Lyre, a region that rises in late evening and climbs nearly overhead by the time twilight commences. Be sure to dress warmly to ward off the morning chill. Then, use your naked eye to scan the sky roughly 30° to 45° from the radiant.




**With a slim crescent Moon rising around 4 A.M. local daylight time, conditions should be great for April's top meteor shower.**

**Lyrid meteors**

**Active dates:** April 16–25
**Peak:** April 22
**Moon at peak:** Waning crescent
**Maximum rate at peak:**
18 meteors/hour

**OBSERVING HIGHLIGHT** Mercury makes its best evening appearance of 2017 in early April, climbing highest at dusk around greatest elongation on the 1st.

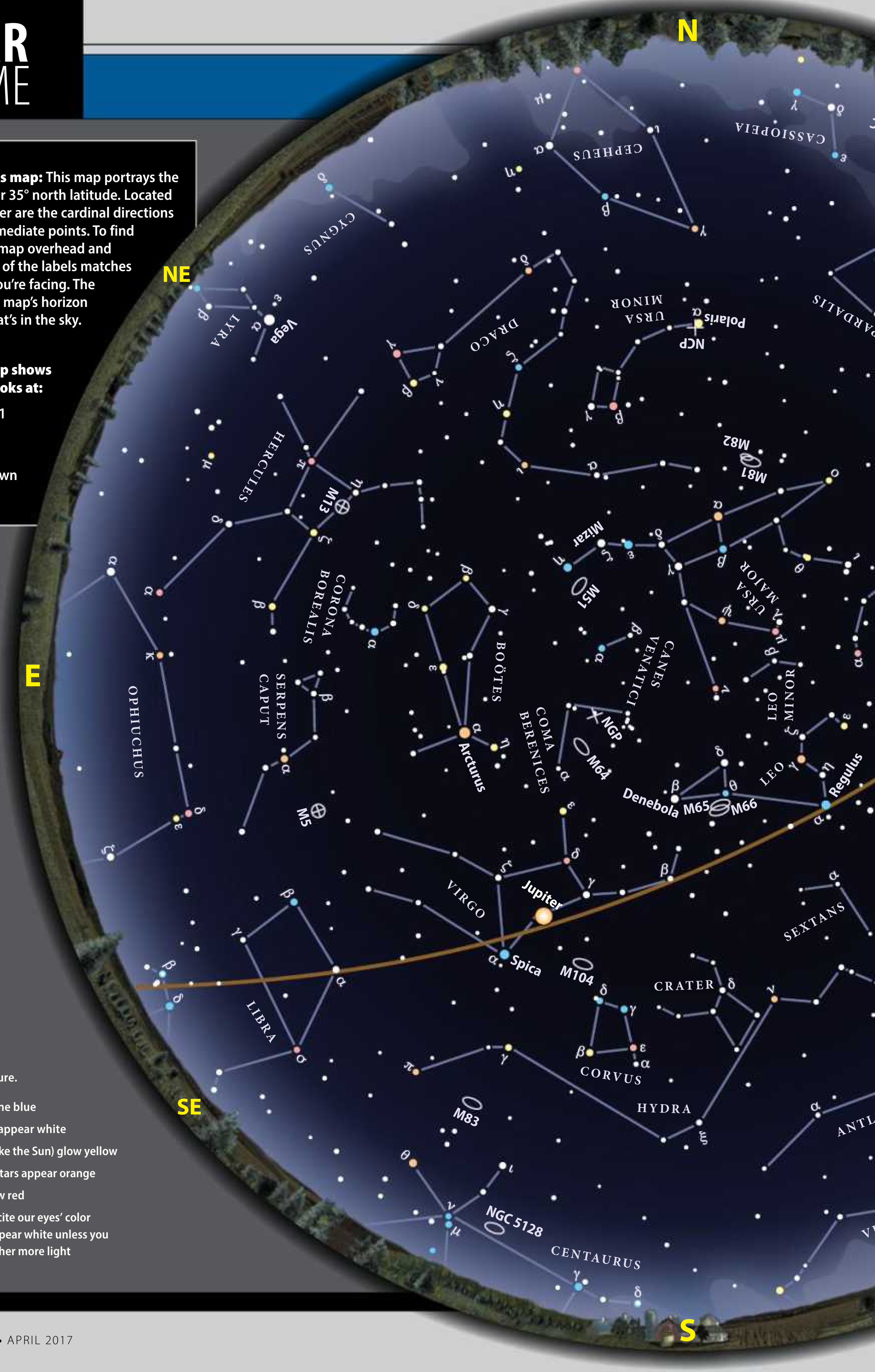
# STAR DOME

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

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

midnight April 1
11 P.M. April 15
10 P.M. April 30

Planets are shown at midmonth




## STAR MAGNITUDES

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

## STAR COLORS

A star's color depends on its surface temperature.

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


**MAP SYMBOLS**

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

# APRIL 2017

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

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

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

## Calendar of events

**1** The Moon passes 0.3° north of Aldebaran, 5 A.M. EDT

Mercury is at greatest eastern elongation (19°), 6 A.M. EDT

**3** First Quarter Moon occurs at 2:39 P.M. EDT

**6** Saturn is stationary, 1 A.M. EDT

**7** The Moon passes 0.7° south of Regulus, 1 A.M. EDT

Jupiter is at opposition, 6 P.M. EDT

**SPECIAL OBSERVING DATE**

**7** Jupiter reaches its 2017 peak today, shining at magnitude –2.5 and appearing 44.3" across through a telescope.

**9** Mercury is stationary, 9 P.M. EDT

**10** The Moon passes 2° north of Jupiter, 5 P.M. EDT

**11** Full Moon occurs at 2:08 A.M. EDT

**12** Venus is stationary, 8 P.M. EDT

**14** Uranus is in conjunction with the Sun, 2 A.M. EDT

**15** The Moon is at apogee (251,950 miles from Earth), 6:05 A.M. EDT

**16** The Moon passes 3° north of Saturn, 2 P.M. EDT

**19** Last Quarter Moon occurs at 5:57 A.M. EDT

**20** Mercury is in inferior conjunction, 2 A.M. EDT

Pluto is stationary, 5 P.M. EDT

**22** Lyrid meteor shower peaks

The Moon passes 0.2° south of Neptune, 4 P.M. EDT

**23** The Moon passes 5° south of Venus, 2 P.M. EDT

**24** The Moon passes 0.8° north of asteroid Pallas, noon EDT

**26** New Moon occurs at 8:16 A.M. EDT

**27** The Moon is at perigee (223,275 miles from Earth), 12:15 P.M. EDT

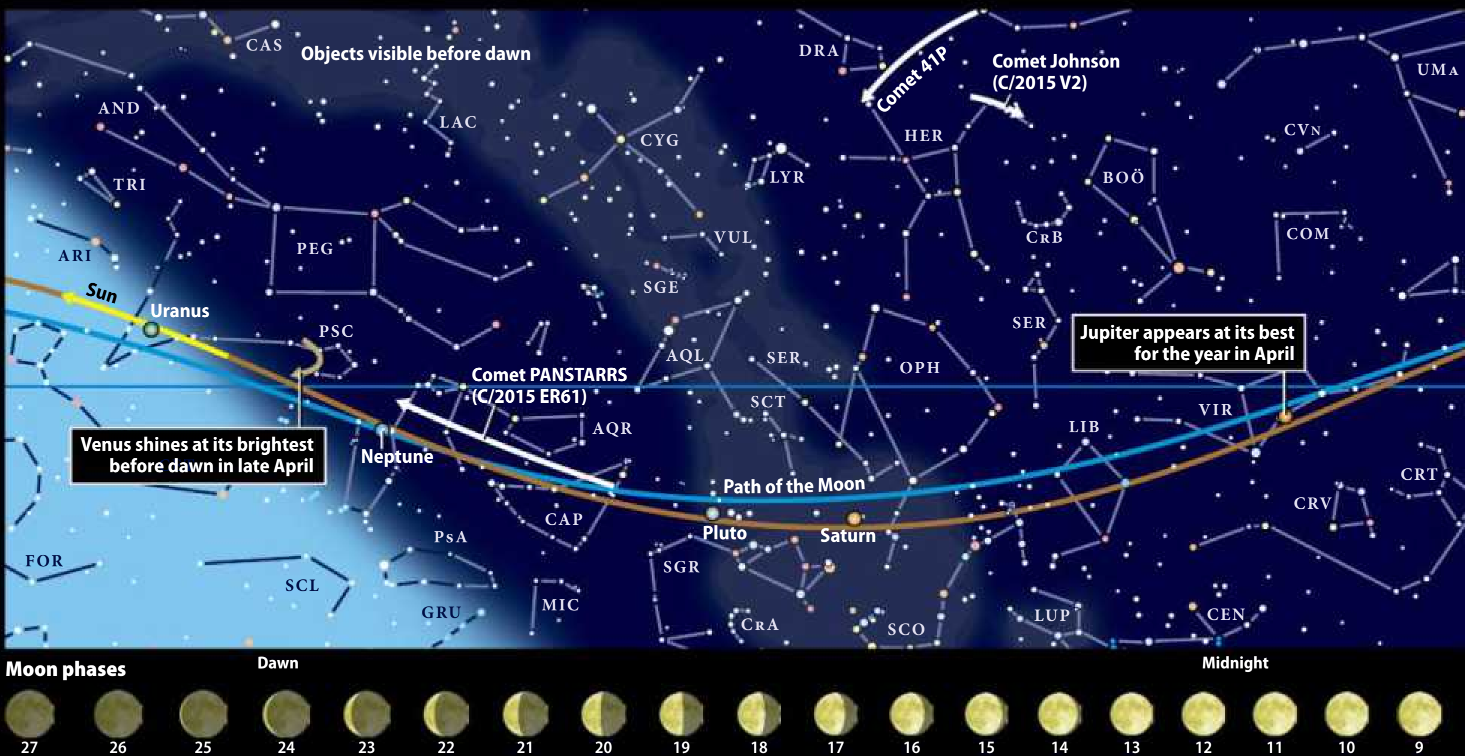
**28** The Moon passes 6° south of Mars, 4 A.M. EDT

The Moon passes 0.5° north of Aldebaran, 2 P.M. EDT

**29** Venus is at greatest brilliancy (magnitude –4.7), 5 P.M. EDT

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

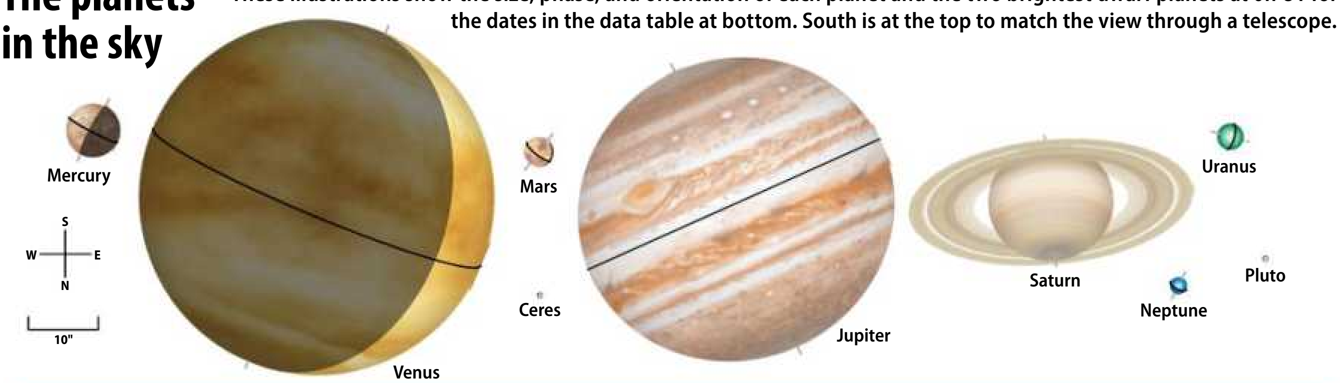
# The planets in April 2017




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

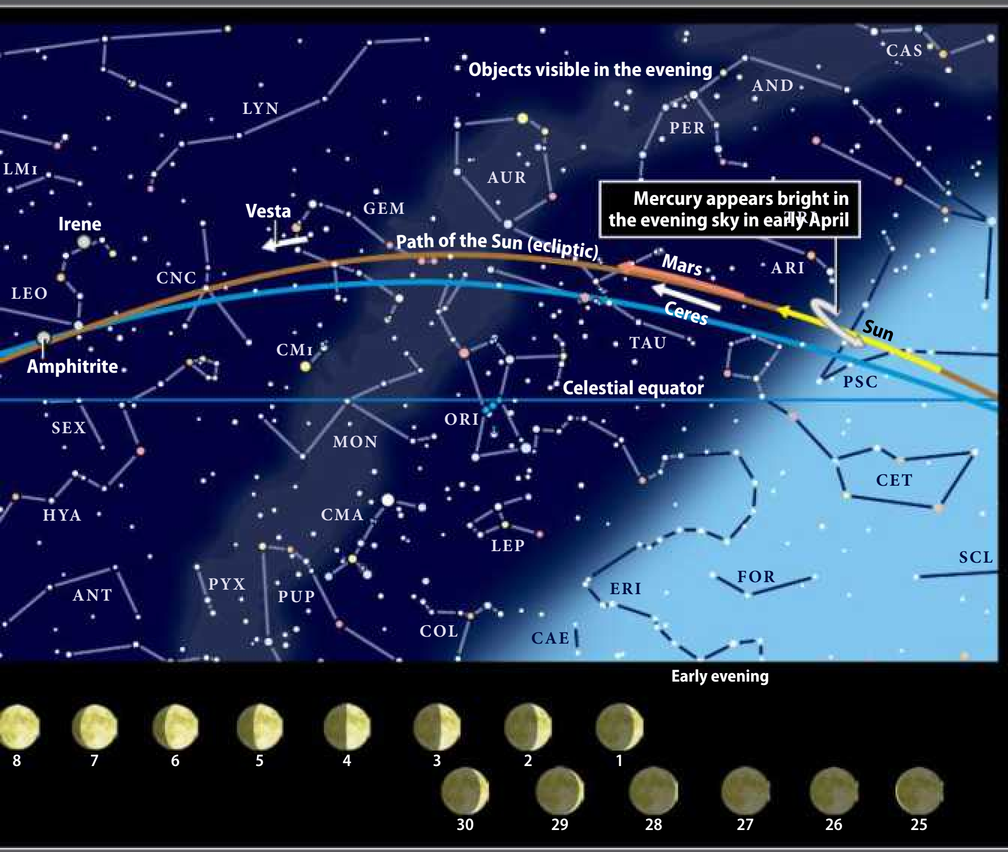
## The planets in the sky

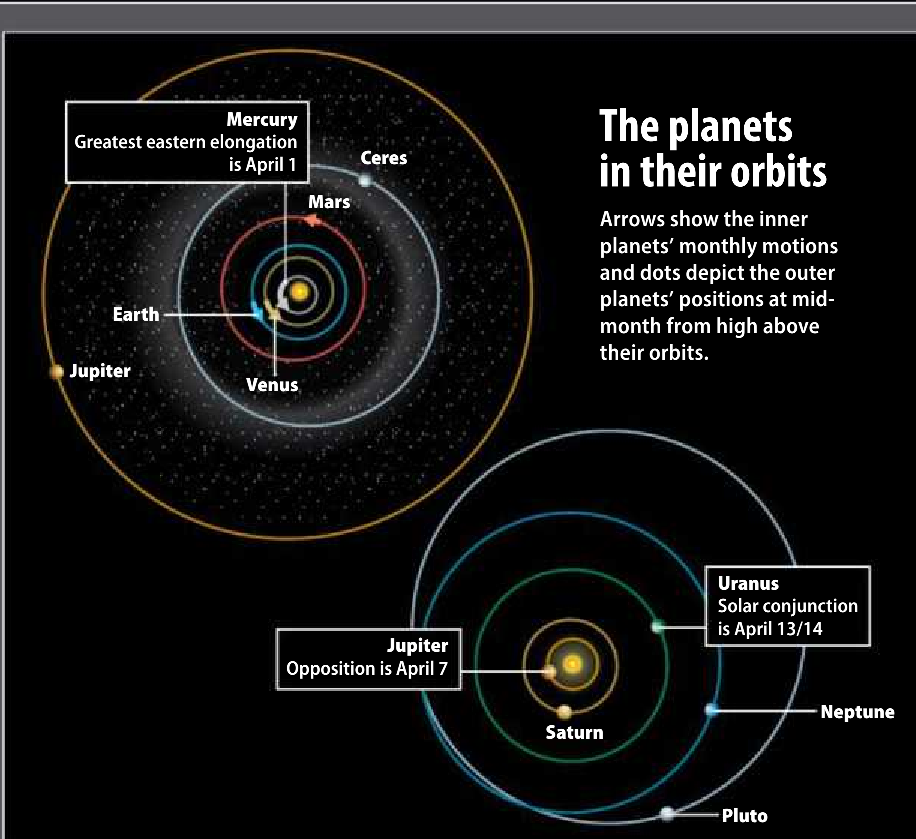
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.




| Planets | MERCURY | VENUS | MARS | CERES | JUPITER | SATURN | URANUS | NEPTUNE | PLUTO |
|---|---|---|---|---|---|---|---|---|---|
| Date | April 1 | April 15 | April 15 | April 15 | April 15 | April 15 | April 15 | April 15 | April 15 |
| Magnitude | –0.2 | –4.7 | 1.5 | 9.0 | –2.5 | 0.3 | 5.9 | 7.9 | 14.2 |
| Angular size | 7.5" | 49.0" | 4.1" | 0.4" | 44.2" | 17.4" | 3.4" | 2.2" | 0.1" |
| Illumination | 43% | 13% | 97% | 99% | 100% | 100% | 100% | 100% | 100% |
| Distance (AU) from Earth | 0.899 | 0.341 | 2.311 | 3.584 | 4.461 | 9.553 | 20.933 | 30.683 | 33.192 |
| Distance (AU) from Sun | 0.328 | 0.723 | 1.531 | 2.750 | 5.456 | 10.055 | 19.930 | 29.950 | 33.309 |
| Right ascension (2000.0) | 1h48.2m | 23h40.6m | 3h31.3m | 3h28.4m | 13h05.5m | 17h49.2m | 1h30.7m | 22h58.7m | 19h22.4m |
| Declination (2000.0) | 13°50' | 2°50' | 19°35' | 16°31' | –5°16' | –22°04' | 8°53' | –7°28' | –21°12' |

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.



