STARS, MOONS, AND PLANETS: Night sky guide

OCTOBER 2017

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REMEMBERING VOYAGER 40 YEARS LATER

The "Grand Tour" of the solar system opened our eyes like never before

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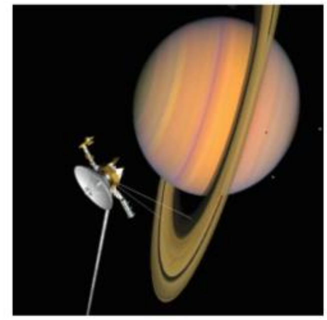
NASA/JPL/USGS

ON THE COVER

Forty years ago, Voyagers 1 and 2 made their "Grand Tour" of the solar system, changing our view of the universe forever.

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FROM THE **EDITOR**

BY DAVID J. EICHER

Voyager's great legacy

The end of the 1970s was a magical time for astronomy enthusiasts. We were still coming off the afterglow of the Apollo program. Comet West had recently dazzled skygazers. Astronomers had discovered rings around Uranus and a moon of Pluto.

With all that we now know about the solar system, it's hard to step back into that era and realize how incredibly important the Voyager program was to science. Launched in 1977, Voyagers 1 and 2 sped outward toward flyby encounters with Jupiter, Saturn, Uranus, and Neptune, comprising a "Grand Tour" of the outer solar system.

The original mission focused on Jupiter and Saturn — Voyager 2 visiting Uranus and Neptune came as a bonus. On August 20, 1977, Voyager 2 launched first, followed two weeks later by Voyager 1. The twin spacecraft carried a battery of instruments, including imaging systems, radio science systems, spectrometers, magnetometers, cosmic ray detectors, and photopolarimeters.

When Voyager 1 whizzed past Jupiter on March 5, 1979, the science world lit up. Some 217,000 miles (349,000 kilometers) from Jupiter's core, the spacecraft imaged volcanic activity on Jupiter's moon Io, a startling discovery. Each aspect of Jupiter and every one of its moons offered scientists a new world of surprises. Voyager 2 had its closest approach to Jupiter four months later, adding to the scientific haul.

Over the next two years, both spacecraft made their closest approach to Saturn, creating the first ultra-detailed images of the planet's rings as well as many amazing discoveries relating to Saturn's moons. Images revealed a substantial atmosphere on the largest moon, Titan.

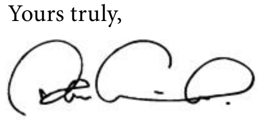
Voyager 2 was in good enough health to carry on to visit the ice giants. Early in 1986, the spacecraft passed within 50,600 miles (81,500km) of Uranus. The spacecraft discovered many moons and studied the planet's unusual axial tilt that resulted from a major collision with another body early in the solar system's history. Three years later, the spacecraft encountered Neptune, recording amazing images of the planet's weather and discovering and examining many moons.

Earth is visible as imaged from Voyager 1 as the "Pale Blue Dot" halfway down the orange-brown band of light at right. The image, made in 1990, shows Earth from a distance of more than 4 billion miles. NASA/JPL

In 1990, the Voyagers were several billion miles from Earth. Voyager 1 turned its camera back home and captured a portrait of Earth from afar. The "Pale Blue Dot" image stunned all who saw it as it captured Earth as a tiny bleb in a sea of dark space.

In the end, the Voyager Grand Tour gave us our most detailed understanding of the solar system up to that time, and also put Earth in cosmic perspective.

Yours truly,



David J. Eicher
Editor

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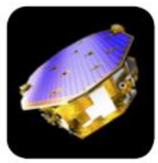
QG QUANTUM GRAVITY

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

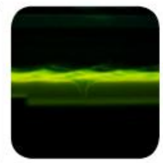
HOT BYTES >>

TRENDING TO THE TOP

IN REVIEW
NASA has established an independent committee to review costs and scheduling associated with the flagship Wide Field Infrared Survey Telescope (WFIRST).



TEAMWORK
The European Space Agency announced its intention to develop LISA, the Laser Interferometer Space Antenna, in collaboration with NASA.



BLACK HOLE ANALOG
Researchers at the University of Nottingham used a water bath to simulate the space around a black hole.

SNAPSHOT

Reflections on Voyager

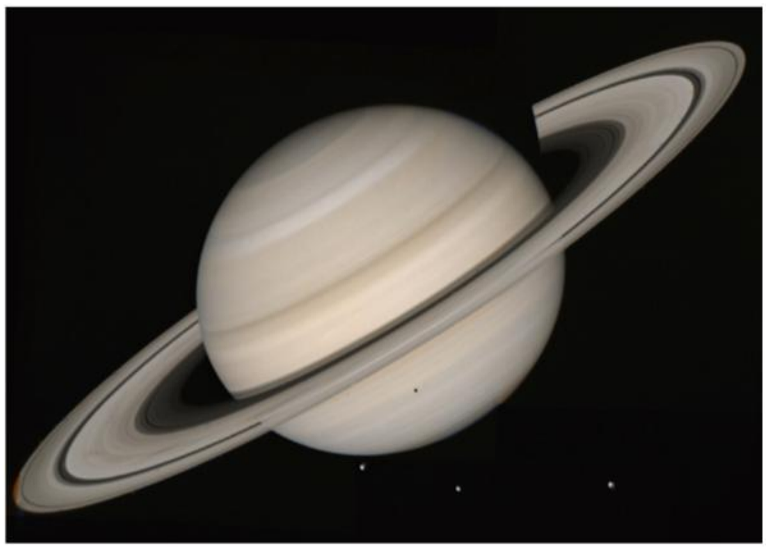
We've come a long way since, but the Voyagers' Grand Tour set the stage.

In 1977, when the twin Voyager spacecraft launched, our knowledge of the solar system was pretty primitive. Twelve years later, after Voyager 2's exploration of Neptune, the first stage in understanding our family of planets — the "Grand Tour" — was over. Now the Voyagers are more than 100 times the Earth-Sun distance away, silently moving still farther out, and still providing data about the outer part of the solar system.

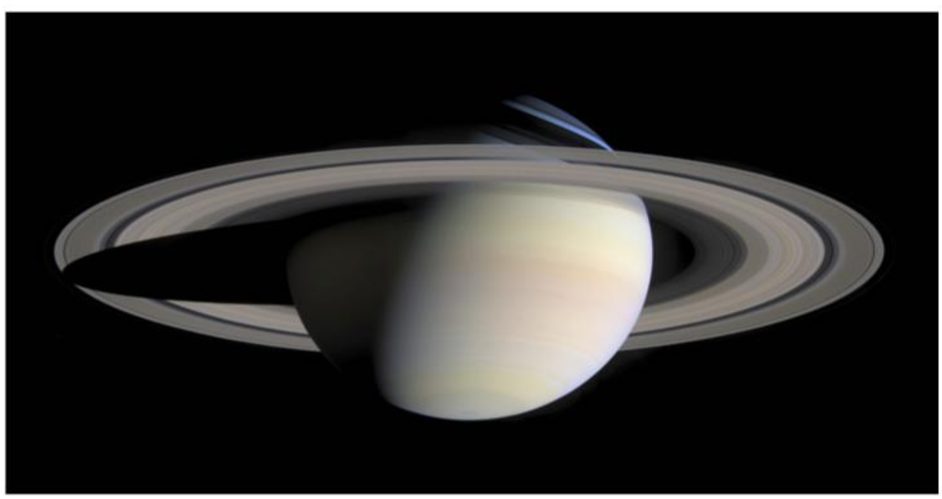
The Voyagers' Grand Tour gave us the first detailed exploration of Jupiter and Saturn, although those missions were flybys, and the initial close-up looks at Uranus and Neptune. We only explored Pluto for the first time, of course, many years later with the New Horizons spacecraft.

For those who weren't around in the 1970s and '80s, it's hard to understand the Voyagers' thunderous impact. Previous explorations of Jupiter and Saturn by the Pioneers were primitive by comparison. When the Voyager flybys took place, the floodgates of data and what were then deemed to be mind-blowing images opened. The whole astronomy community was stunned.

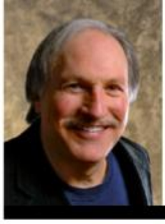
The discoveries of moons, of planetary features, of strange properties of the worlds we had not yet seen up close, seemed endless. It's now tempting to compare Voyager images with more recent ones, such as looking at Voyager Saturns next to Cassini Saturns, and contemplate the quantum leaps in understanding that have taken place since the early '80s. There's no doubt that we have a long way to go to fully understand our Sun and family of planets. But the Voyagers will always mark a time when humans took the first big steps to do so. — **David J. Eicher**



Voyager 2 captured this image of Saturn (left) on its approach on August 4, 1981, from a distance of 13 million miles (21 million kilometers). Aside from the planet's colorful cloud tops and rings, the image shows (in order of distance from the planet) the moons Tethys (closest), Dione, and Rhea, as well as the shadow of Mimas. Some 23 years later, the Cassini spacecraft captured Saturn (bottom) in one of its greatest composite shots.



NASA/JPL AND NASA/JPL/SPACE SCIENCE INSTITUTE; TOP FROM LEFT: NASA; NASA; UNIVERSITY OF NOTTINGHAM



STRANGE**UNIVERSE**

BY BOB BERMAN

Say Betelgeuse

How *do* you pronounce that star, that constellation, or that astronomer's name?

Betelgeuse is returning to the morning sky, but few can pronounce it. That's because almost none of our friends know the stars and constellations, so we rarely hear them spoken. But even during star parties, mispronunciations abound.

Gibberish is nobody's fault. In the case of Orion's alpha star, the movie *Beetlejuice*, starring Michael Keaton, permanently implanted that pronunciation in everyone's mind. Looking it up in the dictionary is of little help — even its meaning varies with each reference book. Grab the nearest dictionary, and you'll find that the word *Betelgeuse* means "the shoulder of the giant," "the armpit of the sheep," "the House of the Twins," or one of several other contradictory things.

The final judge? My favorite authority was the late George Davis of Buffalo, New York, an attorney, avid amateur astronomer, and noted Arabic scholar. Starting in the 1930s, he spent seven years researching star names, traveling to the East to seek original sources. Most star names come from Arabic, but that language, like all others, has changed over the centuries. That's one reason why so many myths and false ideas appear in print. To get at the truth, Davis started with 2,000-year-old Arabic and then traced those star names to their roots from the even earlier Sumerian.

Davis managed to document that, yes, Vega is pronounced VEE-gah, which meant "the falling eagle." As for *Bet'l'jooz*, the name derives from when the Sumerians saw the constellation of Orion not as a hunter, but as a sheep — so "the armpit of the sheep" is the correct meaning.

His research first appeared in 1944 in *Popular Astronomy* and was reprinted in 1971 by Sky Publishing Co. I bought it in 1972 and have treasured that yellowing 24-page booklet all these 45 years. Nowadays, you can find it online at http://articles.adsabs.harvard.edu/full/1944PA.....52....8D.

Bottom line? *Bet'l'jooz* is indeed the most mispronounced bright star, but runners-up include Vega and Spica (say SPY-kuh, not SPEE-kah).

Constellations can be troublesome, too. Seven years ago, our own Michael Bakich created an extremely helpful online pronunciation guide, though I regard cah-RYE-nuh as the preferred way to pronounce the Southern constellation sometimes listed as cah-REE-nuh.

Gibberish is nobody's fault.

But it's the Latin genitive form that really throws people. Stars within constellations are labeled using the Latin genitive form of the constellation, denoting possession or association. Vega is also known as Alpha (α) Lyrae; add an "e" to the constellation of Lyra to form the genitive. But how to say it? This one's simple: You change LY-ruh to LY-ree.

The genitive often seems easy, like with Betelgeuse's designation as Alpha (α) Orionis. But should you simply say "Orion" the normal way and then add an "is" sound? No! You must change every syllable! *Betelgeuse* is pronounced (Alpha) oh-ree-OH-nis.

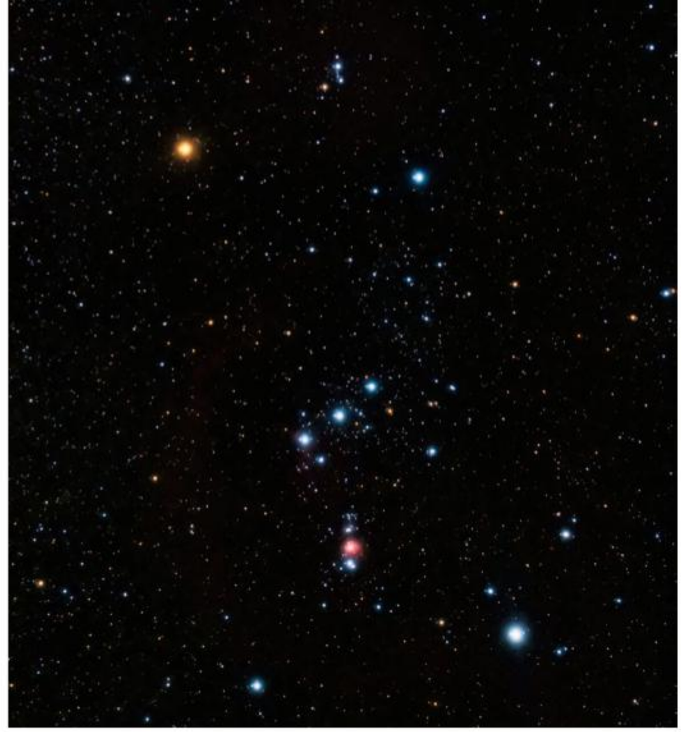
Now go ahead and learn the genitives of all 88 constellations! Those with two words, like Ursa Major, have both changed, making it UR-see mah-JOR-is. Fortunately, no one can force you to memorize all this. I obsessively learned them in the '70s when I started lecturing, to avoid the embarrassment of saying things wrong. But there are issues even today, because the British and Americans often utter genitives (and other things) differently, like with *antennae* pronounced an-TEN-ee versus an-TEN-nay versus an-TEN-nye. So if you'd like to discuss the amazing irregular supernova and nebula named Eta Carinae, you could say either cah-REE-nay or cah-RYE-nee, though I prefer the latter.

Even the Greek letters are controversial. Probably 20 percent of the letters are ambiguous. Returning to Eta Carinae, you can say EE-tuh or AY-tuh. When observing the deep red star Mu (μ) Cephei, do you say "Moo" or "Myoo"? I prefer ZAY-tuh and THAY-tuh, but some pronounce them ZEE-tuh and THEE-tuh. Happily, as with Jupiter's moon Io (say either EYE-oh or EE-oh), increasing numbers of celestial objects are now greenlighted for multiple "correct" pronunciations. A few modern dictionaries even obscenely allow yor-AY-nis for the seventh planet.

I rarely correct people because it's obnoxious, and I want to be liked. Also, many mispronunciations ultimately prove transient: If you wait long enough, your articulation may eventually be deemed OK. Even *transient*, which everyone started pronouncing with three syllables in the 1970s, and which still bugs me because it classically has two (TRAN-shent), is now sometimes listed as acceptable with three.

Maybe all this is an argument for solitary observing. Then any heated dispute would occur only in your mind — which is never a good sign.

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



A red supergiant star, Betelgeuse (or *Bet'l'jooz*) stands out as the shoulder of Orion the Hunter. Its name, however, is derived from a time when the Sumerians envisioned its constellation as a sheep. © PERESANZ | DREAMSTIME.COM

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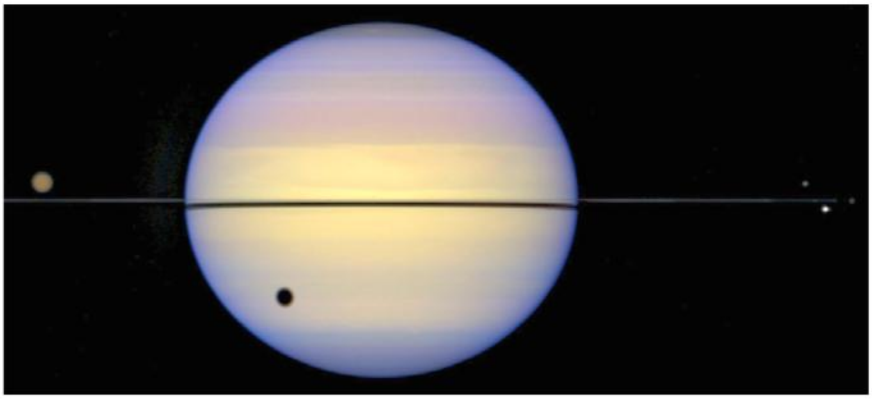
ASTRO**LETTERS**



E. KARKOSCHKA (UNIV. OF ARIZONA LUNAR & PLANETARY LAB) AND NASA/ESA

Fourth time's the charm

There's one astronomy event I latched onto when I got my 58x telescope in the spring of 1980. About every 15 years, Earth's viewpoint crosses Saturn's rings, and they appear edge-on, or even disappear.

I am 65 now and have seen this three times in a row. The second time was January 25, 1996, using the same telescope. That time, the rings appeared as a thin, misty line.

The third time was April 4, 2009, at a public gathering on the grounds of the U.S. Naval Observatory. On that occasion, the rings looked like a thick, bright line.

I recently emailed Geoff Chester at the observatory and he said the next Earth crossing will be March 23, 2025, when I will be 73. Four times in a row — it beats waiting for Halley's Comet.
— John Lockwood, Washington, DC

The concise explanation

I wanted you to know how much I enjoyed the article "Our trillion-galaxy universe" in the June issue. Christopher Conselice is a very good writer who puts important ideas across to us armchair astronomers clearly. Sometimes articles in *Astronomy* have cloudy spots in them where the writer seems to know the issue but does not give us, the reader, quite enough information to understand fully. Some writers might say we now think there are a trillion galaxies, leaving the reader to think that we don't need dark matter because there is much more regular matter out there than we thought. Conselice is careful to point out that the number of galaxies is greater than we thought, but that the early ones were small and numerous and the total mass remains the same. His explanation of why the sky looks dark to us between galaxies is concise and easily understood.

Anyway, thanks for this article. I found it both clear and fun as the author also injects a bit of humor here and there. That is why I also enjoy Bob Berman's writing so much. **— Robert Walty,** Stephens City, VA

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.

A perfect ellipse

Just a quick response to Bob Berman's "A perfect circle" article in the May 2017 issue. The universe prefers ellipses. Most planets are "squished" due to their rotation. Also, most orbits of planets and moons are ellipses. Sorry, but the universe is happy with imperfect circles, aka ellipses! **— Douglas Kaupa,** Council Bluffs, IA

Bob Berman responds

Hey Douglas, maybe you were excessively speed-reading my column because your letter oddly says, "Sorry, but" followed by a "correction" that essentially says the same things I wrote!

My article said: "Reality ultimately intruded. As it turned out, only Venus' orbit would look circular to an alien studying it from a distance, with other planets displaying varying degrees of elliptical shapes. And fair enough: Ellipses rule … "

Indeed, your letter says that "most planets and moons" have elliptical orbits. In fact, all of them do. **— Bob Berman,** contributing editor

RULED OUT. Physicists looking to explain the cosmic inflation that happened shortly after the Big Bang have ruled out the presence of the light inflaton, a particle with properties similar to the Higgs boson but a lower mass.

HUBBLE WEIGHS A WHITE DWARF

NOT QUITE NEIGHBORS. The white dwarf Stein 2051B (bright central object) can be seen superimposed on the sky with a background star (lower left), whose light was bent by the white dwarf passing in front of it. NASA, ESA, AND K. SAHU (STSCI)

According to the theory of general relativity, mass bends space-time like a bowling ball depressing a mattress, causing light to follow a curved path. In 1919, Sir Arthur Eddington measured the deflection of background stars caused by our Sun during a total solar eclipse. Nearly a century later, astronomers have used the Hubble Space Telescope (HST) to observe this effect caused by a star outside our solar system for the first time.

Kailash Sahu of the Space Telescope Science Institute announced the result at the 230th Meeting of the American Astronomical Society. Sahu's team used the HST to capture the deflection of light from a background star as a white dwarf, the remnant of a star once like our Sun, passed in front of it.

Although this deflection was about 1,000 times smaller than the one Eddington measured, Hubble's precision allowed astronomers to see it clearly. From the deflection, they were able to measure the mass of the white dwarf, Stein 2051B. The work appeared in the June 7 issue of *Science*.

Stein 2051B is 17 light-years away. In March 2015, it passed in front of a star 5,000 light-years distant, causing its light to bend by 2 milliarcseconds. Seeing that bend was like trying to watch an insect crawl across the face of a quarter from a distance of about 1,500 miles (2,400 kilometers).

This is the first time a deflection due to general relativity has been measured using a star other than our Sun. And measuring the mass of Stein 2051B is the first "clean test for [the] mass-radius relationship," Sahu explained.

The mass-radius relationship for white dwarfs leads to the Chandrasekhar limit. If a white dwarf accumulates mass over this limit (1.4 solar masses), it will explode as a supernova, which astronomers can use to accurately measure distances. If our understanding of the relationship is incorrect, it would affect the distances calculated.

Only three other white dwarfs have been weighed, but their masses were measured via their gravitational effects on a binary companion. The masses derived for white dwarfs in binary systems could be affected by a process called mass transfer between the stars, which would contaminate the mass-radius relationship. Although Stein 2051B has a binary companion, it's so far away — at least 5 billion miles (8 billion km) — that the two cannot exchange mass.

Once the mass of 2051B was measured, Sahu's team plotted it on the white dwarf mass-radius relation. Their result fit perfectly with the model. "When I saw that it was right exactly on here, I almost fell off my chair," Sahu explained.

Stein 2051B's excellent fit confirms our current evolutionary theory of white dwarfs and agrees with our understanding of the matter that makes up these objects. "This is really a confirmation of the theory that we have been using so far," Sahu said.

— Alison Klesman

BRIEFCASE

COSMIC MAGNIFYING GLASS

A team led by James Lowenthal of Smith College has discovered that gravitational lensing may be responsible for the brightest galaxies in the sky. Of a sample of 31 of the brightest galaxies at infrared wavelengths, 11 have been observed with the Hubble Space Telescope. All of them are gravitationally lensed star-forming galaxies seen 8 billion to 11.5 billion years ago birthing stars at a rate 1,000 or more times that of the Milky Way. Despite the distorted images created by the lenses, the team can use these new, clearer images to reconstruct the galaxies and better understand their high rates of star formation.

OUR LOCAL VOID

Researchers at the University of Wisconsin–Madison have discovered evidence that the Milky Way and its Local Group may exist inside a large void. A local void could explain the "tension" currently observed in the Hubble constant, which measures how fast the universe is expanding. The effects of this void, and the pull of the mass beyond it, might contribute to different values observed when measuring the Hubble constant using nearby versus faraway indicators.

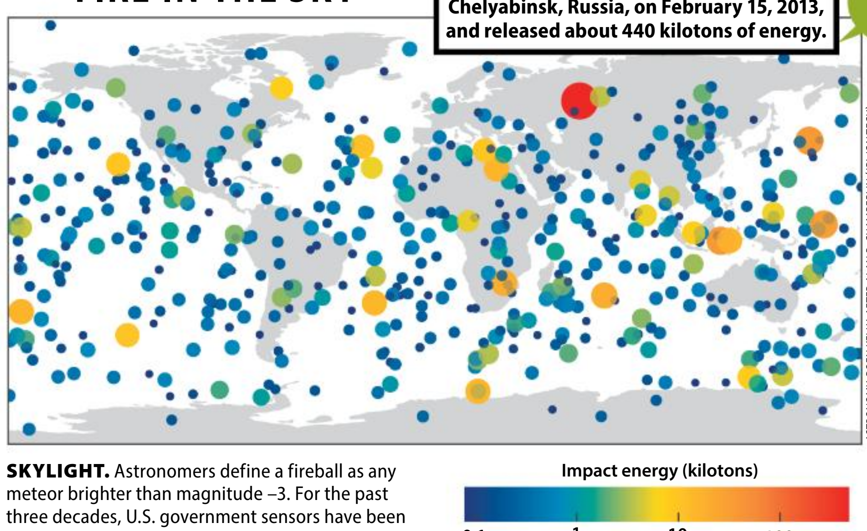
MOLECULAR BLACK HOLE

Scientists unexpectedly generated a "black hole" in a lab using X-ray pulses. Using the Linac Coherent Light Source (LCLS) X-ray free-electron laser at the SLAC National Accelerator Laboratory, researchers stripped iodine atoms of their electrons with a burst of concentrated energy (100 quadrillion kilowatts per cubic centimeter). As a result, the iodine atoms began pulling in electrons from surrounding atoms. This is similar to the forces at work in a black hole, though these objects exhibit a gravitational pull instead of electromagnetic attraction. **— J. W., A. K.**

70 The number of Jupiter masses an object needs to ignite hydrogen fusion as a star.

FIRE IN THE SKY

FAST FACT The largest fireball occurred above Chelyabinsk, Russia, on February 15, 2013, and released about 440 kilotons of energy.



SKYLIGHT. Astronomers define a fireball as any meteor brighter than magnitude –3. For the past three decades, U.S. government sensors have been recording such events across the globe. Although the network doesn't record every fireball, it gives a good picture of the pummeling Earth receives from solar system debris. This chart depicts the brightest events from April 15, 1988, to June 20, 2017; the relative size and color of each circle represents the fireball's estimated total impact energy. **— Richard Talcott**

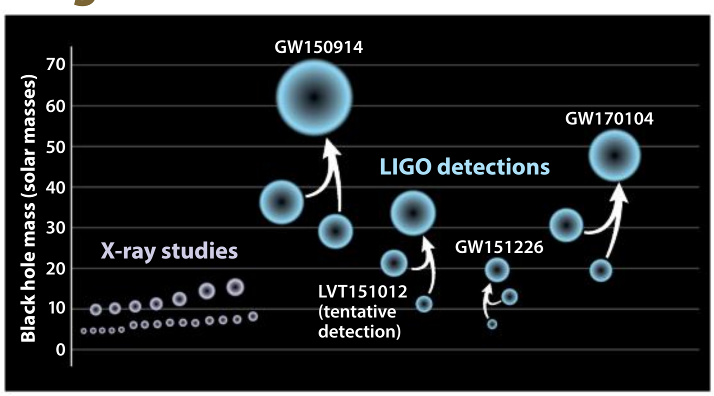
 BROWN DWARF DANCE. Astronomers using the Hubble Space Telescope to watch a pair of brown dwarfs 6 light-years away have determined there is no third object in the system, as was originally suspected.

A new look at the Orion Nebula

GBO/AUI/NSF

STAR-FORMING STRING. The Orion Nebula is visible to the naked eye, located just beneath the Hunter's three-star belt. But gas and dust hide much of what's going on in this nearby stellar nursery. Using radio observations taken of the nebula with the Robert C. Byrd Green Bank Telescope in West Virginia, astronomers have identified a filament of ammonia molecules spanning 50 light-years. The ammonia is visible as orange in this composite image, which also shows other gas, imaged with NASA's Wide-field Infrared Survey Explorer telescope, in blue. Ammonia in particular traces the dense gas that ultimately collapses to form stars. Studying the concentration and location of ammonia in the Orion Nebula will help astronomers determine whether its densest regions of gas are stable or likely to form new stars in the near future. — **A. K.**

LIGO detects third gravitational wave



LIGO/CALTECH/SONOMA STATE (AURORE SIMONNET)

FILLING THE GAPS. LIGO detectors have discovered a pair of merging black holes with masses higher than those detected in X-rays. On the left are previously known black holes found via X-rays; on the right are three strong and one tentative gravitational wave detections made by the observatory, sorted by mass on the vertical axis.

LIGO has detected gravitational waves for a third time, helping astronomers further understand black holes.

All objects distort the fabric of space-time by some amount. The interaction of more massive objects can cause detectable "ripples" in it, sort of like a ripple in a pond, except these ripples move at the speed of light. But these ripples are also small because gravity is the weakest of the fundamental forces.

Finding ripples of gravity is therefore far more difficult than, say, detecting a massive electromagnetic event. That's why LIGO, short for the Laser Interferometer Gravitational-wave Observatory, uses two (soon to be three) locations to tune in to especially violent events, like the merger of two black holes. When black holes merge, the magnitude of their gravitational waves changes from the effects of a "pebble" in the pond of space to the equivalent of tossing in a boulder, sending out much larger gravitational waves in all directions.

LIGO's third detection is a merger that took place 3 billion light-years away and reached Earth on January 4. The event occurred when two black holes combined to create a single black hole 49 times the mass of the Sun. A black hole of this mass helps "fill in" the spectrum of black holes, as it falls between the masses of the two black hole mergers previously detected by LIGO (62 and 21 solar masses). Before LIGO, astronomers had measured black holes a few times the mass of the Sun and those several million times the mass of the Sun, with nothing in between.

The results, published June 1 in *Physical Review Letters*, may indicate a shift toward one of the LIGO team's hopes: that detecting gravitational waves may become commonplace events. The addition of the European Gravitational Observatory's Advanced Virgo detector, as well as a third LIGO observatory recently approved for construction in India, will go a long way toward increasing the sensitivity of the project in the future.
— **John Wenz**

QUICK TAKES

SPECIAL DELIVERY
Observations of Comet 67P/Churyumov–Gerasimenko suggest comets may have delivered up to 22 percent of Earth's atmospheric xenon.

HEAT IT UP
The network of valleys surrounding Mars' Lyot Crater was likely carved by water from an ice layer melted by hot ejecta from the impact.

INFINITE DIVERSITY
Samples collected by the Curiosity rover near Mars' Mount Sharp show diverse mineral content suggestive of changing conditions in the area.

LOCKED IN PLACE
A Lowell Observatory-led study shows that massive galaxy cluster centers have been aligned with their surroundings for 10 billion years.

BIG BANGS
Researchers from the University of Colorado Boulder found that hot intracluster gas may result from turbulence as massive galaxy clusters collide.

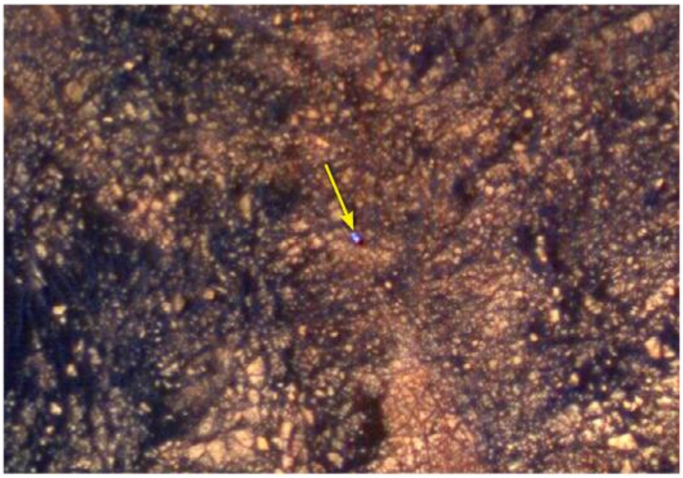
JETTING OFF
Astronomers are using data from the Chandra X-ray Observatory to trace previous outbursts in the R Aquarii binary system, as well as predict future events by watching blobs of hot gas in the jets associated with the stars.

METEORITE MYSTERY
Researchers have used high-pressure experiments to determine how meteorites can contain multiple types of silica, despite the differing conditions required for them to form. The results shed light on impact processes throughout the solar system.

EXTREME HEAT
The gas giant planet KELT-9b has a dayside temperature of 7,800° F (4,300° C), making it hotter than many stars.

GALACTIC WEIGHT LOSS
As galaxies join groups of 20–30 members, they lose up to 40 percent of their initial mass, astronomers have found. This is more than the mass loss experienced by single galaxies falling into clusters of hundreds or thousands of galaxies. — **A. K.**

BIG RINGS. A huge gas giant planet with a ring system is blotting out light from the star PDS 110 as it orbits once every 2.5 years, according to a team led by astronomers at the University of Warwick.