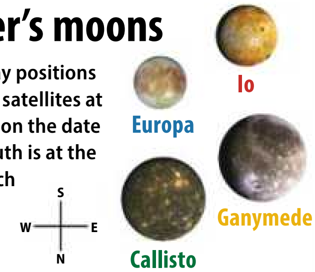



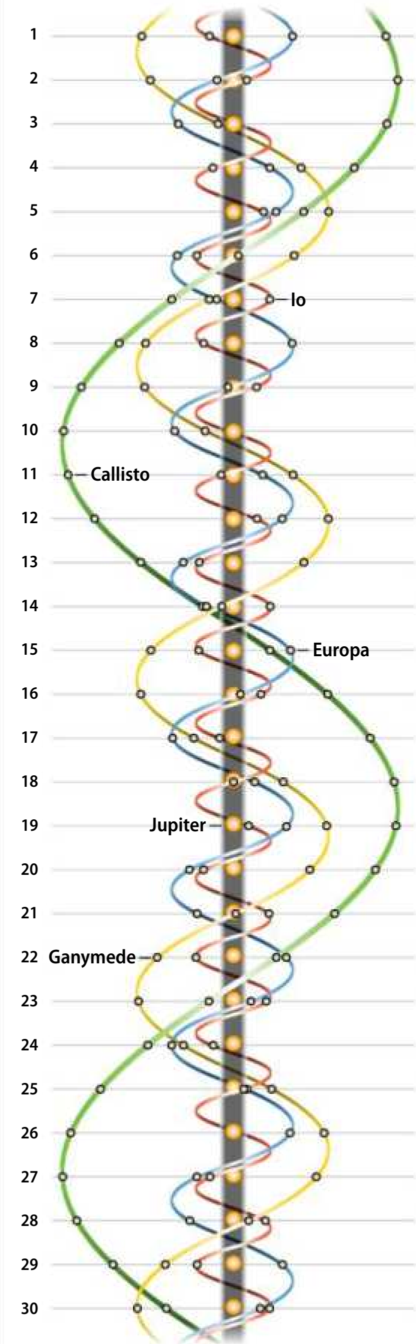

## The planets in their orbits

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

## Jupiter's moons

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




ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

## WHEN TO VIEW THE PLANETS

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

While you relish watching Jupiter's dynamic atmosphere, don't forget that NASA's Juno spacecraft enjoys a better view from orbit. The probe concentrates on the planet's polar regions, with the JunoCam instrument taking images during each close pass. You can follow the mission's progress at missionjuno.swri.edu.

Equally captivating are Jupiter's four big moons: Io, Europa, Ganymede, and Callisto in order of distance from the gas giant. The satellites spend most of their time either east or west of the planet, but each of the three inner ones passes in front of the jovian disk once an orbit. During such a transit, the moon also casts its shadow onto the planet's bright cloud tops, where it appears as a distinct black dot. Half an orbit later, the moon passes behind Jupiter (an occultation) and disappears in the planet's shadow (an eclipse).

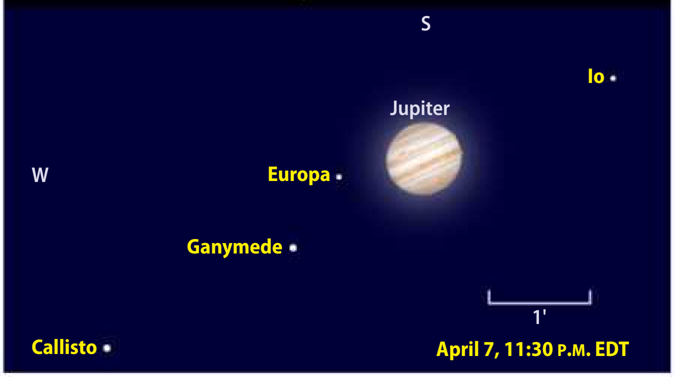
Although satellite events occur every day, some appeal more than others. Here we highlight several of the best for North American observers. Io transits Jupiter on the evening of April 2. The Moon's shadow touches the planet's disk at 11:31 P.M. EDT followed eight minutes later by Io itself. The moon seems to hover just east of the shadow throughout the transits. This is a sign that the Sun lies almost directly behind Earth, as it will at opposition on the 7th.

Compare these transits to the ones the night of April 9/10. In the latter case, Io first appears against Jupiter's cloud tops at 1:22 A.M. EDT followed by the shadow three minutes later. The moon now leads its shadow as they cross the planet's disk.

On the night of opposition, April 7/8, Jupiter's shadow falls directly behind the planet. Although all four moons show up in the evening, Europa passes behind the planet from 1:36 to 4:04 A.M. EDT. In a rare circumstance that can happen only at opposition, Jupiter simultaneously occults and eclipses the moon. A day later, on April 9, Io emerges from behind the planet's eastern limb at 6:15 A.M. EDT, but you won't see it until it emerges from Jupiter's shadow three minutes later.

On the evening of April 14, watch Europa and Callisto approach Jupiter almost in lockstep. After midnight,

### Focus on Jupiter's big moons




**Four bright satellites string out east and west of the giant planet on the night it reaches opposition and peak visibility.**

## COMETSEARCH

### A bright comet's all-night performance

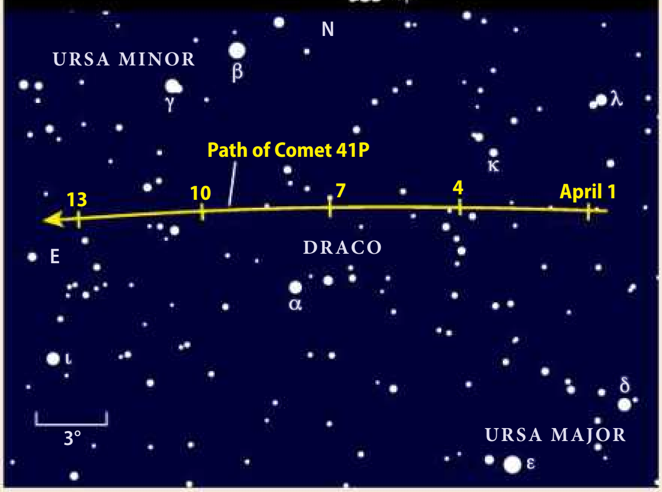
It's hard to believe that just six months ago, we had to scour the sky to find a 12th-magnitude comet. This month, we're not featuring two 7th-magnitude objects because we have something better. Comet 41P/Tuttle-Giacobini-Kresak could reach 5th magnitude and be visible to the naked eye from dark-sky sites.

Comet 41P sails across the northern sky during April. It spends the first half of the month among the background stars of Draco, between the brighter patterns of Ursa Major and Ursa Minor. This region remains on view from dusk to dawn. The periodic visitor passes closest to Earth on April 1 and closest to the Sun on the 13th.

Remember that comets are notorious for defying brightness predictions. Conservative estimates peg 41P at 8th magnitude, which would make it a decent telescopic comet. More optimistic scenarios have it reaching as high as 5th magnitude — within the range of the naked eye from the country and binoculars from the suburbs. Those are the extremes we should plan for, but a plan C exists: In 1973, the surface of this dirty snowball cracked and gushed gas and dust for a couple of weeks, forging an outburst of 10 magnitudes. If that happens again, we could have the comet of the decade on our hands.

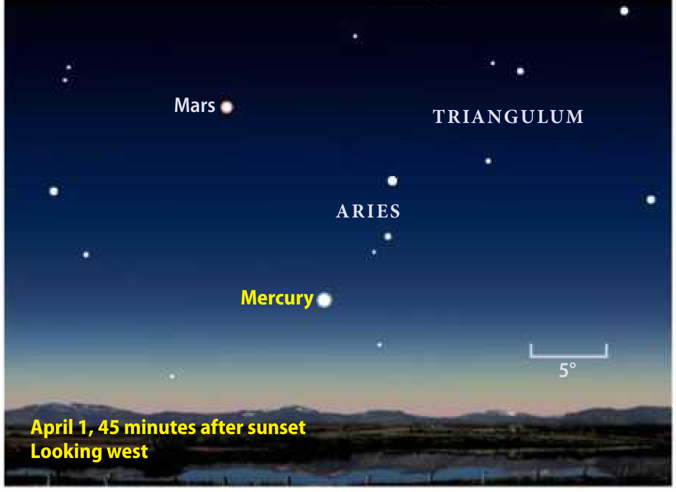
In early April, the best viewing comes in the moonless hours before dawn. Comet Tuttle-Giacobini-Kresak then should be near peak brightness and quite active. As the Moon moves into the morning sky toward the end of April's second week, optimal viewing shifts to the evening sky.

### Comet 41P/Tuttle-Giacobini-Kresak




**This icy visitor puts on a fine show for Northern Hemisphere observers in April when it makes its closest approach to both the Sun and Earth.**

## Mercury stars in evening twilight




**The inner world appears at its best for the year in early April, when it shines brightly and displays a pretty crescent disk through amateur scopes.**

Europa passes behind Jupiter's limb at 3:52 A.M. EDT and emerges from the planet's shadow at 6:38 A.M. (after the planet sets from eastern North America). Meanwhile, outermost Callisto passes above the planet's south pole.

**Saturn** rises near 1:30 A.M. local daylight time at the start of April and some 30 minutes earlier with each passing week. The magnitude 0.3 ringed planet lies against the Milky Way star fields of northwestern Sagittarius. It moves slowly eastward during the month's first few days, then reaches a stationary point on the 6th before starting a westward trek.

Although binoculars won't reveal details on Saturn, they will show the delightful backdrop. Throughout April, the planet lies within 4° of the open star clusters M21 and M23 as well as the spectacular Lagoon (M8) and Trifid (M20) nebulae.

The best views of Saturn through a telescope come when it climbs highest in the south near the start of twilight. The planet's disk measures 17" across at midmonth while the ring system spans 39" and tips 26° to our line of sight. The large tilt lets you see exquisite ring detail. First, take in the Cassini Division — the dark gap between the outer A ring and the brighter B ring. You should be able to see Saturn's disk through this opening. Next, notice the outer edge of the A ring poking above the planet's north pole. Finally, look for Saturn's shadow on the backside of the rings just off the planet's western limb.

Like Jupiter, Saturn has a family of moons, though only 8th-magnitude Titan is bright enough to see through all telescopes. Look for it north of Saturn on April 6 and 22 and south of the planet April 13 and 29. Three 10th-magnitude moons — Tethys, Dione, and Rhea — orbit inside Titan and show up through 4-inch and larger scopes. The quick pace of these inner three satellites means they often change positions noticeably over the course of an hour or two.

The approach of dawn brings the brightest planet into view. On April 1, **Venus** rises an hour before the Sun and climbs 5° above the eastern horizon 30 minutes later. By month's end, it pops above the horizon 100 minutes before sunup and stands 13° high a half-hour before sunrise. The planet brightens considerably in April as well, from magnitude –4.2 on the 1st to its maximum of magnitude –4.7 on the 30th.

# LOCATING**ASTEROIDS**

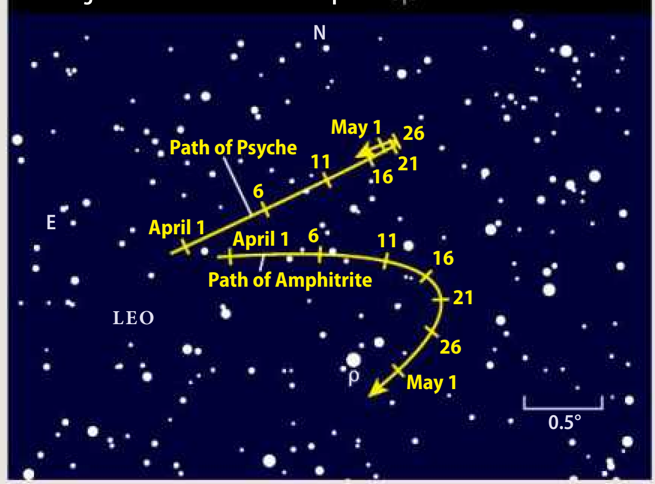
## Two space rocks for the price of one

By late evening in April, you can find Leo about two-thirds of the way from the southern horizon to the zenith. The Lion's heart, 1st-magnitude Regulus, dominates this constellation. Head 7° east-southeast from it and you'll land on magnitude 3.8 Rho (ρ) Leonis. Asteroids 16 Psyche and 29 Amphitrite lurk near this unassuming star during April.

Amphitrite begins the month at magnitude 9.8 while Psyche glows about a magnitude fainter. To snare these minor planets from the suburbs, you'll need a 4-inch or larger telescope. Try a magnification of about 75x to bring in the fainter background stars you see on the map below. Avoid the nights of April 6 and 7, when the nearby Moon's glare overwhelms the faint objects.

To help with your identifications, the asteroids straddle a magnitude 9.5 star April 1. Amphitrite moves a noticeable amount against the background stars each night. It heads west during April's first half before looping south and then east, curving back toward Rho as May approaches. In contrast, we view Psyche's orbit almost edge-on, so its westward motion appears to halt before it turns back to the east.

### Dueling asteroids tickle the Lion's paws




**Psyche nips at the heels of Amphitrite as the two minor planets march through the background stars of southern Leo the Lion.**

Observers who target Venus through a telescope in April will see it undergo striking changes. On the 1st, the planet spans 58" and shows a dramatic, 3-percent-lit crescent. By the 30th, the planet's diameter has dwindled to 38" while the crescent has fattened to 26 percent illumination.

The solar system's ice giant planets fare poorly in April. **Uranus** remains lost in the Sun's glare all month.

**Neptune** briefly returns to view at month's end, but it lies only 5° high in the east as morning twilight begins. You'll be hard-pressed to see the 8th-magnitude planet so close to the horizon.

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

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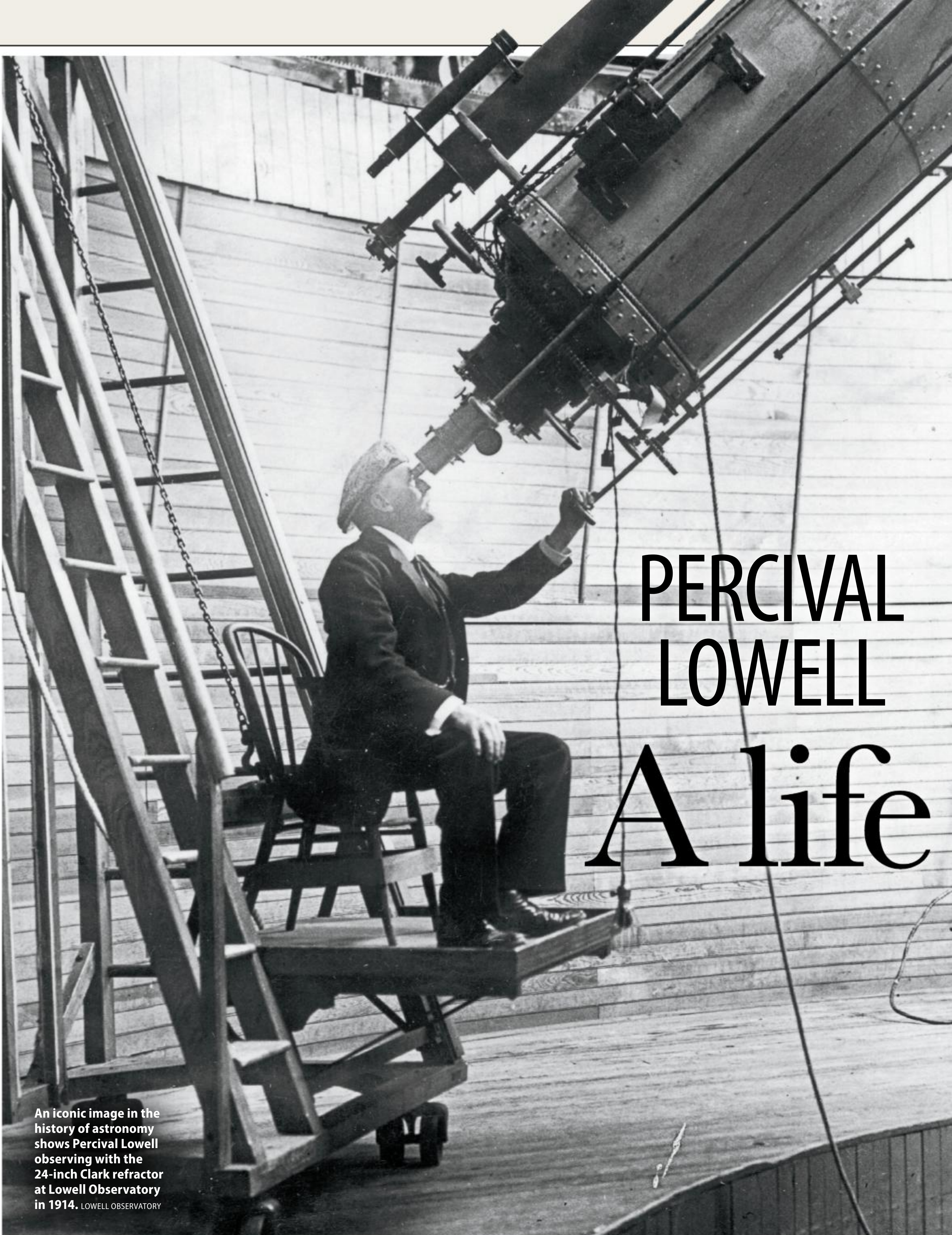


# PERCIVAL LOWELL
# A life

An iconic image in the history of astronomy shows Percival Lowell observing with the 24-inch Clark refractor at Lowell Observatory in 1914. LOWELL OBSERVATORY

One of the most curious characters in the history of astronomy produced a legacy of important work, and established the desert southwest as an astronomical mecca.

**by Kevin Schindler**

**1. Comet Donati, which Lowell remembered viewing when he was 3 years old.**
E. WEISS, BILDERATLAS DER STERENWELT/KEVIN SCHINDLER

# in astronomy

**WHAT DO PERCIVAL LOWELL AND GEORGE BAILEY HAVE IN COMMON? WELL, STICK WITH ME.**

In the beginning of the movie *It's a Wonderful Life*, angel wannabe Clarence Odbody is called to help downtrodden George Bailey realize his life was not a waste of time, but rather one of importance and meaning. Clarence gets his point across by showing George how much differently the future would have played out if George had never been born. George, for example, isn't around to save his brother Harry from drowning during a boyhood accident, and thus Harry is not around to save the lives of a transport of soldiers during World War II. The story goes on, and George finally realizes what a significant impact he had on so many lives.

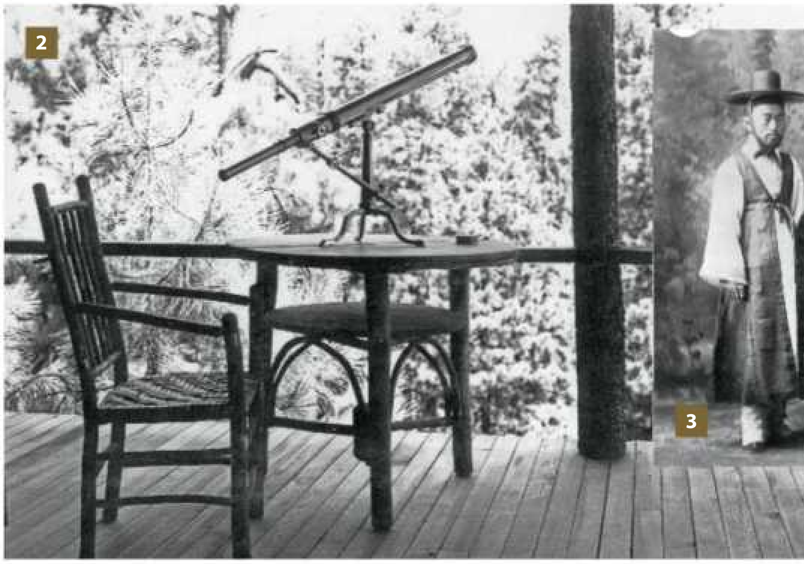
This narrative is an approach that paleontologist Stephen Jay Gould used to illustrate his contingency theory. Essentially, any circumstance is the result of a number of pre-existing factors, and if one of those factors is changed, the future would be altered. This exercise in what might have been can be fruitful in considering how Percival Lowell impacted astronomy as we ponder the 100th anniversary of his death this past November.

## Growing up Lowell

Lowell was born into an elite Boston family known for its accomplishments in areas ranging from commerce to academia. The family produced more than its fair share of businessmen, judges, writers, industrialists, ministers, philanthropists, and architects. The family motto, *occasionem cognosce*, means "know your opportunity," and family members took this to heart in pursuing excellence. To be a Lowell meant not merely relying on the family wealth to sail through life. Instead, family members were expected to assume leadership roles, whether in their chosen vocation or community activities.

Percival arrived in 1855, the eldest of seven children. (Five — two boys and three girls— survived to adulthood.) As Percival's brother, Abbott, noted in his biography of Percival, their father instilled in the children the Lowell work ethic: "Somehow he made us feel that every self-respecting man must work at something that is worthwhile, and do it very hard. In our case it need not be remunerative, for he had enough to provide for that; but it must be of real significance." So was developed the drive and fortitude that would carry Percival through his life, and the passion that would feed his desire to succeed and "plow his own furrow," as Abbott put it.

Percival studied mathematics at Harvard University and then worked at a desk for eight years, overseeing many of the financial aspects of the family's mills and other interests. But for a man instilled with a passionate spirit of adventure, discovery, and wanderlust, this arrangement wouldn't last. He soon bolted overseas, spending the better part of 10 years in Korea and Japan. There he studied the traditions, values, and religious practices of Eastern cultures. In a pattern he would repeat in later years in the field of astronomy, he immersed himself in these studies and then wrote several books articulating his observations and conclusions. His orientology work alone was a contribution of



2. **The 2¼-inch scope Lowell's mother gave to him on his 15th birthday.** LOWELL OBSERVATORY

3. **Lowell (front row, far left) serving as a diplomat to a Korean delegation in 1883.** LOWELL OBSERVATORY

4. **The historic telegram from Lowell to Andrew Douglass clarifying the name of the newly established observatory.** LOWELL OBSERVATORY

"real significance," as Percival's father expected of the family, but remains today a footnote in light of Lowell's far more famous work in astronomy.

## Lowell Observatory

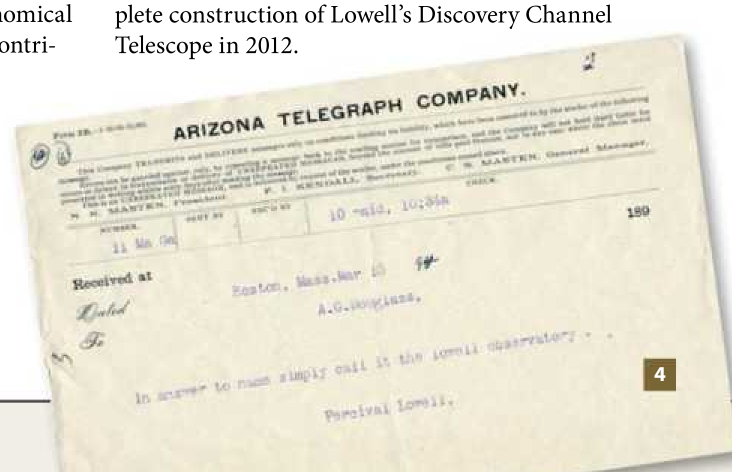
Astronomy was one of Percival's many interests during childhood. Later in life, he recalled, "Donati's Comet of 1858 was my earliest recollection. I can still feel the small boy inside me, halfway up a winding staircase, gazing with all his soul where the stranger stood." For Percival's 15th birthday, his mother bought him a 2¼-inch refracting telescope that he used to observe the polar ice caps of Mars from the roof of the family's home in Brookline, Massachusetts. For his last visit to the Far East, he carried along a newly purchased 1892-model Clark refracting telescope. All of this was prelude to his decision in 1893 to build his own observatory to study Mars, in particular the *canali* made famous by Italian astronomer Giovanni Schiaparelli.

On May 28, 1894, Lowell arrived in Flagstaff, Arizona, symbolically kicking off the final stage of his life, one that would bring him mixed doses of admiration (from the public), ridicule (mostly from the scientific community), fame, and notoriety. The 39-year-old self-taught astronomer entered the field with his typical gusto and would never leave it, even when death called on November 12, 1916. The work of the people he hired, the projects he started, and the philosophies he established at his observatory would long outlive him and establish him as an astronomical visionary. Lowell made at least eight different contributions that had far-ranging impact.

First, Lowell committed himself to building his own observatory to study astronomy and supported this decision by paying all the expenses. He chose to establish this facility independent of any university or existing observatory so that he could maintain control over all decisions, including the focus of research, purchase of equipment, and hiring of staff. In his will, he stipulated, "The Lowell Observatory shall at no time be merged or joined with any other institution." Future observatory leaders maintained this arrangement, and the private, independent nature of the observatory, with no overarching umbrella organization over it, continues to be one of its outstanding features.

Lowell's commitment to building his observatory in Flagstaff had the unanticipated impact of establishing the town as a center for scientific research. Prior to this, early surveyors through the area made a handful of scientific observations as part of their efforts to establish travel routes. Later, dedicated expeditions led by the likes of John Wesley Powell explored northern Arizona. But scientific study of the area didn't begin to mature until Lowell built his observatory, the first permanent scientific establishment in an area that now boasts dozens.

Second, toward the end of his life, Lowell established a trust to financially support his observatory in perpetuity. He devised an organizational structure patterned after his family's educational foundation, the Lowell Institute, in which a sole trustee manages the funds. Again in his will, he stated, "Ten percent of the net income shall be added yearly to the principal, and the balance of the net income shall be used for carrying on the study of astronomy, and especially the study of our solar system and its evolution." This nest egg would prove crucial to the survival of the observatory in future years, first as one of its only sources of income, and later to help balance the ledger sheets during times of reduced outside funding. In recent years, observatory leaders leveraged this trust to help complete construction of Lowell's Discovery Channel Telescope in 2012.



ARIZONA TELEGRAPH COMPANY.

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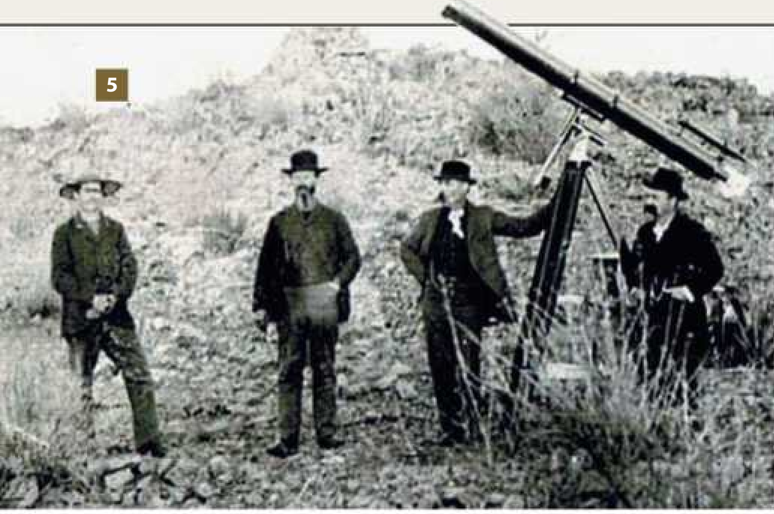
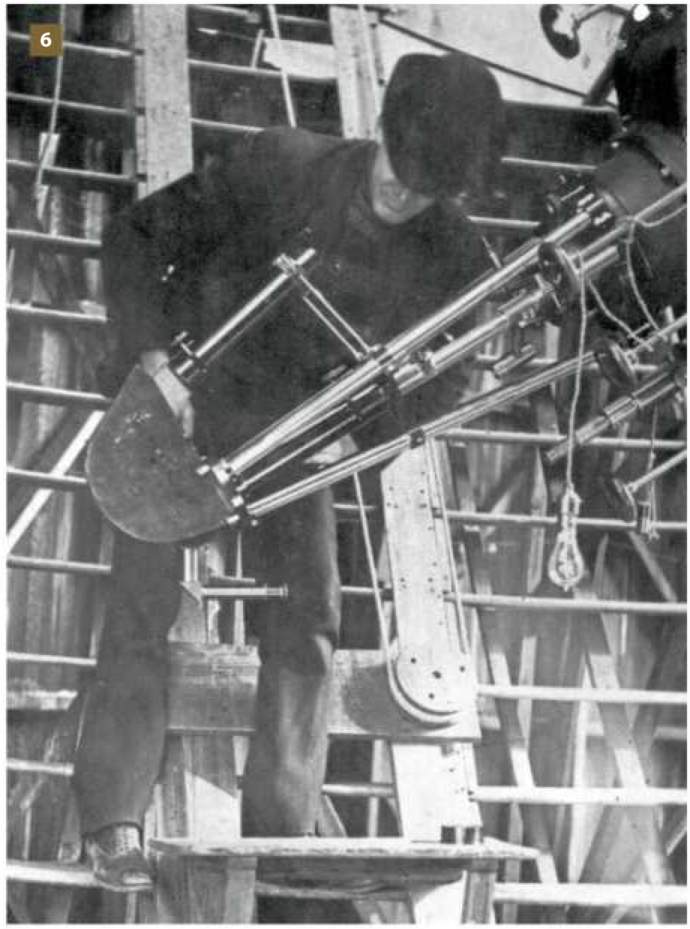
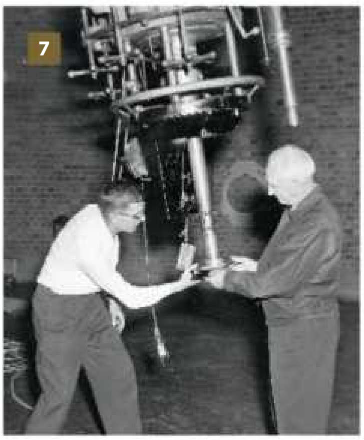
A.E.Douglass,

In answer to name simply call it the Lowell observatory.

Percival Lowell.







Third, Lowell hired some remarkable astronomers who would give the observatory credibility in scientific circles. The first was Andrew Douglass (1867–1962), who helped Lowell found the observatory. Years after being dismissed due to his criticism of Lowell's scientific practices, he founded Steward Observatory and established the science of dendrochronology, both at the University of Arizona. The Slipher brothers, Vesto Melvin (V. M.) and Earl Carl (E. C.) spent their entire professional careers at Lowell. Both served as director at some point but are remembered mostly for their scientific contributions. V. M. (1875–1969) pioneered spectrographic techniques that allowed him to, among other things, measure the radial velocities of several so-called spiral nebulae, critical to unraveling the expanding nature of the universe. E. C. (1883–1964), on the other hand, was a pioneer of planetary photography and laid the groundwork for techniques such as image stacking.

Fourth, Lowell recognized, and located his observatory based on, the need for good atmospheric conditions and dark skies for optimal astronomical observing. In his book *Mars and Its Canals*, he wrote, "Not only is civilized man actively engaged in defacing such part of the Earth's surface as he comes in contact with, he is equally busy blotting out his sky. In the latter uncommendable pursuit he has in the last quarter of a century made surprising progress. With a success only too undesirable his habitat has gradually become canopied by a welkin of his own fashioning, which has rendered it largely unfit for the more delicate kinds of astronomic work. Smoke from multiplying factories by rising into the air and forming the nucleus about which cloud collects has joined with electric lighting to help put out the stars."

Not coincidentally, his chosen home from which to observe, Flagstaff, was in its early days nicknamed the Skylight City because of the brilliance of its stars against the dark background of sky. Thus was born the community's interest in dark skies, increased by the presence of Lowell and other observatories that were later established in the area. In the 1950s, at the prodding of Lowell astronomers, Flagstaff community leaders enacted the world's first legislation concerning light pollution, and in 2001 the International Dark-Sky Association recognized Flagstaff as the world's first International Dark Sky City.

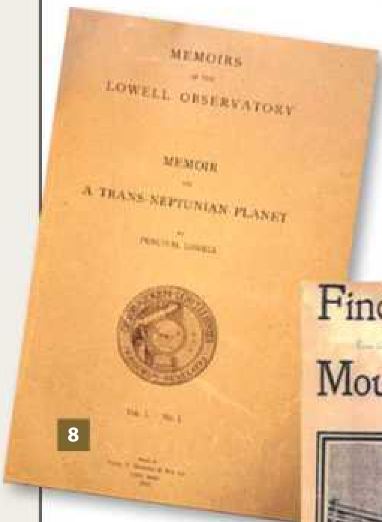
## Far-reaching research

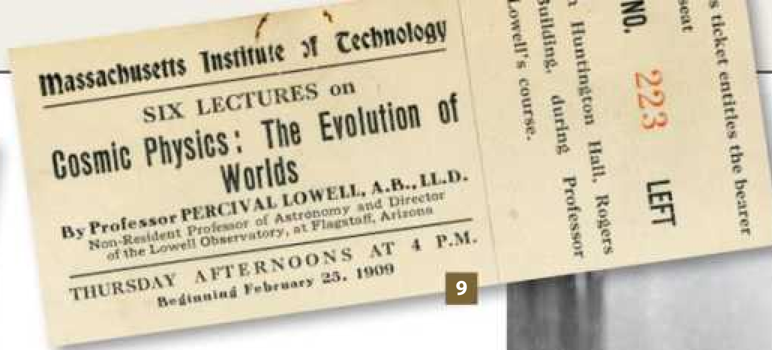
The next three contributions by Lowell focus on research programs that he started. First is the study of Mars, in support of his belief of intelligent life inhabiting that planet. Lowell was not the first scientist to observe the so-called martian canals — linear features on the planet's surface — and he was not the first person to suggest they indicated the presence of intelligent life, but he was certainly the most outspoken on this front, writing books and magazine articles and stimulating standing-room-only crowds with compelling speeches. Contrary to many popular accounts, Lowell and others who believed in the superficiality of the canals did not accidently mistranslate Giovanni Schiaparelli's term, *canali* (meaning "channels," a word implying of natural cause) to canals (implying artificiality). Rather, Lowell intentionally used the latter name to support his idea that some form of intelligent life had built them.