I SPY . . . Curiosity landed on Mars to investigate the possibility of microbial life on the planet and to study the 3-mile-high (5km) Mount Sharp, which sits inside the 96-mile-wide (154km) Gale Crater. HiRISE captures pictures of Curiosity about every three months while monitoring the area for erosion or migration of the surrounding dunes. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

Curiosity climbs Mount Sharp

NASA's Mars Reconnaissance Orbiter has the most powerful telescope ever sent to the Red Planet. While monitoring Mars on June 5, 2017, it captured a picture that included the Curiosity rover climbing Mount Sharp, the mountain inside a crater that Curiosity has been exploring for about five years.

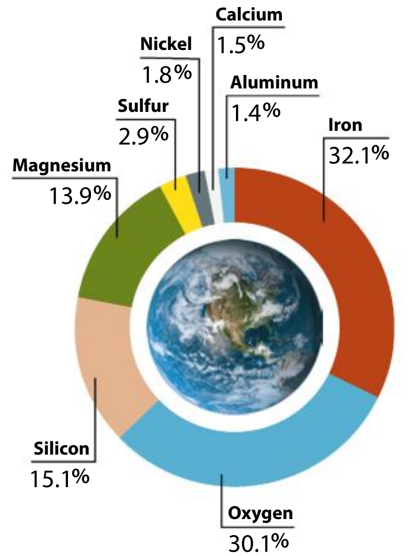
The orbiter was about 169 miles (271 kilometers) away when it took the picture. The rover, which measures 10 by 9 feet (about 3 by 2.8 meters), was headed from the sand dunes on lower Mount Sharp toward the informally named "Vera Rubin Ridge" when the High Resolution Imaging Science Experiment (HiRISE) camera imaged it.

The camera's filters, which are meant to enhance colors to help scientists better pick out subtle differences in the materials that make up Mars' surface, make the rover appear bluer than it really is.

Once Curiosity reaches its next destination, it will take a closer look at the active dunes where the mineral hematite has been spotted from orbit. — **Nicole Kiefert**

WHAT IS EARTH MADE OF?

BREAK IT DOWN. Our planet contains all of the 92 naturally occurring elements. But which ones are most abundant? This chart shows the top eight elements found within Earth — all of it, not just the crust. These elements each account for more than 1 percent of our world's mass. — **Michael E. Bakich**



Earth weighs 6.58 sextillion tons. That's 6,580,000,000,000,000,000,000 tons.

FAST FACT

ALMA uncovers more ingredients for life

THE RIGHT ENVIRONMENT. The Rho Ophiuchi star formation region contains the triple-protostar system IRAS 16293–2422, where astronomers discovered clouds of methyl isocyanate gas surrounding the forming stars. ESO/DIGITIZED SKY SURVEY 2; ACKNOWLEDGEMENT: DAVIDE DE MARTIN

IRAS 16293–2422 became famous in 2012 when astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) detected glycolaldehyde, a simple sugar, in the system. Now, the system is making news again with the discovery that it contains methyl isocyanate, a complex prebiotic molecule.

IRAS 16293–2422 contains three young protostars with masses similar to the Sun and lies about 400 light-years away.

Two groups of astronomers discovered and studied the molecule via observations taken as part of the Protostellar Interferometric Line Survey with ALMA. Their results were published in two papers in the April 17 issue of the *Monthly Notices of the Royal Astronomical Society*. Co-authors Niels Ligterink and Audrey Coutens explained the profundity of the discovery, saying, "This family of organic molecules is involved in the synthesis of peptides and amino acids, which, in the form of proteins, are the biological basis for life as we know it."

The ALMA observations, which covered several wavelengths in the radio spectrum, indicate that methyl isocyanate is found in the cocoons of gas surrounding the young, still-forming stars. After isolating the molecule's signature, the teams used a combination of computer modeling and laboratory experimentation to better understand how the molecule had formed in the system.

This discovery allows astronomers an indirect peek into the past of our own solar system, which likely formed under similar chemical conditions. It also has far-reaching implications for the possibility of Earth-like life on other planets, because a star's planets form from the material that surrounds it.

"Our laboratory experiments show that methyl isocyanate can indeed be produced on icy particles under very cold conditions that are similar to those in interstellar space. This implies that this molecule — and thus the basis for peptide bonds — is indeed likely to be present near most new young solar-type stars," said Ligterink. — **A. K.**

ASTRONEWS

FLARE-UPS. A new catalog based on data from the Galaxy Evolution Explorer spacecraft will allow astronomers to determine how stellar flares from cool dwarf stars could affect the habitability of their planets.

TRAPPIST-1's planets may trade life

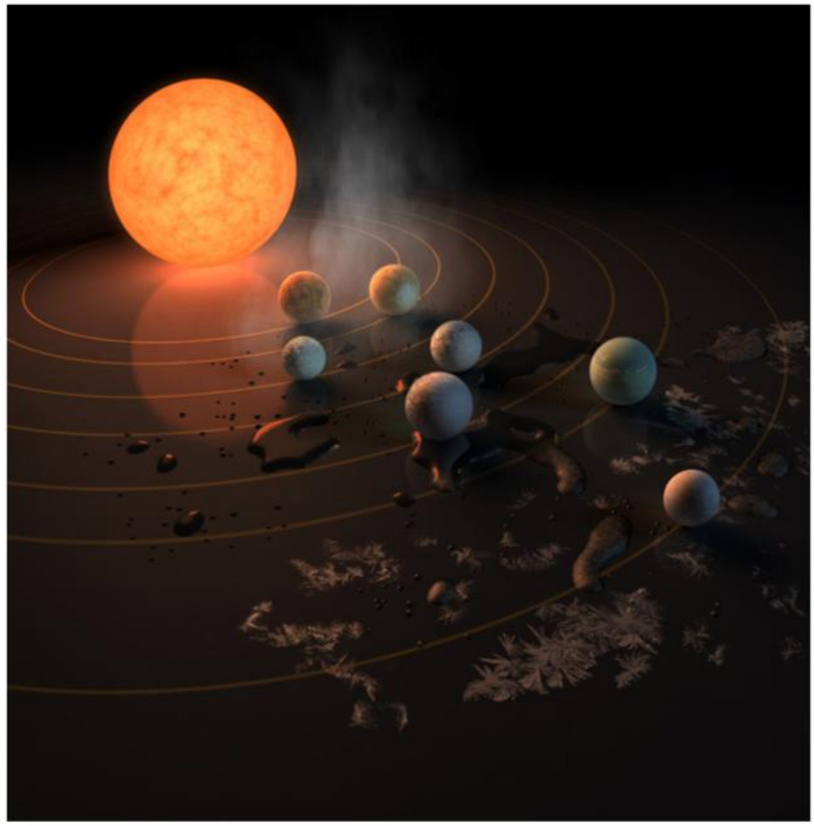
The TRAPPIST-1 planetary system could be one of the most promising places to find life — if its star isn't too volatile. A paper by Manasvi Lingam and Abraham Loeb, published June 14 in the *Proceedings of the National Academy of Sciences*, suggests that if the system is habitable, its planets might more or less share the same life.

The TRAPPIST-1 system was initially announced in May 2016 as a three-planet system around a star slightly larger than Jupiter. At the time, astronomers believed two of its planets were habitable. Further study revealed that the third, erratic planet was actually several planets, bringing the total number of planets (so far) to seven.

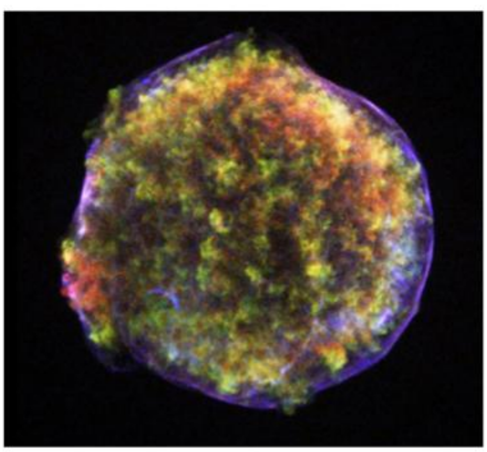
The planets are tightly packed, with distances between them similar to the separation of Earth and the Moon. Each orbits in resonance with the others. But these close distances could have a strange effect: It wouldn't be hard for meteorites to hop from one planet to another, bringing life along with them.

The likely "passengers" would be microbial. The paper suggests this hypothesis could be proven if the same biosignatures are found on multiple planets, something that might be possible by comparing the planets' atmospheres using the upcoming James Webb Space Telescope.

Like many small M-dwarf stars, TRAPPIST-1 is fairly active, shooting out flares that could strip its planets of their atmospheres. A recently discovered planet around an M dwarf appears to have retained its atmosphere, however, meaning it is possible that these planets could cling to their gas layers. **— J. W.**



CLOSE NEIGHBORS. The TRAPPIST-1 system, seen here in an artist's depiction, is packed so tightly that the planets orbit in resonance with less than a million miles between neighbors. If the star hasn't fried away the planets' atmospheres, the system could be a promising place to find alien life. NASA/JPL-CALTECH



NASA/CXC/RUTGERS/J. WARREN AND J. HUGHES ET AL.

Tycho in 3-D

WHAT'S IN A SHAPE? Researchers built this 3-D image of the Tycho supernova remnant to better understand the expansion of the violent stellar event. The NASA-led team sought to understand asymmetries in supernova remnants to determine if their shape develops during or after the supernova. The model used 12 years' worth of data from the Chandra X-ray Observatory to determine that various "knots" are moving at different velocities. They concluded the explosion was likely symmetric; the asymmetries were caused by interactions with matter in the interstellar medium as the shock wave expanded outward. **— J. W.**

Amateur sleuths find a new nearby brown dwarf

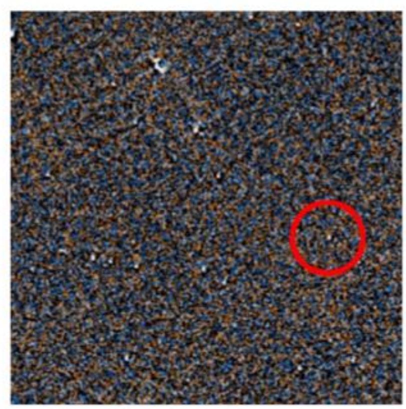
Citizen scientists using Zooniverse's Backyard Worlds: Planet 9 tool have discovered a brown dwarf just over 100 light-years from Earth, increasing the number of objects in our Sun's neighborhood.

The project, which launched in February, almost immediately began yielding results. For instance, the dim brown dwarf pictured was found just six days into the effort. Australian schoolteacher Bob Fletcher is credited with the initial discovery, and three other teams identified it around the same time.

Brown dwarfs, often called "failed stars," are more massive than planets but less massive than stars, so they are unable to fuse hydrogen into helium. While some brown dwarfs can be quite warm because they fuse deuterium (a relatively scarce isotope of hydrogen), WISEA J110125.95+540052.8 — some just call it "Bob's dwarf" — is comparatively cold, just a few degrees warmer than Jupiter.

The object was too faint to be detected by previous sky surveys, but Backyard Worlds: Planet 9 was designed with a hard-to-find target in mind: Planet Nine, a possible cold ice giant about the size of Neptune at the margins of our solar system. Because of the search parameters required to find such an object, the Backyard Worlds project is also primed to discover other nearby cold objects, including dwarf planets and brown dwarfs.

The research was published May 24 in *The Astrophysical Journal Letters*. **— J. W.**



NEW FIND. Citizen scientists discovered this dim brown dwarf through the Backyard Worlds: Planet 9 project. It had eluded detection by surveys looking for brighter objects. NASA

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Entropy's rainbow

The statistically likely path to complexity.

The early universe was remarkably uniform. Today's universe is anything but. What gives? The details of how we got from there to here form one of the grand themes of science. But viewed from 30,000 feet, the transformation can be summed up in one word — entropy.

"Hold on a minute," you say. "Entropy doesn't build stuff. Entropy tears stuff down!" That is certainly the common impression people have about the Second Law of Thermodynamics. It's also dead wrong.

Rewind the clock to the middle of the 19th century. In one of the all-time greatest advances in the history of science, Ludwig Boltzmann has just used the statistics of how molecules move to explain why heat always flows from hot things to cold things. It is a beautiful, elegant piece of work. It is also counterintuitive to a generation of scientists who are only beginning to get used to the atomic theory of matter.

Boltzmann has trouble explaining what he is on about, until he starts talking about entropy as "disorder." A low entropy state, says Boltzmann, is more ordered. A high entropy state is more disordered. It's easier to jumble things up than to go the other direction, which is why entropy always increases. It is a simple, visually compelling explanation that people can sink their teeth into. The idea of entropy as disorder sticks. And sticks. And sticks …

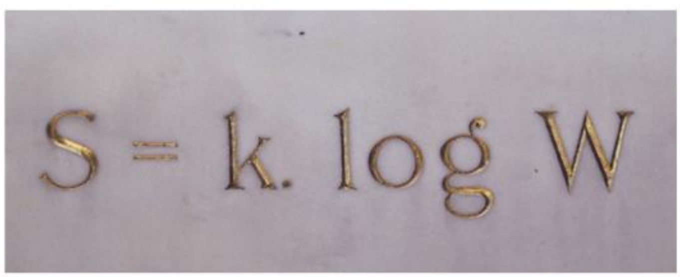
"The Second Law of Thermodynamics says that disorder increases with time." To this very day, that statement remains de rigueur in classrooms (and blogs) any time the subject crops up. But it is an oversimplification that does more harm than good.

Identifying entropy with "disorder" is a lot like equating energy with "bombast." It may well be that adding energy often makes things more bombastic. Talking about bombastic events might even help someone visualize what can happen when lots of energy is dissipated at one time. But there is no such thing as "conservation of bombast." Trying to apply such a notion to the physical world would lead to all sorts of absurdity.

In like fashion, it is wrong, even nonsensical, to identify entropy with disorder. "Increasing disorder" is not a physical law. It can't be. Disorder isn't even a physical quantity. Rather than a measure of disorder, entropy is actually a quantitative measure of how many different ways you can rearrange the components of something without changing its bulk properties. (If you want that in more formal terms, entropy is a constant times the logarithm of the number of microstates corresponding to the same macrostate.)

Rather than "disorder increases," what the Second Law of Thermodynamics actually says is that random changes tend to move things toward statistically more likely configurations. What happens along the way can be really amazing.

Imagine watching a giant cloud of interstellar gas as it starts to collapse under its own weight. As the cloud gets smaller, it sure looks like things are getting more "ordered," so perhaps you complain about the seeming violation of the Second Law.



The tombstone of Ludwig Boltzmann (1844–1906), who defined entropy, carries the equation for the Boltzmann constant. MICHIGAN STATE UNIVERSITY

What you don't see is that the collapsing cloud is also getting hotter, meaning that the molecules in the gas have the energy to move faster. The wider range of velocities (more correctly momentum states) that molecules can take on more than makes up for the decrease in places the molecules can be. Entropy increases as it must.

But that hot molecular gas gives off radiation, which takes energy away from the molecules, reducing the available momentum states. OK, surely this is a violation of the Second Law!

Nope. The molecules are indeed more localized in both space and momentum, so their entropy is clearly lower than it started out. But what about the photons that were radiated away? There are all sorts of possible ways for those photons to be arranged, meaning that there are lots and lots of possible configurations for the system as a whole. The increased entropy of the photons is more than enough to make up for the decreased entropy of the cloud itself.

As energy (and entropy) is radiated away, the cloud loses pressure support and collapses further. Eventually that collapsing cloud settles into a disk. Stuff in the disk clumps up. The gas at the center gets so hot and dense that a fusion reaction kicks in. Where once there was a big, spread out, "disordered" clump of interstellar gas, now there is a young star surrounded by planets. So much for tearing things down!

As it goes with the formation of a planetary system from an interstellar cloud, so it goes for everything beginning with that early uniform universe, right up to you sitting there reading this article. The glorious, complex, awe-inspiring structure that surrounds us is a byproduct of increasing entropy, the blind, unguided, inexorable march of the universe toward ever-more statistically likely states.

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.**

 RADIATION WARNING. NASA's Human Research Program is studying simulated space radiation to determine the long-term effects of space flight on astronauts' health in preparation for manned missions to Mars.

Juno's early results reveal a mysterious Jupiter

Since arriving at Jupiter on July 4, 2016, the Juno spacecraft has been showing planetary scientists a brand-new view of the planet, including a deeply turbulent atmosphere and a "lumpy" magnetic field.

"It was a long trip to get to Jupiter, but these first results already demonstrate it was well worth the journey," said Diane Brown, a Juno program executive at NASA's Washington Headquarters, in a May press release. The results from Juno's first data-collection pass of the planet — at an altitude of 2,600 miles (4,200 kilometers) on August 27, 2016 — were recently published in *Science* and *Geophysical Research Letters*.

Those results include images from JunoCam, which showed Earth-sized storms clustered at the planet's north and south poles. Data from the Microwave Radiometer demonstrated that Jupiter's equatorial belt penetrates deep into the planet's atmosphere, while bands at other latitudes spawn additional atmospheric structures.

Juno revealed a magnetic field 10 times stronger than any on Earth, varying in strength across the planet. "This uneven distribution suggests that the field might be generated by dynamo action closer to the surface, above the layer of metallic hydrogen," said Jack Connerney, the mission's deputy principal investigator and leader of the probe's magnetic field investigation at NASA's Goddard Space Flight Center.

"We knew, going in, that Jupiter would throw us some curves," said Scott Bolton, Juno principal investigator from the Southwest Research Institute in San Antonio. "But now that we are here, we are finding that Jupiter can throw the heat, as well as knuckleballs and sliders. There is so much going on here that we didn't expect that we have had to take a step back and begin to rethink of this as a whole new Jupiter." — **A. K.**

NASA/JPL-CALTECH/SwRI/MSSS/GERALD EICHSTÄDT/SEÁN DORAN

LIGHT AND DARK. Jupiter's atmosphere contains numerous bands and belts; each band in this JunoCam image is wider than Earth. Three white, oval-shaped storms are visible, part of the planet's "String of Pearls."

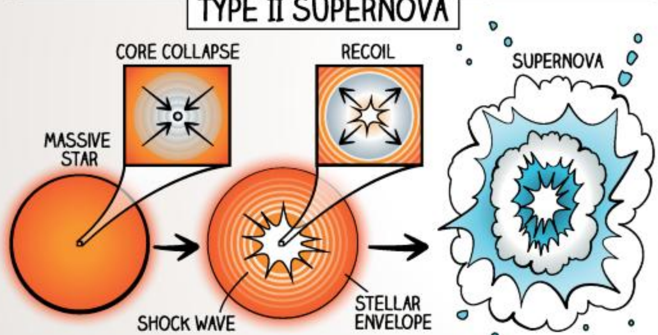
4,034

The number of potential exoplanets currently identified using data from the Kepler spacecraft.

RECIPE FOR A SUPERNOVA

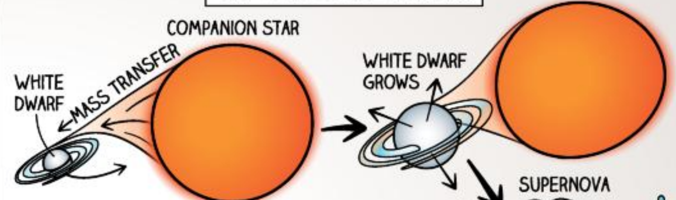
EXPLOSIVE END. Though there are many subclasses, supernovae fall into two general types: massive stars reaching the end of their lives (type II) and white dwarfs accreting more matter than they can physically support (type Ia). Type II supernovae are responsible for distributing heavy elements throughout the cosmos; type Ia supernovae are "standard candles" used to accurately measure distances to very distant galaxies, thereby determining the expansion rate (and acceleration) of the universe. — **A. K.**

TYPE II SUPERNOVA

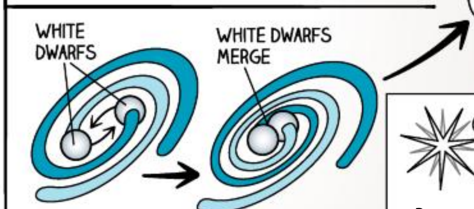


During a massive star's (≥8 M_{Sun}) lifetime, pressure generated by fusion processes hold the core up. As fusion slows, the pressure diminishes and the core shrinks. Eventually, the material inside the core reaches a critical point, triggering a recoil effect. The resulting explosive shock wave tears through the star's outer layers. Stars of any mass greater than 8 M_{Sun} can cause a type II supernova, so these events vary greatly in brightness.

TYPE IA SUPERNOVA



White dwarfs are themselves remnants of Sun-like stars (<8 M_{Sun}) that did not explode upon death. If a white dwarf has a binary companion, it can pull material off this nearby star and grow until a critical mass (called the Chandrasekhar limit, about 1.4 M_{Sun}) is reached. This triggers a runaway nuclear reaction that tears the white dwarf apart, causing a type Ia supernova.



Alternatively, type Ia supernovae may occur when two white dwarfs in a binary system spiral inward (left) and eventually merge (right). If the resulting object is greater than the Chandrasekhar limit, it will also explode in a type Ia supernova.

Because type Ia supernovae always occur at roughly the same mass (1.4 M_{Sun}), they have the same intrinsic brightness and the observed brightness can be used to calculate distance.

ASTRONOMY: ROEN KELLY

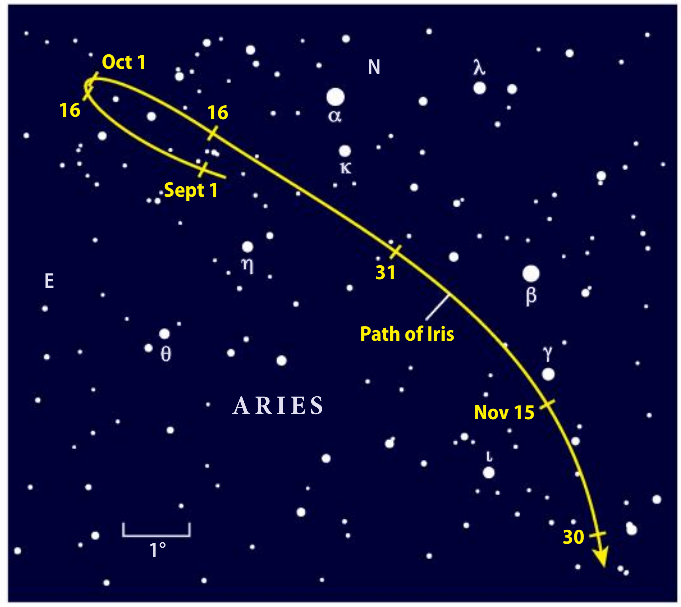
FAST FACT **Supernova 1987A is one of the most famous modern supernovae. This type II supernova had a progenitor about 18 times the mass of our Sun.**

OBSERVING**BASICS**

BY GLENN CHAPLE

Track an asteroid pair

Pallas and Iris come within reach of small telescopes these October nights.



The brightest asteroid this autumn is 7th-magnitude Iris, which conveniently lies near the brightest stars in Aries. *ASTRONOMY:* ROEN KELLY

Over the years, I've taken attendees at public star parties on telescopic voyages to all corners of the universe. We've viewed the Sun during daytime (with an over-the-front filter or by solar projection, of course) and explored virtually everything the night sky has to offer, except for one class of objects: asteroids.

Most observers can recognize the Sun and the Moon, planets and comets, and deep-sky objects from double stars to nebulae, clusters, and galaxies at first glance. But an asteroid? As the name implies — *aster* is the Latin word for "star" — it looks like a star, so it doesn't stand out when real stars clutter the same field. Things would get more interesting if the viewer were to return the next night and notice that one of the "stars" had moved. But star parties typically are one-night deals, so asteroids aren't on the menu.

Before I continue, let me explain why I use *asteroid* rather than the broader astronomical term *minor planet*. Simply put, I like "asteroid" better. Maybe it's the negative connotation of "minor planet." Asteroids aren't minor at all. Just ask the dinosaurs.

Asteroids may not be jaw-dropping telescopic sights, but it's fun to track their motion over several evenings. I enjoy taking out a finder chart for a particular asteroid, star-hopping with my telescope to the appropriate location, and looking for a "star" in the position where the asteroid is supposed to be. I make a sketch that plots my suspect and the surrounding stars, being sure to include those near where the asteroid's path will take it on subsequent evenings.

If a follow-up observation confirms that my suspect is no longer there and a new "star" appears where I saw none earlier, I carve another notch in my telescope tube. Well, actually, I record the asteroid name and date of sighting in a logbook. Through my little 3-inch Edmund Scientific reflector, I've seen more than 100 asteroids. If I'd notched the tube each time I captured one, I'd have whittled the poor thing down to nothing!

Through my little 3-inch reflector, I've seen more than 100 asteroids.

All eyes on Iris

This month, two of the first 10 asteroids discovered — 2 Pallas and 7 Iris — will be within reach of small telescopes and even binoculars. Because I gear this column to the novice, let's set our sights on Iris, which is brighter and conveniently located near some bright guide stars.

English astronomer John Hind discovered Iris on the evening of August 13, 1847. This was Hind's first asteroid find; over the next seven years, he would add nine more. Hind is perhaps better known for discovering the striking red-hued carbon star R Leporis, also known as Hind's Crimson Star, and Hind's Variable Nebula (NGC 1555), which the star T Tauri illuminates.

Like most asteroids, Iris orbits the Sun in the gap between Mars and Jupiter. Studies of its brightness indicate that this 130-mile-wide asteroid rotates once every 7.1 hours. Astronomers classify it as an S-type, or silicaceous. Most of these stony asteroids inhabit the inner part of the asteroid belt.

Iris reaches opposition and peak visibility October 29, when it lies about 2° south of the 2nd-magnitude star Hamal (Alpha [α] Arietis). At a typical opposition, Iris glows at 8th or 9th magnitude, but this time around, opposition occurs when the asteroid is about as close to Earth as it can get, just 79 million miles away, and thus it peaks at magnitude 6.9.

If you've never seen an asteroid, this is one you'll want to check out. Not only is it bright enough to be picked up through binoculars, but it also spends autumn close to the three bright stars that form the head of Aries the Ram. To capture Iris and put a notch in your telescope tube (or, preferably, a note in your logbook), use the process I described earlier. If you're successful, go ahead and try your luck with October's other bright asteroid, Pallas. It's a bit more than a magnitude fainter than Iris and drifts across a rather barren region near the border between Eridanus and Fornax, but you can do it.

Although asteroids might not be high on the list of showpiece celestial sights, asteroid hunting is a fun and relaxing way to test your observing skills.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: touring Andromeda the Princess with a small telescope. Clear skies!

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

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

ASTRO**NEWS** **DEATH BLOW.** Using data from LIGO, Rochester Institute of Technology researchers have determined that an exploding star may give the resulting black hole a "kick" that affects its alignment in space.

ESO

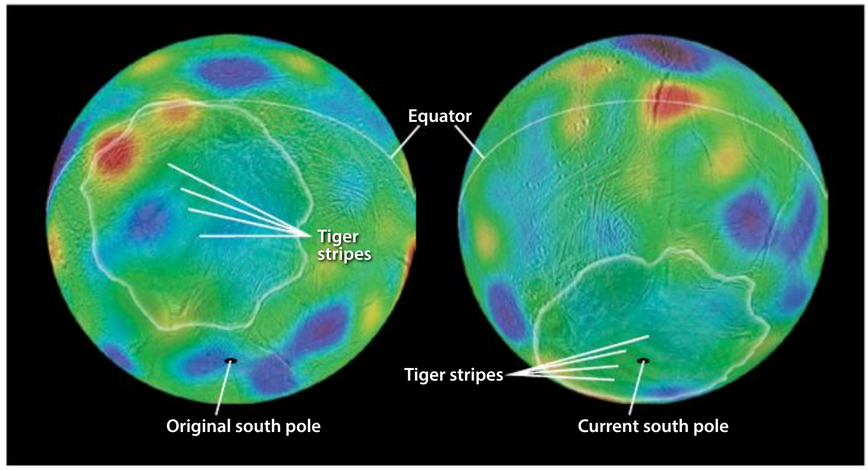
Three for the price of one

SEEING TRIPLE. The European Southern Observatory snapped this 3-gigapixel picture of (bottom to top) the Omega Nebula, the Eagle Nebula, and a gas cloud called Sharpless 2–54. The objects are all about 7,000 light-years away and may have formed from the same primordial gas clouds. Each has since become an area of star formation. The Eagle Nebula is home to the so-called "Pillars of Creation," a star forming region that is one of the most famous images taken with the Hubble Space Telescope. **— J. W.**

20 years

How long the United States has been continually operating spacecraft on or around Mars.

Enceladus' odd tilt from an ancient collision?



NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE/CORNELL UNIVERSITY

POLAR WANDERER. Enceladus' "tiger stripes" are geological scars normally associated with equatorial regions. The left-hand image depicts what may have been the moon's original orientation, while the right-hand image shows how the moon's tilt has dramatically changed likely due to a large asteroid impact.

Saturn's oddball moon Enceladus may be a jumbled mess, according to research published April 30 in *Icarus*.

Researchers at Cornell University, NASA, and the University of Texas say the poles of the moon are about 55 degrees off from where they should be. The telltale signs of this misalignment are a group of basins forming a rough line across the moon's surface that would be expected at its equator — except this chain is currently far off from the current equator as defined by its spin.

This means something changed Enceladus' tilt, likely an asteroid striking near the moon's equator, shifting that region toward the current south pole. Incidentally, that's where the moon's geysers are most active. Enceladus has an ocean underneath its ice crust that frequently spurts water into space.

The initial aftermath of the collision would have left Enceladus without a stable axis, instead chaotically wobbling around for a time. The moon would have resettled after about a million years with an entirely new orientation.

Such a collision may also explain why the moon's south pole is rife with geological activity, while its north pole is relatively inert. **— J. W.**

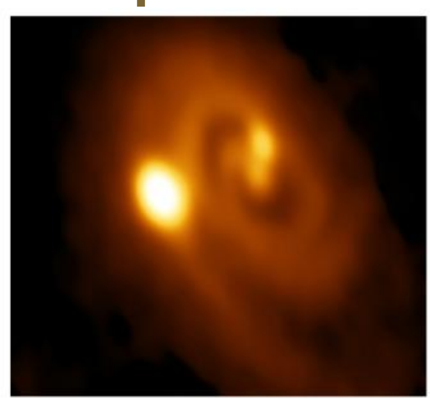
All stars may be born in pairs

The Perseus molecular cloud may be revealing a strange truth about the universe: Most stars, if not all, are born in pairs. This means that the Sun could have lost a companion that's somewhere out there — and it may be one of several known stars.

All stars form in molecular clouds, such as the one in Perseus. Radio observations of the area showed many of its stars are forming in multiple-star systems. Models based on the data further showed that the conditions inside the cloud could be reproduced only if all the stars were originally born in pairs.

Protostars have been observed to form in egg-shaped cores within larger molecular clouds. The models based on the Perseus molecular cloud show that these cores tend to form two concentrations of mass as they collapse, and thus two stars rather than one.