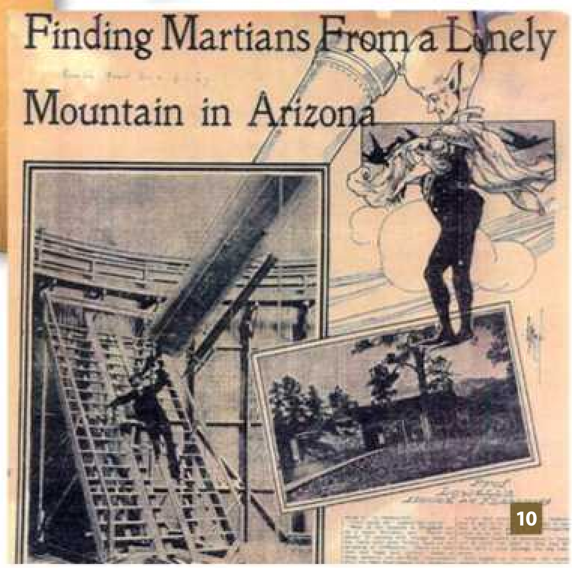
**5. Lowell Observatory's 6-inch Clark refractor is set up for testing in Tombstone, Arizona, in 1894.** LOWELL OBSERVATORY

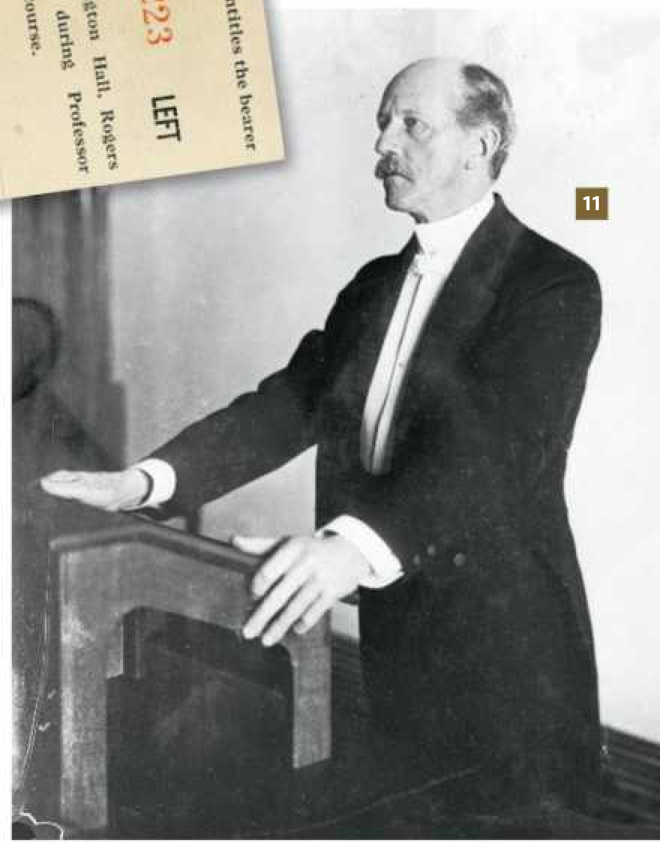
**6. One of the observatory's most important astronomers, V. M. Slipher, uses a spectrograph attached to the 24-inch Clark telescope to measure radial velocities of spiral galaxies.** LOWELL OBSERVATORY

**7. Another of the observatory's most influential astronomers, E. C. Slipher (right), with an assistant, taking pictures of Mars at Lamont-Hussey Observatory in Bloemfontein, South Africa, in 1956.** LOWELL OBSERVATORY





Finding Martians From a Lonely Mountain in Arizona



**8. Lowell's memoir about Planet X, published in 1915, in which he estimated the location of this hypothetical planet.** LOWELL OBSERVATORY

**9. A ticket from one of the many sold-out lectures by Lowell.** LOWELL OBSERVATORY

**10. One of many newspaper articles highlighting Lowell's ideas about the existence of life on Mars.** LOWELL OBSERVATORY

**11. Lowell speaking on Mars and other astronomical topics.** LOWELL OBSERVATORY

Furthermore, Lowell did not speculate much on the exact nature of this supposed life, except that it would likely be much larger than that on Earth due to Mars' weaker gravitational pull. In his book *Mars*, Lowell wrote, "The existence of extra-terrestrial life does not involve 'real life in trousers,' or any other particular form of it with which we are locally conversant. Under changed conditions, life itself must take on other forms." With his research and popular accounts, Lowell built a consciousness about life in the universe. While most scientists dismissed his ideas, the general public remained intrigued, thanks largely to subsequent writers — particularly in the burgeoning genre of science fiction — and science popularizers who, often indirectly, built stories based on Lowell's ideas. Even today, many news stories about life or water on Mars include some mention of Lowell. Last year, for instance, in reporting about NASA's discovery of water on Mars, Flagstaff's newspaper, the *Arizona Daily Sun*, led with the headline "Was Uncle Percy right after all?"

Another research program Lowell started was V. M. Slipher's observations of spiral nebulae. Lowell believed these to be protoplanetary systems, and in his theory of planetology (the evolution of planets), the gases in these nebulae would eventually coalesce to form gas planets. Lowell thus directed Slipher to observe their spectra to see if they matched those of the gas giants like Jupiter and Saturn, which would prove the link between the nebulae and planets. The spectra did not match, but the exercise allowed Slipher to detect the incredibly high redshifts of the nebulae (which astronomers now identify as galaxies).

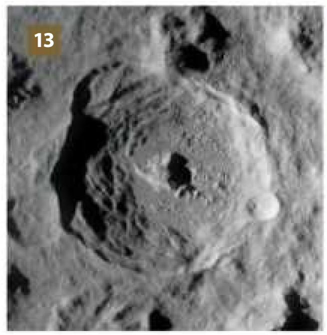
The third research program Lowell started was a search for Planet X, a hypothetical ninth planet. While astronomers later concluded that this planet, as defined by Lowell, doesn't exist (Lowell was looking for a large planet that was perturbing the orbits of Uranus and Neptune), it did lead to the discovery of Pluto 14 years after Lowell died.

In all three of these research programs, Lowell was fundamentally wrong or made assumptions that were inaccurate. Yet his conviction to carry out the programs led to other results and often to unexpected discoveries. Furthermore, by deciding on what research to pursue, without interference from outside concerns, Lowell set the standard by which the observatory would be operated, a legacy that continues today.

The last of Lowell's significant contributions was the popularization of science. He captured his sentiments on the subject in *Mars and Its Canals*: "To set forth science in a popular, that is, in a generally understandable, form is as obligatory as to present it in a more technical manner. If people are to benefit from it, it must be expressed to their comprehension." Soon after Lowell established his observatory, he invited Flagstaff residents to come and peer through the telescopes, and he became a popular speaker around the country. His engaging style captivated audiences and helped establish him as a promoter of science, a role at which many of his fellow astronomers scoffed. He was in many ways the Carl Sagan or Neil deGrasse Tyson of his time, a scientist who stepped into the spotlight to explain science.

**Kevin Schindler** *is historian at Lowell Observatory in Flagstaff, Arizona, and the author of several books about astronomy.*


# Lowell on Pluto



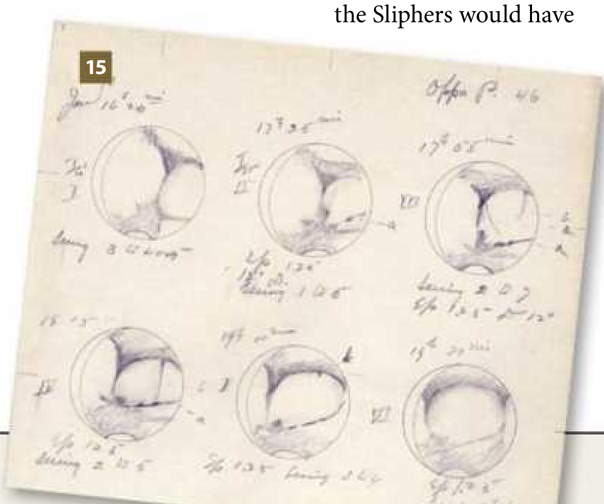
As a result of Lowell's efforts, the observatory later established education as one of its core mission components and through the years has reached millions of people during traditional on-site visits (97,000 people visited the observatory in 2015), through off-site programs (such as the Navajo-Hopi Astronomy Outreach Program, developed by astronomers Deidre Hunter and Amanda Bosh and now in its 21st year), and via media such as television, radio, and the internet (Disney, Sagan, Bill Nye the Science Guy, Leonard Nimoy, and many others have filmed educational programming at Lowell).

## A wonderful life

So what was Lowell's impact on astronomy, given the benefit of a century of hindsight? If we try to imagine, in the spirit of George Bailey, what astronomy would look like today if Percival Lowell had never entered the field, Lowell's impact was substantial. Who knows what the science landscape of Flagstaff would look like? There would be no Lowell Observatory and likely no Flagstaff Station of the U.S. Naval Observatory, which was established in the 1950s largely because of the presence of Lowell. Beyond Flagstaff, Douglass likely never would have come to Arizona and thus not established Steward Observatory, which, along with Lowell Observatory, was critical to establishing Arizona as a center for astronomical studies — one that today brings in a quarter of a billion dollars annually to the economy.

Without Lowell, who knows where Douglass and the Sliphers would have worked, and what they would have studied? Without Lowell's direction, V. M. Slipher likely would not have mastered use of the spectrograph and detected the recessional velocity of the spiral nebulae. Astronomers would have eventually made these discoveries, but probably not for years. The same goes for Pluto. Without Lowell's searches that inspired the discovery of Pluto, this small body would not have been discovered until much later, perhaps not until the 1990s, and then possibly would not have been classified as a planet. In fact, the course of planetary research and the search for life in the universe would have played out much differently. In addition, Mars likely would not have been nearly as popular a topic for science fiction writers and, later, moviemakers. The list goes on, but these are a few of the more salient examples.

Lowell craved the acceptance of his ideas by the fraternity of astronomers of his generation, but would never realize it during his lifetime. He was dismissed by many because of his apparent failings in the field, but his vision and conviction resulted in a number of exceptional discoveries and events that would fundamentally impact our understanding of the cosmos. In many cases, the results were unintentional. Yet intentional or not, they came about because of Lowell's characteristic take-action mentality and willingness to financially back programs in which he believed. Lowell wanted to make a positive impact in his field and had the conviction to follow through with his efforts, even in the face of occasional strong opposition. And with a century of hindsight, we can say that he achieved this goal and left quite an imprint on the field of astronomy.



**12. The as-yet informally named Lowell Regio on Pluto (left-hand portion of the image), observed for the first time in the New Horizons flyby of Pluto in 2015.** NASA/JHUAPL/SwRI

**13. One of several solar system features named for Percival Lowell: Lowell Crater on the Moon.** NASA/JPL/MSSS

**14. Lowell Crater on Mars, also named for the astronomer.** NASA/JPL/MSSS

**15. Drawings of Mars made by Lowell.** LOWELL OBSERVATORY


**Canon is king when it comes to astroimaging, so the author's recommendation is to look no further than a new or used camera from this reputable manufacturer. This model, the 6D, incorporates a full-frame sensor, though an APS-C sensor also will do the job.** CANON

# How to choose the right camera for the eclipse

*Tips from* Astronomy*'s photo editor could help you capture a spectacular event.* **by Michael E. Bakich**

If you've read anything I've written in this magazine or elsewhere, you know where I stand on first-time eclipse viewers trying to photograph the spectacle. If you don't know, I am dead set against it. For most of you, it will dramatically cut into the time when you should be viewing the event. And for some of you, I predict trying to capture the eclipse will ruin your experience.

But maybe I'm overstating the problem. After all, you're a tech-savvy soul brimming with confidence. And who knows? You might take that 1-in-a-million shot that will make it into *Astronomy* magazine. Frankly, your chances aren't that good, but, hey, keep hope alive.

On a more positive note, as the magazine's photo editor, I can help you figure out what features to look for if you're buying a camera for the August 21 event. But first, let me save many of you some time:

For best results, you must shoot through a digital single-lens reflex camera, or DSLR. If you plan to photograph the eclipse with your phone or with a point-and-shoot camera, you can stop reading now. Those devices will allow you to capture a memory, but little else. The graphic on page 51 shows why.

## Which sensor?

Having a larger sensor — often called the camera's chip — is one of the main reasons why you'll get much better results when you shoot the eclipse (actually, anything) through a DSLR.

You will have two choices when it comes to the sensor inside your chosen model. One is the Advanced Photo System type-C (APS-C) sensor, which has an image ratio of 3-to-2. This mimics the Advanced Photo System format developed by several film manufacturers in 1996. The size of the "C" film was 25.1 by 16.7 millimeters, which is a 3-to-2 ratio.

The second choice is a full-frame sensor, which measures 36mm by 24mm, the same size as 35mm film. The first successful commercial full-frame DSLR was the Canon 1D, introduced in 2002.

These days, professional photographers demand nothing less than full-frame sensors because they collect more light than their smaller counterparts, and that produces a better signal-to-noise ratio. This translates to a better overall image, especially if you shoot at high ISO numbers. ISO, formerly known as ASA, is the numeric equivalent to the "speed" setting on old photographic film.

The larger sensors also capture more of an image from whichever lens you choose, while smaller ones crop in on the image, producing a view with a narrower angle. For example, let's say you take a picture through a full-frame DSLR with a 20mm lens. If you took the same shot using the same lens through a camera with an APS-C sensor, the view would appear like you used a 31mm lens on the full-frame DSLR. One benefit, then, of the larger sensor is that it makes wide-angle photography easier.

The other main difference between DSLRs with the two types of sensors is that full-frame models tend to be more expensive. So, when we consider the upcoming solar eclipse, is the extra cash worth it? No. All things being equal, you will get images from APS-C sensors that will blow your mind. Why spend $2,000 or more for a

**Michael E. Bakich**, *a senior editor of* Astronomy, *will be conducting Earth's largest solar eclipse event in St. Joseph, Missouri, on August 21.*

camera (just the body; we're not adding lenses yet) when a $500 model will do?

## More megapixels?

Manufacturers measure camera resolution in megapixels, each of which equals 1 million pixels. Each pixel is a light-collecting element on the camera's sensor, so it's also the smallest unit of a digital photo. So what makes a camera a 12-megapixel model? If its chip contains rows 4,000 pixels wide and columns 3,000 pixels high, then the area is 12,000,000 pixels, or 12 megapixels.

Because of all the advertising on television and in magazines, you probably think that a sensor with more megapixels will deliver better resolution, and, therefore, a superior image. That would be true only if all pixels were the same. They're not.

Ads for cellphones often tout huge numbers of megapixels. Forty million pixels on a sensor? Wow! But wait a minute. Cellphone chips are roughly 2 percent the size of a full-frame sensor. So, to pack those millions of pixels onto such a small sensor, camera phones, and even point-and-shoot cameras, use much smaller pixels than DSLRs. Unfortunately, small pixels don't measure up. The larger pixels used on full-frame or APS-C sensors capture more light, produce better color, and have less noise.

## The camera's processor

If you're a beginning photographer, or even an experienced one who will be upgrading your camera, having a high-quality image processor will help you a lot. If you're more experienced, and especially if you shoot images in RAW format, the internal processor won't matter much to you. RAW images are just the data the sensor sees, completely unprocessed. Use this setting if you want to process the images yourself using software like Photoshop.

But if you're like most people and shoot JPEGs, the processor matters. (Side note: There's one other reason why people shoot JPEGs rather than RAW images. JPEG is a compressed format that takes up a lot less space on your camera's memory card compared with a RAW image.) Processors that produce JPEGs handle operations that can fix lighting issues and adjust other settings. They also let the camera capture images in quick succession. While this doesn't affect image quality, being able to capture images quickly can mean the difference between a good shot and a great one.

## Lens differences

The camera's lens is its eye to the universe. If it doesn't perform well, you will not be happy with your images. Cellphones and point-and-shoot cameras won't produce high-quality images because their lenses are tiny and fixed to the camera.

Manufacturers measure lenses by their aperture, which is how wide the lens can open. A wider aperture means more light. More light means you can take photos more easily where there isn't a lot of it.

"But Michael," you may ask, "aren't we dealing with the Sun here? There will be plenty of light, right?" Not during totality. The illumination will be a scant one-millionth what it was when the disk was visible. So, indeed, you do need to factor in the light-grasp of a lens.

## Eclipse considerations

So, which DSLR should you buy? Before I answer, let me tell you the first place you should look: eBay. I dialed up the giant online auction house and entered a few criteria. Frankly, I was amazed at the quality of camera body you can get for under $500 (my self-imposed upper limit for this story), and some came in significantly below that mark.

A bit less than half were new, and the others were used but seemingly in immaculate condition. And I was just surfing the "Buy It Now" options. You might get a screaming deal if you select "Auction." Be sure the seller has a good rating.

I selected Canon as my manufacturer. I'm quite familiar with Canon cameras, plus more than 90 percent of the images I receive at *Astronomy* come from that brand. As far as astroimaging goes, this manufacturer is the giant, so I suggest you look no further and go with Canon.

And like I mentioned earlier, get a camera with an APS-C sensor, though that's pretty much the default here. You won't find a new or used full-frame-sensor DSLR for under $500.

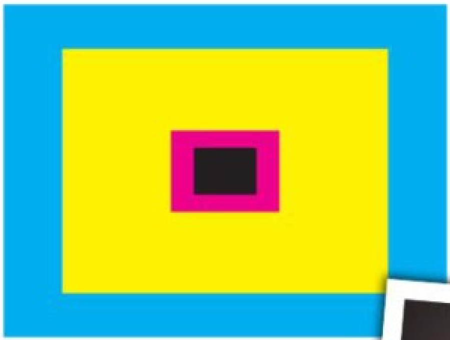
For the imaging chip, set 12 megapixels as your minimum. That will produce images with dimensions of 4000x3000 pixels, which will allow you to zoom in for your final composition, if that's what you want. I've seen Canon EOS Rebel T5 bodies for less than $300, and they sport an 18-megapixel sensor.

## Beyond the eclipse

Your choice really boils down to how much you want to spend on your new or used DSLR. I can't help you here, but I can advise you to factor in any other types of pictures you'll want to shoot. Thinking about getting into portraits? Bird or wildlife photography? Nighttime astrophotography? Each is a worthy pastime with lots of followers and lots of easily available information.