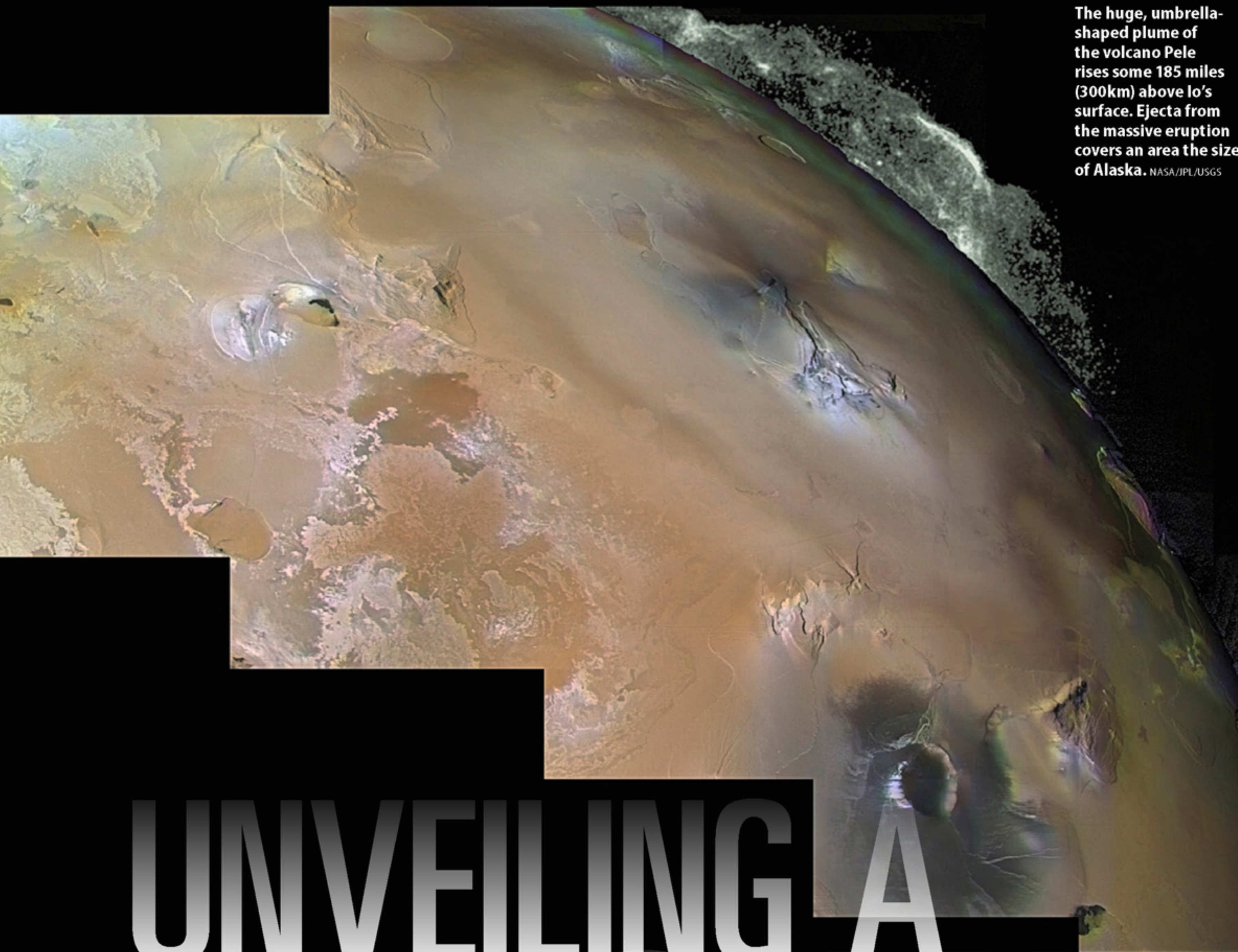
So why doesn't the Sun have a binary companion (well, depending on whom you ask)? It seems that 60 percent of stars lose their binary sister over time, gaining a wider distance from their partner until they are gravitationally severed. The pairs that form also may not include two objects with similar masses, meaning that some former companions could be brown dwarfs cast out by larger stars.



BILL SAXTON, ALMA (ESO/NAOJ/NRAO), NRAO/AUI/NSF

MISSING SIBLING. ALMA captured this radio image of a multiple-star system forming inside the Perseus molecular cloud. Modeling based on observations of the cloud indicates that all stars may be born in systems of two or more stars.

The authors of the paper, published in the *Monthly Notices of the Royal Astronomical Society*, say more work is needed to confirm their hypothesis. But if it's true, the hunt may be on for the companion the Sun once had. **— J. W.**



The huge, umbrella-shaped plume of the volcano Pele rises some 185 miles (300km) above Io's surface. Ejecta from the massive eruption covers an area the size of Alaska. NASA/JPL/USGS

UNVEILING A GIANT

A storm-wracked world and moons with erupting volcanoes and underground oceans were just some of the surprises the Voyager spacecraft revealed.

by Francis Reddy

Until the mid-1990s, when planets were at last being discovered orbiting distant stars, Jupiter was the largest world known. Eleven times Earth's diameter and 318 times our planet's mass, Jupiter possesses more than twice the combined matter of all the other planets, moons, asteroids, and comets in the solar system. Made mostly of hydrogen (89.8 percent by volume) and helium (10.2 percent), Jupiter is essentially a bottomless atmosphere that, beneath the clouds, transitions into an exotic fluid. Its largest moons, so big they rival Mercury in size, appear to hold substantial amounts of liquid water and beckon scientists as potential abodes for life beyond Earth.

For centuries, humanity could view this giant world only through ground-based telescopes. But in 1973 and 1974, respectively, the Pioneer 10 and 11 spacecraft raced past the planet, providing the first close-up images of its stormy atmosphere, probing its internal structure, and charting its intense radiation belts and magnetic field. The Pioneer probes blazed a trail for further exploration of the outer solar system. Even as scientists reveled in the data the probes returned, NASA already was working on a far more ambitious encore.

The mission, originally called Mariner Jupiter-Saturn 1977, received a name change before launch to the one we know today: Voyager, the longest-running space mission in history. The twin Voyagers carried better cameras, more advanced instruments, and more computing power than the Pioneers. Both spacecraft launched in 1977 and are still returning data as they cruise away from our planetary system and journey into the unending night of interstellar space. Voyagers 1 and 2 are now so far away that their radio signals take more than 15 hours to reach us. The more distant probe, Voyager 1, has passed beyond the heliopause, a boundary separating the interstellar environment from charged particles and magnetic fields flowing from the Sun, known as the solar wind. Voyager 2 is cruising through the heliosheath, a zone where pressure from interstellar gas begins slowing the solar wind.

Voyager's views of Jupiter's colorful cloud tops reminded many people of an impressionist painter's canvas. Fine details in and around the Great Red Spot changed significantly in the four months between the Voyager 1 flyby and Voyager 2 (pictured). NASA/JPL

Voyager 1 captured this view of Jupiter on January 9, 1979. Even though the spacecraft was 34 million miles (54 million km) away, its camera captured details impossible to see from Earth. NASA/JPL

"It's been a remarkable journey," says Voyager project scientist Ed Stone at the California Institute of Technology in Pasadena. "We keep discovering things nobody knew we were going to discover." He says both spacecraft may be able to return measurements from a single science instrument until 2030 if their power sources — called radioisotope thermoelectric generators — hold out as expected.

Encounter with Jove

On January 6, 1979, Voyager 1 was 36 million miles (58 million kilometers) from Jupiter and two months from its closest approach. Views of the planet's cloudy, banded disk already exceeded the best images from Earth. Among other assignments, the probe began accumulating a time-lapse movie by taking images every 10 hours, one for each Jupiter rotation.

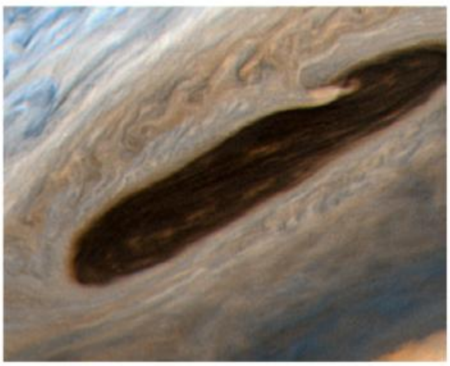
By early February, the resolution and image quality were comparable to the best pictures returned by the Pioneers. From that point on, Jupiter would be seen as never before.

When viewed from Earth through a small telescope, the planet's atmosphere shows alternating bright white zones and darker brown belts. These are the visible manifestations of east-west jet streams that alternate direction from the equator to the poles and carry oval-shaped weather systems of all sizes.

The Voyager imaging team tracked a pair of similarly sized brown ovals, watching them merge, tumble, and eject a dark streamer. Atmospheric models had not predicted such strange behavior. Eddies, waves, and turbulent clouds churned everywhere. At a February 28 press briefing, imaging team leader Bradford Smith described his team as "happily bewildered" by what they were seeing. "Jupiter is far more complex in its atmospheric motions than we had ever imagined," he said.

The planet's largest feature, a vast southern storm called the Great Red Spot, had been observed continuously from Earth for 150 years. But now, for the first time, scientists could study its rotation and watch it interact with neighboring features. Large enough to hold a pair of Earth-sized planets, the Great Red Spot rolls between two jet streams and completes a rotation in

Io (in front of the Great Red Spot) and Europa appear against Jupiter's cloud tops in this Voyager 1 image from February 13, 1979. Io's odd coloration already stands out from a distance of 12 million miles (20 million km). NASA/JPL



The Voyagers revealed several brown ovals in Jupiter's atmosphere. These appear to be openings in the high-level clouds that give a peek to darker regions below. Note the high white cloud protruding over this oval's northern edge. NASA/JPL

about six days. It spins counterclockwise, the opposite direction as hurricanes in Earth's Southern Hemisphere, classifying it as a high-pressure system. Its cloud tops extend nearly 5 miles (8km) above neighboring layers. Although winds whip around its periphery at 425 mph (680 km/h), the interior is calm. Its size and position vary slightly, and long-term ground-based monitoring shows that the longest-lived storm known to science is shrinking steadily.

Amy Simon at NASA's Goddard Space Flight Center in Greenbelt, Maryland, leads a team studying Jupiter with the Hubble Space Telescope. The observations show the storm's long axis is half what was reported in the 1880s and about 30 percent smaller than during the Voyager flybys. And since 2014, the Great Red Spot has turned an unusually intense shade of orange.

Kevin Baines and colleagues at NASA's Jet Propulsion Laboratory (JPL) in Pasadena have conducted laboratory experiments that suggest the storm's color, which has ranged from pale orange to brick red, is a result of reddish coloring agents produced when ultraviolet (UV) sunlight breaks down ammonia and acetylene, gases common in Jupiter's upper atmosphere. The high clouds within the Great Red Spot and similar storms receive more solar UV, and the storms' rotation helps retain colored particles that result in stronger shades. Scientists suspect these changes in color and size are related to storm strength, but they remain poorly understood.

In 1998, two of three 60-year-old white oval storms in a cloud band south of the Great Red Spot merged, and in early 2000, the third oval joined them. The resulting weather system, named Oval BA, is about half the size of the Great Red Spot and persists today. In August 2005, amateur astronomers noticed it was acquiring a reddish color. The hue gradually deepened; by 2006, the storm was nicknamed "the Little Red Spot" and "Red Spot Jr."

DESPITE THE VOYAGER PROBES AND LATER MISSIONS, VITAL QUESTIONS ABOUT JUPITER'S ATMOSPHERE REMAIN.

Yet despite the Voyager probes and later missions, vital questions about Jupiter's atmosphere remain. Why are the jet streams and large storms stable for so long? What's the energy source for the jets? And do the winds continue into the planet's interior?

Diving into Jupiter

The top of Jupiter's atmosphere consists of haze layers formed by complex hydrocarbons like ethane, ethylene, and acetylene. These chemicals assemble from the fragments of methane molecules broken apart by solar UV, a process similar to how smog forms in Earth's atmosphere. About 25 miles (40km) deeper, the pressure approaches 60 percent of that at Earth's surface (1 bar), but the temperature is only –193° F (–125° C). A deck of bright white clouds formed by ammonia ice crystals occupies this level.

Plunge deeper, to twice Earth's surface pressure, and the temperature rises to –76° F (–60° C). Here we encounter a tawny, yellow-orange cloud deck built from droplets or crystals of ammonium hydrosulfide. Usually we cannot see past these clouds, but spacecraft measurements and models indicate that the next cloud layer — at pressures of about 3 to 7 bars and temperatures from freezing to about 60° F (16° C) — contains water ice crystals at the colder levels and water droplets lower down, just like clouds on Earth. Any familiarity pretty much ends there, though.

Minute frequency changes in spacecraft radio signals allow scientists to map the structure of Jupiter's gravitational field; this enables them to develop models of what lies beneath the clouds. Pressures and temperatures increase steadily, but the hydrogen atmosphere simply grows denser and hotter with depth until, hundreds of miles beneath the clouds, molecular hydrogen starts to resemble a hot liquid. At depths 10 times greater, only 20 percent of the way to Jupiter's center, pressures approach a million bars, and temperatures soar to 10,000° F (5,700° C) — nearly as hot as the Sun's surface. Here the interior transforms into a more exotic substance called liquid metallic hydrogen, an electrically conductive soup of protons and electrons that makes up most of Jupiter's mass.

Some 28,000 miles (45,000km) farther down, about 80 percent of the way to the planet's center, the composition may change to a mix of water, methane, and ammonia at enormous temperatures and pressures. Another 4,400 miles (7,000km) down, and we're 10 percent from the center; the pressure rises to around 40 million bars and the temperature to some 40,000° F (22,000° C). At this point, Jupiter's composition may gradually morph into a dense core, perhaps containing up to 20 Earth masses in a mix of rock and iron that may also include water, methane, and ammonia.

At these pressures, dense materials may become soluble in liquid hydrogen, some scientists suggest. This means Jupiter's original core may have dissolved partially or

UNDER THE VEIL

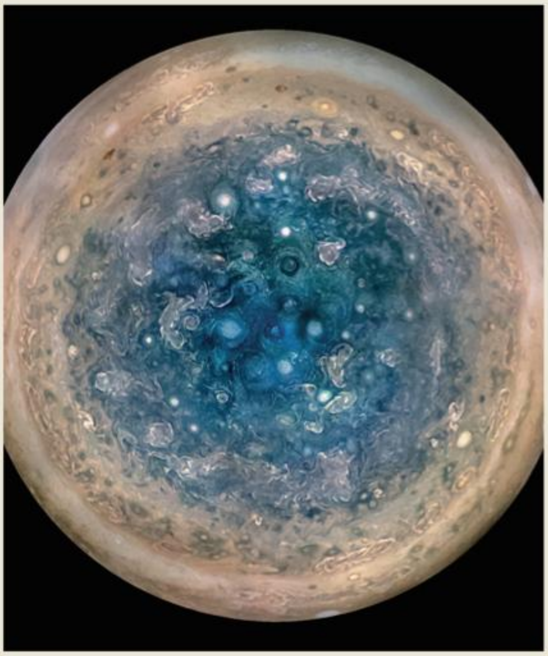
NASA's Juno mission entered an elongated 53-day orbit around Jupiter on July 4, 2016. The spacecraft is mapping the planet's gravitational and magnetic fields in unprecedented detail, allowing scientists to understand how material moves deep within the planet. Juno also is measuring atmospheric dynamics to pressures beyond 100 bars, far below Jupiter's visible clouds, and providing scientists with an improved upper limit on the mass of a possible solid core.

Meanwhile, Juno's magnetometer is creating the first 3-D map of the planet's magnetic field, providing additional insights into Jupiter's internal structure. The movement of electrically charged material, called a dynamo, generates the field somewhere within the planet.

Juno's observations could provide scientists with their most detailed look at a planetary dynamo. Earth's dynamo lies about halfway to its center, but the abundant iron-bearing materials in the crust makes mapping its location from orbit complicated.

"On Jupiter, a gas planet, there is no iron-bearing crust between us and the dynamo, and the dynamo is much, much closer to the surface of Jupiter than is the case in the Earth," says John Connerney at NASA's Goddard Space Flight Center, lead scientist for Juno's magnetometer instrument. Initially, scientists thought Jupiter's dynamo might be between 15 and 25 percent of the way down, or 0.85 to 0.75 Jupiter radii from the planet's center. "More contemporary thinking is that maybe the dynamo is actually closer, up to 0.93 jovian radii, in which case it's really just beneath the visible surface," adds Connerney.

To perform its mission, Juno flies over Jupiter's poles, passing about 2,600 miles (4,100 kilometers) from its cloud tops. The elongated polar orbit helps limit the spacecraft's exposure to Jupiter's punishing radiation belts, but more protection still was needed. So Juno's critical electronics are placed in a radiation-shielded "vault," a titanium cube with walls a third of an inch (1 centimeter) thick. — *F. R.*



The Juno spacecraft's camera preferentially targets Jupiter's poles. This view of the south pole reveals several oval cyclones up to 600 miles (1,000km) in diameter. NASA/JPL-CALTECH/SwRI/MSSS/BETSY ASHER HALL/GERVASIO ROBLES

completely away, its high-density materials dispersed throughout a larger portion of the planet. One of the main goals of NASA's Juno mission, which has been orbiting the planet since July 2016, is to answer the many remaining questions about how the solar system's largest world is put together. (See "Under the veil," above.)

Magnetic tango

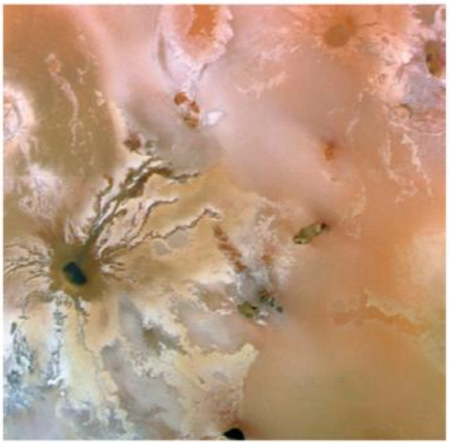
Like Earth, Jupiter generates a magnetic field, which at the cloud tops is about 15 times stronger than our planet's. The field traps, stores, and controls the flow of charged particles inside it, forming a vast, comet-shaped bubble — called a magnetosphere — that shields the planet from direct exposure to the solar wind. Pressure from the solar wind pushes the Sun-facing side into a rounded bow shock that slows and deflects most of the incoming charged particles in much the same way that water flows around the bow of a moving ship. The opposite side tapers into an immense magnetotail whose farthest portions wave and flap like the tattered end of a windsock.

Jupiter's magnetosphere is the solar system's largest planetary structure. "If you look up and identify Jupiter in the sky, its magnetosphere would be about the size of the Moon," says Goddard's John Connerney, deputy principal investigator for the Juno mission. Its bow shock typically lies about 40 Jupiter diameters sunward of the planet and its magnetotail stretches some 3,500 diameters behind it, nearly reaching Saturn's orbit. We know this because as Voyager 2 approached Saturn in 1981, two years and 400 million miles (650 million km) after its Jupiter encounter, the spacecraft slipped in and out of Jupiter's frayed magnetotail multiple times. (By comparison, Earth's bow shock lies three to five Earth diameters toward the Sun, and its magnetotail may extend hundreds of diameters.)

Between February 28 and March 2, 1979, the magnetosphere seemed to be playing hard to get with the approaching Voyager 1. The solar wind was gusty, producing unusually strong and variable pressures that pushed the bow shock closer to the planet. When the wind eased, the bow shock re-expanded. Pioneers 10 and 11 made their crossings 50 diameters from Jupiter, but Voyager 1 crossed it five times, the last at scarcely half that range (28 diameters).

On March 5, the spacecraft made its closest approach, passing within 128,400 miles (206,700km) of Jupiter's cloud tops, barely one-third the distance at which Voyager 2 would pass July 9. Scientists selected this path so they could measure a hypothesized

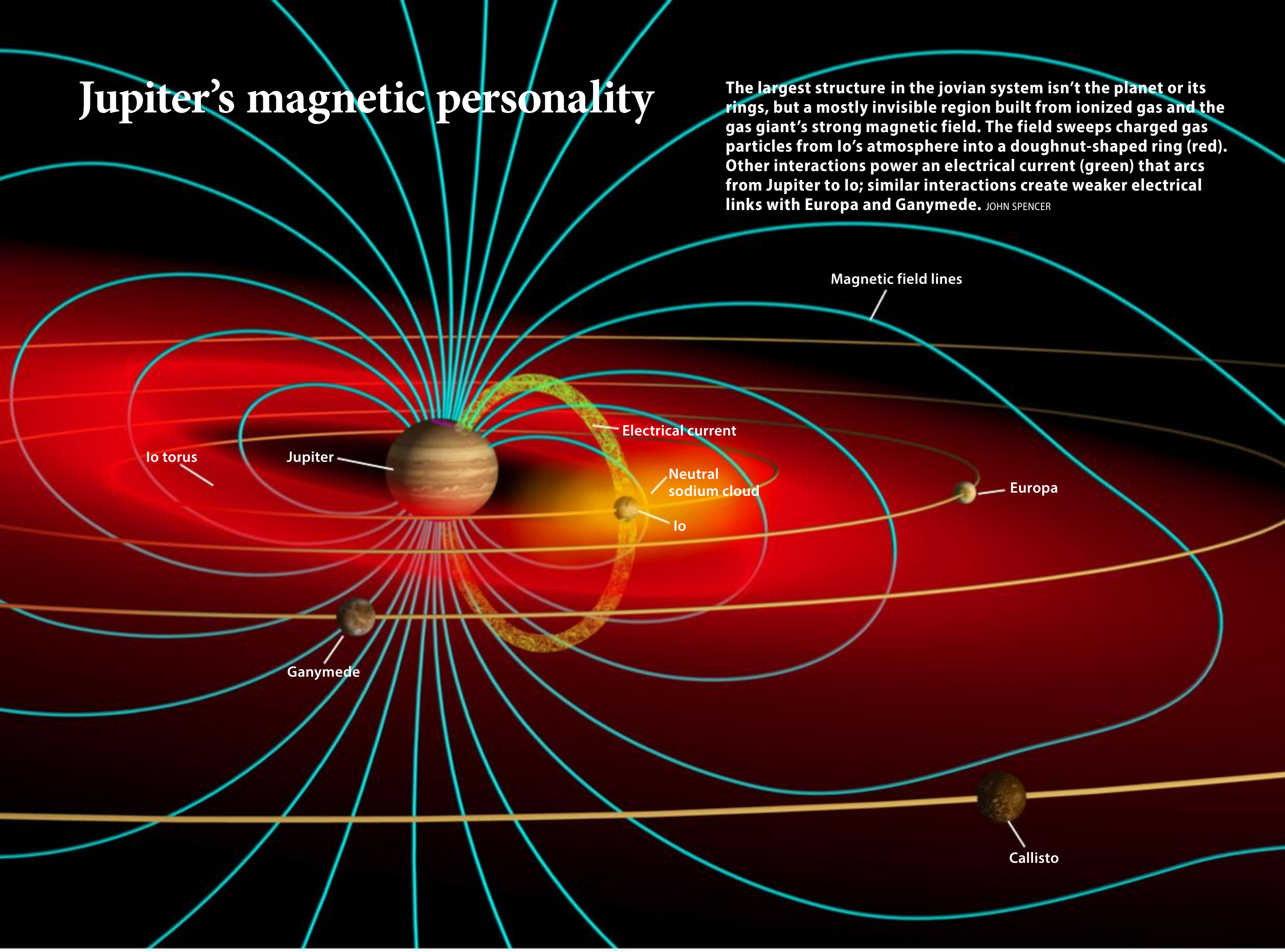
Scientists discovered the first volcanic eruptions beyond Earth on this navigation image taken March 8, 1979. The photo shows a crescent Io with a volcanic plume rising more than 150 miles (260km) above the limb. A second plume catches the rays of the rising Sun. NASA/JPL



Sinuous rivers of lava flow down the flanks of Io's volcano Ra Patera. The volcano's vent measures about 19 miles (30km) across, while the lava flows extend up to 155 miles (250km) from there. The summit rises only about 0.6 mile (1km) above the surroundings. NASA/JPL

Jupiter's magnetic personality

The largest structure in the jovian system isn't the planet or its rings, but a mostly invisible region built from ionized gas and the gas giant's strong magnetic field. The field sweeps charged gas particles from Io's atmosphere into a doughnut-shaped ring (red). Other interactions power an electrical current (green) that arcs from Jupiter to Io; similar interactions create weaker electrical links with Europa and Ganymede. JOHN SPENCER



electrical circuit connecting Jupiter and its moon Io, and it took Voyager 1 deep into the most hazardous radiation belts in the solar system. Based on measurements from the Pioneers, the Voyager design included shielding that hardened sensitive electronics to the bombardment of high-energy electrons, protons, and ions stored in Jupiter's equivalent of Earth's Van Allen Belts. But an unprotected human passenger riding aboard Voyager 1 during closest approach would have received a thousand times the lethal radiation dose.

AN EXTRAORDINARY PLANET DESERVES EXTRAORDINARY MOONS, AND JUPITER'S FOUR BIG SATELLITES DO NOT DISAPPOINT.

Four new worlds

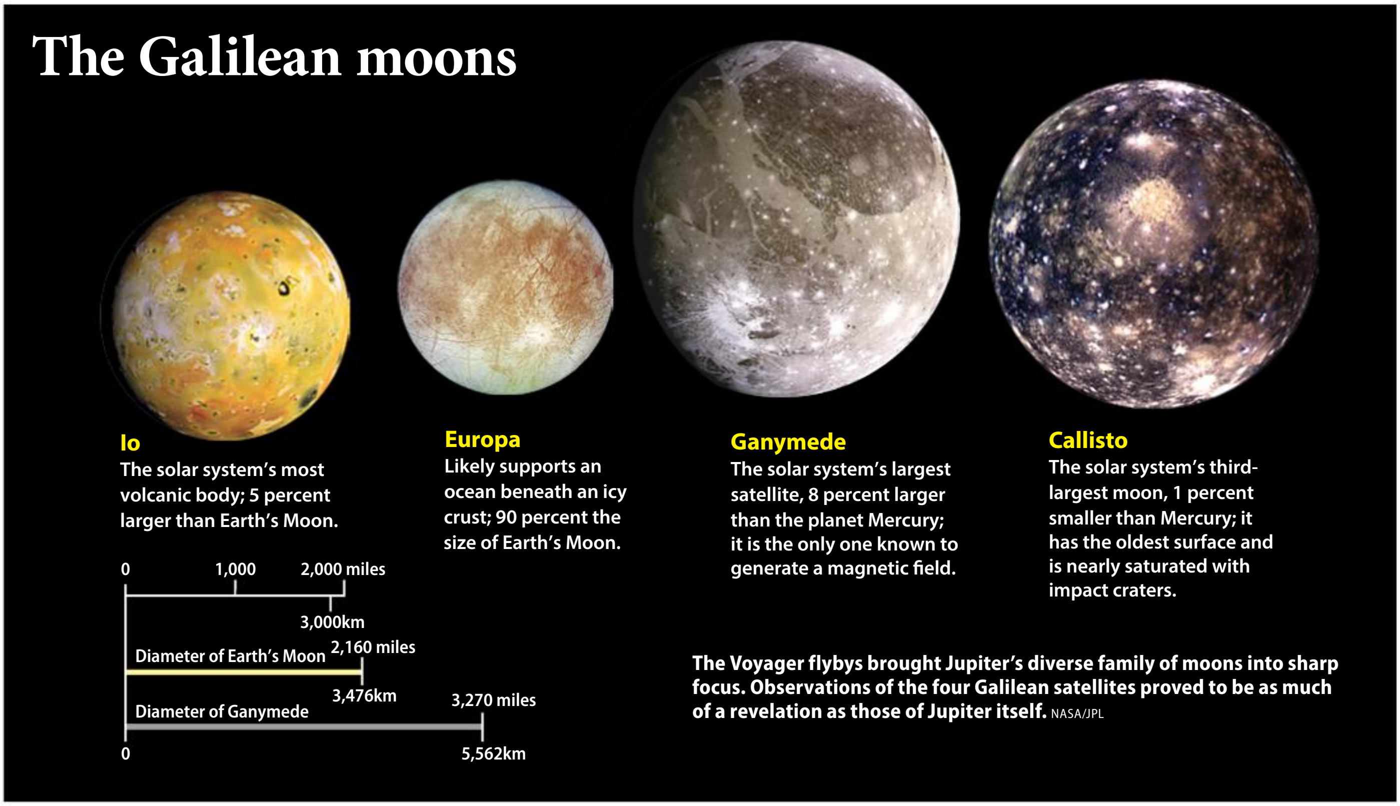
An extraordinary planet deserves extraordinary moons, and Jupiter's four big satellites do not disappoint. Discovered by Galileo Galilei in 1610, they are Io, Europa, Ganymede, and Callisto (in order of distance from the planet). Ganymede, the largest and most massive moon in the solar system, is slightly bigger than Mercury, while Callisto is nearly the planet's diameter. Both Io and Europa are roughly the size of Earth's Moon.

The moons' complexity and individuality, which scientists hardly suspected despite centuries of telescopic observations, proved a major surprise of the Voyager missions. Reporting their results in the journal *Science* three months after the Voyager 1 encounter, the imaging team noted that the large moons do not closely resemble either the planets in the inner solar system or one another. "The sense of novelty," they wrote, "would probably not have been greater had we explored a different solar system."

"They're quite distinct," says Stone, "and I think the one thing we have learned is that nature is remarkably diverse, and you don't see replicas. Each body seems to have its own life history written on the surface and in its interior."

There had long been hints that the big moons might be doing something interesting. Galileo's 17th-century plots showed that Europa and Io always meet up on the side of Jupiter exactly opposite from where Europa and Ganymede do. In the 7.15 days it takes Ganymede to go around Jupiter once, Europa orbits twice and Io four times. This 1:2:4 resonance forces the moons' orbits to maintain a slight eccentricity, which in turn causes their bodies to flex slightly due to tides raised by Jupiter's gravity. Just as repeatedly bending a paper clip warms up the metal, this forced flexing warms the interiors of Jupiter's big moons.

Stanton Peale at the University of California, Santa Barbara, and his colleagues first described the mechanism in a



The Voyager flybys brought Jupiter's diverse family of moons into sharp focus. Observations of the four Galilean satellites proved to be as much of a revelation as those of Jupiter itself. NASA/JPL

paper submitted to *Science* in January 1979. They presciently concluded: "Voyager images of Io may reveal evidence for a planetary structure and history dramatically different from any previously observed." The paper was published March 2, *three days* before Voyager 1's closest approach. By then, images of the weirdly colored moon, reminiscent of a cheese pizza, already were making headlines. Scientists had expected Io to resemble our Moon, but it lacked anything that looked like an impact crater and was coated with richly colored deposits that wouldn't look out of place around active fumaroles on Earth.

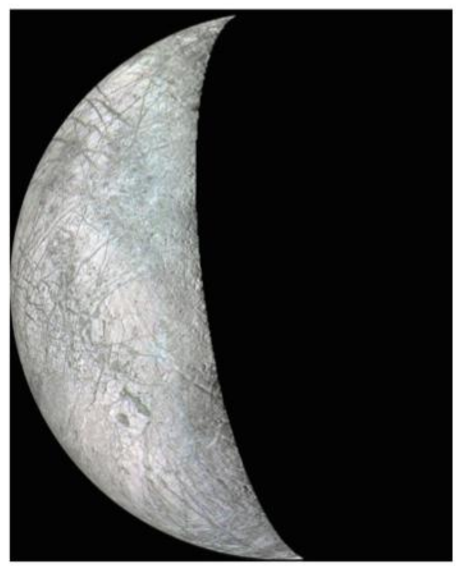
On March 8, as Voyager 1 raced out of the Jupiter system, its camera captured a routine navigation image of a crescent Io as part of a program to refine knowledge of the spacecraft's trajectory. The next day, JPL engineer Linda Morabito enhanced this image to locate background stars and uncovered another crescent shape on Io's sunlit limb. It looked like the edge of another satellite peeking out from behind Io, but scientists determined that an unknown satellite so large would have been detectable from Earth. "No one understood what they were seeing, reinforcing the degree of difficulty associated with interpreting this image," she later wrote.