After you buy the camera, you'll have to invest in a lens (if you bought just the body) or decide whether to add a lens. With respect to the eclipse, the size of the Sun's disk in the field of view will be the main factor for you to consider.

Good luck, and be sure to send that 1-in-a-million shot to me at ReaderGallery@Astronomy.com.



**Above: This graphic shows the exact ratios of chip sizes in various cameras. The blue rectangle represents a full-frame DSLR chip. The yellow shows the APS-C sensor. The red is the average size of the sensor in a point-and-shoot camera, and the black rectangle shows the size of a cellphone chip.** HOLLEY Y. BAKICH

**Right: If you follow the author's tips, you could get a spectacular result. This image from the total solar eclipse March 9, 2016, captures one of the diamond rings plus a large prominence group at the Sun's left edge.** HAN-CHANG WENG

# Stormy skies and starry nights

*The more you know about meteorology, the better your observing will be.* **by Raymond Shubinski**

The photo at left combines aspects of meteorology and astronomy. That said, although stars are visible, this would not be a good night to set up a telescope to observe. © MARAFONA738 | DREAMSTIME.COM

You've driven for an hour and a half to your favorite dark-sky site. The apps on your phone earlier declared that the night will be clear. Your equipment is set up and ready to go. After a beautiful sunset, you finally look through the eyepiece of your telescope, only to see the stars dancing about. Out of frustration, you look for the cooler and that bottle of wine you brought along.

Welcome to our ocean of turbulent air. Both professional and amateur astronomers have experienced this problem at one time or another. No matter how well your equipment performs, in the end, it's no match for all the air above our heads and the fact that it is in constant motion.

## Atmospheric facts

According to the National Oceanic and Atmospheric Administration, Earth's atmosphere extends from sea level to about 300 miles (480 kilometers) up, where it thins and transitions to outer space.

This protective blanket of air has four major layers plus a thinner, fifth layer called the exosphere. The exosphere begins at a minimum distance of about 300 miles (480km) above Earth's surface. But it can start at twice that distance from our planet, depending on whether solar activity swells it, and continue outward several thousand miles. Our atmosphere is so thin out there that it's hard to detect, and it represents a near vacuum that fades into space, where solar wind blows the few molecules of gas away. Containing mostly nitrogen, helium, and hydrogen, with atoms spaced so far apart that they scarcely interact at all, the exosphere has no meteorological effect at all for us on the surface of Earth.

Things get more interesting in the thermosphere. It extends about 50 to 300 miles (80 to 483km) up, where it merges with the exosphere. The International Space Station orbits through this extremely low-density, weatherless region of the atmosphere. Aurorae (also known as the northern and southern lights) occur mainly in the thermosphere.

Next closest is the mesosphere, the region where noctilucent clouds (the highest clouds in Earth's atmosphere, visible only after sunset) form. The mesosphere's upper boundary, known as the mesopause, is the coldest spot "on" Earth. The temperature there can drop below –225° F (–140° C).

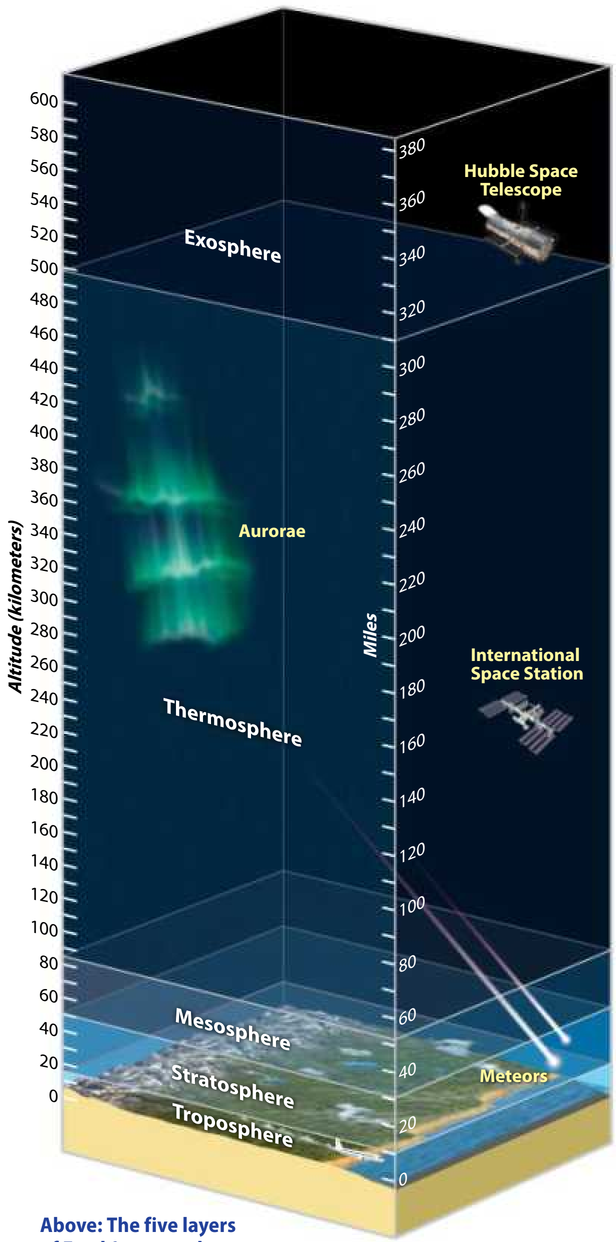
Below the mesosphere is the stratosphere. If you've ever taken an overseas flight, you may have skimmed the lower layer of the stratosphere at around 6 miles (10km) up. But don't bail out at this altitude — you'd freeze within seconds! The stratosphere is also where most meteors disintegrate and become bright.

The troposphere is the atmosphere's lowest level and the troublemaker. This layer, the densest part of atmosphere, is where the climate acts out. All ground-based observers must peer though this mass of air, water vapor, and dust.

Because all weather happens in the troposphere, observers take it into consideration when choosing an observing site. Three-fourths of Earth's atmospheric mass

**Raymond Shubinski** *is a contributing editor of* Astronomy. *Based in Las Vegas, he keeps a careful eye on how the weather will affect his observing.*

# Atmospheric divisions




**Above: The five layers of Earth's atmosphere.** *ASTRONOMY*: ROEN KELLY

**Right: These images of Jupiter, captured with the same equipment in the same location, dramatically show the difference seeing can make. The image at left was captured March 11, 2016. The image at right, taken under excellent seeing, was captured March 18.** DAMIAN PEACH

concentrates in the troposphere, making for an ever-changing soup of air that determines how well your equipment will perform.

The troposphere is constantly in motion because it's full of churning thermal cells of air with different temperatures and moisture content. The turbulence they create has a great effect on what you can see, and it also alters the quality of the image your telescope delivers, along with being the reason the stars twinkle. You can use how much they twinkle (or scintillate) to measure the "seeing" (atmospheric steadiness) on any given night.

But weather is only one factor influencing the seeing at any location. Star motions also can be affected by radiant heat from concrete surfaces, the movement of high- and low-pressure fronts, updrafts, and a host of other reasons. Achieving good seeing depends not only on the weather, but also on where you set up your telescope. Bad seeing prevents observers from spotting fine details, and it's such a critical factor that professional astronomers go to great lengths to assure good weather patterns and steady seeing.

## Folklore preceded science

Long before there was a weather service to provide current conditions, agrarian societies used observation combined with experience to make both short- and long-term weather predictions. For centuries, this folk science appeared in almanacs. The best of these were, and are still, published in America. The most famous is the *Old Farmer's Almanac*, published since 1792. The weather wisdom found in these books can be useful to amateur astronomers especially in predicting local weather circumstances.

"Red sky at night, sailor's delight. Red sky in the morn, sailors be warned." This old weather saying, like many others, is fairly accurate. You can even find a version of this idea in the Gospel of Matthew.

In the Northern Hemisphere, weather typically moves from west to east. When the Sun sets in a red sky, a high-pressure system has trapped dust particles, which scatter blue light and produce a red sunset. When this type of system moves in, it usually brings dry and pleasant weather. Observing on such a night can provide transparent and steady skies — maybe. Local variations often trump general conditions, but this is a useful rule of thumb. Observing a red sunrise, on the other hand, means the good weather has passed and the next night's observing might suffer.

Other almanac wisdom includes, "When the stars hide, soon the rain it will betide." In other words, it will become more difficult to see faint stars as the humidity increases, which usually means rain is on the way.

Another popular saying goes, "When halo rings Moon or Sun, rain's approaching on the run." Rings or halos around the Moon or the Sun indicate ice crystals in the upper atmosphere. These ice crystals refract light to create the halos and can be a strong indicator of approaching clouds and storms.

English astronomer Sir John Herschel developed a detailed chart using the Moon as a weather predictor. He created a system that indicated forthcoming weather based on the times of day the phases of the Moon occurred. It wasn't precise, but it was popular. Various sources reproduced the chart for more than a century, especially in almanacs in America.

## Scoping out a site

David O. Woodbury relates a story of the search for perfect seeing in his 1939 book, *The Glass Giant of Palomar*. In the 1930s, George Ellery Hale had pushed through the largest observatory project in history. The giant telescope was to have an objective mirror 200 inches (5.1 meters) in diameter. The location for the observatory was of extreme importance.

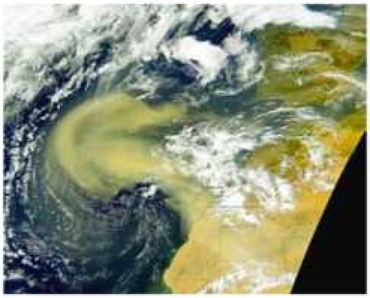
John A. Anderson, an astronomer at Mount Wilson Observatory outside Pasadena, California, worked with Hale and used student "scouts" from the California Institute of Technology to look for sites with outstanding seeing. Ten teams headed to different locations. Each had small telescopes designed by Russell W. Porter, the famous amateur astronomer and engineer.

One scout ended up in the Mojave Desert. As he set up camp, he met a local woman who assured him that it was just the place for the telescope because the stars "twinkled so beautifully." Within a few nights, the scout found that heat radiating from the desert sands created terrible seeing.

Anderson used a modified scale of his own to measure seeing in each of the chosen locations. Several such scales exist.

The most common is the Antoniadi scale, named for the Greek astronomer Eugene Antoniadi, who developed it. His scale runs from I to V, with I being perfect seeing and V being so unstable that useful observations are impossible. William H. Pickering of Harvard College Observatory developed a 10-point scale based on the diffraction disks of stars visible though a telescope. This is the scale I most often use while observing. In Pickering's scale, 1 is very bad, while 10 is nearly perfect.

In addition to affecting seeing, weather also limits telescope resolution because of the average size of the turbulent cells in the atmosphere. The late O. Richard Norton of the University of Nevada did a study demonstrating the advantages of small telescopes with regard to resolution. In fact, other studies have also shown that an 8-inch scope provides as good a resolution as much larger ones because of the average size of turbulent cells.



## Clarity

On March 5, 1983, I observed numerous objects through a 3-inch refractor. I noted in my log that the observing location was "very clear" but that there were "some signs of stormy weather all around the horizon with occasional flashes of lightning." I observed for several hours until the telescope began to fog up from increasing humidity. This is only one of the challenges all astronomers have faced since the invention of the telescope.

I also noted that seeing was rather poor, demonstrated by the fact that the stars were twinkling a lot. With the incoming weather front, turbulence was increasing. I was well away from ambient light, so the sky early in the evening was quite clear; I could see stars as faint as 6th magnitude. Double stars were hard to resolve through the scope, but extended objects such as the Orion Nebula (M42) looked fine. So, I persevered because I had learned years before not to give up (and waste all the effort of driving to the site and setting up), no matter how much the stars twinkle.

If the transparency is good, look at larger objects like nebulae as I did. On that night, however, the humidity kept increasing. Soon, I could barely discern 3rd-magnitude stars. I knew then that it was time to head home.

Home is the desert Southwest, where I have lived for many years. I am always amazed at how the

**Above: Earth's atmosphere scatters predominantly blue light when the Sun is high, giving us a blue sky. But when the Sun is near the horizon, we're viewing our daytime star through a much thicker layer of air. So sunrises and sunsets appear red because the thicker layer of air can scatter other wavelengths, like those of green and yellow, leaving a predominantly red or orange-red Sun. Sometimes, as shown in this image, only the bottom of the Sun appears red.** JAMIE COOPER

**Left: Next to rain, dust does the most damage to image quality, in some cases reducing the transparency to zero. Planetary scientists often must deal with dust on another planet as well: Mars. These images show how dust storms appear similar on the Red Planet (top) and Earth. A process called aeolian transport, which relies on wind, lifts dust particles into massive dust clouds on both planets.** TOP: NASA/JPL/MSSS; BOTTOM: NASA/GSFC AND ORBIMAGE/SEAWIFS PROJECT

**Above: Crepuscular rays are columns of sunlit air that originate at the Sun's location in the sky. They even can appear in an otherwise clear sky after sunset (or before sunrise) because they pass through gaps in distant clouds. Observers don't like to see them after the Sun sets because it means clouds lie just to the west.** MIGUEL CLARO

**Right: Occasionally, even severe weather won't pose a problem to your astronomical pursuits. While observing in Tucson, Arizona, the imager captured this lightning strike on a distant peak. The storm raged for half an hour, during which time the stars shone brightly and steadily overhead.** HOLLEY Y. BAKICH

appearance of the mountains changes not just day to day, but hour to hour. At times I can see every hard ridge and fold, and at other times, they seem soft and distant. This is due to an atmospheric affect called transparency, and it is important to skygazers as well.

Transparency is a measure of how clear the air is. It can change not only with the weather but also because of pollution levels, city lights, the amount of dust aloft, and the humidity. At night, the faintest magnitude star you can see is a good way to judge transparency. But doing so is subjective. On average, a 6th-magnitude star is the lower limit of what the human eye can detect. As always, there are exceptions. The scale for judging transparency runs from 1 to 6. If you can see 6th-magnitude stars, that would rank as a 1. At the other end of the scale, 6, you should just give up and go home; it may start to rain at any moment.

Some years ago, on an exceptionally clear night, *Astronomy* Senior Editor Michael Bakich and I were observing through the 72-inch Perkins Telescope at the Anderson Mesa site of Lowell Observatory near Flagstaff, Arizona. We experienced both phenomenal seeing and stunning transparency all night long. As a testament to the sky conditions, we could clearly see the faint apparition of the gegenschein. At some point during the night, large, dark "holes" appeared in the star fields. It took a moment for us to realize the holes were clouds!

Transparency can also be reduced by light pollution, simply by reflecting light from the bottoms of clouds. In fact, clouds as high as 6,000 feet (1.8km) can reflect city lights, distorting a beautiful night.

To mitigate the effects of weather, and in looking for the best seeing and finest transparency, astronomers have fled to the mountains. One reason is to simply get above as much of the muck and mass of the lower troposphere as possible. At just 10,000 feet (3,050m), about one-third of Earth's atmosphere already lies below an observer.

About 40 miles (64km) southwest of Tucson, Arizona, sits Kitt Peak Observatory. The complex of observatories rises to around 7,000 feet (2,130m) in altitude. However, this location is far from being free of weather worries. In 1972, Gary Ladd, one of the nation's premier Southwest landscape photographers, captured a stunning photo of a lightning storm over the 4-meter Mayall Telescope dome. Kitt Peak also gets soaked during the summer monsoons, limiting time on the instruments. So even at this altitude, they do not escape occasional bad weather.

As far back as the 1960s, astronomers began looking at the remote summit of the Hawaiian volcano Mauna Kea. Today observers work with instruments there at an elevation of nearly 14,000 feet (4,200m). Oxygen tanks are nearby for those who suffer altitude sickness. With 40 percent of the troposphere's mass below the observatories, this is an

ideal site for optical, infrared, and submillimeter astronomy. From this airy perch, astronomers watch clouds from above, not from below.

The desert of northern Chile has also become a mecca for high-tech observatories that need rarified air and stable seeing. This area of South America is one of the driest and darkest places on Earth. At altitudes of 10,000 feet (3,000m) and higher, the telescopes in this region almost have escaped the effects of weather.

For those of us who can't reach such great heights, we will continue to deal with weather and all its vagaries. Every dedicated observer has some tale of woe about well-planned nights ruined by unexpected clouds, high humidity, dust, wind, and more. Worse is taking an expensive eclipse trip, only to stand under a light rain as the Moon swallows the Sun. This happened to me during the total solar eclipse of 1991. I didn't watch the weather signs and was clouded out completely. For the upcoming eclipse August 21, millions of people will undoubtedly be praying for just a few minutes of clear skies.