By March 12, the imaging team had confirmed the presence of active volcanoes. What Morabito had noticed was a plume of

Giant Ganymede — larger than Mercury — sports two different types of terrain. The dark material is oldest, while the lighter bands cut by grooves and ridges are significantly younger. A relatively recent impact threw out the bright material at bottom. NASA/JPL

ejecta associated with a heart-shaped volcano now known as Pele. Remarkably, the same picture also held a second plume, one erupting from a feature now called Loki and catching sunlight as it rose high over Io's night side.

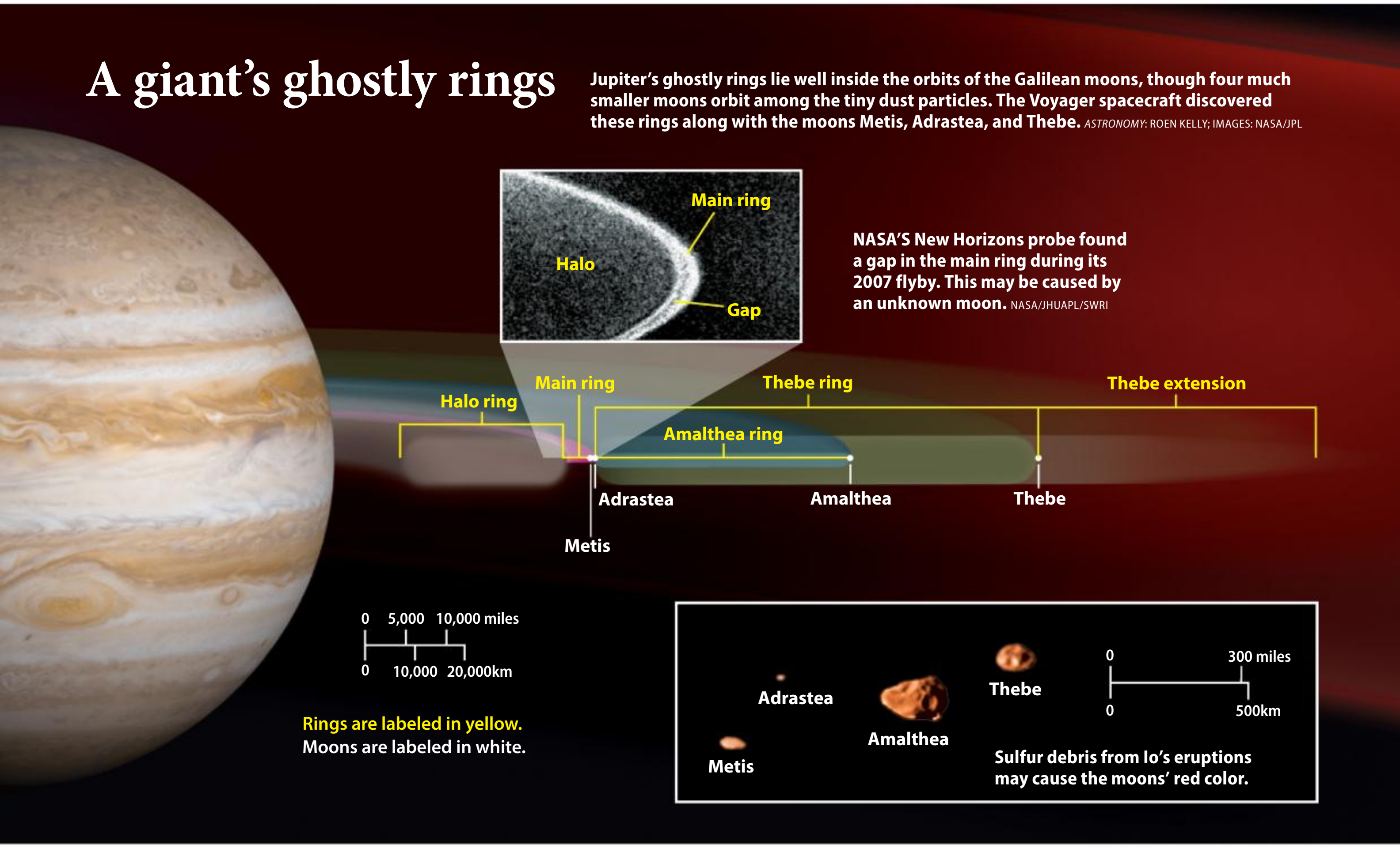
Scientists now know of at least 150 active volcanoes on Io. Some of them blast umbrella-shaped plumes containing sodium, potassium, sulfur, sulfur dioxide, and more to altitudes as high as 310 miles (500km). Some of the ejecta falls back to



The Voyagers revealed dark streaks crisscrossing the surface of Europa, the smallest of Jupiter's Galilean moons. In some cases, the streaks stretch more than 1,000 miles (1,600km). Scientists later deduced that the streaks are cracks in the moon's icy crust filled with material from its interior. NASA/JPL/USGS

paint Io's terrain in garish hues, and the rest forms a thin, distended atmosphere around the moon. Particle interactions ionize some of these atoms, and they then become swept up in Jupiter's fast-moving magnetic field, which rotates with the planet's 10-hour rotation. "About a ton per second of that material is picked up by the

A giant's ghostly rings



Jupiter's ghostly rings lie well inside the orbits of the Galilean moons, though four much smaller moons orbit among the tiny dust particles. The Voyager spacecraft discovered these rings along with the moons Metis, Adrastea, and Thebe. *ASTRONOMY:* ROEN KELLY; IMAGES: NASA/JPL

jovian magnetic field, and that mass of stuff inflates the Jupiter magnetosphere to about twice the size it should be," Stone says.

The ionized gas spreads along Io's orbit to form a doughnut-shaped cloud called the Io plasma torus. Some of the heavy ions in the torus migrate outward, and their pressure supersizes the magnetosphere. As Io moves through the torus, it continuously generates an electrical current that flows along a conduit, called the Io flux tube, linked to Jupiter's upper atmosphere. Two billion kilowatts flow through the flux tube, comparable to the average global power consumption on Earth. The Voyager 1 team deliberately tried to pass through the tube, but the material around Io shifted its position from what was expected, and the spacecraft instead flew alongside it.

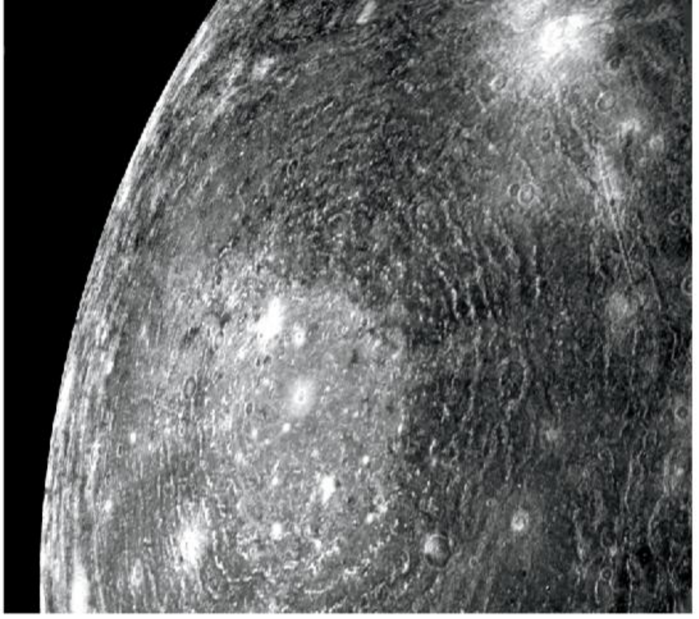
While imaging from Earth in 1993, Connerney and his colleagues discovered a spot of infrared emission in Jupiter's polar atmosphere. The glow tracked with Io in its orbit and arose from energy coursing down the flux tube. But Io isn't alone in this regard. In 2002, Hubble imaged Io's spot in the UV and found two more glows from Europa and Ganymede, showing they generate their own flux tubes. "The system is highly coupled and connected, where the magnetic fields and the particles are all interacting with the moons," Stone says. And the phenomenon isn't unique to Jupiter. In 2011, scientists identified a UV spot associated with the active moon Enceladus in images from the Cassini mission orbiting Saturn.

THE JUPITER FLYBYS MARK THE FIRST CHAPTER IN THE VOYAGER'S EXPLORATION OF THE OUTER SOLAR SYSTEM.

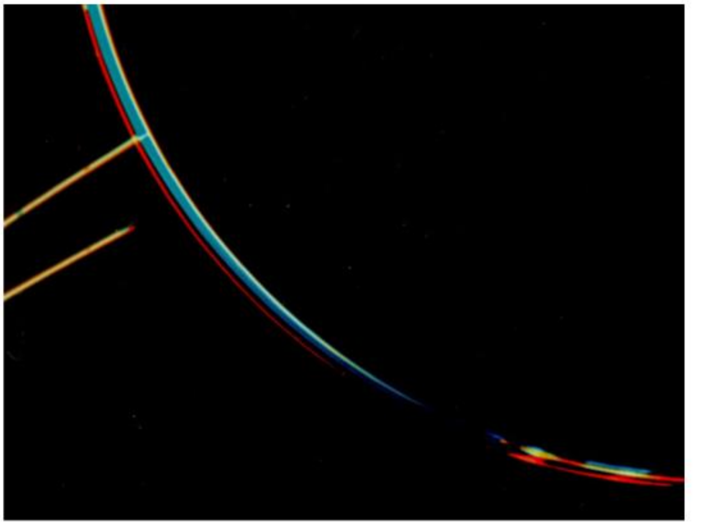
The outer trio

Europa, the next moon out from Jupiter, couldn't be more different from its siblings. Low-resolution images from Voyager 1 showed a bright surface of frozen water with no discernible craters, along with hints of dark linear features. Voyager 2 passed much closer to Europa on July 9, and its images revealed frozen plains crisscrossed by dark streaks, giving it the look of a cracked egg. Europa's surface is the smoothest in the solar system. Features display so little topographical relief that imaging team member Larry Soderblom compared the moon to a billiard ball. Later that year, the scientists who explained the heating of Io suggested that tidal flexing of Europa could provide enough heat to sustain an ocean beneath its icy shell, which is widely thought to be 10 to 15 miles (16 to 24km) thick. The ocean itself may be at least 30 miles (48km) deep, or more than 10 times the average depth of Earth's seas.

In fact, several lines of evidence now support the presence of briny global oceans within Europa, Ganymede, and Callisto, each containing more water than Earth's seas. NASA's Galileo spacecraft, which in 1995 became the first to orbit Jupiter, flew close to these moons and found that Jupiter's rotating magnetic field induces currents in electrically conducting layers within them. These currents, in turn, generate secondary magnetic fields Galileo could detect. Europa's induced response matches what researchers would expect for a salty subsurface ocean many miles thick.



The multiple-ring impact basin Valhalla dominates this Voyager 1 view of Jupiter's outermost major moon, Callisto. The lighter, central area spans about 375 miles (600km) while the outer rings extend about 1,100 miles (1,800km) from the center. NASA/JPL



Voyager 1 discovered Jupiter's faint, dusty rings during its flyby, and they posed for this Voyager 2 portrait once the probe passed into the planet's shadow. The curved rings appear orange-red; Jupiter's multicolored limb comes from the long exposure through two filters. NASA/JPL

And different teams using Hubble in 2012 and 2016 discovered tantalizing evidence that Europa occasionally erupts plumes of water vapor reaching heights of 125 miles (200km), suggesting the icy shell may be quite thin in some locations.

The first low-resolution glimpses of Ganymede revealed two starkly different terrain types. A dark material covers about 35 percent of the surface. Peppered with impact craters and their bright halos of icy ejecta, this is the moon's geologically oldest surface. The rest of the moon features light materials crosscut by an intricate patchwork of grooves and ridges. Voyager 1 images showed that fault lines cut some of the light bands, which were then offset by surface movement. "There is transverse motion along these faults," Soderblom said at a March 6 briefing. "Things get offset, apparently, for hundreds of kilometers." This suggested that tidal heating had powered a brief period of intense tectonic activity in Ganymede's icy crust early in its history.

The Galileo mission revealed in 1996 that Ganymede generates its own permanent magnetic field, the only moon in the solar system known to do so, and therefore makes its own miniature magnetosphere. This complicates the interpretation of its induced field, but recent models, as well as Hubble observations of Ganymede's aurorae, suggest the interior contains shells of different phases of water ice separated by salty seas.

Callisto, the farthest of Jupiter's big moons, hosts the solar system's most heavily cratered and geologically ancient surface. Its terrain is nearly saturated with bright impact craters. The largest visible feature, named Valhalla, resembles a bull's-eye about 2,200 miles (3,600km) across, the frozen remnant of a giant impact. Galileo spacecraft observations indicate the presence of a salty, subsurface global ocean despite little tidal heating at Callisto now. Perhaps ammonia and other contaminants lower the freezing point enough for a liquid layer to survive.

Opening act

The Jupiter flybys mark the first chapter in the Voyagers' exploration of the outer solar system. They provided new views of an enormous, complex, and dynamic atmosphere that is still far from understood. They explored a vast magnetosphere loaded with particles from its moons, especially Io, and intimately connected to them. Close-ups of unique new worlds uncovered incredible properties, including the first example of active extraterrestrial volcanism and the first clues that frozen moons could sport internal seas. Further discoveries included a faint ring of dust extending 80,000 miles (129,000km) from the planet's center, and two new moons, Metis and Adrastea, orbiting just beyond it. The probes also found a third satellite, Thebe, in a more distant orbit, though still well inside Io's.

With Jupiter now in the rearview mirror, Voyager scientists could begin digging deeper into the data — and wondering what awaited them at their next destination, Saturn.

SPACECRAFT VISITS TO JUPITER

Probe	Status	Agency
Pioneer 10	Flyby and gravity assist, 1973	NASA
Pioneer 11	Flyby and gravity assist, 1974	NASA
Voyager 1	Flyby and gravity assist, 1979	NASA
Voyager 2	Flyby and gravity assist, 1979	NASA
Ulysses	Flyby for gravity assist, 1992 and 2004	NASA/ESA
Galileo	Orbiter, 1995 to 2003	NASA
Cassini-Huygens	Flyby for gravity assist, 2000	NASA/ESA
New Horizons	Flyby for gravity assist, 2007	NASA
Juno	Orbiter, reached Jupiter in 2016	NASA
Jupiter Icy Moons Orbiter	Orbiter, in development for 2022 launch	ESA
Europa Clipper	Orbiter, in development for 2020s launch	NASA

Francis Reddy *is the senior science writer for the Astrophysics Science Division at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

Close encounters with the

The probes not only returned stunning images of Saturn and its rings — they also set the stage for the highly successful Cassini mission. **by Liz Kruesi**

2

1

Some call Saturn the jewel of the solar system, with its distinctive rings, variety of moons, and swift atmospheric winds. The first glances of the planet through a telescope certainly form a memory that sticks in peoples' minds. Whether you're a backyard observer or a planetary scientist, Saturn is a fascinating world.

For centuries, astronomers using telescopes spied a ring of material circling the planet's equator. Pinpricks of light, the planet's moons, floated nearby. Technical advances led to better views, until scientists could see gaps or divisions in the material ringing Saturn. They also saw oddities on its moons: One seemed to hold a methane atmosphere laced with clouds, while another was two-faced, bright on one half but dark as asphalt on the other.

But it would take Voyager 1 and 2, a pair of visiting spacecraft, to fully reveal the beautiful and intriguing ringed world and its equally fascinating system of moons. The planet hosts a wide array of astronomical processes and structures, and the Voyager probes were the first to show scientists how incredible the Saturn system truly is. The system they uncovered was too intriguing not to revisit, laying the foundation for the groundbreaking Cassini mission decades later.

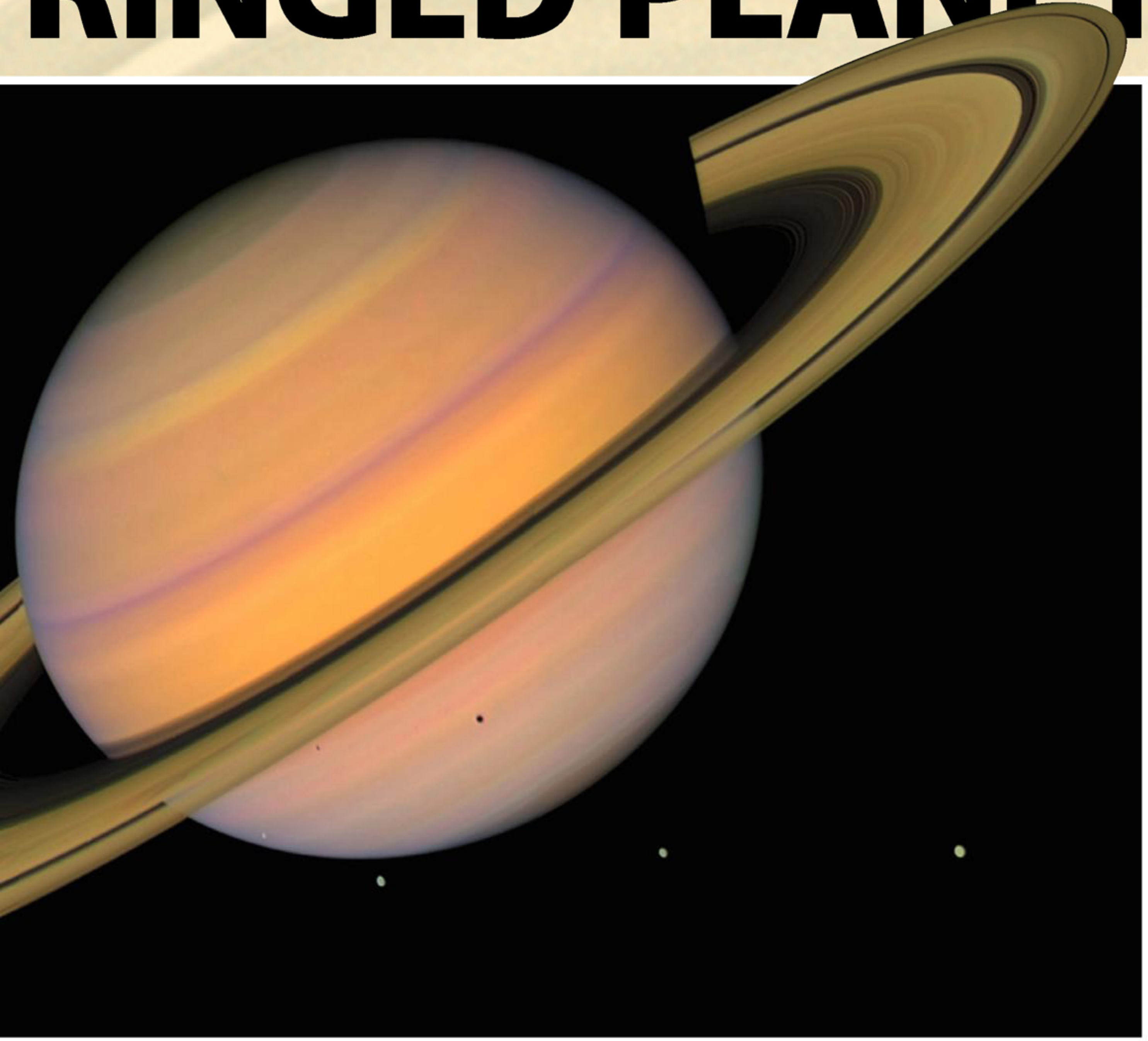
Toward the ringed world

The twin Voyager spacecraft launched 16 days apart in 1977, beginning their Grand Tour of the outer solar system. They took separate journeys to the ringed planet and its diverse moons. Voyager 1 arrived in November 1980, and afterward used the planet's gravity to slingshot itself out of the solar system's plane. Voyager 2 swung through in August 1981, continuing on to Uranus and Neptune.

The pair of probes revealed many unexpected details about the Saturn system, but Voyager 1 was not the first mission to snap an up-close view of the planet. That title belongs to Pioneer 11, which flew by the ringed world in 1979. Its photographs, combined with ground-based detections, helped planetary scientists better plan the Voyagers' Saturn flyby routes, as well as choose which targets to focus on.

Each closest approach was a quick encounter — after all, the probes were traveling faster than 9 miles per second

RINGED PLANET



(15 km/s). But the mission team began collecting detailed observations of each target weeks in advance. And for the two weeks surrounding each nearest encounter of Saturn, all the science teams would converge at the Jet Propulsion Laboratory in Pasadena, California, for an intense observing session.

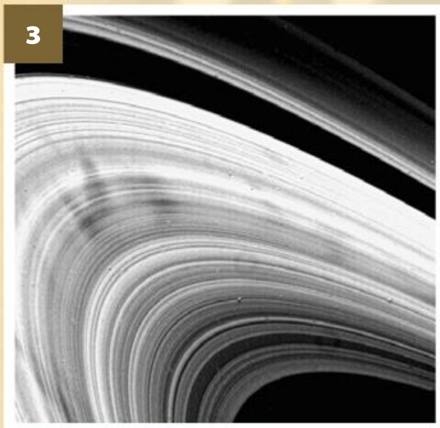
Remarkable features of the rings

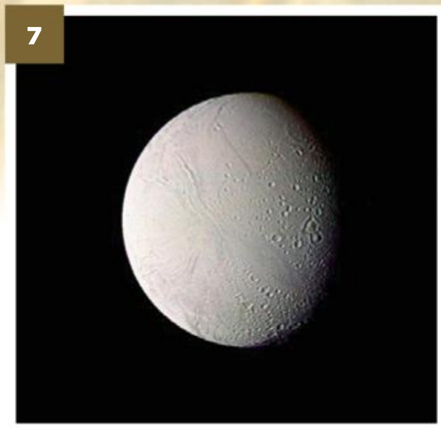
Before Voyager arrived at Saturn, scientists knew of two empty paths splitting Saturn's rings: the Cassini Division and the Encke Gap. But based on observations from both Pioneer and ground-based telescopes, "we thought we would find bland, featureless sheets of material separated by gaps," says Linda Spilker, who studied the rings as part of the Voyager team and is now the Cassini project scientist. Instead, the twin spacecraft revealed the rings are anything but bland.

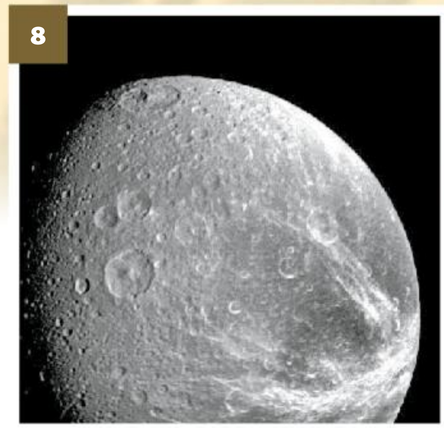
On October 6, 1980, when Voyager 1 was still 30 million miles (50 million kilometers) from Saturn, researchers first made

1 and 2. Although Pioneer 11 holds the distinction of taking the first close-up image of Saturn (left, with its largest moon Titan also in the frame), the superior resolution afforded by the Voyager probes (right, seen with moons Tethys, Dione, and Rhea to the lower right, while Mimas appears as a dim shadow just beneath the rings on the left) uncovered details previously unimagined by planetary scientists.

1: NASA AMES; 2: NASA/JPL/USGS







3. Voyager was the first to image Saturn's rings in enough detail to make out features like the "spokes" seen here in the B ring on August 22, 1981, from a distance of 2.5 million miles (4 million km). These dusty features, which can stretch up to 12,400 miles (20,000km) in length, vary with time and have no agreed-upon origin. NASA/JPL-CALTECH

4. Saturn's skinny F ring, imaged November 12, 1980, from 466,000 miles (750,000km), is a complex structure composed of two bright rings encircling a third, fainter ring. Clumps, kinks, and other structures in these rings give them a braided appearance. NASA/JPL-CALTECH

5. The Voyagers unveiled not only a dynamic planet, but an intriguing and varied system of moons as well. Voyager imaged Mimas on November 12, 1980, from a distance of 264,000 miles (425,000km). The moon's terrain is marred by the huge Herschel crater, which is 80 miles (130km) across and covers more than a quarter of Mimas' surface. NASA/JPL

6. Tethys, imaged by Voyager 2, showed areas of both old (brighter, more heavily cratered areas) and new (darker) crust, as well as a vast system of canyons that nearly encircles the small moon from top to bottom. NASA/JPL-CALTECH

out dark streaks in the rings. The streaks didn't circle the planet, but instead looked like they radiated away from it. These "spokes" were the first of many unexpected details in the ring system.

As Voyager 1 neared closest approach and the resolution improved, the team could make out more details. "It looked like grooves on a phonograph record," says Spilker of the rings. Hundreds of concentric rings circled Saturn. Scientists saw waves along the edges of gaps between those rings, as well as braided features and spiral structures within the rings — all due to the gravitational influence of small moons embedded in and sitting just outside of the rings. They even saw patterns that looked like propeller wings spiraling out from moonlets, showing how large boulders clear material along gaps in their orbit. Studying the behavior of moonlets in a "debris disk" such as Saturn's rings has allowed scientists to indirectly study how planets form around stars in protostellar disks. "The rings were just so much more than I had imagined," adds Spilker.

But it wasn't just the beautiful images of the photogenic ring system that surprised scientists. When Voyager 2 approached Saturn in August, it observed starlight from Delta Scorpii as the rings passed in between that background star and the spacecraft. Called an occultation, this filtered view allowed researchers to see even finer details in the rings. In fact, they saw the particles in the rings with a resolution 10 to 20 times better than by just photographing the rings directly.

On the evening of nearest approach, when Voyager 2 was just over 100,000 miles (161,000km) from Saturn, the photopolarimeter (an instrument that records how light scatters off particles) observed the rings for two and a half hours. Those data were printed on a roll of paper using a pen-plotter. "I remember unrolling it out in the hallway, putting a book on one end and a book on the other end and walking through and just looking at the data," recalls Spilker. "It was like walking through the rings."

With those data, scientists could estimate the thickness at the edge of each ring: between 33 and 656 feet (10–200m). They saw smaller structures in the rings: clumps, twists, and waves — all due to the gravity of Saturn's satellites. That occultation using Delta Scorpii was one of the most crucial observations Voyager made at Saturn. And with only one such event, the data was extremely precious, says Spilker.

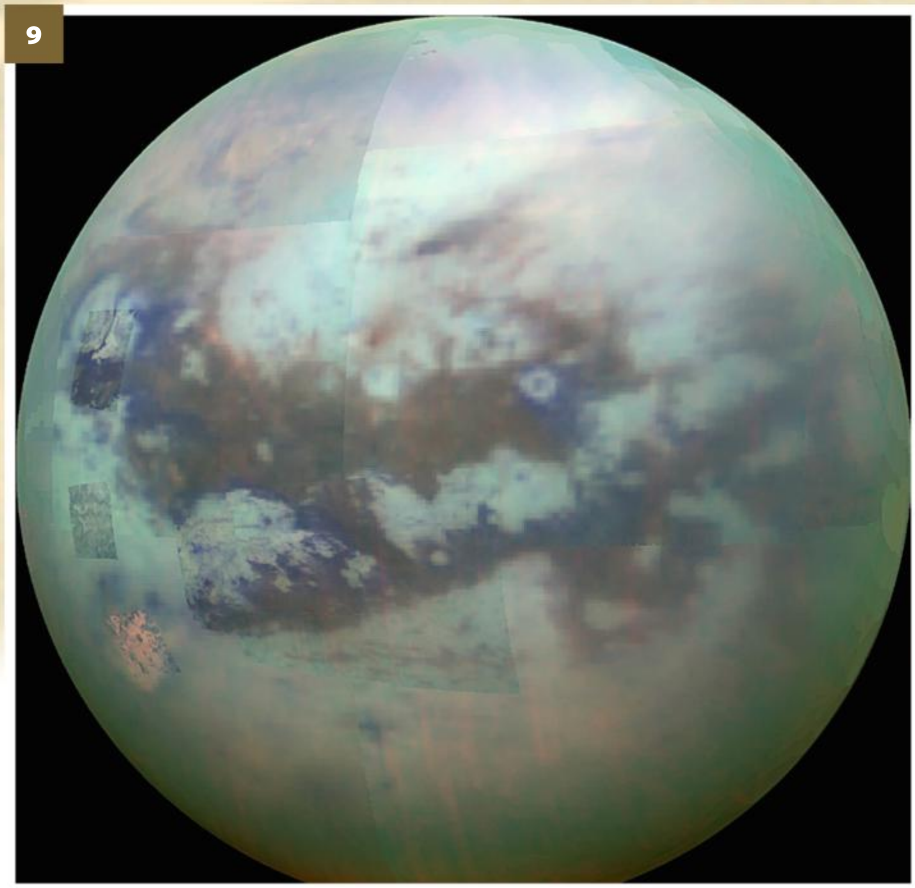
WHAT IF?

When Voyager 2 flew by the Saturn system in August 1981, one of its goals was to further study Enceladus. Unfortunately, the spacecraft's swiveling platform malfunctioned for several hours, and its five instruments were out of commission during closest approach to Saturn and its inner moons.

That meant the science team didn't get all the images and measurements they were hoping for, including close-up mosaics of Enceladus. During the flyby, that moon and the Sun aligned in such a way to illuminate Enceladus' south polar region, where scientists now know geysers of water and organic materials spew.

Would sunlight have glinted off the icy particles in those jets, revealing their presence in 1981? "I always wonder: Would we have found Enceladus' plumes with Voyager had the Voyager 2 scan platform not gotten stuck?" asks Linda Spilker. Instead, the Cassini spacecraft discovered the geysers more than two decades later, during a 2005 flyby. — *L. K.*

9



What a difference a generation of technology design makes: Today, scientists have hundreds of occultation observations from the Cassini spacecraft, which studied the Saturn system from 2004 until September of this year. Cassini's 13 years of observations provided answers about how the moons and Saturn itself shape the rings.

Saturn's satellites

Before either Voyager arrived at Saturn, most of the planet's moons were no more than pinpricks of light. Ground-based telescopes couldn't resolve their surfaces, so scientists had little information about the immense variation these worlds hold.

First up was Titan, the planet's largest moon. Voyager 1 made its closest approach to the orange sphere in the late hours of November 11, 1980, when it flew less than 310,000 miles (500,000km) from the moon. Scientists hoped to see through the thick atmosphere to learn about the surface, but Titan's mysteries weren't so easy to solve. The visible and infrared cameras could not penetrate the clouds. Fortunately, researchers could get a radio signal to the surface and back, and used it to calculate the atmosphere's density: 1.6 times that of Earth.

During the analysis of the radio data, a hushed rumor spread among the dozens of Voyager scientists stationed at JPL, recalls planetary scientist Carolyn Porco, that liquid nitrogen might exist on the surface of Titan. "It turned out the initial analysis was incorrect," she says. "But I'll never forget the indescribable thrill of hearing that rumor. It felt, for a moment, like all of us ... were crewmates on the starship Enterprise, and we had just come upon the most alien of worlds yet seen. We were indeed planetary explorers." Porco later explored the Saturnian system as a member of the Cassini team.