## Effects far and near

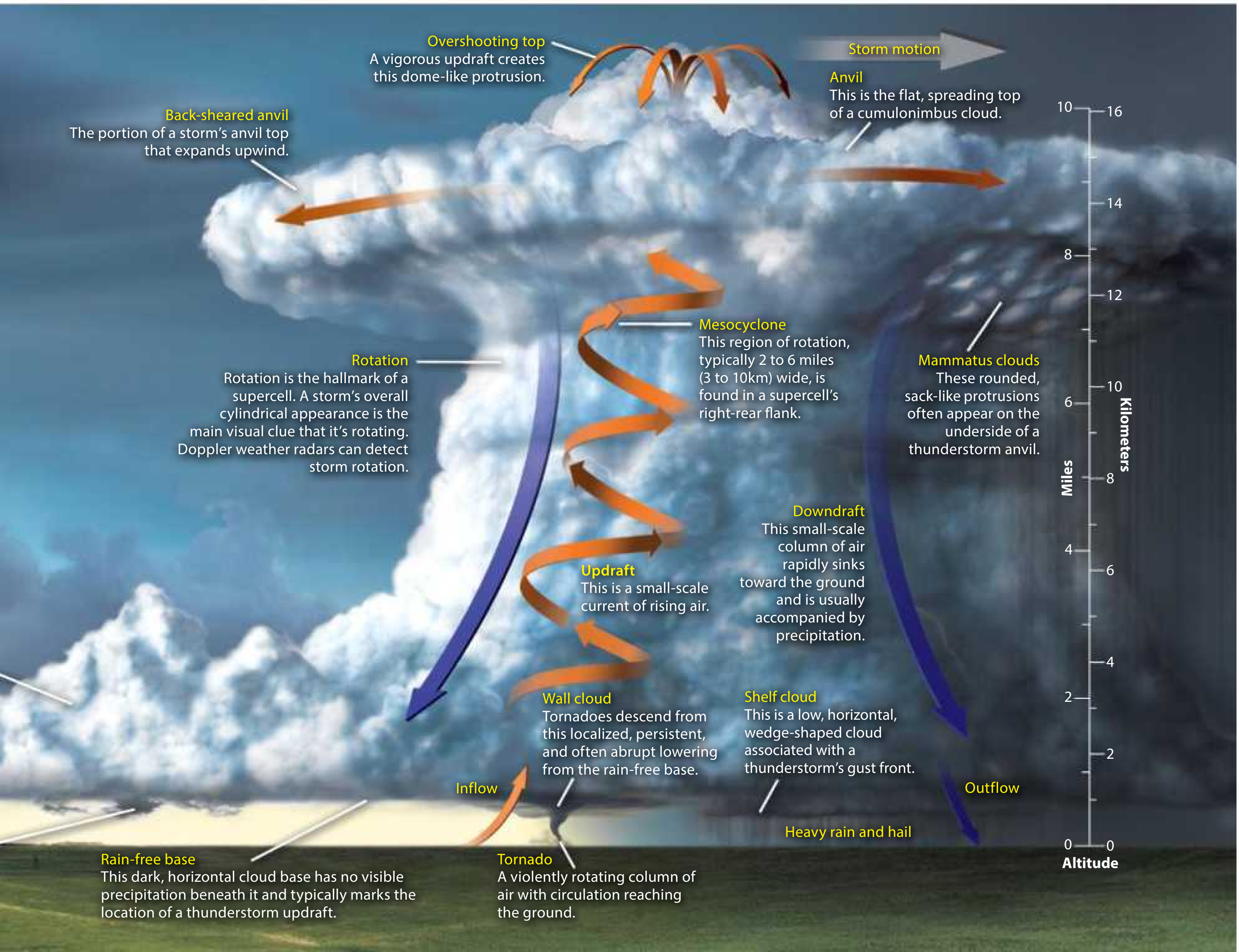
For some time, researchers pondered the question, "Can an astronomical event in space affect the weather here on Earth?" Researchers from the University of Reading, England, wondered about this. So in 2015, during a partial solar eclipse, they recruited 4,500 volunteers to make meteorological measurements. The university staff also combed through solar eclipse records going back to 1834. And they did find a correlation.

For some time, scientists have known that the temperature in the path of totality drops during an eclipse. Observers also have reported a strange "eclipse wind." Giles Harrison, professor of atmospheric physics at Reading, reported in a 2016 paper published in *Philosophical Transactions of the Royal Society* that "as the Sun disappears behind the Moon, the ground suddenly cools, just like at sunset. This means warm air stops rising, causing a drop in wind speed and a shift in its direction, as the slowing of the air by Earth's surface changes." So, weather is always a factor in observing any astronomical event.

Websites, apps, weather radios, and local weather reports can help you plan for that special night (or day) of observing. None of these sources is perfect.

So, keep a weather eye out for signs of change and be prepared to adapt to either postpone or save your session. As you do, remember the old saying: "If you don't like the weather, just wait a few minutes."

**When severe weather approaches, there's nothing else to do but secure your gear and take shelter. The graphic below shows the absolute opposite of what amateur astronomers want to experience when they observe: the components that make up a supercell.** *ASTRONOMY*: ROEN KELLY



M100 is a beautiful grand design spiral that shows a tight nucleus and closely wound spiral arms.
ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

# Skipping through the Virgo Cluster

This springtime cloud offers a galaxy hunter's paradise, with spirals, ellipticals, and oddball galaxies for every size telescope.

**by Stephen James O'Meara**

M60 and its little, close companion NGC 4647 make up an intriguing field of elliptical galaxies north-northeast of Rho Virginis. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The barred spiral galaxy M58 is similar to our Milky Way in terms of overall structure. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The Coma-Virgo Cluster is the closest large cluster of galaxies within 100 million light-years of our Milky Way. Its core region spans some 10° of sky, offering backyard telescope observers more galaxies per square degree than any other region in the heavens. The size and magnitude of this blizzard of galaxies (which includes 16 Messier objects) presents us with both an opportunity and a challenge; without the aid of go-to assistance, one could easily get lost among the multitude. The key to eliminating confusion is tackling the cluster bit by bit, using recognizable stars or the cluster's brightest members. Let's begin.

## Rho Virginis region

The core of the Virgo Cluster lies roughly midway along a line running between 3rd-magnitude Vindemiatrix (Epsilon [ε] Virginis) and 2nd-magnitude Denebola (Beta [β] Leonis). We'll start about 5° west-southwest of Vindemiatrix, at 5th-magnitude Rho (ρ) Virginis.

**M59**, **M60**, and **NGC 4647**. M59 and M60 are a conspicuous pair of 9th-magnitude elliptical galaxies only 1½° north-northeast of Rho. M60, the brighter and larger of the two, is a giant elliptical that harbors a black hole of 4.5 billion solar masses — one of the largest ever found. Visually, it is a round glow with a highly condensed core and starlike center. NGC 4647 is M60's 11th-magnitude visual companion only 2.5' to the northwest. M59 lies just 25' to the brighter galaxy's northwest and appears fainter and more elongated.

**NGC 4638**. Avert your gaze slightly south of the midpoint between M59 and M60 and look for a "spectral spindle" — the 12th-magnitude lenticular galaxy NGC 4638.

## M58 region

Return to M59, then move about 50' west and slightly north to reach **M58**. This extragalactic twin to our Milky Way appears about as bright and large as M59, but it has a more curdled-milk texture, especially toward the core, where larger telescopes may start to resolve the galaxy's two main spiral arms.

**NGC 4567** and **NGC 4568**. From M58, move ½° southwest to this intriguing 11th-magnitude galaxy pair known as the "Siamese Twins," which are in the early stages of a merger. Look for a tiny, fuzzy "V."

## M89/M90 region

**M89**. Return to M58, then head 1° northwest to elliptical galaxy M89, a highly compact 9th-magnitude glow with a sharp

The interacting galaxies NGC 4567 and NGC 4568 are sometimes called the "Siamese Twins." Over time, they will merge into one supergalaxy. KEN CRAWFORD

M87 contains a colossal central black hole weighing in at 6.6 billion suns; its core spews a jet of superheated gas.

The highly inclined spiral galaxy M90 shows tightly wound arms and a brilliant nuclear region. PAUL AND DANIEL KOBLAS/ADAM BLOCK/NOAO/AURA/NSF

nucleus. Its tight active core, which could be the remains of a dwarf galaxy that M89 consumed long ago, harbors a supermassive black hole with a mass of about 700 million suns.

**M90**. From M89 move 50' north-northeast to spiral galaxy M90. Although M90 is as bright as M89, it looks bigger and bolder, appearing as a strong oval glow elongated slightly southwest to northeast. It is a prototypical so-called anemic galaxy, whose arms do not stand out well from its disk.

## M87 region

Return to M89 and move a degree west and slightly south to **M87**. This elliptical goliath resembles an unresolved globular star cluster with a bright spherical shell that gradually condenses inward to a soft core. It contains a colossal central black hole weighing in at 6.6 billion suns. Its core also spews a jet of superheated gas at 99 percent the speed of light out to some 5,000 light-years from the core.

## M84 and M86 region

**M84** and **M86**. A 1½° skip northwest of M87 will take you to this dynamic duo of giant elliptical galaxies. You're looking for two sizable 9th-magnitude circular glows separated by a mere 17'. Each of these tremendous systems has about 400 billion stars. Through the telescope, both display a condensed core with a bright nucleus. These galaxies, along with M87, form the nucleus of the Virgo Cluster and probably all resulted from the merger of many smaller galaxies.

**NGC 4402** is a nearly edge-on spiral just 10' north of M86, seemingly adding to its apparent size. The companion's disk is being violently bowed upward and stripped of its star-forming material as it plunges into the core of the Virgo Cluster.

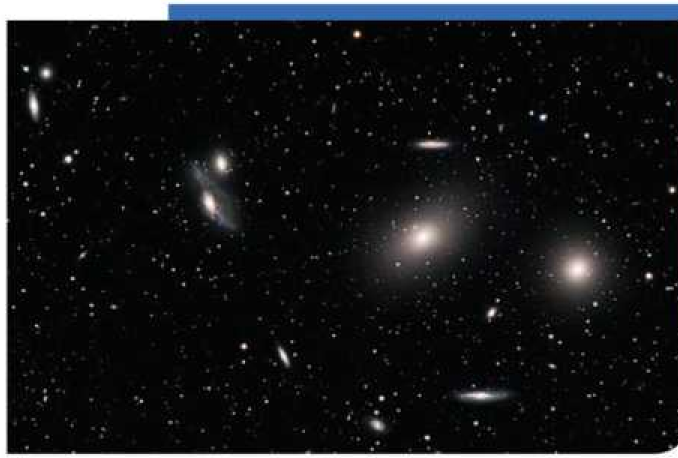
**NGC 4388**. If you imagine an equilateral triangle with M84 and M86 as the base, the 11th-magnitude spiral NGC 4388 marks the triangle's apex to the south; look for a little east-west-oriented streak of light with a central pip.

## Markarian's Chain +1

Markarian's Chain is a 3°-long curl of galaxies extending from M84/M86. Center M86 and move 20' east and slightly north to **NGC 4435** and **NGC 4438** — a pair of interacting galaxies known as "The Eyes." NGC 4438 shines at 10th magnitude as a ghostly ellipse with a central bead of light, while NGC 4435 appears as a sharp star surrounded by a tight and faint circular haze. In images, NGC 4438 looks like extragalactic roadkill — its body ripped asunder by a close encounter with another galaxy about 100 million years ago.

From NGC 4438, move 20' east to the pair of elliptical galaxies **NGC 4458** and **NGC 4461**. NGC 4461 is the brighter of the two and appears as a gently glowing spindle of light with a smooth elliptical center. NGC 4458 lies only 3' to the north, appearing as a tiny and pale circular fog. Although you cannot see it, the two galaxies lie in a streamer of diffuse intracluster

The dominant galaxy in the Virgo Cluster is the supergiant elliptical M87, which contains a huge black hole in its central region. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA



The line of galaxies called Markarian's Chain contains the bright elliptical galaxies M84 and M86 (at center and right), and many more. BERNHARD HUBL

M88 is rushing toward M87 at the core of the Virgo Cluster; it will make a close approach in 200 million to 300 million years.

**Interacting galaxies NGC 4435 and NGC 4438 are sometimes called "The Eyes." They are undergoing transformation as material from them is drawn away from the encounter.** ADAM BLOCK/NOAO/AURA/NSF

gas that the cluster itself is stripping from one of the galaxies.

A 10' skip northeast of NGC 4461 will bring you across the Virgo border and into Coma Berenices — to the 10th-magnitude elliptical gem **NGC 4473**. Look for a 2'-wide lens of uniform light; hidden within its tight core is a supermassive black hole with a mass of some 75 million suns. Its partner, the ghostly barred spiral **NGC 4477**, lies just 10' to the north-northeast, its bright core surrounded by a mottled outer envelope. The two galaxies appear to be weakly interacting.

From NGC 4477, move 25' north-northwest to the 10th-magnitude spiral **NGC 4459**. The galaxy abuts a 9th-magnitude star and appears as a tiny condensed glow surrounded by a small and tight halo of light.

Markarian's Chain ends at **M88** in Coma Berenices — the largest spiral galaxy in the Virgo Cluster. M88 is rushing headlong toward M87 at the core of the Virgo Cluster and is expected to make a close approach to it in about 200 million to 300 million years. This magnitude 9.5 bright spindle of light has a pinpoint nucleus surrounded by a mottled disk that larger telescopes can separate into a multitude of knotty arms. Images show its disk to be fractured by a maelstrom of blue star-forming regions blossoming from a scrim of reddish older stars.

**M91**. Although not an official member of Markarian's Chain, M91 lies only 50' east-northeast of M88. A 10th-magnitude barred spiral, M91 displays a modest oval disk with a dim bar ripping through its condensed core. Larger telescopes will reveal its intricate spiral structures, including knots, arcs, and loose arms that glide graciously outward from its core like those of a ballerina.

**M88 is the largest spiral galaxy in the Virgo Cluster and is rushing toward M87, where it will make a close approach to the giant elliptical a few hundred million years from now.** ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

## 28 Comae Berenices region

Our next target lies near that Virgo-Coma border and the 6th-magnitude stars 28 and 29 Comae Berenices. You may need binoculars to find these stars.

**NGC 4710** is a bright (magnitude 9.5) nearly edge-on spiral galaxy about 50' north-northeast of 29 Com. Look for a thin spindle of light oriented north-northeast to south-southwest, with a delicate bulge. Concentrate on the bulge; Hubble Space Telescope images have shown this bulge to have a ghostly X-shaped glow similar to that of our own Milky Way. What's most interesting is that this icon of galaxy formation reveals that its center assembled slowly long after the galaxy's disk had formed.

## 6 Comae Berenices region

We now skip over to the western edge of the cluster's core region, starting at 5th-magnitude 6 Comae Berenices.

**M98**. Center 6 Com in your telescope and move ½° west to the nearly edge-on spiral M98. The 10th-magnitude galaxy shines as a refreshingly bold ellipse of light with a sharp starlike core. Large telescopes will reveal a wealth of dust paths and seemingly warped spiral features.

**M99**. From M98, make a generous 1½° skip to the southeast, where you'll find the 10th-magnitude barred spiral M99. Its pale form contains a beadlike nucleus set inside a round, unassuming outer glow. Larger telescopes will reveal its two brightest arms and some graceful knots that look like diamonds balanced on a fingertip.

**NGC 4302** and **NGC 4298**. Look about 20' east of M99 for this pair of spiral galaxies that look like a cricket bat and ball. NGC 4302 is an 11th-magnitude nearly edge-on spiral (oriented northwest to southeast) that looks like a tiny anemic

**M98 is a 10th-magnitude galaxy oriented nearly edge-on to our line of sight. It has a starlike core.** ADAM BLOCK/NOAO/AURA/NSF

**The face-on barred spiral M91 makes a pretty sight in moderate-sized telescopes.** ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

**The beautiful barred spiral M99 has a bright, beadlike nucleus and is one of the favorite Virgo Cluster targets for many observers.** ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

streak, while the 12th-magnitude face-on spiral NGC 4298 is but a minuscule fuzzy dot to its west.

**M100**. Return to 6 Com and move 2° along a northeast-trending chain of stars to the magnitude 9.4 grand design spiral M100. Its pale round form will show two spiral arms through modest to large telescopes.

## 11 Com region

We now move to the Virgo Cluster's core northern region, which surrounds the 5th-magnitude star 11 Comae Berenices.

**NGC 4293** is a beautiful 10.5-magnitude lenticular only 35' north-northeast of 11 Com. This phantom ellipse with a diffuse central lens (oriented east-northeast to west-southwest) has structure that appears similar to that of M98 as seen through a large telescope.

**M85** and **NGC 4394**. Return to 11 Com and then move a little more than 1° east to M85 — a 9th-magnitude face-on lenticular galaxy interacting with an 11th-magnitude barred spiral about 8' to the northeast. M85 is a powerfully glowing oval mass with a distinct core; NGC 4394 is but a delicate thought of elliptical light. Do you see a blue coloration in M85?

**NGC 4450**. This 10th-magnitude spiral galaxy lies about 1½° southeast of M85. Look for a conspicuous oval glow (oriented north to south) with a bright circular core and starlike nucleus that harbors a supermassive black hole.

## 20 Virginis region

Once again we return to Rho Virginis, before sweeping 2° west to 6th-magnitude 20 Virginis.

**M49**. To find this enormous elliptical galaxy, you'll need to skip 2½° southwest of 20 Vir. Look for a very compact and conspicuous 8th-magnitude glow nestled between two 6.5-magnitude stars. High powers reveal a bright nucleus surrounded by a tight inner core and a diffuse halo. The galaxy is the nucleus and grand pooh-bah of a subcluster of galaxies within the Virgo Cluster. It is a voracious cannibal of smaller galaxies and harbors a supermassive black hole some 565 million times more massive than our Sun.

## Vindemiatrix region

We end our journey with a stunningly thin galaxy at the cluster's far eastern core region near 3rd-magnitude Vindemiatrix.

**NGC 4762** is a perfectly edge-on lenticular galaxy about 2° west and slightly north of Epsilon Virginis. This sharp needle of light (oriented northeast to southwest) spans about 4' in length and has a bright bulge, tapered core, and starlike center. The razor-sharp galaxy has warped tips, indicating it may have cannibalized one or more of its neighbors over time.

I hope you've enjoyed skipping through the core of the Virgo Cluster and that these descriptions have made it easier to manage. We have only touched the bright surface of this deep and mysterious wonder — the largest and most explored galaxy cluster in the nearby universe.

**Stephen James O'Meara** *is a contributing editor of* Astronomy, *a frequent contributor, and author of many books on astronomical observing.*


# Grab **Explore Scientific's 80mm APO,** and go!

*An innovative design lets you easily switch between high-quality photography and satisfying visual observing.* **by Glenn Chaple**

In the past, my only experience with apochromatic refractors was with an occasional cursory glance through the eyepiece of one set up at a star party. For this reason, I was eager to test-drive Explore Scientific's Triplet Essential Series 80mm Apochromatic Refractor ED80.