What Voyager *did* reveal of Titan, though — knowledge of its atmosphere's density and composition, the possibility of

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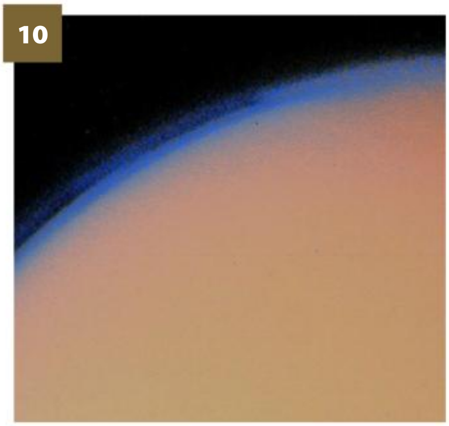


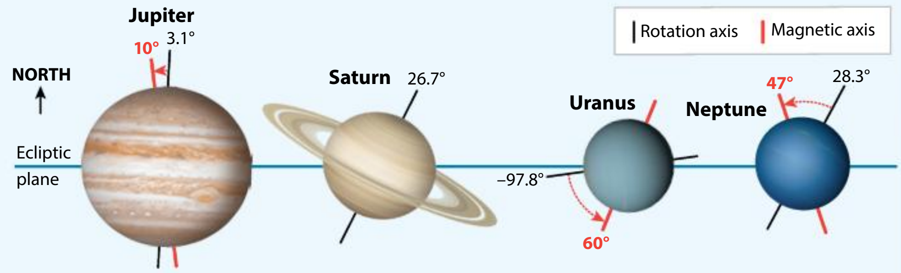
7. Enceladus is one of Saturn's most compelling moons. Voyager 2 passed much closer to the moon than Voyager 1, and it took this image August 25, 1981, from a distance of 74,000 miles (119,000km). Looking at data from the probes, planetary scientists became intrigued by Enceladus' widely varying terrain. Swaths of the moon appeared devoid of craters, indicating ages in those areas of less than a few hundred million years. NASA/JPL-CALTECH

8. Voyager 1 sent back images of Dione on November 12, 1980, from 149,000 miles (240,000km), that showed numerous impact craters marred by fractures. These fractures appeared as bright, wispy streaks, and range from tens to hundreds of thousands of miles long. NASA/JPL

9. More than 30 years after Voyager's last glimpse of Titan, Cassini finally revealed the moon's surface via infrared imaging November 13, 2015. The surface is surprisingly Earth-like, with features that include sand dunes, mountain ranges, and liquid hydrocarbon seas. NASA/JPL/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO

10. Haze layers sit just above Titan's thick atmosphere, at heights of about 300 miles (500km), above the moon's surface in this Voyager image. NASA/JPL-CALTECH

Measuring a day



The outer planets have no solid surface to track as they rotate in order to measure the length of their day. Instead, astronomers track the rotation of the planets' magnetic poles, which typically are offset from the axis of rotation. Jupiter's magnetic pole is offset from its rotational axis by about 10°, while Uranus' axes are offset by 60° and Neptune's by 47°. Saturn's magnetic and rotational axes are almost perfectly aligned, with an offset of less than 1°, making measurements of the length of its day challenging. Both Voyager spacecraft measured the length of Saturn's day to be about 10.7 hours, but the Cassini spacecraft has measured the length to be slightly shorter (10.6 hours) or longer (10.8 hours), depending on the hemisphere in which measurements are taken. *ASTRONOMY*: ROEN KELLY

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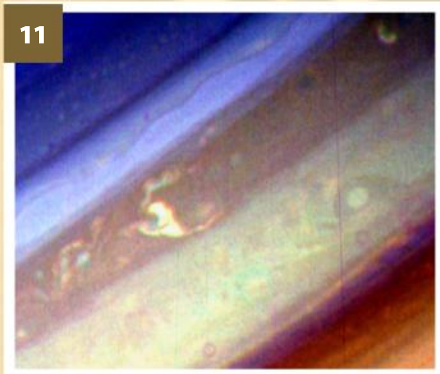

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11. Enhanced color image processing increases the ability to see clouds and storms in Saturn's atmosphere, such as the convective clouds in this image taken November 5, 1980, from a range of 5 million miles (8 million km). NASA/JPL-CALTECH

12. The spacecraft revealed oval-shaped storms in Saturn's atmosphere, similar to those seen on Jupiter. Imaged November 7, 1980, from a distance of 4.6 million miles (7.5 million km), these brown ovals in Saturn's northern hemisphere span about 6,000 miles (10,000km) in diameter. NASA/JPL

13. Winds in Saturn's upper atmosphere are estimated to reach speeds of 1,118 mph (1,800km/h), faster than the winds on Jupiter. This ribbonlike feature is the result of a westward jet stream imaged on November 10, 1980, from a distance of 2.2 million miles (3.5 million km). It was still visible to Cassini in 2012, though its shape had changed in the intervening years. NASA/JPL

14. Saturn's polar hexagon spans a diameter of 20,000 miles (32,000km) and reaches depths of 60 miles (100km) in the planet's atmosphere. The bizarre feature was first identified in Voyager images and later confirmed by the Cassini spacecraft, which snapped this image June 14, 2013. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

hydrocarbons perhaps in liquid form at the surface — made Titan even more intriguing for further study. In fact, says Spilker, "it was really the Voyager flyby of Titan, and what we learned and what we didn't learn, that led to this strong desire to go back." And ultimately, it was that flyby that sparked the Cassini mission.

The Titan discoveries were just the beginning of revealing the saturnian satellites. From afar, two of the planet's closer-in moons, Mimas and Enceladus, had been considered twins due to their similar sizes. But on November 12, 1980, Voyager found that their surfaces look vastly different. While Mimas was pockmarked with the evidence of billions of years of collisions from space debris, Enceladus, oddly, was not. Scientists had expected a heavily cratered surface, "and yet there were parts of Enceladus that were smooth," says Caltech's Andrew Ingersoll, who was a member of the Voyager imaging team. The world was also very reflective, similar to the brightness of freshly fallen snow.

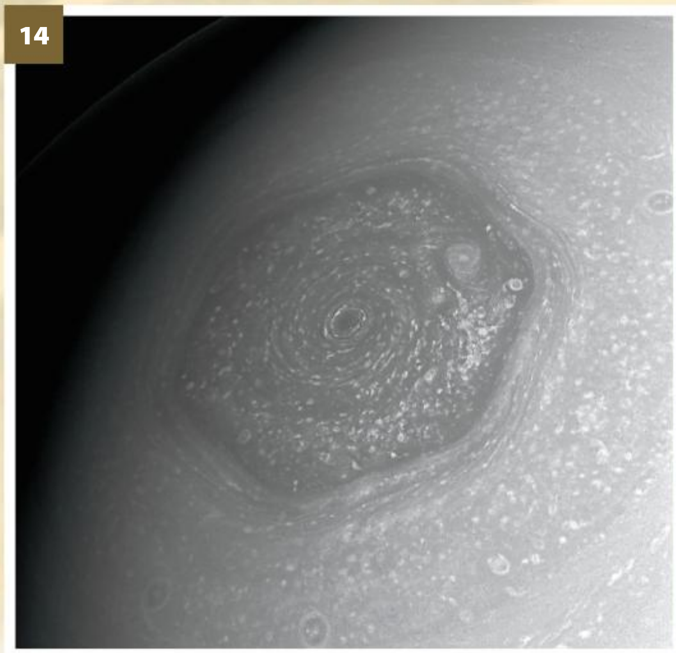
Observations from Earth of a ring around Saturn at the distance of Enceladus' orbit already hinted that perhaps that small moon somehow feeds the ring. Could there be ice volcanoes on Enceladus, providing the sloshy material that would fill in impact craters? If so, some of that gushing material perhaps could escape the surface and orbit Saturn as part of the E ring. Those first detailed observations from Voyager triggered an ongoing fascination with this small, reflective moon, adds Ingersoll.

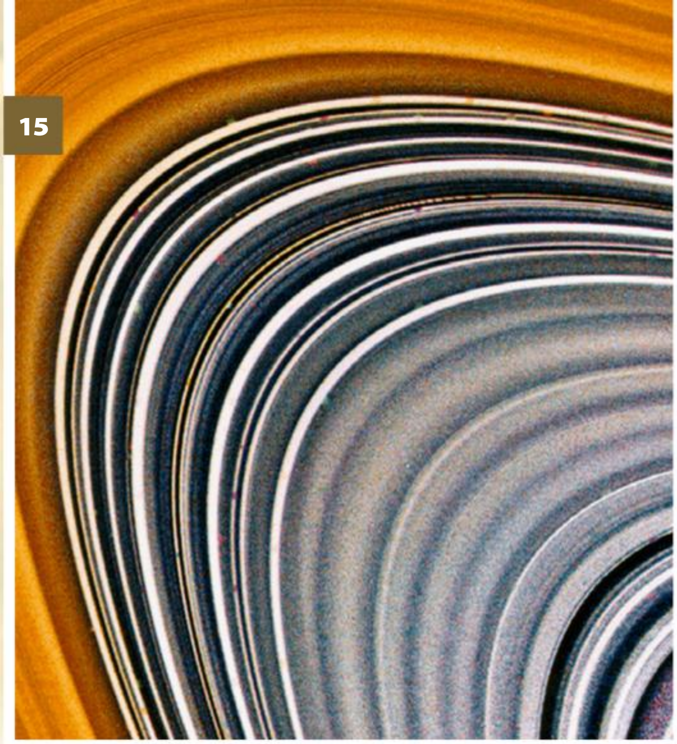
Scientists now know from the Cassini mission that an underground water ocean feeds geysers at Enceladus' south pole. They've also discovered likely hydrothermal activity at the ocean floor. On Earth, biological ecosystems thrive in such environments. Could they do the same on Enceladus? That's a question a future dedicated mission to the small moon might answer.

The weather out there

Scientists didn't send Voyager to Saturn to study only its rings and moons. The planet and its atmosphere were also a science focus. Like that of its sister giant planet, Jupiter, Saturn's atmosphere hosts incredible storms and enormous jet streams, and the Voyager twins were the first spacecraft to photograph the details in those cloud tops up close.

While reanalyzing Voyager images of Saturn's poles, astronomer David Godfrey discovered a hexagonal shape surrounding the northern pole. That surprising shape comes from jet streams moving at different speeds. "It's really just a meandering current flowing east a little faster than the rest of its neighbors," explains Ingersoll, who was also the head of the Voyager





atmosphere working group. This hexagon was still there decades later, when Cassini reached Saturn.

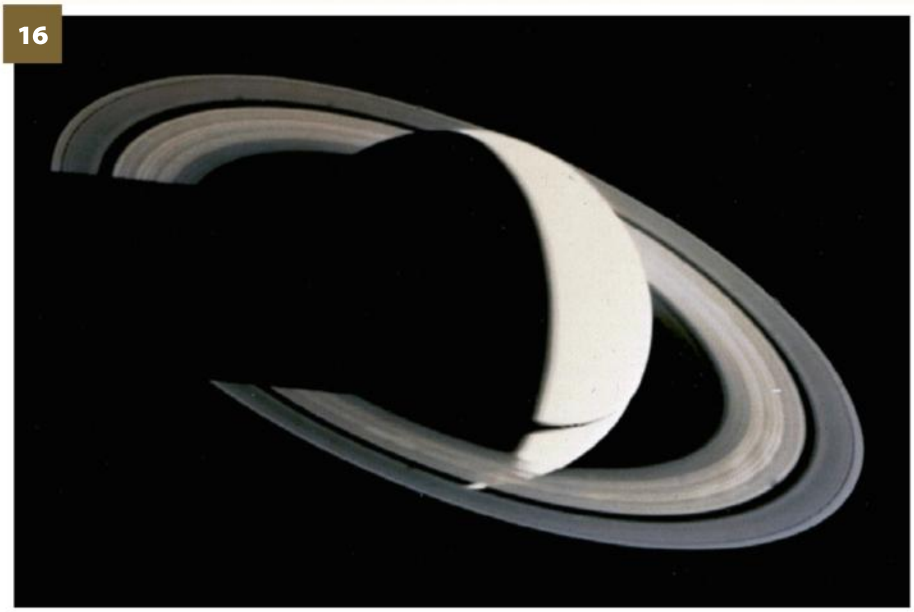
And then there are Saturn's winds themselves. "I remember being amazed at how fast the winds were blowing," recalls Ingersoll — although how fast isn't actually known yet. That's because scientists don't have a reference against which to measure the wind speeds, explains Ingersoll, who has studied planetary atmospheres for decades. "On Earth, we measure the wind relative to the continents," explains Ingersoll, and Saturn, of course, doesn't have any continents. But if scientists could measure how fast the planet's solid core rotates, that speed would serve as the reference.

To get at that rotation rate for a giant planet, researchers track the planet's magnetic field, which is produced in the solid core. On Jupiter, the magnetic field's axis is tilted in relation to the rotation axis, which means as the core rotates, the magnetic field wobbles. "You see the magnetic field wobble back and forth like a … top, and so that tells you how fast the interior of the planet is rotating," says Ingersoll. Unfortunately, Saturn's magnetic field axis and rotation axis are too similar to produce a measurable wobble on the Voyagers' instruments. But in its final mission phase, skimming just above the cloud tops, Cassini may finally get close enough to the planet to better track the wobble.

On September 15, Cassini will end its study of Saturn, closing the door on up-close observations of the ringed planet, just like Voyager's departure in 1981. Both missions have answered long-standing questions about the ringed world and its system, as well as introduced new mysteries for future spacecraft to resolve.

This world holds beautiful rings that mimic some characteristics of disks around young stars, intense atmospheric storms, and a variety of moons — including one with an Earth-like weather system and another with the ingredients of a habitable environment. "The study of Saturn has provided scientists the means to study processes that are at work all across our solar system and scale-invariant across the cosmos," says Porco. "No other planet can claim as much."

Because of Voyager 1 and 2, we know why the Saturn system continues to tempt planetary explorers.



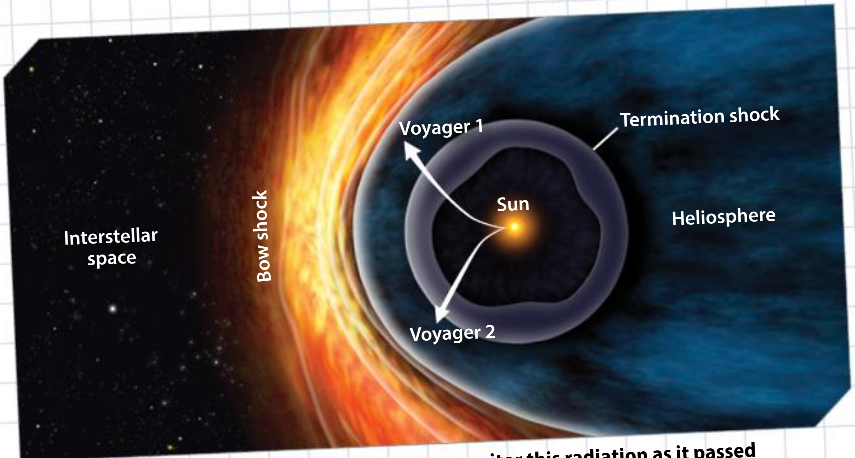
15. False-color images, such as this one taken August 23, 1981, from 1.7 million miles (2.7 million km), highlight the varying chemical composition of the rings, seen as different colors. The C ring appears blue in this composite, while the B ring appears yellow-orange. NASA SPACE SCIENCE DATA COORDINATED ARCHIVE

16. Voyager 1 took this image of Saturn as it departed, looking back from its vantage point of 3.3 million miles (5.3 million km) four days after closest approach. Spokes can be seen as bright patches in the rings from this distance. NASA SPACE SCIENCE DATA COORDINATED ARCHIVE

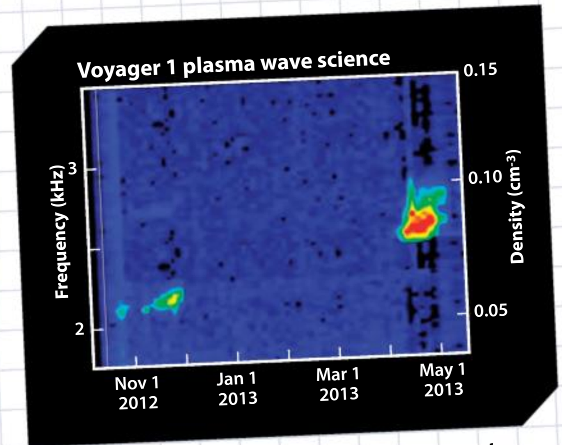
Liz Kruesi *is an* Astronomy *contributing editor who writes about distant objects from her Earthbound home in Austin, Texas.*

VOYAGER

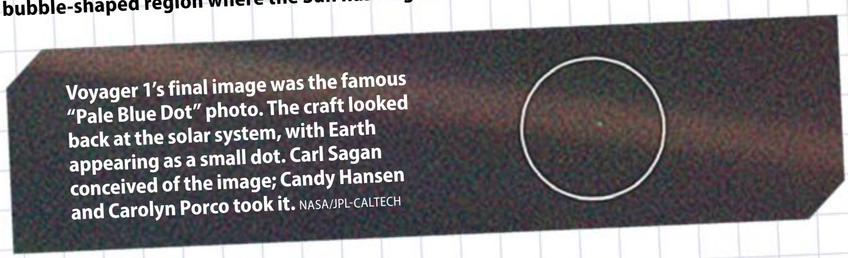
Incredibly, a few instruments aboard both spacecraft continue to function. **by John Wenz**



Above: Voyager had a Cosmic Ray Subsystem to monitor this radiation as it passed through the crafts. An increase showed the escape of both craft from the termination shock, where solar wind particles travel at speeds less than that of sound. Voyager 1 crossed this threshold in 2003. Voyager 2 crossed in 2007. The heliosphere is the entire bubble-shaped region where the Sun has its greatest influence. *ASTRONOMY:* ROEN KELLY



Above: Voyager 1's Plasma Wave Science instrument measured the bursts of energy seen in this image, all but confirming the spacecraft had finally entered interstellar space, where the Sun's magnetic fields end. Voyager 1 still has a few thousand years to go before exiting the solar system entirely. NASA/JPL



Voyager 1's final image was the famous "Pale Blue Dot" photo. The craft looked back at the solar system, with Earth appearing as a small dot. Carl Sagan conceived of the image; Candy Hansen and Carolyn Porco took it. NASA/JPL-CALTECH

Right: Two engineers install the Golden Record, an encapsulation of humanity as it was in the mid-1970s. This LP-sized object represents a message from Earth to whomever may find the probe. The record's cover shows where the spacecraft came from. The Voyagers will not encounter other stars for tens of thousands of years. This may turn out to be a last message from humanity should our civilization come to an end. NASA

1. HIGH-GAIN ANTENNA

SHUTDOWN DATE: Still active
PURPOSE: Communications
KEY FINDING: This is the craft's main contact point with Earth. It once sent back the robust data from the craft; today, it sends out basic information from the low-power instruments still online.

2. MAGNETOMETERS AND LOW-FIELD MAGNETOMETER

SHUTDOWN DATE: Still active
PURPOSE: Measure the magnetic fields of the Sun and the outer planets.
KEY FINDING: In 2015, the craft discovered that even past the heliopause, solar winds can redirect the magnetic field of charged particles they encounter.

3. ULTRAVIOLET SPECTROMETER

SHUTDOWN DATE: 1998
PURPOSE: Monitor the composition of planetary atmospheres in ultraviolet wavelengths, which also show solar interaction.
KEY FINDING: This instrument gathered the bulk of the data regarding planetary atmospheres, helping establish what the gas giants were made of — and that Uranus and Neptune were different from Jupiter and Saturn in composition.

4. INFRARED RADIOMETER, INTERFEROMETER, AND SPECTROMETER (IRIS)

SHUTDOWN DATE: 1998
PURPOSE: Monitor temperature and other information inside the planets.
KEY FINDING: The IRIS instrument discovered a heat source deep within Neptune that leaves the planet roughly the same temperature as Uranus. This is likely due to slightly higher methane content trapping more heat and making the planet a few degrees warmer.

5. PHOTOPOLARIMETER SUBSYSTEM (PPS)

SHUTDOWN DATE: 1991
PURPOSE: Gather information on the gas giants while monitoring their atmospheres.
KEY FINDING: The PPS instrument discovered a more detailed structure to Uranus' and Neptune's ring systems, including discovering additional rings in each.

6. LOW-ENERGY CHARGED PARTICLE INSTRUMENT

SHUTDOWN DATE: Still active
PURPOSE: Measure ions and their distribution in the outer solar system.
KEY FINDING: A violent burst of solar activity in 1993, coupled with the Low-Energy Charged Particle Instrument, helped researchers locate the heliopause.

7. HYDRAZINE THRUSTERS

SHUTDOWN DATE: Still active
PURPOSE: Propel the craft and keep it warm.
KEY FINDING: While Voyager 1 was in transit to the outer solar system, the Pioneer 11 craft revealed a substantial atmosphere on Saturn's moon Titan. Rather than steer toward a possible encounter with Pluto, NASA used the craft's thrusters to send it toward Titan, eventually flinging Voyager 1 above the plane of the solar system.

8. MICROMETEORITE SHIELD

SHUTDOWN DATE: Essentially never
PURPOSE: Protect the instruments at the rear of the craft from dust and other particles that could interfere with their operations.
KEY FINDING: Unknown, but it may have spared the craft plenty of headaches from tiny particles.

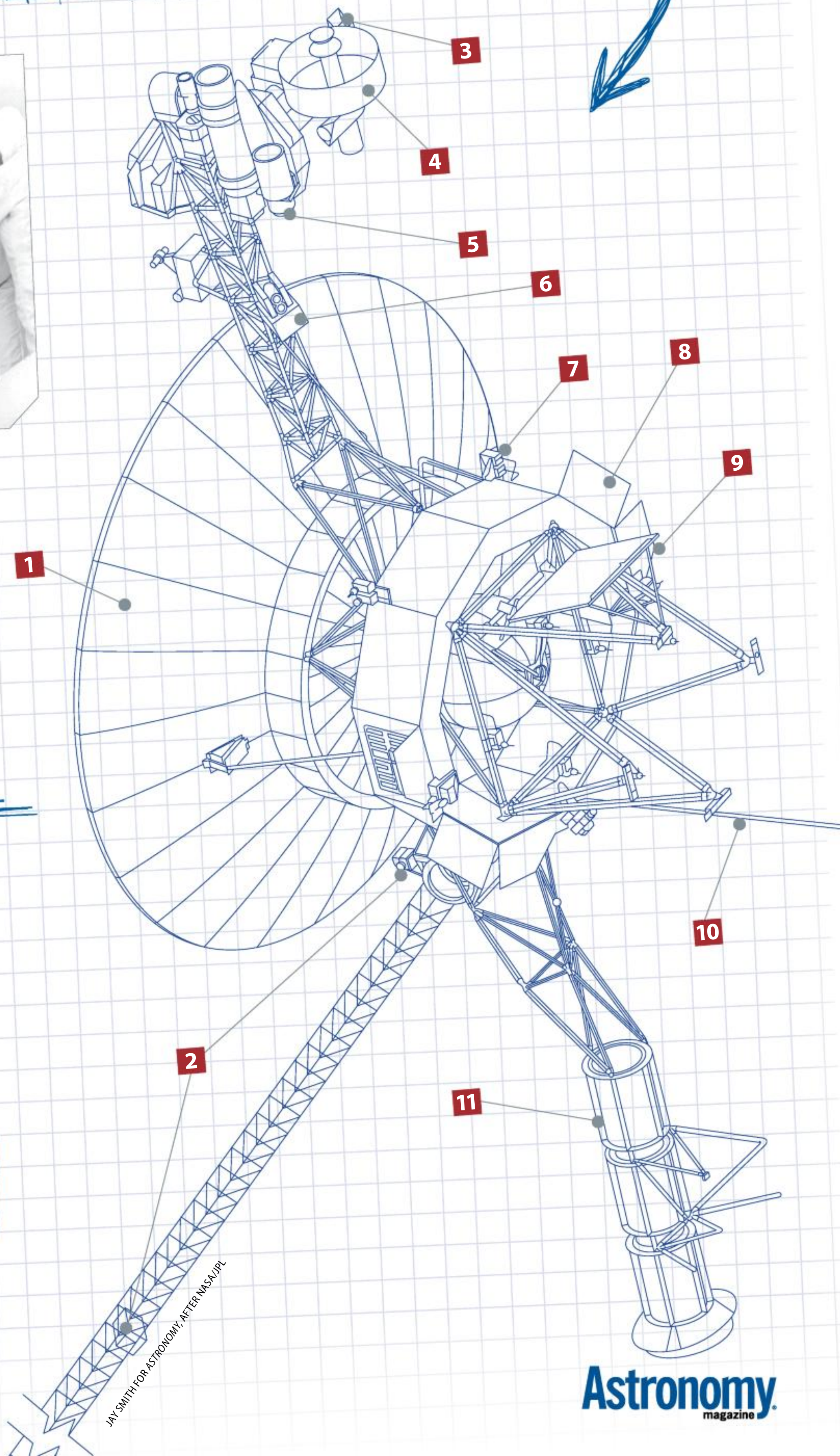
9. OPTICAL CALIBRATION TARGET

SHUTDOWN DATE: Still active
PURPOSE: Help calibrate the craft's charged particle instrument, infrared radiometer, and cameras.
KEY FINDING: Voyager's instruments pointed to the target plate for calibration countless times in its travels.

10. PLANETARY RADIO ASTRONOMY AND PLASMA WAVE ANTENNA

SHUTDOWN DATE: 2008
PURPOSE: Measure radio emissions from the gas giants.

REVEALED!



JAY SMITH FOR ASTRONOMY, AFTER NASA/JPL

KEY FINDING: It measured radio waves from Jupiter and Saturn, resulting in a creepy album called *Voyager: Sound of the Cosmos* which makes Jupiter sound like even more of a monster.

11. RADIOISOTOPE THERMOELECTRIC GENERATOR

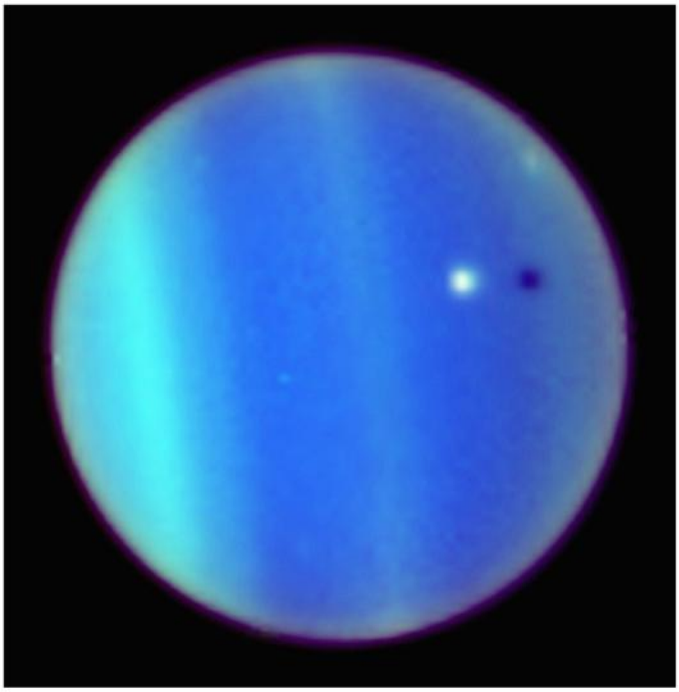
SHUTDOWN DATE: Still active, but waning.
PURPOSE: Power the craft and keep it warm with Plutonium-238.
KEY FINDING: It has allowed for the 28-year extended mission of both craft, though the radiation given off may drop too low to continuously power the craft past the early 2020s.

John Wenz *is a former associate editor of Astronomy.*

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

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

October 2017: Uranus glows brightly



Earth-based telescopes easily show Uranus' distinctive blue-green color. This 2006 Hubble Space Telescope image also reveals banding in the atmosphere as well as a rare transit by the planet's moon Ariel (the white dot) and its shadow (to the right). NASA/ESA/L. SROMOVSKY (UNIVERSITY OF WISCONSIN–MADISON)

The giant worlds of the outer solar system take center stage on October evenings. While Jupiter hangs low in twilight, Saturn stands higher in a dark sky. The more distant world should look spectacular because its rings open wider than they've been in 14 years.

But the stars of the evening show lie even farther afield. Neptune grabs the spotlight October 5/6 when its largest moon, Triton, dramatically cuts off the light of a distant sun. And Uranus reaches opposition and peak visibility this month, making it a tempting target all night. As this planet sinks low in the west before dawn, Venus and Mars make a striking pair in the east.

Early October provides observers with their final chance to see **Jupiter** in the evening sky this year. Those with a clear, unobstructed western horizon can find the giant planet 3° high a half-hour after sunset. Fortunately, it's bright — shining at magnitude –1.7 — so you can track it nearly to the horizon despite the bright twilight.

Jupiter dips lower each evening and finally succumbs to the Sun's glare after October's first week. It passes behind the Sun on the 26th and will reappear before dawn in early November.

Mercury plies nearly the same parcel of real estate as Jupiter. The innermost planet slides behind the Sun at superior conjunction October 8. Viewers in the southern United States and points south might glimpse Mercury in evening twilight at the end of the month. The planet then shines at magnitude –0.4 and hangs a couple of degrees high in the west-southwest 30 minutes after sunset.

After straining to see our first two targets, skygazers get some welcome relief with the appearance of **Saturn**. The ringed planet lies 20° above the southwestern horizon at the end of twilight in early October. Although it dips lower as the month progresses, it remains conspicuous. Saturn shines at magnitude 0.5 against the backdrop of southern Ophiuchus.

The planet drifts slowly eastward relative to these background stars, beginning October 3° north-northeast of 3rd-magnitude Theta (θ) Ophiuchi and ending the month 4° northeast of this star.

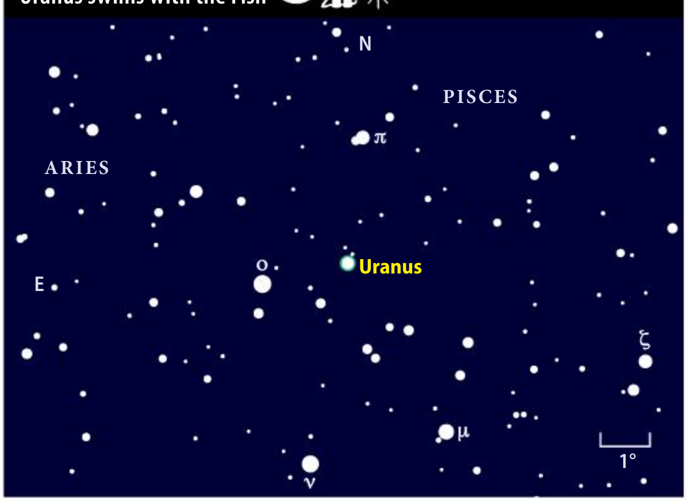
Now swing your telescope to Saturn. The planet's disk appears 16" across, and the rings span 36" in mid-October. But more significantly, the ring system tilts 27.0° to our line of sight — the maximum angle possible. The rings haven't appeared this open since 2003, and they won't approach this tilt again until 2032.

The steep angle means observers will get superb views of ring structure. The Cassini Division — the dark gap that separates the outer A ring from the brighter B ring — will be obvious through any scope. And this will be a great chance to spot the Encke Division, a narrow, challenging feature near the A ring's outer edge.

If you can tear yourself away from the rings, Saturn also boasts a family of bright moons. The biggest and brightest, 8th-magnitude Titan, completes a circuit of the planet once every 16 days. Look for it due south of Saturn on October 5 and 21 and due north on the 13th and 29th. It appears 1.2' from the ringed world on those dates.

Outermost Iapetus glows at 10th magnitude when it reaches greatest western

Uranus swims with the Fish



Uranus reaches magnitude 5.7 at opposition October 19. It then lies among the background stars of Pisces the Fish. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

See the Moon in a new light

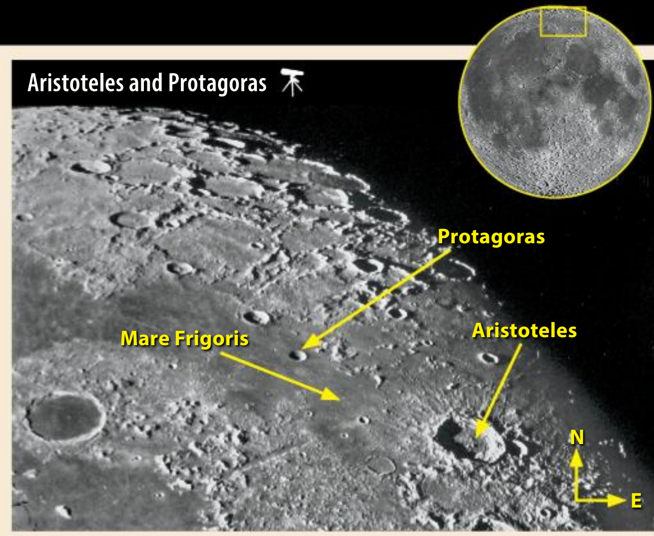
Most skywatchers observe during the evening and shun the morning hours except for special events. That's why lunar observers tend to focus on the Moon's waxing phases visible after sunset and ignore the waning phases best seen before dawn. But this month provides a nice opportunity to view the waning gibbous Moon before midnight. You might be surprised at what the different lighting reveals.

Target Luna around 11 P.M. local daylight time October 9. As you scan along the terminator — the dividing line between day and night — features may look odd because you're viewing lunar sunset and not sunrise. The reverse lighting makes it easy to see the relationship between the snaking Serpentine Ridge and Mare Serenitatis.

From there, jump halfway to the pole and find the large crater Aristoteles. The low Sun angle transforms its apron of impact splatter into a finely textured expanse. Check out the shadow cutting across Aristoteles' middle and trace the huge "divot" of light back to the small crater that breaches the western flank and allows sunlight to reach the floor.

Farther to the northwest lies the crater Protagoras, which resembles a golf hole in the putting green formed by the solidified lava of Mare Frigoris. Normal craters are surrounded by a raised rim whose western flank glows brightly in the setting Sun. But an ancient lava flow came right up to the western lip of Protagoras, so there's no rim to catch the Sun's rays. Under the more familiar lighting conditions of a waxing crescent Moon on the evening of October 25, you might never suspect this unusual feature was hiding in plain sight.

The shadows intensify on the 10th as the Sun drops lower in the lunar sky, though the Moon doesn't climb to a decent altitude until midnight.



Two distinctive craters show up on the frozen lava of Mare Frigoris on October 9's gibbous Moon. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

elongation October 13. It then lies 8' from Saturn and shows up nicely through 4-inch and larger scopes. The same instrument reveals a trio of similarly bright moons — Tethys, Dione, and Rhea — that circle the planet inside Titan's orbit.

As Saturn prepares to set, turn your attention to **Neptune**. This distant ice giant reached opposition and peak visibility in early September, but the view in October barely suffers in comparison. It appears in the southeast as darkness falls in early October and climbs highest in the south around 11 P.M. local daylight time. (It reaches the same position two hours earlier by month's end.)

Neptune glows at magnitude 7.8, so you'll need binoculars or a telescope to see it. The planet resides in Aquarius, less than 1° from magnitude 3.8 Lambda (λ)

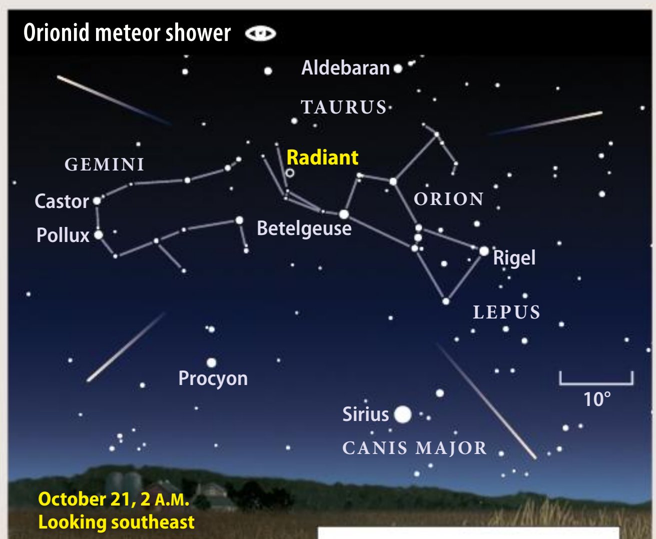
— *Continued on page 42*

METEORWATCH

Dark skies for the Hunter's show

Halley's Comet last appeared in our sky more than 30 years ago, but it still makes its presence known. Every October, Earth plows into debris left behind by the periodic comet during its trips through the inner solar system. As this dusty debris burns up in our atmosphere, we see flashes of light known as meteors. The flashes appear to radiate from the constellation Orion the Hunter, which lends its name to the Orionid meteor shower.

Conditions this year should be ideal. The shower peaks before dawn October 21, just two days after New Moon. Observers under a dark sky can expect to see close to the maximum rate of 20 meteors per hour in the hours before dawn.



With the Moon absent for this month's premier shower, observers can expect to see up to 20 meteors per hour.

Orionid meteors

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

OBSERVING HIGHLIGHT The zodiacal light glows in the predawn sky for Northern Hemisphere observers at dark sites from October 17 to November 2.

STAR DOME

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

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

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

Planets are shown at midmonth

STAR MAGNITUDES

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

STAR COLORS

A star's color depends on its surface temperature.

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

MAP SYMBOLS

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

OCTOBER 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	31				

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

3 The Moon passes 0.7° south of Neptune, 8 A.M. EDT

5 Venus passes 0.2° north of Mars, 9 A.M. EDT

Full Moon occurs at 2:40 P.M. EDT

6 The Moon passes 4° south of Uranus, noon EDT

7 Mars is at aphelion (154.9 million miles from the Sun), 6 P.M. EDT

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

9 The Moon is at perigee (227,953 miles from Earth), 1:55 A.M. EDT

The Moon passes 0.6° north of Aldebaran, 3 P.M. EDT

12 Last Quarter Moon occurs at 8:25 A.M. EDT

15 The Moon passes 0.2° north of Regulus, 7 A.M. EDT

17 The Moon passes 1.8° north of Mars, 6 A.M. EDT

The Moon passes 2° north of Venus, 8 P.M. EDT

19 Uranus is at opposition, 2 P.M. EDT

New Moon occurs at 3:12 P.M. EDT

SPECIAL OBSERVING DATE

21 The annual Orionid meteor shower peaks before dawn under a Moon-free sky.

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

The Moon is at apogee (251,751 miles from Earth), 10:26 P.M. EDT

26 Jupiter is in conjunction with the Sun, 2 P.M. EDT

27 First Quarter Moon occurs at 6:22 P.M. EDT

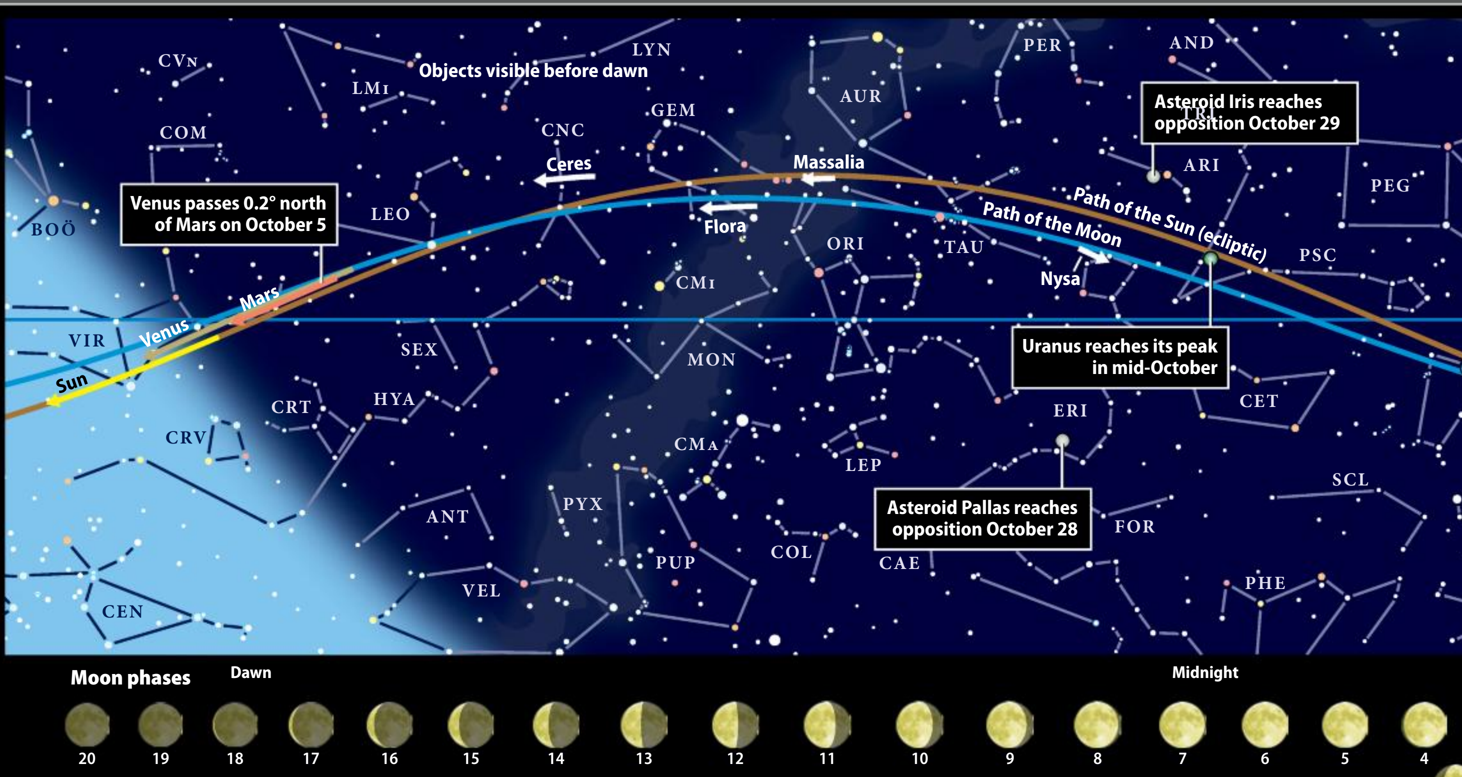
28 Asteroid Pallas is at opposition, 8 P.M. EDT

29 Asteroid Iris is at opposition, 8 P.M. EDT

30 The Moon passes 0.9° south of Neptune, 5 P.M. EDT

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

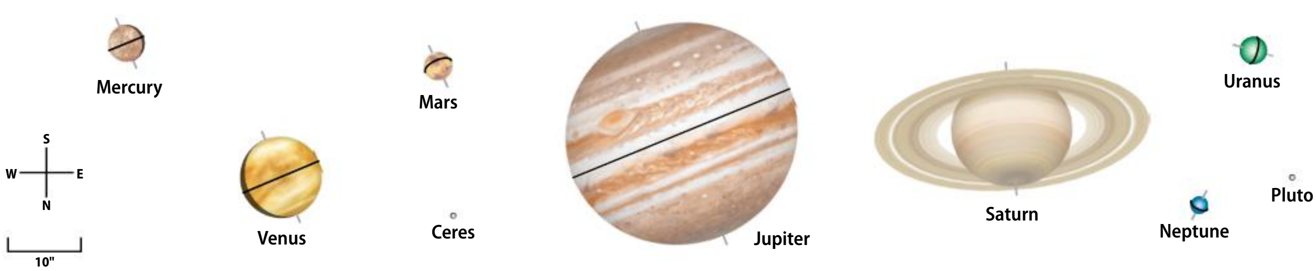
The planets in October 2017



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.

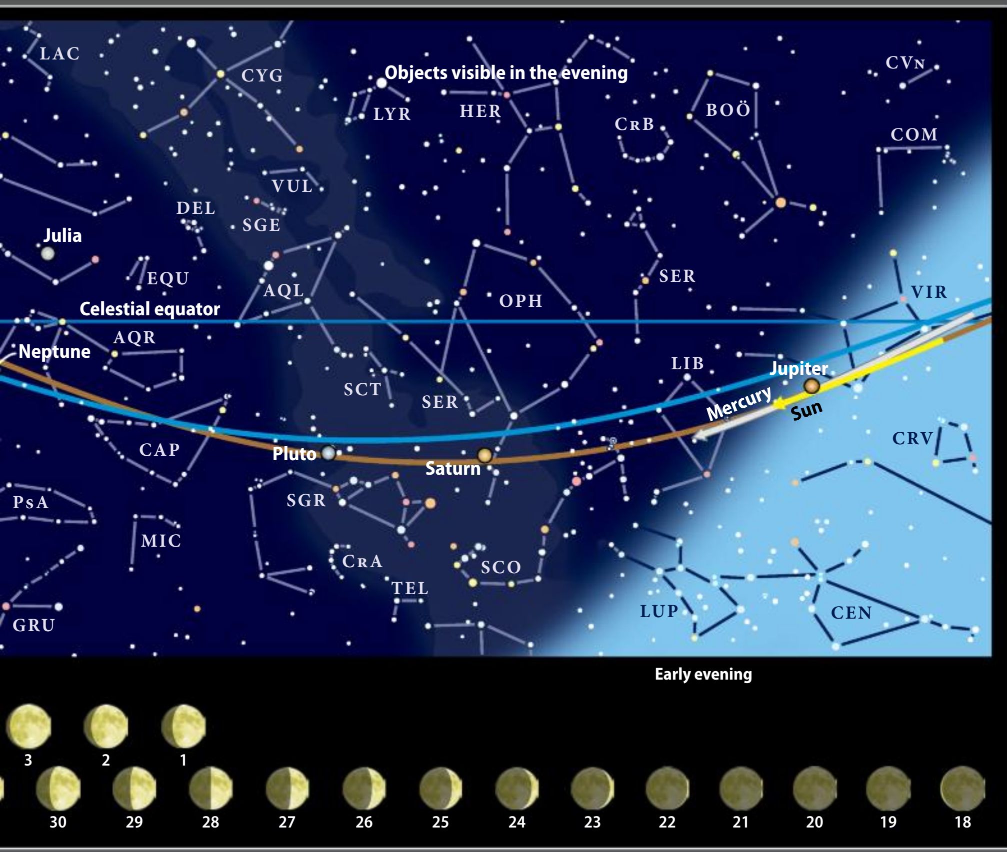
The planets in the sky

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.



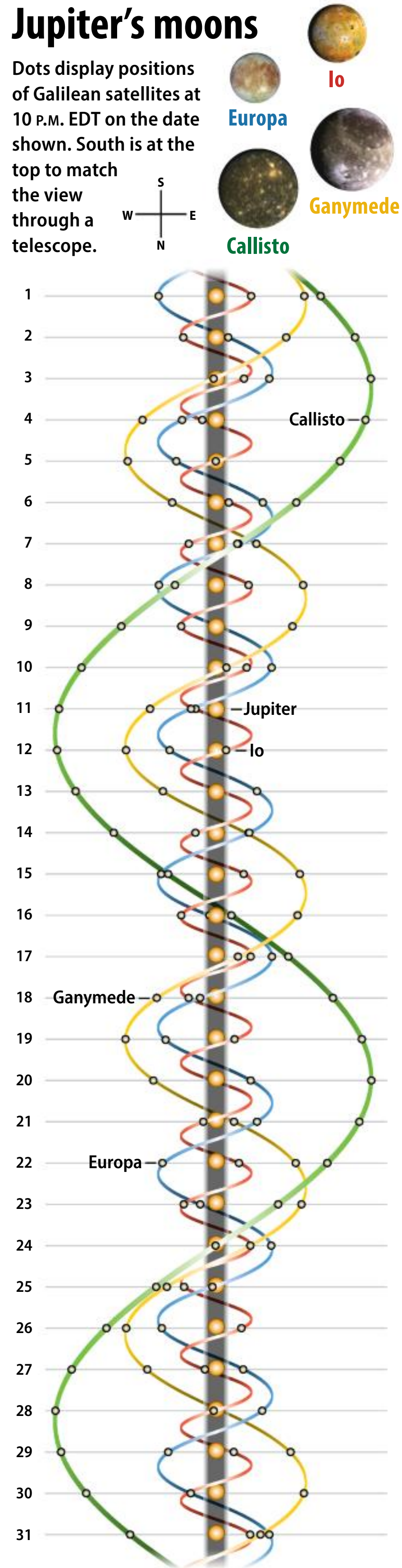
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Oct. 31	Oct. 15	Oct. 15	Oct. 15	Oct. 1	Oct. 15	Oct. 15	Oct. 15	Oct. 15
Magnitude	–0.4	–3.9	1.8	8.7	–1.7	0.5	5.7	7.8	14.2
Angular size	4.9"	10.8"	3.8"	0.5"	30.9"	15.8"	3.7"	2.3"	0.1"
Illumination	93%	93%	98%	96%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.367	1.552	2.495	2.694	6.374	10.503	18.917	29.175	33.496
Distance (AU) from Sun	0.466	0.719	1.666	2.619	5.444	10.063	19.911	29.946	33.426
Right ascension (2000.0)	15h13.5m	12h04.1m	11h42.9m	8h41.0m	13h44.5m	17h29.4m	1h39.1m	22h53.6m	19h12.0m
Declination (2000.0)	–19°19'	1°12'	3°07'	22°49'	–9°42'	–22°13'	9°39'	–8°04'	–21°49'

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



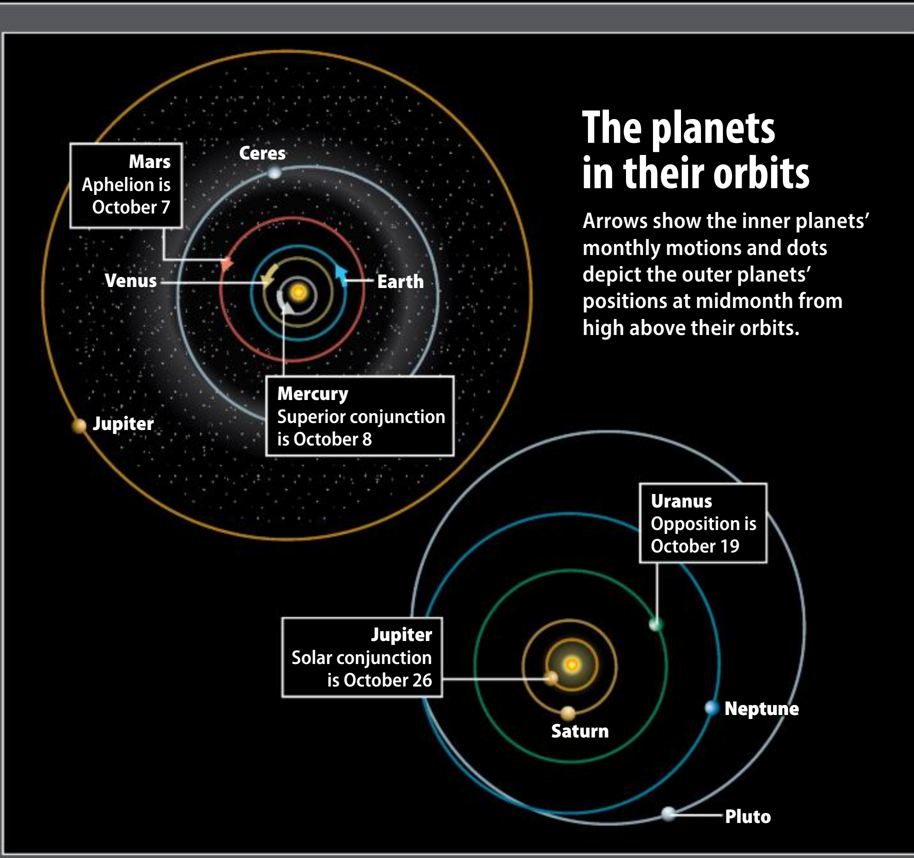
Jupiter's moons

Dots display positions of Galilean satellites at 10 P.M. EDT on the date shown. South is at the top to match the view through a telescope.



The planets in their orbits

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



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

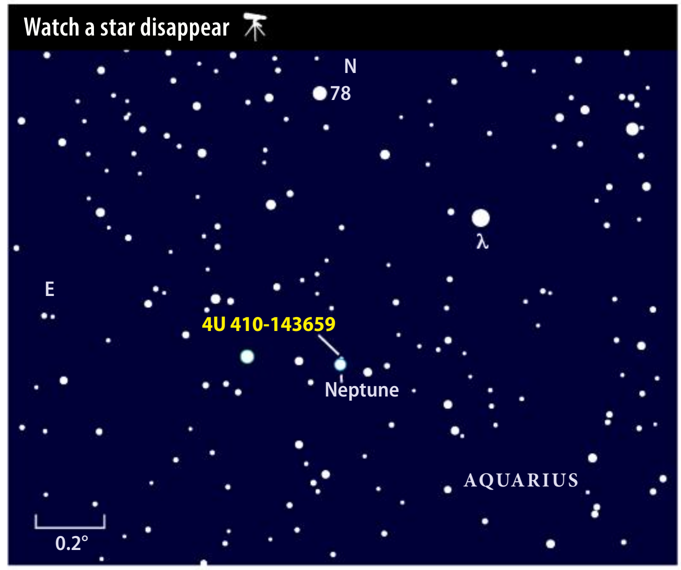
EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Uranus (southeast)	Venus (east)
Jupiter (west)	Neptune (southwest)	Mars (east)
Saturn (southwest)		Uranus (west)
Uranus (east)		
Neptune (southeast)		

Aquarii. Neptune appears 0.6° east-southeast of Lambda on October 1 and the same distance due south of the star on the 31st.

You should be able to identify Neptune from its position because no star in the immediate area shines as brightly. But you can remove any doubt by pointing a telescope in its direction. Only the planet shows a discernible disk, which has a diameter of 2.3" and a distinctive blue-gray color.

Keep your scope handy for Neptune's event of the month: On the night of October 5/6, the planet's big moon, Triton, passes directly in front of a star. Viewers in the northeastern United States and eastern Canada can view this rare occultation on the evening of the 5th; those in the United Kingdom, western Europe, and northwestern Africa can witness it on the morning of the 6th. A 6-inch scope will show the event.

The magnitude 12.4 star, cataloged as 4U 410-143659, dims by 1.4 magnitudes as the magnitude 13.5 moon occults it. Viewers will see the star disappear for up to 161 seconds sometime between 7:44 and 8:00 P.M. EDT (23h44m and 24h00m UT), depending on their location. The finder chart above pinpoints the star.



Neptune's moon Triton slides in front of 12th-magnitude 4U 410-143659 the night of October 5/6. The star will dim visibly for up to 161 seconds.

Uranus reaches opposition October 19. It then lies directly opposite the Sun in our sky, so it remains visible all night. It also lies closest to Earth at opposition, rendering it as bright as possible. But the appearance of an outer planet changes slowly, and Uranus maintains its magnitude 5.7 peak throughout October.

The ice giant lies among the background stars of Pisces. It starts the month 1.3° northwest of magnitude 4.3

COMETSEARCH

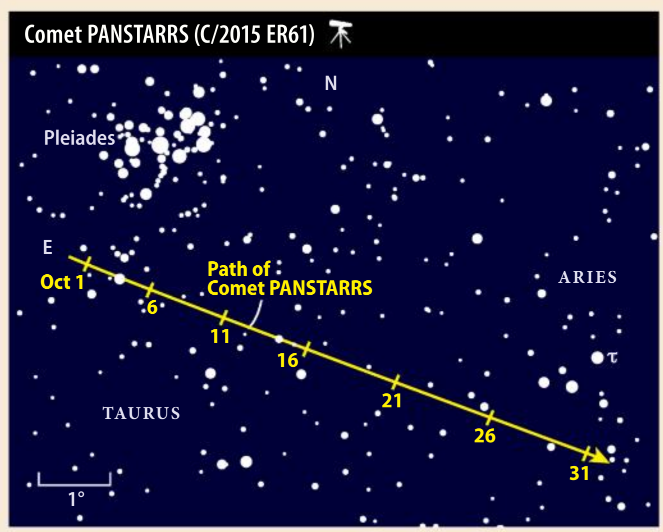
The Pleiades adds a sister

For the past two months, Comet PANSTARRS (C/2015 ER61) has been floating near the Pleiades star cluster (M45), or Seven Sisters, in northwestern Taurus. They remain neighbors during October, though PANSTARRS' slow westward motion carries it into eastern Aries by the month's final week. The solar system object should glow around 11th magnitude as it heads back toward the distant Oort Cloud from which it came. That brightness pushes the limits of a 4-inch telescope under a dark sky, but should pose little problem through an 8-inch or larger instrument.

You'll want to avoid viewing during October's first 10 days, when a bright Moon shares the evening sky. The two-week window of dark skies that follows should be ideal. PANSTARRS then appears some 30° above the eastern horizon at 11 P.M. local daylight time.

Apart from sharing the same area of sky, the comet and Pleiades showcase a common phenomenon of physics: light scattering (or reflecting) off dust. Comet dust arises when sunlight turns the ices on the body's nucleus directly into a gas, and carries dust away in the process. These particles form a shroud around the nucleus that appears yellow because it reflects sunlight. Far in the background, the Pleiades' stars are plowing through a cloud of cosmic dust. These particles scatter the blue light radiated by the cluster's many hot, young stars.

As Comet PANSTARRS moves steadily away from the Sun, its dust production is dropping with each passing night. Through most telescopes, it likely will look like an unimpressive elliptical galaxy — mostly round and a bit brighter toward the center. The comet's small size and low surface brightness mean you might not see this structure at first under low power, but at 120x or more, it should show quite nicely.



This visitor from the distant Oort Cloud should glow at 11th magnitude in October as it gradually moves away from the Pleiades star cluster.

Morning planets greet the Moon

Venus appears 0.2° from Mars on October 5. On the 17th, a crescent Moon joins the two, mirroring this scene from January 31, 2017. MATTHEW DIETERICH

Omicron (ο) Piscium and ends the month 2.2° due west of this star. Once you locate Uranus through binoculars, set them aside and try to spot the planet with your naked eye. You should be able to from under a dark sky. A telescope reveals Uranus' 3.7"-diameter disk and impressive blue-green color.

The telescopic view should be especially good this month because Uranus appears so high. From mid-northern latitudes on the night of opposition, the planet lies 60° above the southern horizon at its peak around 1 A.M. local daylight time. This is the highest it has appeared at opposition since February 1963.

By the time twilight starts to paint the morning sky, Uranus dips low in the west. The action then shifts to the eastern sky, where **Venus** and **Mars** put on a marvelous show. On October 1, they appear 2.5° apart against the background stars of Leo. Magnitude –3.9 Venus rises 13 minutes before magnitude 1.8 Mars.

The gap between the two closes until October 5, when just 0.2° — about half the Full Moon's diameter — separates them. The two haven't been this close since November 1995. If you view the pair through binoculars, you'll also notice the 4th-magnitude star Sigma (σ) Leonis 0.3° north of Venus. Unfortunately, a telescope doesn't add much. Venus spans 11" while Mars measures 4" across, and both appear nearly full.

The two planets move eastward relative to the background stars during October, with Venus in its inner orbit moving faster. It crosses the border into Virgo on the 9th, setting up a string of close stellar conjunctions. The bright planet passes 0.8° northeast of 4th-magnitude Beta (β) Virginis on October 12, 0.2° north of 4th-magnitude Eta (η) Vir on the 18th, 1.3° southwest of 3rd-magnitude Gamma (γ) Vir on the 22nd, and 0.3° south of 4th-magnitude Theta Vir on the 29th. By the 31st, Venus stands 16° east of Mars.

The Red Planet runs a similar gauntlet, but at a slower pace. It crosses into Virgo on October 12 before sliding 0.5° north of Beta Vir on the 18th. On the 30th, it lies 0.3° southwest of Eta Vir and nearly on top of 6th-magnitude 13 Vir. As twilight begins on the East Coast, they lie just 44" apart; from the West Coast, 4.2' separate the two.

But the most spectacular conjunction takes place when the waning crescent Moon passes the two planets just after midmonth. On October 17, the 5-percent-lit crescent Moon stands 2° to Mars' left and 6° above Venus. Our satellite is much harder to see the following morning, when it appears only 2 percent illuminated and 6° to Venus' lower left.

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

LOCATING**ASTEROIDS**

Keep an eye on Iris

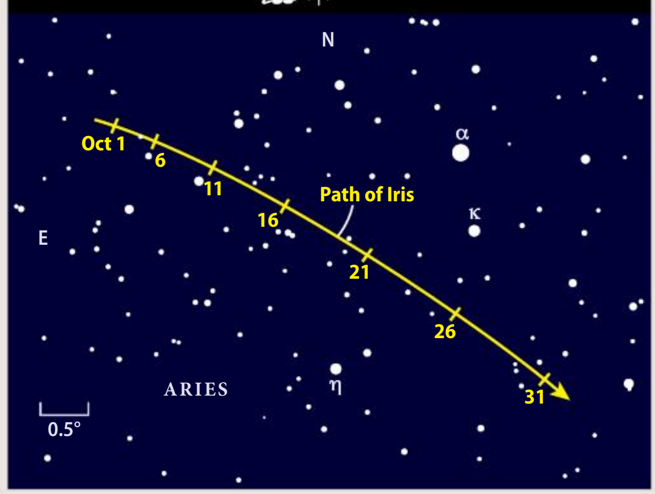
The space between the orbits of Mars and Jupiter is packed with hundreds of thousands of small bodies known as asteroids. Only a handful of these objects are big enough and come close enough to Earth to show up easily through binoculars. Fortunately, October's sky features a fine specimen of this rare breed.

Asteroid 7 Iris ranks second only to 4 Vesta as the brightest asteroid of 2017. Iris glows at magnitude 6.9 when it reaches opposition and peak visibility late this month. Eagle-eyed observers under pitch-black skies might be able to glimpse it with their naked eye, but even newcomers should have little trouble finding it through binoculars from the suburbs.

Iris lies within one binocular field of Aries the Ram's brightest star — magnitude 2.0 Hamal (Alpha [α] Arietis) — all month. This area stands high in the east by midevening. Simply walk outside, dark adapt for five minutes, and then focus in on Hamal.

The easiest time to find Iris comes during October's final week, when it shines brightest and slides 1.7° due south of Hamal and 1.0° due south of magnitude 5.0 Kappa (κ) Ari. To confirm a sighting, sketch the field with Alpha, Kappa, and several of the stars near the asteroid's position plotted below. Return a night or two later and identify the point of light that changed position. That "star" is Iris.

Iris butts the Ram's head



This 7th-magnitude asteroid should be easy to find as it slides south of 2nd-magnitude Alpha (α) Arietis, the brightest star in Aries the Ram.

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

THE HIDDEN EARTH

Q: IF ANOTHER PLANET EXISTED THAT WAS PRECISELY OUR SIZE AND IN OUR EXACT ORBIT, BUT PLACED BEHIND THE SUN, WOULD WE HAVE THE MEANS TO DETECT ITS EXISTENCE?

Gary Pyke, *McEwen, Tennessee*

A: The first person we know to have proposed such a "counter Earth" was Philolaus, a Greek philosopher who lived in the fifth century B.C. In the days before English mathematician Isaac Newton introduced his theory of gravitation, a few other notable philosophers brought forth similar ideas. Today, however, we know that such a world could not remain undetected for many reasons. Let's examine just two of them.