I was well aware of the incredibly sharp optics delivered by APOs (and of Explore's great reputation with them), but I've been skeptical of their typically short focal ratios. What would be the capability of an 80mm scope (whose lens measures a scant 3.15 inches in diameter) with a focal ratio of just f/6?

## Improvising a mount

First, I had to get the ED80 up and running, not an easy task because the model I tested came with just the optical tube assembly — no mount, finder, or eyepieces. The last was no problem because this scope accepts both 1¼" and 2" eyepieces. The mount was a different matter. The ED80 comes with a standard Vixen dovetail plate. Standard to most amateur astronomers, but I didn't have a match for it. Seems like I need an upgrade.

Anyway, I made a quick trip to a local hardware store looking for anything (hose clamps, nuts and bolts, etc.) that would let me affix the scope to one of my equatorial mounts. I finally settled on that universal of all fixer-uppers: duct tape. Not pretty, but it worked. (In case you're wondering, I wrapped paper around the tube first so the tape didn't leave a residue.) None of my finders was compatible with the ED80


**With a tube only 15 inches (38 centimeters) long and a weight of only 7.5 pounds (3.4 kilograms), Explore's 80mm refractor is a great example of a grab-and-go telescope.** ALL IMAGES: *ASTRONOMY*: WILLIAM ZUBACK

Explore Scientific's ED80 comes with a dovetail, two-speed focuser, and 2" diagonal. Just attach it to a mount, add an eyepiece, and you're ready!

either, but a green laser pointer fit into the finder notch, and I was ready to go.

## Initial confusion

First light was the traditional first stop for most scopes — the Moon. The images were as razor sharp as I'd expected without the usual color distortion that hampers traditional refractors with two-element lenses. From the Moon, I moved to Saturn. Atmospheric turbulence due to the planet's low altitude distorted the image, but at times the Cassini Division really stood out. Not bad for a 3-inch scope.

There seemed to be a problem, however. With most of my eyepieces, the focuser (a smooth, two-speed rack-and-pinion version) would reach its back limit before I could obtain a sharp image. I resorted to slowly raising each eyepiece until the image became sharp, and then securing it with the eyepiece-holding screw. The following day, I figured out the focusing problem.

When I unpacked the ED80, I noticed there wasn't a user's manual. Without one, I was unable to identify a pair of threaded metal tubes that came in the box. Thinking about them and my dilemma, I realized they were tube extenders. Sure enough, when I fit one between the main tube and the focuser, that solved my problem.

Actually, by including extension tubes for visual use, Explore solves a common photographic problem: not enough in-focus travel. Camera CCD chips sit at the back of the units, so you have to really crank the telescope's focuser inward for a focused image to fall on the chip. By making its scope shorter, Explore avoided this problem, and a simple addition lets users scan the heavens visually. This has the added benefits of making the model shorter and lighter, real considerations when you want to travel to observe.

## Under the sky

The next night, I really put the ED80 to work. I began with Epsilon (ε) Lyrae, the famous Double Double. Using an eyepiece that would normally notch this system with the long-focus refractors I'm familiar with didn't provide the necessary magnification. So I changed to a 5mm orthoscopic, an eyepiece I rarely use because the images are sharp only on nights of exceptional seeing. With a resulting 96x, the two stellar pairs were just resolvable. Then I really went nuts. Or so I thought.

I switched to a 3.2mm planetary eyepiece that upped the magnification to 150x, which approached the theoretical upper limit for a 3-inch scope. Now the Double Double was beautifully resolved with each star displayed as a pinpoint. But I wasn't finished yet.

On a whim, I placed the 3.2mm eyepiece into a 2x Barlow lens to achieve 300x — way beyond the supposed magnification limit for a 3-inch. When I gazed into the eyepiece, the four members of the Double Double showed surprisingly well, leaving me to wonder what this scope might do on a night of optimal seeing conditions. I have no doubt the ED80 can achieve its advertised resolving limit of 1.45".

I then turned to a trio of popular Messier objects — the Wild Duck Cluster (M11), the Hercules Cluster (M13), and the Ring Nebula (M57). I wasn't disappointed. At 150x, M11 was a superb sight, M13 was partially resolved, and the Ring Nebula actually appeared ringlike. The Ring did appear faint, but I reminded myself that I was working with a 3-inch scope under suburban skies with a 5th-magnitude visual limit.

On the third evening, I decided to test the magnitude reach of the ED80. (Specs claim a limiting magnitude of 12.) Working with an American Association of Variable Star Observers chart of the long-period variable RY Cephei, I was able to obtain a steady view of a magnitude 12.1 star and caught fleeting glimpses of one listed at magnitude 12.5. The little APO passed the test with flying colors!


The front lens of the ED80 is a 3.15-inch (80 millimeters) air-spaced triplet with a focal length of 480mm and a focal ratio of f/6.

## PRODUCT INFORMATION

**Explore Scientific ED80**
**Type:** Apochromatic refractor
**Aperture:** 3.15 inches (80 millimeters)
**Focal length:** 480mm
**Focal ratio:** f/6
**Tube length:** 15 inches (381mm)
**Weight:** 7.5 pounds (3.4kg)
**Included:** Vixen-style dovetail plate, 2" star diagonal with 1¼" adapter, photographic extension rings
**Price:** $699.99
**Contact:** Explore Scientific
621 Madison Street
Springdale, AR 72762
[w] www.explorescientificusa.com
[t] 866.252.3811

## The bottom line

Overall, the performance of Explore Scientific's Essential Series 80mm Apochromatic Refractor was nearly flawless. My experience with it certainly sold me on this type of optical configuration. Small and portable, it's an ideal grab-and-go telescope.

It's also extremely versatile, able to capture wide-field views spanning several degrees while also providing the high-power punch to tease out lunar and planetary detail and split close double stars. And in the future, I'll have the proper mount for it!

**Glenn Chaple** *is a longtime unrepentant lover of astronomy equipment and a contributing editor and columnist for* Astronomy.

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

# Telescopic sprites

Try detecting these small plasma discharges.

One of the most electrifying experiences in visual observing is catching sight of something you don't expect — and also can't explain.

Many of us are familiar with unexpected events, like an exploding meteor or a vivid aurora. Although we cannot predict these events precisely, we can maximize our chances of seeing one by looking skyward when, say, there's a meteor shower or solar storm. In time, constant vigilance will reward our efforts.

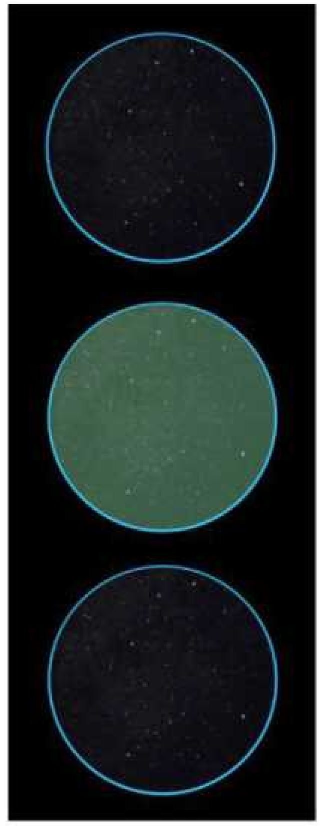
But what of the unexplained? Ah, here we have an uncommon beast that can lead to nights of research, speculation, and, in the end, head scratching. This happened to me the night of November 1, 2016.

## A plasma flow?

In northern Botswana, November usually ushers in the rains, leading to a high probability of dramatic thunder and lightning storms over this country in southern Africa. These powerful events march across the flat and spartan landscape, tossing brilliant bolts and creating rolling waves of guttural thunder. Such conditions — when the storms are well in the distance and stars are visible in clear skies above the distant thunderheads — are excellent for observing sprites.

Sprites are luminous discharges that can occur above large thunderclouds, 30 to 60 miles (50 to 100 kilometers) high. They're caused by atmospheric gravity waves that grow in the electric fields produced by lightning strikes. They can create bizarre naked-eye phenomena that look like giant ghostly carrots or jellyfish. The show is over in milliseconds, and it can leave you wondering if you need medical attention. I discussed the naked-eye view of these celestial flashcards in my June 2010 "Secret Sky" column. But what about the telescopic view?

On the evening of November 1, 2016, I went out with my 3-inch f/7 refractor and, using a magnification of 22x, swept the northeastern sky for galaxies. The horizon was lined with distant thunderheads, but my search took me over them to an altitude of about 25°. Amorphous sheets of distant lightning occasionally flashed, uniformly brightening the field of view. At one point, I decided to take a break and target the lightning itself through the telescope. After a few flashes, I saw a light phenomenon that amazed and perplexed me.



These through-the-eyepiece images show how distant lightning (sometimes erroneously called "heat" lightning) appears. ALL IMAGES: STEPHEN JAMES O'MEARA

A pale luminescent cloud flashed through the field of view from the bottom (the direction of the horizon) upward. It did not fill the field like distant lightning, and it was not uniform. What I witnessed covered only part of the field of view. It looked like pale plasma with an irregularly round outline. The "plasma" moved like a curl of smoke through air. The whole phenomenon was over in a breath, and I wondered if I had seen a section of a sprite.

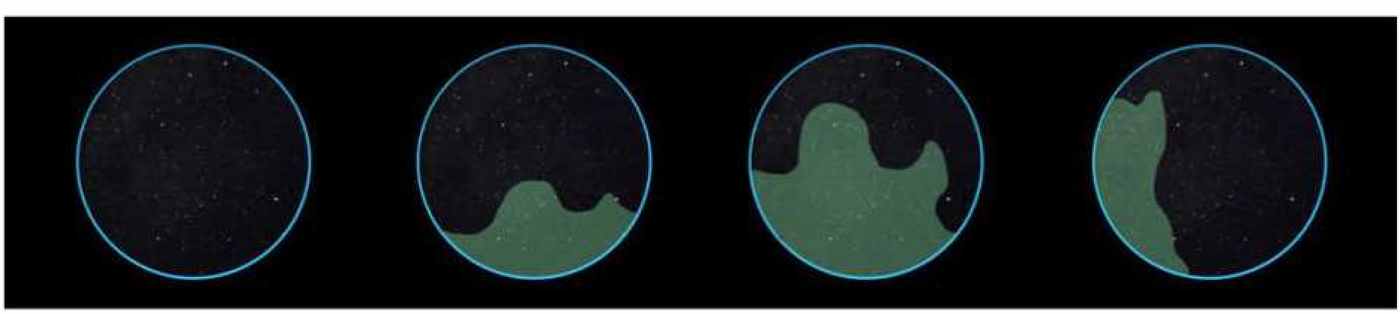
## Telescopic imaging

Observers have been imaging sprites since 1989. Much research has focused on the downward tendrils of the carrot or jellyfish structures. But as early as 1996, Davis Sentman and colleagues at the Space, Telecommunications, and Radioscience Laboratory at Stanford University reported sprites with isolated patches (a few kilometers wide) that resemble plasma beads and balls. They also detected upward propagating explosions known as "fireworks structures."

Did I witness a segment of these plasma fireworks or some other plasma feature visually through the telescope? In a 2015 issue of *Nature Communications*, Ningyu Liu of the Florida Institute of Technology, who researched sprites as gravity waves, noted that intense lightning could be causing dim glows in the upper atmosphere that are rarely detected.

Have you witnessed a strange or rare visual phenomenon associated with sprites? As always, let me know what you see, or don't see, at sjomeara31@gmail.com.

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



While observing the stars above a distant lightning storm, the author saw this ghostly phenomenon flash across the field of view of his 3-inch refractor at low power. The glowing cloud had well-defined edges against the starry background. Was it sprite-related? He created this image by overlapping a computer-generated sketch of the sprite over a photo of a star field.

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

OBSERVING**BASICS**

BY GLENN CHAPLE

# Trekking the terminator

Savor the sights of a First Quarter Moon.

In the past, I've railed about the inconsistency in lunar phase nomenclature. Why do people call a seven-day-old Moon "First Quarter" and a 14- to 15-day-old Moon "Full"? If we label the evening phases according to the sunlit fraction seen from Earth, a seven-day-old Moon would be a Half Moon, and a 14- to 15-day-old Moon would be Full. But by the portion of orbit covered, they become First Quarter and Half.

The first way of thinking makes more sense to me. Most people call a seven-day-old Moon "Half" anyway, and we all agree that the 14- to 15-day-old Moon is Full. We could complete the scenario by calling a three- or four-day-old Moon "Quarter" and the 10- to 11-day-old Moon "Three Quarters." The latter would eliminate "gibbous," a word that bewilders many beginners.

Relax, purists. I'm not going to petition astronomers to rename the phases of the Moon. Instead, I'm going to petition you to go outside with your telescope and spend an evening exploring the First Quarter Moon (or Half Moon, if you're more poet than astronomer). This month's First Quarter Moon occurs April 3, with subsequent ones May 2, June 1, June 30, and July 30.

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

A perfect First Quarter Moon would see the Moon's line of 0° longitude aligned precisely with the terminator, the dividing line between lunar day and night. Because the Moon wobbles side to side as it orbits Earth (an effect called libration), this rarely happens. As a result, features positioned along the terminator vary from one First Quarter Moon to the next.

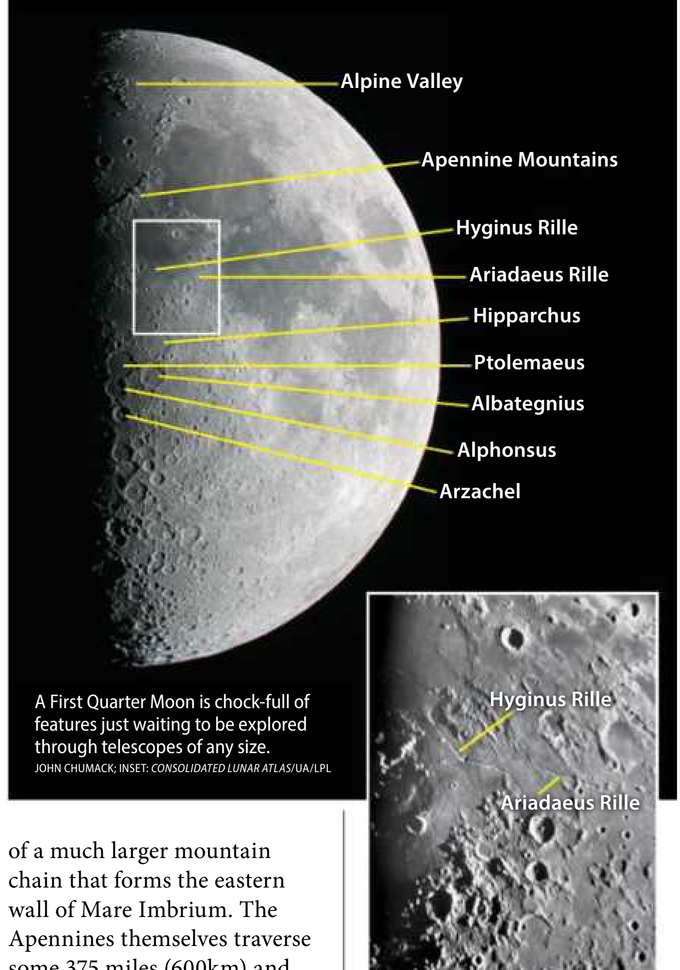
Here's a rundown of some notable First Quarter sights. All lie near 0° longitude and are within range of any backyard telescope operating at magnifications of 50x or higher. If you can't see a feature at First Quarter, chalk it up to libration and try again the next evening.

## Alpine Valley

Starting at the lunar north pole and working south along the terminator, you'll find a noticeable gash in the lunar Alps. This is the Alpine Valley, which extends about 110 miles (180 kilometers) long and 6 miles (10km) wide. Astronomers used to think a glancing blow from a large projectile created this feature, but they now believe it's the result of tectonic movement in the lunar crust.

## Apennine Mountains

About a third of the way down the terminator, you'll encounter what is arguably the most rugged First Quarter feature: the Apennine Mountains. This magnificent range is part of a much larger mountain chain that forms the eastern wall of Mare Imbrium. The Apennines themselves traverse some 375 miles (600km) and include peaks as high as 16,000 feet (5,000 meters).




A First Quarter Moon is chock-full of features just waiting to be explored through telescopes of any size.
JOHN CHUMACK; INSET: *CONSOLIDATED LUNAR ATLAS*/UA/LPL

## Hyginus and Ariadaeus rilles

Halfway down the terminator are the Hyginus and Ariadaeus rilles, visible as relatively straight hairline cracks. You'll need to boost the magnification to 100x or higher for a good view. The 135-mile-long (220km) Hyginus Rille lies closer to the terminator and is shaped like a wide-open "V" bisected by the crater Hyginus. The similarly long Ariadaeus Rille resides farther east and runs in an east-west direction. Like the Alpine Valley, these features appear to be a product of faulting in the lunar crust.

## A quintet of craters

We can't leave the Moon without examining some of its craters. South of the lunar equator and straddling 0° longitude are five of our satellite's most prominent. To the east lie Hipparchus and Albategnius — a pair of giants, each large enough to hold the state of Rhode Island with room to spare. Hipparchus, the more northerly of the two, is much older, its rim greatly eroded by eons of bombardment. Slightly smaller Albategnius has a loftier rim and sports a central peak.

Just west of these giants and visible at First Quarter when lunar libration allows is an eye-catching trio of (north to south) Ptolemaeus, Alphonsus, and Arzachel. Ptolemaeus appears similar to Hipparchus, and it's about the same size, too. Alphonsus is slightly smaller and contains a central peak. So does Arzachel, the smallest of the five at 60 miles (95km) in diameter. It also is the youngest of the three and by far the most rugged and spectacular.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Solar eclipse — from Jupiter!