The gravitational influence of another Earth in that part of the solar system would have a wide-reaching effect on all nearby objects: Mercury, Venus, us, the Moon, Mars, and beyond. Over time, astronomers would be able to detect the tiny variations in position and, using the law of gravitation, quickly calculate the source of the problem.

These disparities would show themselves in the motions of comets, and in spectacular ways. Comets appear large, but the actual bodies are no more than a few miles in diameter. The gravitational influence of another body as massive as Earth would throw their orbits — that astronomers calculate with such precision — into chaos.

So, a counter-Earth would affect the motions of all nearby objects, but the reverse also is true. Let's take Venus as an example. It approaches Earth as close as 25 million miles every 584 days. Logically, Venus would also approach the counter-Earth that closely. Venus has about 80 percent of Earth's mass, so after even a few dozen passes, Venus' gravitational influence would move the hidden world to a position where we could view it directly. And all the while Mercury, Mars, and even Jupiter would be adding their not insignificant influences.

Michael E. Bakich
Senior Editor

Earth is the only planet in its orbit. There can be no other body hidden from our view on the opposite side of the Sun — the law of gravitation would quickly make such an object known to us. NASA/GSFC/NOAA/USGS

This Sun pillar was captured about 20 miles (35 kilometers) from Lisbon, Portugal, on April 26, 2010. The photographer was struck by the pillar's height and its white color. MIGUEL CLARO

Q: ONE WINTER MORNING AS I WAS DRIVING TO WORK, I LOOKED TO THE EAST, AND THE SUN WAS ABOUT 20° ABOVE THE HORIZON. A SOLID BRIGHT COLUMN OF LIGHT CAME STRAIGHT DOWN FROM IT TO THE HORIZON. WHAT CAUSES THIS, WHAT IS IT CALLED, AND IS THIS RELATED TO ANY ARCHAEOLOGICAL FINDS SUCH AS THE OBELISKS OF EGYPT?

John Dally
Colorado Springs, Colorado

A: What you saw was an optical effect called a Sun pillar, also sometimes called a light pillar. And although the Sun is usually the object associated with light pillars, they also can originate with the Moon or even bright terrestrial lights.

Tiny six-sided ice crystals slowly falling through the atmosphere create the effect. As they fall, the crystals align themselves parallel to the horizon, in effect simulating a colossal mirror made of billions of individual pieces. Wind moving the crystals causes the reflected light to stretch into a column.

You saw the pillar below the Sun. But pillars also occur that are above it or the Moon. Indeed, either of these celestial objects can be below the horizon while still creating pillars. And pillars formed by earthbound lights (which sit on the horizon) are always seen above the lights.

Indeed, some Egyptologists believe that Sun pillars were the inspiration for the great obelisks created by that culture in the same way that crepuscular rays inspired them to construct the pyramids. For more about this, see "Stargazing in ancient Egypt," by Patricia Blackwell Gary and Richard Talcott, in the June 2006 issue of *Astronomy*.

Michael E. Bakich
Senior Editor

Q: I OFTEN READ ABOUT A SUNSPOT ON THE WESTERN LIMB OF THE SUN, OR A CRATER ON THE EASTERN LIMB OF THE MOON, ETC. AS THERE IS NO "UP" IN SPACE, HOW ARE NORTH, SOUTH, EAST, AND WEST DETERMINED?

Tom Bennett
Bagley, Wisconsin

A: For more than 350 years, cartographers drew lunar maps showing the edge of the Moon that was nearest the eastern horizon as the eastern limb. For north and south, they adopted the traditional naked-eye orientation, with north up.

In 1961, Commission 16 of the International Astronomical Union determined that there should be two types of lunar maps: those intended for exploration (think astronauts) and those intended for use at the telescope. The first type labels east in the same direction as Mare Crisium (Sea of Crises). As we gaze at the Moon when it lies highest in the south, that feature lies near the right edge. So, for the past 57 years and on into the future, east is to the right, just as all terrestrial maps label it.

The second type, telescopic maps, show south up, as it would be in a telescope that inverts the image. This type of map doesn't carry any "east" or "west" directions.

The direction east is to the right on maps of all other objects in the solar system except one: the Sun. For whatever reason, astronomers have never changed the convention of labeling directions on the face of our daytime star. This means that, for maps dated post-1961, the Sun is the only solar system body on which a "north up" map will have east to the left.

Michael E. Bakich
Senior Editor

Vast clouds called dark nebulae, such as SAC SL 17 in the constellation Scorpius, are known to contain high concentrations of dust that block out background starlight. You can find dust in every corner of the universe. FRED HERRMANN

Q: *ASTRONOMY* MAGAZINE HAS LOTS OF REFERENCES TO DUST CLOUDS. WHAT IS "DUST" COMPOSED OF?

Dan Baum
Pendleton, Oregon

A: Three types of dust exist in space, and none of them resembles what we call "dust" on Earth. Here, outdoor dust consists mainly of small particles of soil and rock carried into the atmosphere by wind. Indoor dust is a combination of soil attached to our shoes that we carry in, human and animal hair, tiny bits of paper and other fibers, pet dander, and a tiny percentage of human skin.

Astronomers find cosmic dust in the areas between galaxies (intergalactic dust), among the stars of individual galaxies (interstellar dust), and within our and other solar systems (interplanetary dust). Two elements that arise from different types of stars form intergalactic and interstellar dust.

Dust made primarily of silica begins its life as particles condensing out of the atmospheres of cool red giant stars that contain lots of oxygen. Carbon dust (which also includes carbon compounds such as silicon carbide) forms in similar red giant stars that are different in one way: Their atmospheres are rich in the element carbon. Another type of intergalactic/interstellar dust made of graphite comes almost exclusively from supernovae.

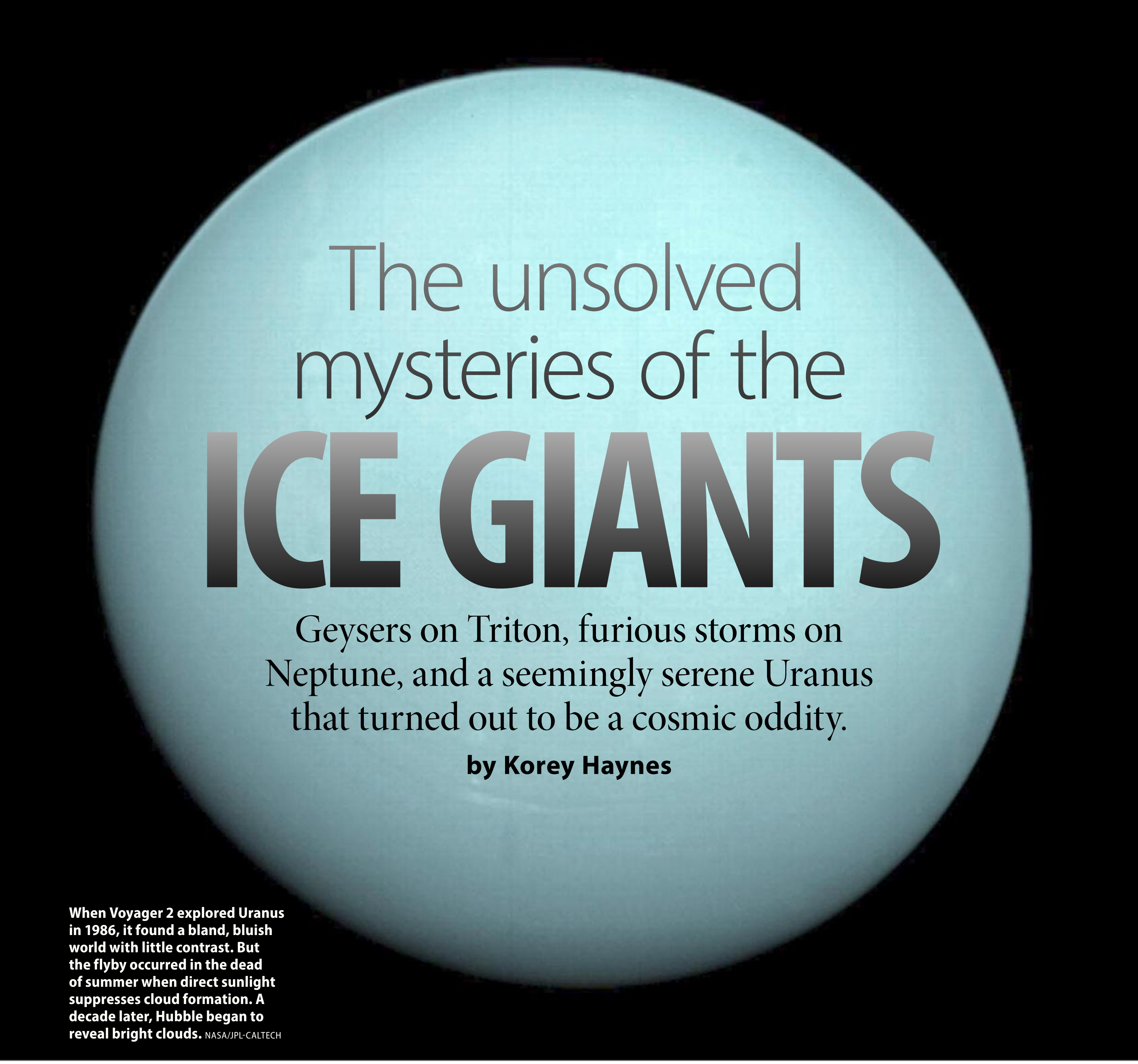
Interplanetary dust contains some of the dust that floats between galaxies and stars, but it has some local components as well. Asteroid and even planetary collisions early in the solar system's history contributed to what astronomers call the interplanetary dust cloud. Researchers are currently trying to figure out what percentage of the local dust results from such encounters.

Another contribution, albeit minor, comes from comets. Cometary dust is probably the most famous type in the interplanetary dust cloud. Most of it lies dormant, frozen within the icy nuclei of comets. When one of those objects nears the Sun, however, the ice in the comet vaporizes and releases the dust all along the comet's orbit. Earth, in its yearly trip about the Sun, passes through dozens of these dust trails and the result in each case is a meteor shower.

Michael E. Bakich
Senior Editor

Send us your questions

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



The unsolved mysteries of the ICE GIANTS

Geysers on Triton, furious storms on Neptune, and a seemingly serene Uranus that turned out to be a cosmic oddity.

by Korey Haynes

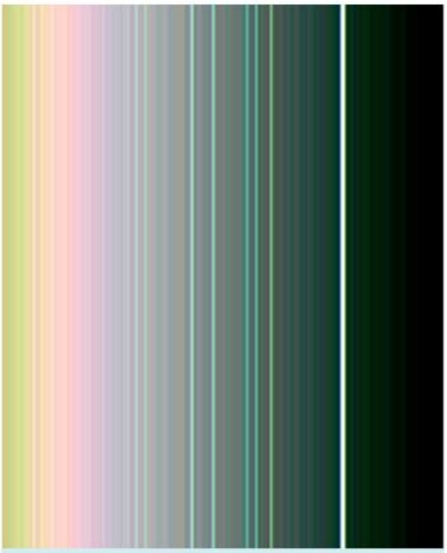
When Voyager 2 explored Uranus in 1986, it found a bland, bluish world with little contrast. But the flyby occurred in the dead of summer when direct sunlight suppresses cloud formation. A decade later, Hubble began to reveal bright clouds. NASA/JPL-CALTECH

After visiting Saturn, the twin Voyagers parted ways substantially for the first time. As Voyager 1 raced out of the solar system, Voyager 2 struck out on its own toward the last two unvisited giant planets: Uranus and Neptune. Smaller and more distant than Jupiter and Saturn, these ice giant worlds were better hidden from Earth's prying telescopic eyes, and therefore more mysterious. And, to some extent, they remain so. No spacecraft since Voyager has visited them, and there are no missions currently scheduled to either planet. The secrets that Voyager teased out remain the most up-close views that scientists have to work with.

Big blue nothing

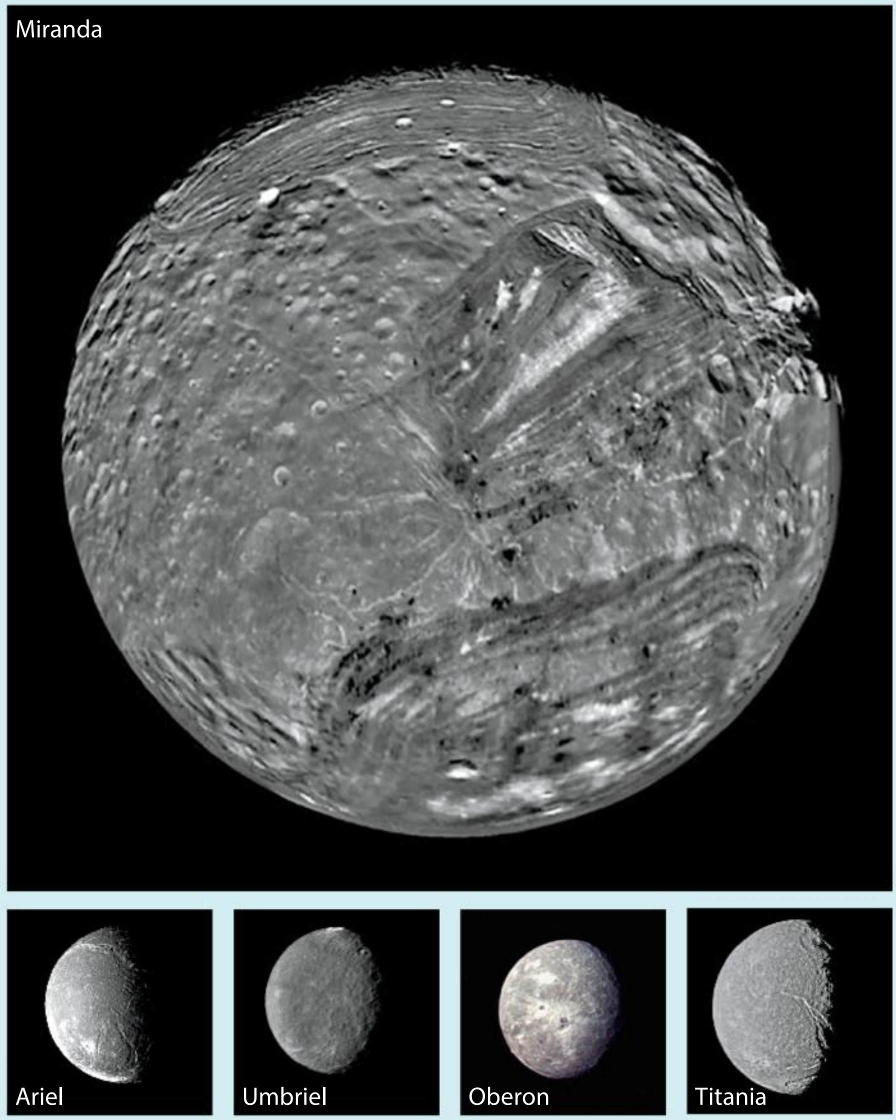
Voyager 2 flew past Uranus on January 24, 1986, more than four years after the probe visited Saturn. Following the excitement at that ringed world (and Jupiter before it), scientists were eager to see what Voyager would reveal at the more distant and enigmatic uranian system.

Suzy Dodd, the project manager for Voyager's interstellar mission, worked on the sequencing teams for Uranus and Neptune. The group determined exactly when Voyager's instruments should take data in order to return the information the science team wanted. This meant understanding in minute detail how the planets and their moons moved. The sequencing team orchestrated the various instruments to use every second of the precious flyby windows to image the most valuable targets: the limb or edge of the planets, the terminators where day and night meet, the moons in their orbits, and the planets' own broad faces.



Voyager 2 captured the first good photos of Uranus' ring system. These dark, faint rings glow in false color in this computer-enhanced image, which reveals the nine rings known before the spacecraft's arrival. (The fainter pastel lines are processing artifacts.) Scientists have since discovered four more rings. NASA/JPL

Uranus' menagerie of major moons



The planet's Frankenstein moon, Miranda, looks like a mad scientist stitched it together from unrelated parts. Some regions feature heavily cratered ancient terrains while others are younger and display canyons, cliffs, and steep ridges. Craters dominate Ariel's surface, though this moon also shows some major canyons and ridges. Heavily cratered Umbriel is the planet's darkest large moon; the white ring at top resides on a crater's floor. Bright rays surround several of the big craters that dot the surface of Oberon. Abundant craters also cover Uranus' largest moon, Titania, though several canyons and steep cliffs break up the monotony. MIRANDA: NASA/JPL/USGS; ALL OTHERS: NASA/JPL

After the rich and complex atmospheres of Jupiter and Saturn, Uranus seemed pretty bland, Dodd recalls. "You didn't get all the great storms you got at the other planets," she says. Instead, Uranus "looked like a fuzzy, blue tennis ball."

Voyager did reveal a previously undetected magnetic field around Uranus, comparable in strength to Earth's. Due to its nearly 90° axial tilt, Uranus rolls around its orbit like a ball. And while Earth's orbital and magnetic fields are offset by roughly 12°, Uranus' are 60° apart. This results in a corkscrewing magnetic field trailing millions of miles behind the planet.

What's more, scientists still aren't sure why the magnetic field exists at all, since Uranus lacks the standard liquid metallic inner layer that powers such fields on other planets. Voyager also revealed intense radiation belts around the planet, similar to those seen at Saturn.

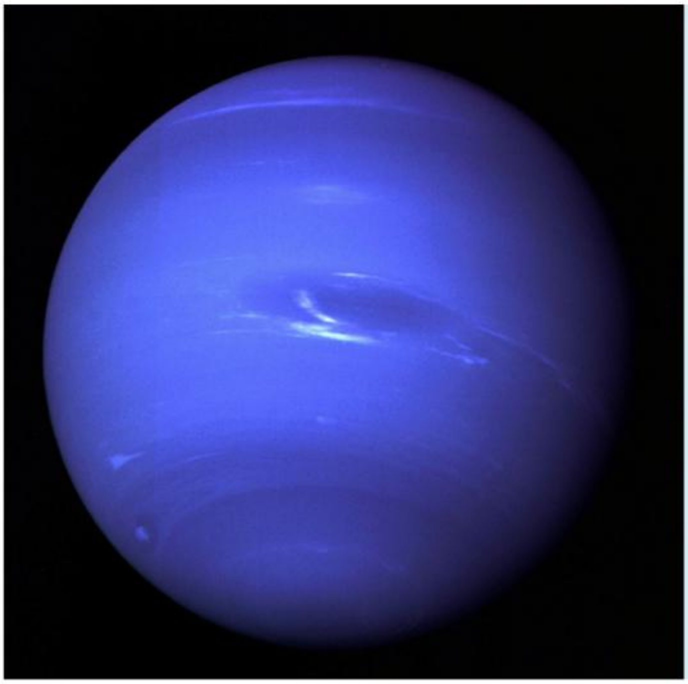
But the highlights, Dodd says, were centered on Uranus' rings and moons. Compared with Saturn's rings, visible since the earliest days of the telescope, Uranus' were still recent discoveries, and scientists were eager to learn more.

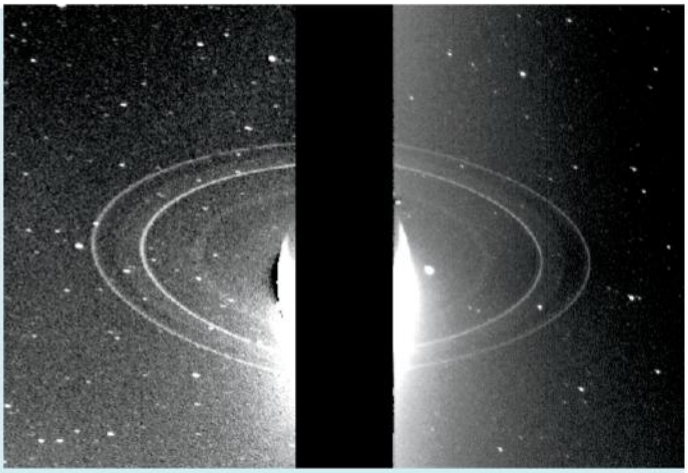
Astronomers at Cornell University discovered Uranus' ring system in early 1977, just before Voyager's launch. The sighting was a happy accident, when a chance alignment carried Uranus in front of a distant star. Scientists had planned to use the occultation to study Uranus' atmosphere, but the star's repeated appearance and disappearance before it slid out of view behind the planet made astronomers realize that a series of rings surrounded our far-off neighbor. The flyby was a chance to investigate them up close.

Voyager imaged the ring system for the first time, informing astronomers of its detailed structure. The spacecraft also discovered two entirely new rings. The close-up views confirmed that Uranus' subtle bands are not like Saturn's bright icy rings; they are dark and reflect little light, making them difficult to see. Scientists think the rings are probably made mostly of ice, like Saturn's, but covered in organic material such as methane, and then baked dark by the planet's radiation belts.

Uranus' moons, too, camouflage well against the dark of space. When Voyager left Earth, astronomers knew of only five satellites around the planet. From observations during its brief visit, the spacecraft tripled that number, yielding 10 new moons.

"I really think the satellites were the highlight of Uranus," says Dodd. Voyager images lent the five larger known moons





Above: Voyager captured Neptune's three brightest rings after it flew past the planet. (The dark bar blocks the ice giant's crescent.) The outer ring's clumpy nature doesn't show up well from this angle. NASA/JPL

Left: Neptune's dynamic atmosphere surprised scientists, who expected the planet to resemble its dull cousin, Uranus. The Earth-sized Great Dark Spot lies at center; several smaller storms also appear. NASA/JPL

detail and character, telling varied stories of violent pasts.

Two of the new moons, Cordelia and Ophelia, were identified as shepherd moons. They orbit on either side of Uranus' outer Epsilon ring, and their gravitational pull herds the small particles in that ring along their orbital path and keeps them from dissipating into space. Uranus' rings are uncommonly narrow; without shepherd moons, the small particles would disperse over long timescales.

Over the years, astronomers have used imagery, mostly from Hubble, to add more moons to Uranus' count, which currently stands at 27. But Cordelia and Ophelia remain the only observed shepherds of the ring system. Astronomers have long wondered whether more moons are hiding from view, or whether other forces are at work.

Last year, astronomers from the University of Idaho revisited the Voyager data. Thirty years after the flyby, they found evidence for two more tiny moonlets shaping Uranus' rings. "Nobody — or not many people — had looked at this in a very long time," says Robert Chancia, who led the investigation. In fact, the Voyager data were taken before he was born. Chancia and his adviser, Matthew Hedman, usually study Saturn's rings. But recent discoveries by the Cassini spacecraft have added greatly to astronomers' understanding of planetary rings. So Chancia and Hedman decided to take another look at the Voyager findings, applying new theories to old data.

"There are several narrow ringlets within the rings of Saturn" that provide reasonable proxies for Uranus' system, Chancia explains. So he and Hedman adopted techniques that planetary scientist Mark Showalter used to find the moonlet Pan in Voyager 2's observations of Saturn's ring system.

They found distinct patterns in Uranus' rings consistent with "wakes" carved by moonlets circling a planet within a ring system. The predicted moonlets are tiny, only 2 to 9 miles (4 to 14 kilometers) across. And they are likely dark, like the rest of the moons and ring system. Confirming the moonlets will be a challenge. But even 30 years later, Voyager is still helping to crack Uranus' secrets.

Final surprises

Voyager's last planetary encounter came August 24, 1989. Far from Uranus' "fuzzy tennis ball," Neptune was alive with storms and bright, quick-moving clouds, delighting unsuspecting astronomers. Clouds not only appeared clearly in Voyager images, but they also cast shadows on deeper cloud layers, allowing scientists to measure the planet's atmosphere in great detail. The "Great Dark Spot," as astronomers termed the largest tempest, was as big as Earth, swirling in Neptune's southern hemisphere and boasting wind speeds as high as 750 mph (1,200 km/h). In the decades since, that storm has died, while new storms have risen in its place.

"That was a bit of a surprise to me when you consider the Great Red Spot on Jupiter has been going on for 400 years," Dodd says.

More surprises waited on Triton, Neptune's biggest moon. Triton was already a hotbed of intrigue; it's by far the solar system's largest retrograde satellite, meaning it orbits in the direction opposite to its planet's rotation. This is usually a sign of a captured object, but most other retrograde moons are small, misshapen asteroids. Triton is three-quarters the size of our Moon, and survived its capture intact. Scientists wanted close-up views of the satellite, and since it was the last target, they were free to adjust Voyager's trajectory as needed. So the spacecraft swooped only 3,075 miles (4,950km) above Neptune's north pole — its closest approach to any object during the mission — and flew toward its encounter with Triton.

The last world Voyager 2 visited stunned scientists. The moon boasted a thin atmosphere, polar caps, and active geysers that spewed icy material miles high. The active cryovolcanism puts Triton in a select group of satellites, in the company of other dynamic moons such as Europa and Enceladus.

Voyager also discovered six new moons orbiting Neptune and delivered clear pictures of its ring system for the first time, revealing the rings to be clumpy but complete, unlike those at Uranus.

And as it did at Uranus, Voyager discovered that Neptune's magnetic pole is misaligned from its rotational pole, causing extreme variations in its magnetic field as the planet rotates. Furthermore, both planets' magnetospheres are offset from center

by a large fraction: about one-third the planet's radius for Uranus, and nearly half a radius for Neptune. Both planets could have oceans of conductive icy slush that perform the work of the liquid metallic cores at Earth and Jupiter, but inconclusive models and observations have left scientists with little more than guesswork as to what exactly drives the magnetic fields that Voyager observed.

Voyager also detected aurorae on Neptune. Due to the strange and complex nature of the planet's magnetic field, these aurorae don't occur only at the poles; instead they are scattered across Neptune's upper atmosphere.

End of an era

Voyager also closed a contentious chapter in astronomy history by revising Neptune's mass downward by around half a percent — or roughly the mass of Mars. This miscalculation had sent astronomers on a wild goose chase through the years as they tried to make sense of Uranus' and Neptune's orbits, usually by invoking the existence of a mysterious Planet X tugging on both of them. (Pluto was found as a direct result of this hunt, but its small size was never enough to resolve the initial problem.) Voyager settled the issue, as Neptune's smaller mass means it and Uranus orbit just as they should.

To mark the final flyby, NASA's Jet Propulsion Laboratory hosted a special event celebrating Voyager's journey and accomplishments. Scientists shared images with the public, and rock-'n'-roll legend Chuck Berry, whose music lives on as part of Voyager's Golden Record, played in a special concert.

At the edge of our planetary system, 2.75 billion miles (4.43 billion km) from Earth, Voyager turned its cameras back for a last look, imaging farewell shots of a crescent Neptune. Dodd recalls her reaction to the images: "Wow. The planetary mission is done. We're going off into the deep dark and cold realms of space. Who knows how long the mission will last?"

Epilogue

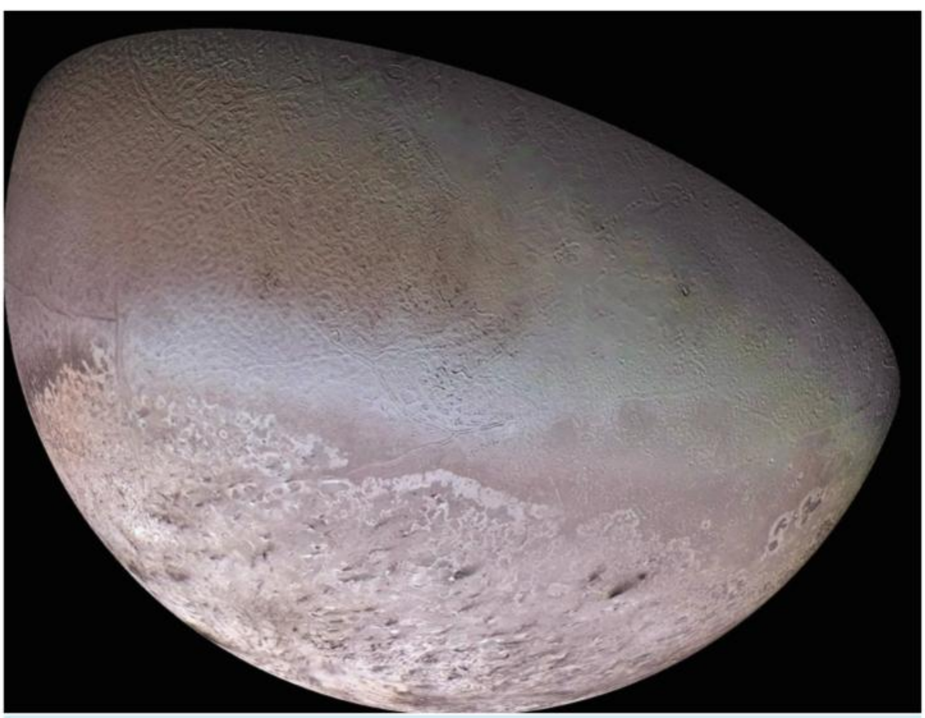
When she left her position with the Neptune team, Dodd says, no one then imagined Voyager would continue as long as it has. She returned to Voyager's interstellar mission in 2010, 21 years after she left the project. In many ways, she admits that the spacecraft is an artifact — memory and power limited, with many of its specialists long since retired or passed on. Since Voyager's departure from Neptune, many of its instruments have gone quiet. There is no need for imaging cameras in the dark void of space. But that does not mean the project is defunct.

Voyager 2 captured a crescent Neptune as it sped away from its final planetary encounter. Now, 28 years later, the spacecraft continues to explore the outer realm of the solar system. NASA/JPL

Voyager continues to measure magnetic fields, charged particles, plasma density, and more as it cruises the solar system's hinterlands, teaching scientists about the subtle edges of the solar system's boundaries. Voyager 1 has passed beyond the reach of the solar wind, and thus is sampling aspects of interstellar space, though it still lies well within the Sun's gravitational influence. Voyager 2, following a slower trajectory from its two-planet detour, tags behind, still sampling the solar wind. From their distance, it takes more than 15 hours for their signals to reach Earth.

Sometime in the next decade, the spacecraft will lose power and begin to shut down. Dodd's team will turn the Voyagers' heaters off first, and one by one, the science instruments will succumb to the cold of space. But the spacecraft themselves and their Golden Records will journey on, carrying humanity's imprint into the cosmos.

It will be years before any spacecraft retreads Voyager's path to Uranus or Neptune. With at least half a century of technological advances behind it, any future craft will undoubtedly revolutionize our understanding of the ice giants all over again. But it's safe to say that nothing will match Voyager for sheer adventure and scope. Decades after its primary mission, Voyager continues to teach, to inspire, and to explore.