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# NEW PRODUCTS

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

## Solar filter

**DayStar Instruments**
**Warrensburg, Missouri**

DayStar's Camera Quark adapts a manually focusable Nikon or Canon mount lens to a DayStar Quark Hydrogen-alpha filter. Then you can use the lens-to-body adapter to photograph the Sun. You can also choose to use the 1¼" eyepiece adapter to view visually through the lens. Both the adapter and the eyepiece come with the filter.

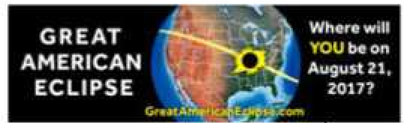
**Price: $1,095**
**[t] 866.680.6563**
**[w] www.daystarfilters.com**

## Android software

**United Soft Media**
**Munich, Germany**

United Soft Media's Redshift products help you identify what's in the sky, follow spacecraft, and even explore alien planets. The Android app, available on Google Play in 10 languages, provides detailed information on astronomy and reminds you about upcoming celestial events.

**Price: $9.99**
**[t] 49.89.29088.161**
**[w] www.redshift-live.com**


## Car magnet

**GreatAmericanEclipse.com**
**Santa Fe, New Mexico**

GreatAmericanEclipse.com has created a way for you to announce the upcoming total solar eclipse without saying a word. You can place this magnet on cars, refrigerators, filing cabinets, and more. The magnet has a UV coating so it won't fade, and it leaves no sticky residue. Quantity discounts are available.

**Price: $3**
**[e] greatamericaneclipse@gmail.com**
**[w] www.greatamericaneclipse.com**

## Historical replica

**Vixen Optics**
**San Clemente, California**

Vixen's Isaac Newton's Original Reflector is a limited-edition, fully operational 2.6-inch (70 millimeters) f/4 handmade telescope that replicates Newton's telescope on the outside while still using modern optics. Vixen includes 10mm and 20mm 1¼" eyepieces.

**Price: $549**
**[t] 949.429.6363**
**[w] www.vixenoptics.com**

SEE REPORTS ON 350+ PRODUCTS AT **www.Astronomy.com/equipment.**

MARKETPLACE

## INDEX *of* ADVERTISERS



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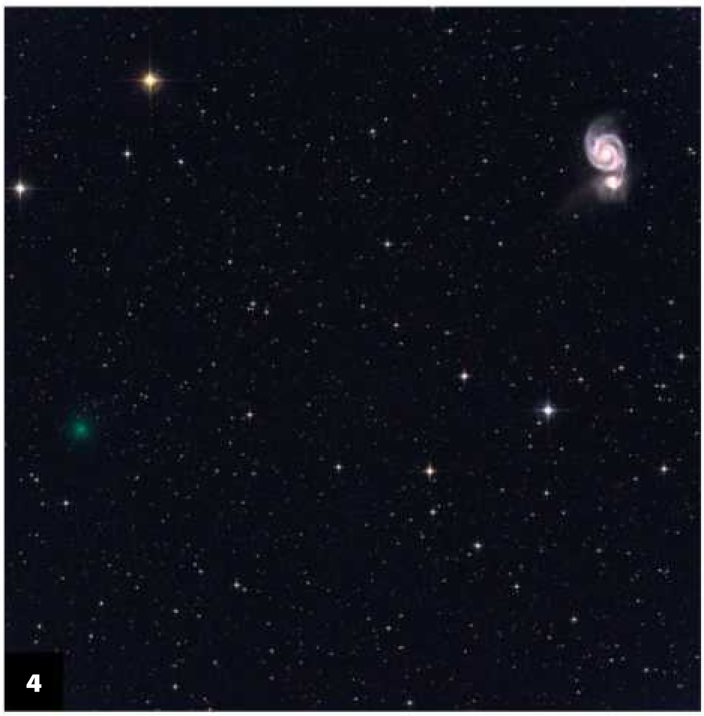
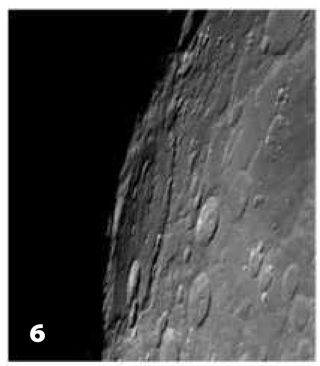
1

**1. IT'S NOT A COMET**
At center is Trumpler 5, an open cluster of golden stars some 3 billion years old. The Cone Nebula and the Christmas Tree Cluster (NGC 2264) are at the upper left, and reflection nebula IC 2169 is at the bottom right. The small object at lower left isn't a comet, but rather Hubble's Variable Nebula (NGC 2261). *• Lynn Hilborn*

**2. DUSTY CURTAIN**
Although you can spot spiral galaxy NGC 7497 in Pegasus easily enough in this image, some of its light doesn't penetrate interstellar dust in the Milky Way. The cloud, known as Magnani, Blitz, and Mundy 55, lies 800 light-years away, while the galaxy floats some 60 million light-years away. *• Scott Rosen*

2





**3. CAROLINE'S ROSE**
English astronomer Caroline Herschel discovered open cluster NGC 7789 in 1783. It lies some 8,000 light-years away and has a diameter of 50 light-years. All the stars in NGC 7789 formed at the same time, but the more massive ones have evolved into red giants in the billion and a half years since the cluster's birth. • ***Behyar Bakshandeh***

**4. ICEBALL AND SPIRAL**
On November 30, 2016, as Comet NEOWISE (C/2016 U1) passed through Canes Venatici, this photographer captured it near the Whirlpool Galaxy (M51). The comet's green glow is easy to pick out against the mostly white stars. • ***Gerald Rhemann***

**5. SKY CHEMISTRY**
This panorama shows the night sky at the photographer's chosen campsite in the Himalayas, on the border between China and Bhutan. The yellowish-green light is airglow, a weak emission from atmospheric gases like nitrogen and oxygen. Airglow appears brightest at altitudes of 10° to 15°. • ***Jeff Dai***

**6. DEPRESSED REGION**
Sporting a diameter of 188 miles (303 kilometers), Bailly Crater is the largest such feature on the Moon's nearside. It lies near our satellite's southwestern edge and testifies to 3 billion years of impacts. • ***Brian Ford***

**7. MOST TRANQUIL**
Lucy (the horse) poses calmly beneath a worthy group of celestial objects. The bright crescent of the Moon cradles our satellite's dark portion, here illuminated by earthshine. At its right is brilliant Venus, blazing at magnitude –4.0. Above Venus, magnitude 3.0 Pi (π) Sagittarii glows. At lower left, just above Lucy, Mercury shines at magnitude 0. • ***Jared Bowens***

**Send your images to:**
*Astronomy* Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

BREAK
THROUGH

## Float like a butterfly

Ultraviolet radiation pouring from the hot, young stars in this cloud of gas and dust excites its hydrogen atoms into incandescence. Cataloged as N159, the glowing nebula belongs to the Milky Way's biggest satellite galaxy, the Large Magellanic Cloud. Intense star formation takes place throughout N159, a region that spans more than 150 light-years. Scientists suspect that the small, butterfly-shaped gas cloud known as the Papillon Nebula (arrow) cloaks the early stages of a particularly massive star's birth. Astronomers captured this view with the Hubble Space Telescope's Advanced Camera for Surveys. ESA/NASA/HUBBLE

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

# June 2017: Saturn dazzles all night

As darkness falls in June, **Jupiter** dominates our view of the heavens. Shining at magnitude –2.2, it appears twice as bright as any other point of light in the evening sky. The giant planet climbs highest in the north shortly after 8 P.M. local time in early June, reaching the same point about a half-hour earlier with each passing week. It resides among the background stars of Virgo the Maiden, between 3° and 4° southeast of magnitude 2.7 Gamma (γ) Virginis and roughly 10° northwest of 1st-magnitude Spica.

Jupiter is a great telescopic sight when it rides so high in the sky. Notice its obviously flattened disk, which spans 39.2" across the equator but just 36.6" through the poles in mid-June. You also should see a series of alternating bright zones and darker belts running parallel to the planet's equator. Jupiter's four bright moons — Io, Europa, Ganymede, and Callisto — also show up through any telescope as long as none of them is passing in front of or behind the planet's disk.

Shift your gaze toward the eastern sky after darkness falls and you'll immediately spot **Saturn**. The ringed planet reaches opposition and peak visibility June 15. It then shines brightest, at magnitude 0.0, and remains visible all night. Saturn lies in Ophiuchus the Serpent-bearer, directly below the more familiar shape of Scorpius the Scorpion. The planet appears noticeably brighter than any star in its vicinity.

Saturn climbs nearly overhead around midnight local time, though it's a magnificent sight through any telescope from around 9 P.M. to 3 A.M. The planet's disk measures 18" across at opposition while the rings span 42" and tip 27° to our line of sight. This large tilt — the biggest at opposition since 2003 — means that even small telescopes will deliver splendid views of the planet and its rings. You'll also see Saturn's giant moon, 8th-magnitude Titan.

Our final evening planet provides a greater challenge. **Mars** lurks low in the northwest after sunset in early June and sets during twilight. The planet glows at magnitude 1.7 and won't be easy to spot against the bright background. Use binoculars and scan for it one field of view above the horizon about 30 minutes after sundown. Mars disappears into the Sun's glare by mid-June as it makes its way toward solar conjunction in late July.

Although both Jupiter and Saturn appear prominent, they pale in comparison to **Venus**. The brightest planet shines at magnitude –4.5 in early June, fading to magnitude –4.2 by month's end. It dominates the morning sky from the time it rises before 4 A.M. until near daybreak. The background stars of its host constellations — it crosses parts of Pisces, Cetus, Aries, and Taurus during June — pose little competition.

Venus reaches its peak at greatest elongation June 3, when it lies 46° west of the Sun and climbs 25° above the northeastern horizon by the start of twilight. It's always worth viewing the inner planet through a telescope around this time. Venus appears 24" across and approximately half-lit during June's first week. By month's end, the planet has shrunk to 18" in diameter and it shows a distinctly gibbous phase.

Look well below Venus in early June and you should see **Mercury**. On the 1st, the innermost planet lies about 10° high in the east-northeast 45 minutes before sunrise. Shining at magnitude –0.4, it easily pierces the twilight. Use a telescope to see Mercury's 6"-diameter gibbous disk. The Sun's glow swallows the planet by mid-June.

## The starry sky

Often when I present night-sky sessions at the planetarium, I find myself mentioning the extent to which early astronomers used their imaginations to name the constellations. Although several constellations bear some resemblance to the object, character, or creature after which they were named, many others remain a puzzle. This is particularly true with many of the constellations in the far southern sky.

One of these is the rather obscure star grouping of Chamaeleon the Chameleon, which rides high in the south after nightfall in June. Octans the Octant marks its southern border, while its northern border is split among Musca the Fly, Carina the Keel, and Volans the Flying Fish. The constellation looks nothing like a chameleon.

Chameleons are lizards that have long tongues for capturing prey and, in some species, the ability to change their color. Most species live in sub-Saharan Africa or on Madagascar. This island is where chameleons became associated with the sky.

The constellation got its name after Dutch explorers Pieter Keyser and Frederick de Houtman made their first observations of the southern sky. They visited Madagascar for four months in 1595 while traveling to the East Indies. Astronomer Petrus Plancius included Chamaeleon on a celestial globe he produced in 1597, and it appeared in Johann Bayer's famous sky atlas, *Uranometria*, in 1603.

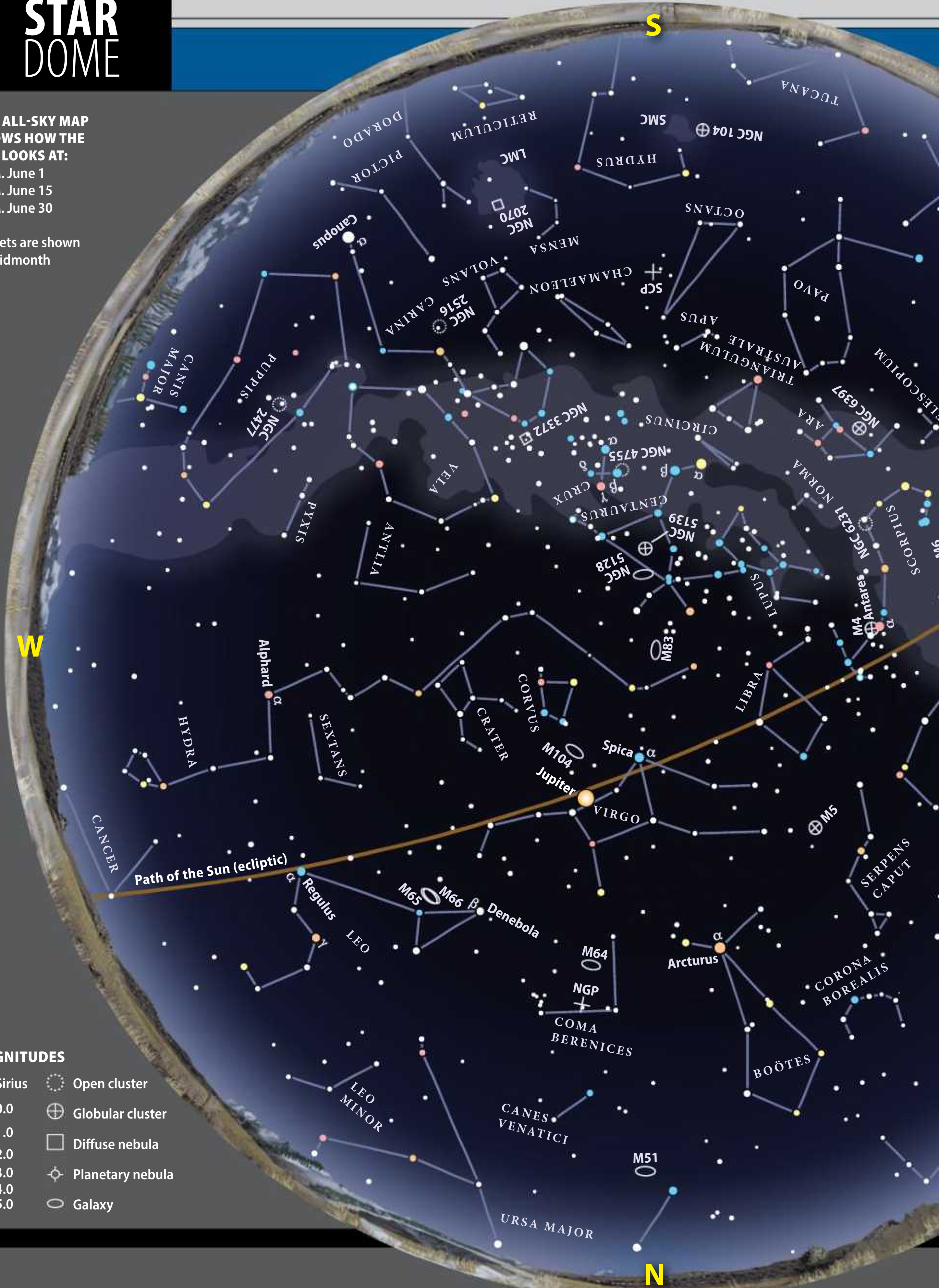
Chamaeleon offers a few good targets for those with telescopes. First, locate Delta$^1$ ($\delta^1$) and Delta$^2$ ($\delta^2$) Chamaeleontis with your naked eye. The 4.4' that separate these two correctly hints that they are not physically associated. But Delta$^1$ itself is a challenging telescopic double, with 0.8" separating its two 6th-magnitude components. With good optics and a steady night, you can resolve the pair through a 20cm scope.

Another object worth your time is the 11th-magnitude planetary nebula NGC 3195. You can find it midway between Delta$^2$ and Zeta (ζ) Cha. It appears as a faint, bluish patch of light about 30" across. Under a dark sky, it shows up nicely through a 20cm instrument.

# STAR DOME

**THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:**
9 P.M. June 1
8 P.M. June 15
7 P.M. June 30

Planets are shown at midmonth




**MAGNITUDES**

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

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


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

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

Illustrations by *Astronomy*: Roen Kelly

# JUNE 2017

## Calendar of events

**1** First Quarter Moon occurs at 12h42m UT

**2** Venus passes 1.8° south of Uranus, 15h UT

**3** Venus is at greatest western elongation (46°), 13h UT

**4** The Moon passes 2° north of Jupiter, 0h UT

**6** Dwarf planet Ceres is in conjunction with the Sun, 0h UT

**8** The Moon is at apogee (406,401 kilometers from Earth), 22h21m UT

**9** Full Moon occurs at 13h10m UT

**10** The Moon passes 3° north of Saturn, 1h UT

Jupiter is stationary, 5h UT

**12** Mercury passes 5° north of Aldebaran, 11h UT

**15** Saturn is at opposition, 10h UT

**16** The Moon passes 0.7° south of Neptune, 13h UT

Neptune is stationary, 23h UT

**17** Asteroid Hebe is at opposition, 3h UT

Last Quarter Moon occurs at 11h33m UT

**19** The Moon passes 4° south of Uranus, 16h UT

**20** The Moon passes 2° south of Venus, 21h UT

**21** Winter solstice occurs at 4h24m UT

Mercury is in superior conjunction, 14h UT

**22** The Moon passes 0.5° north of Aldebaran, 15h UT

**23** The Moon is at perigee (357,937 kilometers from Earth), 10h52m UT

Asteroid Harmonia is at opposition, 11h UT

**24** New Moon occurs at 2h31m UT

**28** The Moon passes 0.03° south of Regulus, 1h UT

**29** Asteroid Hygiea is at opposition, 19h UT

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