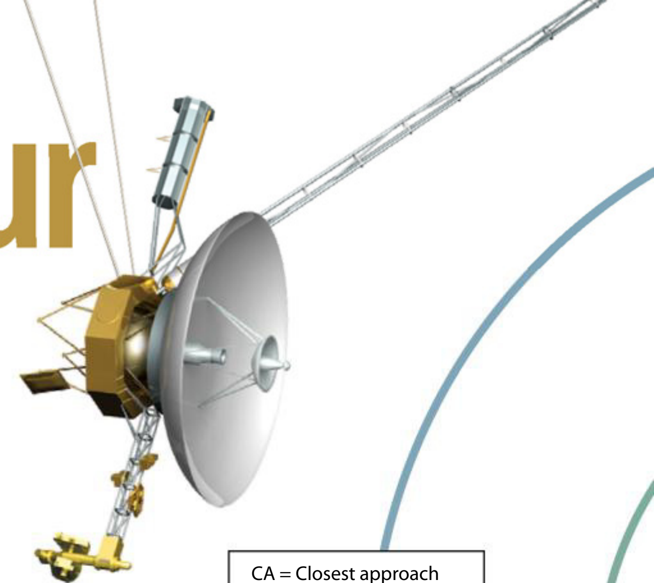


Neptune's largest moon, Triton, boasts some of the solar system's most unusual landscapes. The unique "cantaloupe terrain" in the top half of this image is riddled with crevices and depressions but few impact craters. The south polar region at bottom shows dark streaks deposited by huge geysers that were active during the Voyager 2 flyby. NASA/JPL/USGS

Korey Haynes *is a contributing editor to* Astronomy. *You can find her on Twitter @weird_worlds.*

The Grand Tour

The twin spacecraft took long, looping journeys to explore the outer solar system. **by Richard Talcott; illustrations by Roen Kelly**

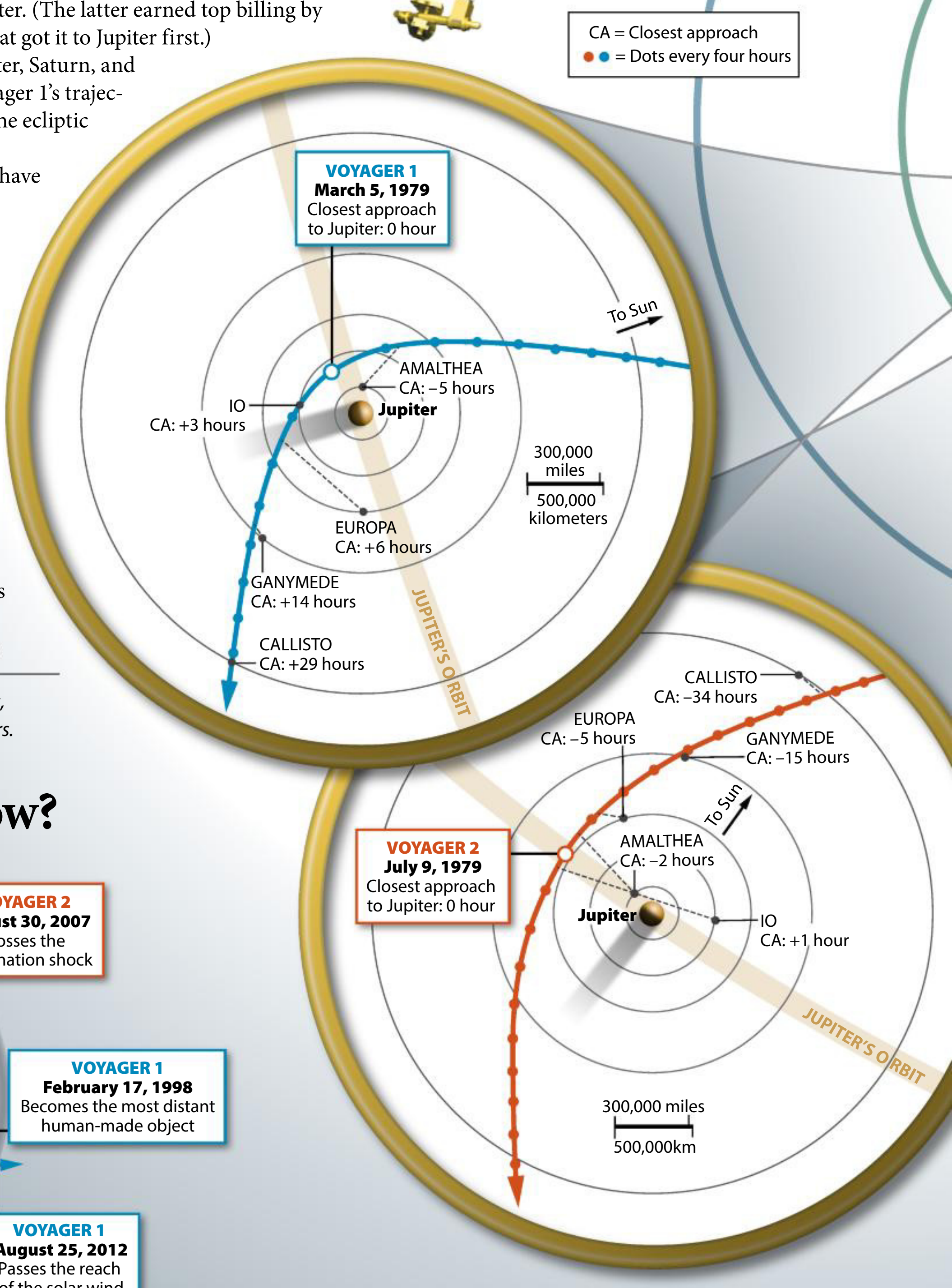


The Voyager 1 and 2 probes delivered the first detailed views of the solar system's four giant planets and their large, shockingly diverse moons. Voyager 2 lifted off from Cape Canaveral, Florida, on August 20, 1977, with Voyager 1 following 16 days later. (The latter earned top billing by taking a shorter, faster trajectory that got it to Jupiter first.) Scientists designed both to investigate Jupiter, Saturn, and their surroundings in exquisite detail. Voyager 1's trajectory past Saturn ultimately flung it out of the ecliptic plane where all the planets reside.

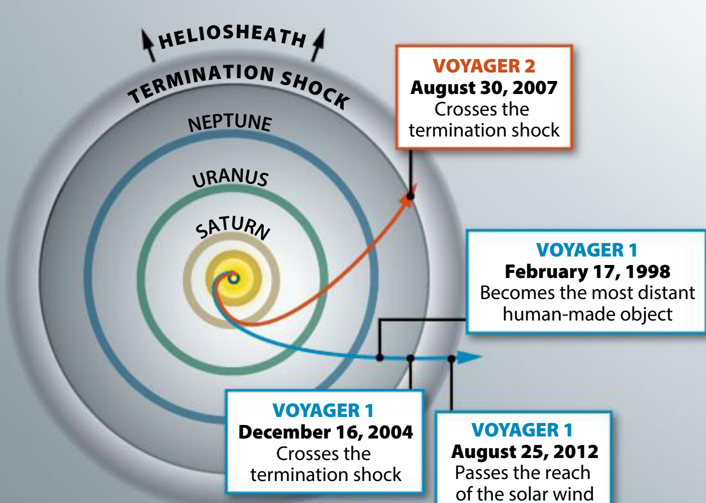
Mission planners targeted Voyager 2 to have the option to continue on to Uranus and Neptune, provided Voyager 1 achieved its goals. Once it did, NASA gave the go-ahead for Voyager 2's "Grand Tour." The trajectory exploited a rare planetary alignment that allowed a spacecraft to fly past all four outer worlds in a relatively short period of time using a minimal amount of fuel. The alignment of the late 1970s and 1980s occurs only every 175 years or so.

Now, 40 years after launch, Voyager 1 lies 140 astronomical units (AU; the average Earth-Sun distance) from the Sun, and Voyager 2 resides 116 AU away. Both probes continue to explore the solar system's outer reaches from their unique vantage points.

Richard Talcott *is a senior editor of* Astronomy, *and vividly remembers all six Voyager encounters.*



Where are they now?



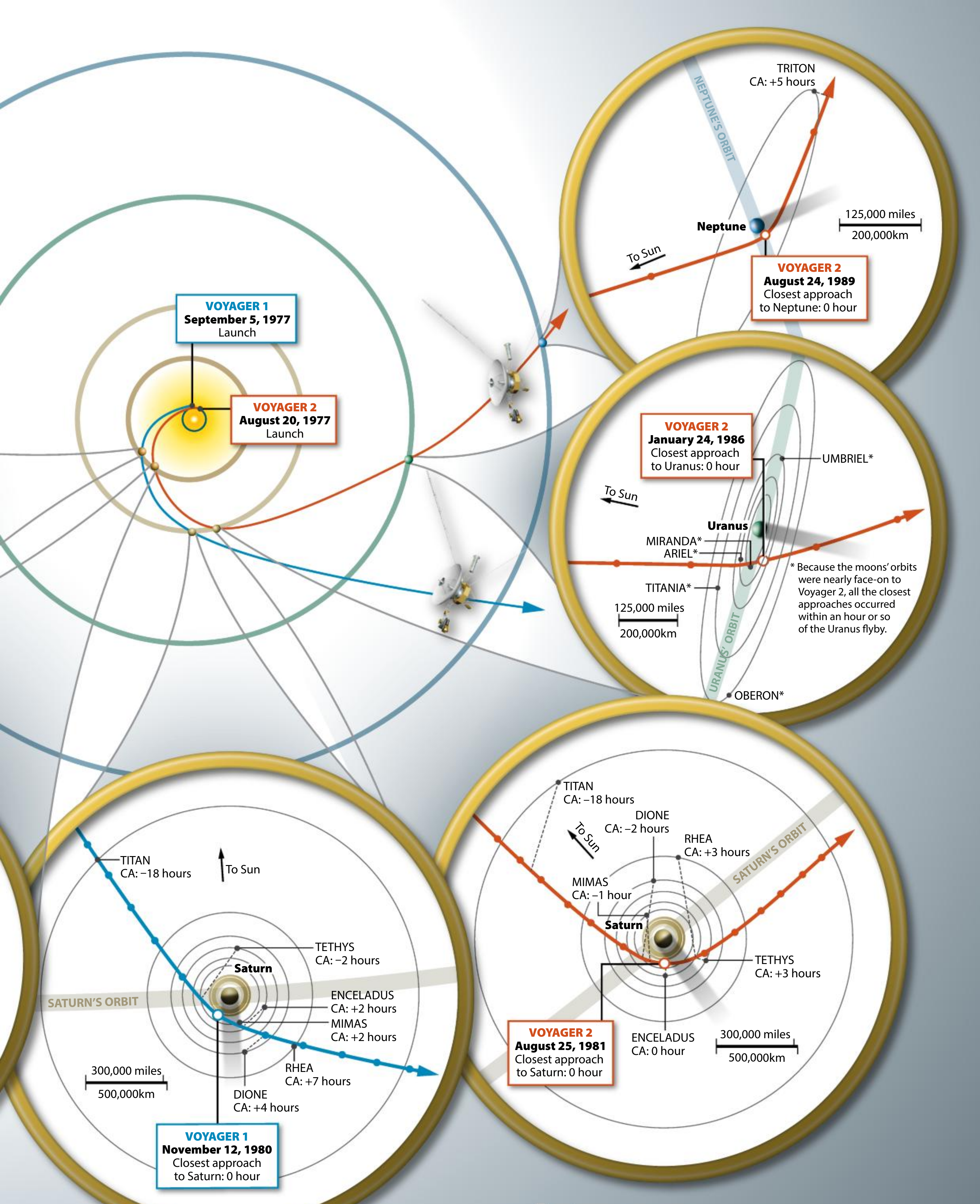

VOYAGER 1
September 5, 1977
Launch
VOYAGER 2
August 20, 1977
Launch
TRITON
CA: +5 hours
NEPTUNE'S ORBIT
Neptune
To Sun
125,000 miles
200,000km
VOYAGER 2
August 24, 1989
Closest approach
to Neptune: 0 hour
VOYAGER 2
January 24, 1986
Closest approach
to Uranus: 0 hour
UMBRIEL*
To Sun
Uranus
MIRANDA*
ARIEL*
TITANIA*
125,000 miles
200,000km
URANUS' ORBIT
OBERON*
* Because the moons' orbits were nearly face-on to Voyager 2, all the closest approaches occurred within an hour or so of the Uranus flyby.
TITAN
CA: −18 hours
To Sun
TETHYS
CA: −2 hours
Saturn
SATURN'S ORBIT
ENCELADUS
CA: +2 hours
MIMAS
CA: +2 hours
300,000 miles
500,000km
RHEA
CA: +7 hours
DIONE
CA: +4 hours
VOYAGER 1
November 12, 1980
Closest approach
to Saturn: 0 hour
TITAN
CA: −18 hours
DIONE
CA: −2 hours
To Sun
RHEA
CA: +3 hours
SATURN'S ORBIT
MIMAS
CA: −1 hour
Saturn
TETHYS
CA: +3 hours
VOYAGER 2
August 25, 1981
Closest approach
to Saturn: 0 hour
ENCELADUS
CA: 0 hour
300,000 miles
500,000km

Image the GIA

The author uses this 14-inch Celestron Schmidt-Cassegrain telescope for many of the images he has produced during the past several years.

Photographing the planets has long been a mainstay of both amateur and professional astronomers. It wasn't so long ago that images from Voyager were wowing astronomers and scientists while amateurs struggled with photographic film to capture clear images of our nearest neighbors. It's fair to say they were falling well short of not only the images spacecraft were taking, but even the sketches visual observers were recording with pencil and paper.

Since then, a revolution has occurred within this field of astronomy. Gone are the days of blurry and fuzzy photographs showing little fine detail. Major leaps in technology have enabled today's amateur astronomers to produce images better than the best film photographs ever obtained with the world's largest telescopes.

Telescopes for planetary imaging

Telescopes come in many designs, shapes, and sizes, and selecting the right one for high-resolution imaging is important. In general, almost any good-quality telescope can produce great images, but certain designs are more favored than others. Today the most popular choices among experienced amateurs are large-aperture Newtonian or Schmidt-Cassegrain telescopes. These provide plenty of light-gathering power at affordable prices and, in experienced hands, can produce highly detailed images.

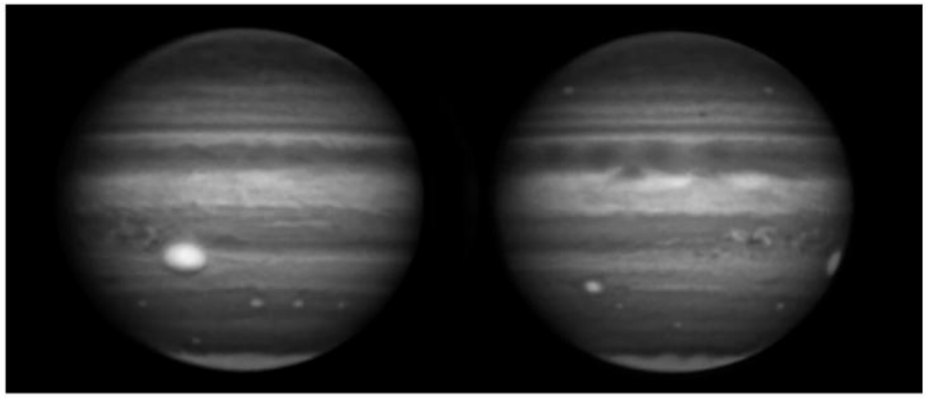
With modern cameras, even a 6-inch telescope can record considerable detail on Jupiter, while larger apertures are needed for Saturn, Uranus, and Neptune. Regardless of the type of telescope you decide to use, there are several key points to consider from a telescope/hardware perspective:

- **Collimation of the optics.** This is vital, especially with reflectors. Many guides are available online and are often provided with the purchase of a new telescope. Also keep in mind that it is a good idea to check the telescope collimation regularly, especially if you store it indoors and must move it outside each time.
- **Thermal equilibrium.** Allow the telescope as much time as possible to reach the same temperature as the outside air. This is especially important for larger apertures.

NT planets

With the right camera and a small telescope, you can go on the same planetary "Grand Tour" that the Voyagers took.

Text and images by Damian Peach



On March 18, 2016, the author imaged Jupiter through an 889-nanometer methane band filter. Methane absorbs sunlight, producing the dark regions. Brighter areas, such as the Great Red Spot, contain little methane and probably represent high-altitude ammonia clouds.

Above: Several storms are visible at different latitudes in this pair of Saturn images, taken during a period of excellent seeing June 11, 2016. The author captured the left image at 3h28m18s UT and the right one at 4h20m12s. North is up.

Left: A wealth of detail is visible across Jupiter's disk. The author took this image March 18, 2016, at 3h18m UT through his 14-inch telescope.

• **Focusing.** Do not fight an inadequate focusing mechanism, such as the standard focusing knob on a Schmidt-Cassegrain. Invest in a decent motorized system that allows fine focusing adjustments without touching the telescope.

• **Usability.** Overlook this at your peril! Nothing is worse than ending up with a telescope that is difficult and cumbersome to use. Choose one that you think you'll be able to use easily and frequently.

• **Focal length.** Invest in a high-quality Barlow lens to increase your telescope's focal length and image scale. Aim for an f-ratio between f/20 and f/30.

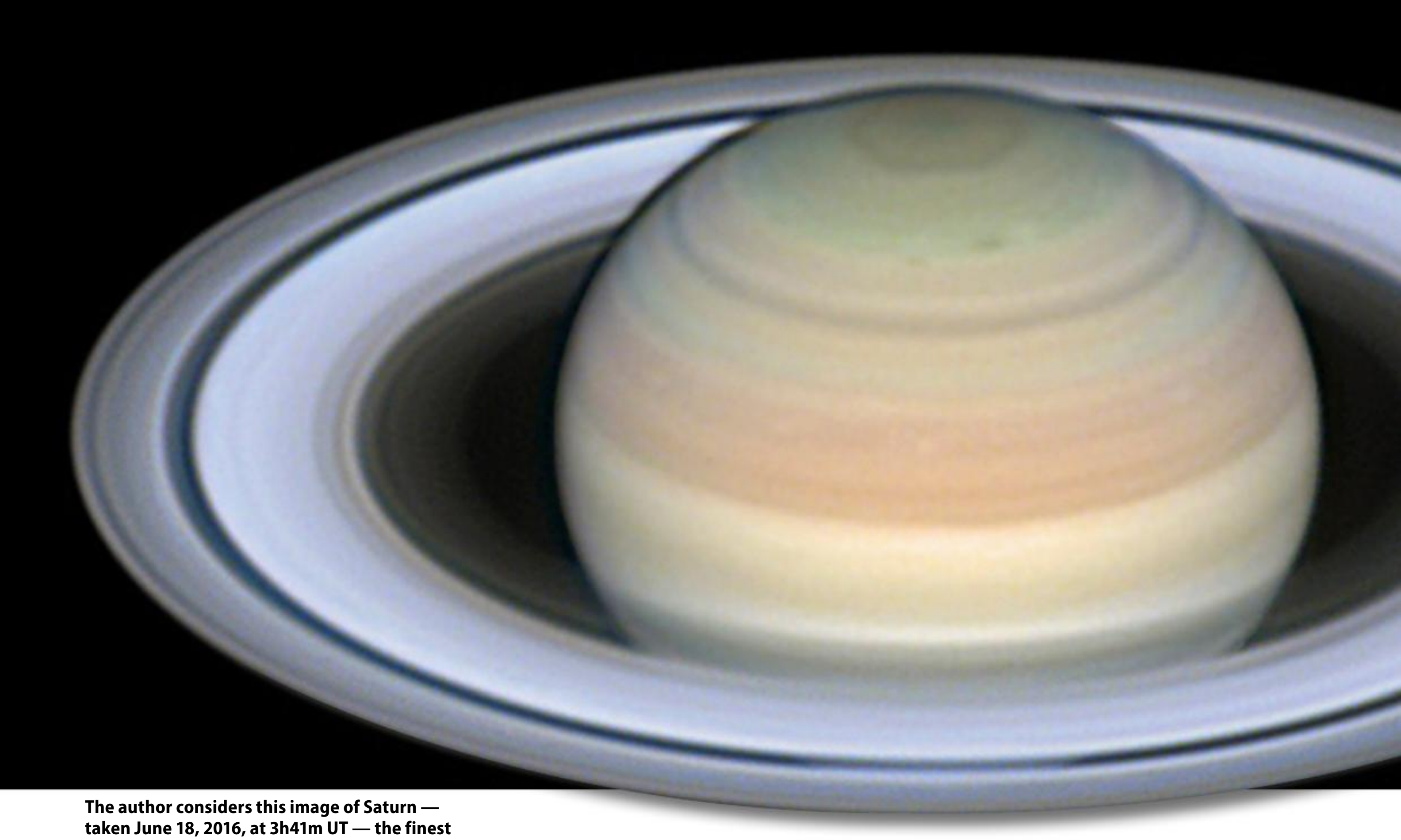
• **Dispersion.** Planets low in the sky are affected by an atmosphere-induced effect, known as optical dispersion, that causes their light to spread out into a spectrum. A dispersion corrector can remove the deleterious effects and help sharpen the view.

Cameras, filters, and software

Camera technology is a fast-moving field and is primarily responsible for the vast leaps in image quality over the past decade. Gone are the slow transfer rates of old CCD cameras, when a photographer could obtain perhaps only one image every few seconds. The best cameras in use by amateurs today can shoot at rates of more than 100 frames per second (fps). All typically operate via similar software packages that allow control over important settings such as exposure, frame rate, and gain.

For those starting out, I recommend a one-shot color camera. For more experienced observers, a monochrome camera with a set of filters will provide higher-quality results. A wide range of camera choices that perform well is available today from several different manufacturers. Companies such as ZWO Optical and Point Grey Research have led the way in recent years, but other companies, such as Imaging Source and Celestron, also produce an excellent range of cameras for planetary imaging.

Any serious planetary observer should own a set of filters to image in different wavelengths. Longer-wavelength filters, such as infrared (IR), allow us to see deeper into planetary atmospheres, while shorter-wavelength filters focus on the high-altitude regions. Also available are specialized filters that focus on specific absorption



The author considers this image of Saturn — taken June 18, 2016, at 3h41m UT — the finest he's ever captured with his 14-inch telescope. Note the great detail visible within the ring system and on the planet's globe.

bands. By far the best for planetary imaging is the 889-nanometer methane band filter. This narrowband IR filter focuses on sunlight absorption due to methane in the atmospheres of the giant planets and is especially useful for Jupiter and Saturn.

One particularly nice aspect of planetary imaging today is that many software packages you'll need are available for free. Below you'll find a few of the key titles:

• **Firecapture.** This program is by far the most popular for planetary camera operation. It supports almost every model and has an advanced and well-designed user interface. (www.firecapture.de)

• **Autostakkert!** For aligning and stacking the frames taken by today's planetary cameras, this software leads the way. (www.autostakkert.com)

• **Registax.** This program has gone hand in hand with the advancements we have seen in planetary imaging over the past decade or so. It allows both image alignment and processing of image data. (www.astronomie.be/registax)

• **WINJUPOS.** Originally intended to measure the position of atmospheric features within the jovian atmosphere, this program now contains sophisticated processing routines that allow imagers to compensate for rapid planetary rotation, thereby creating higher-quality images. (http://jupos.org/gh/download.htm)

Image the giant

The solar system's largest planet is the jewel of the night sky. Jupiter is one of the few truly dynamic astronomical objects that can be studied closely with amateur equipment. Its huge size means it presents a large apparent disk as seen from Earth, and even small telescopes can show considerable detail. It also rotates rapidly — a jovian day lasts 9 hours, 55 minutes — so you can see much of the planet during just a single night under the right circumstances.

Jupiter's rapid rotation makes it challenging to photograph. The time window available before rotation begins to smear detail is quite short compared with the other planets. For those using large apertures in good seeing conditions, 60 seconds is probably the upper limit per single capture. For an RGB sequence, 3 minutes is the upper limit before too much rotation occurs between the color channels.

Having a smooth routine in place is really important to use every second for RGB imaging of Jupiter, and this only comes from practice. Such a routine also helps render the tones of the planet accurately. Of course, for those using color cameras, the procedure is far less frantic. Using image de-rotation in WINJUPOS allows a much longer capture window overall (up to 15 minutes), making the process much easier.

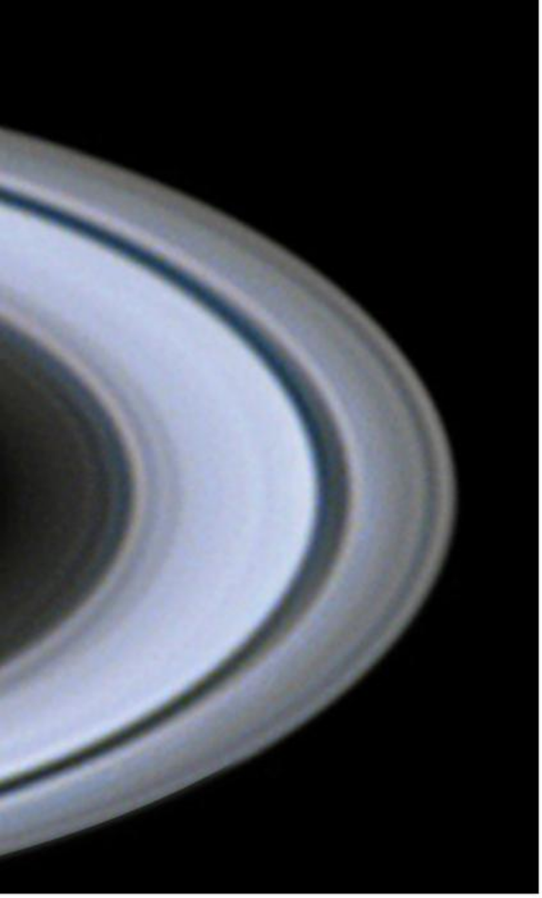
In terms of video frame rate, shooting through the R and G filters at around 80 fps should work well. You'll have to use a slower rate when you image through a B filter, though. Because most camera chips are more sensitive to red light than blue, your frame rate in blue may need to be as much as one-half that as with the other filters. Finally, you'll need to stack at least a thousand frames to create a reasonably noise-free result that will allow sharpening.

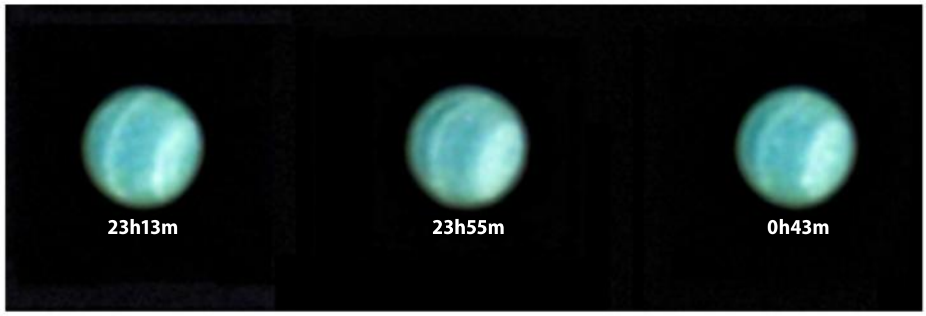
Narrowband methane filters also can help bring out lots of detail. Such filters are typically quite expensive but a worthwhile investment for those keenly interested in imaging Jupiter with the highest quality.

Image the ringed world

With its captivating ring system, Saturn is without question one of the most spectacular sights visible through any telescope. Larger amateur scopes can capture a wealth of detail across the globe and rings.

Minor storms appear as small bright spots and are typically quite frequent. Larger storms also can erupt, such as during the 2011 apparition when observers were treated to a planet-encircling storm,





Distant Uranus showed some belts and bands in its atmosphere October 7/8, 2015. The author took these shots through a near-infrared filter and then processed them to give the planet the correct color appearance based on how it looks to the eye. At the time of these images, the planet's diameter was only 3.68".

The author captured Neptune and Triton September 19, 2015, at 23h15m UT (left) and five days later on the 24th. The earlier shot was a 50-minute exposure, and the later one was 25 minutes. Both images show bright storms. Amateur astronomers have discovered several such bright spots in recent years.

the largest seen on Saturn in more than 20 years. The ring system also shows many interesting details, such as brightness variations, and occasionally you can image even the famous spoke features. When the rings are presented edge-on to Earth, large scopes will allow you to capture shadow transits of the saturnian moons easily.

Photographically, Saturn is challenging. Although it has a large angular diameter, its low surface brightness means that larger scopes (8 inches or more) are needed to get detailed results, and the frame rates achievable are much lower compared with its larger and brighter neighbor. Using typical RGB filters, frame rates will range from around 20 to 40 fps. Color cameras work well with the planet, and around 50 fps should be achievable. During RGB imaging, you can speed things along by taking a luminance image, as the frame rates are much higher and the resulting shorter exposure time can help produce a sharper result.

Saturn rotates more slowly than Jupiter, and at only half the apparent angular diameter (not including the rings), a far more generous capture window is usable. For a single capture, 3 to 4 minutes is usable, and for a total RGB capture, twice this length works fine. It can help to take a series of images over a 30-minute period to show any small spots or features that move with rotation, because sometimes these features are not immediately apparent.

Image the ice giants

The distant ice giants have been two largely neglected worlds in terms of amateur study, although this has started to change. At their great distances, they present only tiny disks even through large telescopes. Both planets exhibit interesting activity with occasional bright storms, though any hope of capturing such events is reserved for those using large apertures.

Both planets are also challenging objects to photograph well at high resolution. RGB or color imaging serves little purpose with these planets because much of the transient activity and even the belt and zone patterns are best seen in near-infrared wavelengths.

An important filter to use on these planets is a near-IR 600nm long-pass filter. For larger apertures, a 700nm IR filter (which passes somewhat less light) works well. These filters stand the best chance of picking up atmospheric detail while still delivering a bright enough image that is realistically usable with amateur-size telescopes. All of the most detailed images of these planets produced in recent years have been through IR filters. Because both planets are so distant and rotate fairly slowly, time windows of around 15 minutes are usable for single captures, and you should try to stack plenty of data into each single image — up to 30 minutes' worth works well. Bright storms have been detected on both planets in recent years, most of them discovered by amateurs.

Not just pretty pictures

While the majority of deep-sky work is primarily aesthetic in its appeal, this is not the case with planetary images. Amateur work on the outer planets remains important to professional researchers, and in recent years many discoveries have been made using amateur data. Science based on amateur images is also more detailed and credible than it has ever been. Image quality today is good enough that detailed papers about the atmospheric dynamics of Jupiter have been written based purely on the analysis of amateur data.

With recent advances in camera technology, we have moved even further, discovering storms on the distant worlds of Uranus and Neptune.

Indeed, amateurs continue to make significant discoveries and contributions to studying the four planets of Voyager.

Damian Peach *is one of this planet's finest astroimagers. He collects photons from around the world and processes them from his home in Selsey, England.*

HOW AN INTERPLANETARY CHANGED THE

Voyager 1 and 2 revealed much about the cosmos — and left a giant mark on pop culture.

There are missions to space, and then there are missions like Voyager. The pair of ambitious space explorers launched from Earth in 1977 and have been speeding through our solar system for the past 40 years on a mighty course for the stars. In the interim, the mission shaped not just our understanding of the solar system, but also our pop culture landscape.

The once-in-more-than-a-lifetime mission was born from a rare alignment of the planets that happens only every 167 years. With the right amount of planning and engineering, NASA realized it could send not just one, but two identical spacecraft on a journey from Earth to visit the four giant planets in the outer solar system.

At the time of their flybys, both craft brought incredible clarity to Jupiter and Saturn and their moons, which had previously been visited by Pioneers 10 and 11 and their more primitive cameras. At the time the Voyagers launched, there were no close-up images of Uranus and Neptune; two of our outermost planets were mysteries. The world waited for the spacecraft to fly past each planet and send back whatever treasures they found. Glimpses of the light teal of Uranus, the bright blue of Neptune, and those textured rings of Saturn infiltrated the nightly news and the collective consciousness.

"At the time, the mission was all over the news," explains Voyager Project Manager Suzy Dodd. "In those days, the press came in person, and we would have these live press conferences every day from JPL."

Each week, people watching the news would see the planets grow in size as each spacecraft got closer, and the public followed loyally along with the mission. Earthlings suddenly knew more about their home solar system, and that excitement bled into popular culture, especially science fiction. Just two years after the launch of the Voyagers, *Star Trek: The Motion Picture* was released, featuring a familiar spacecraft. In the film, they called it "V'ger."

"The main thing people reference when they talk about Voyager in the media is *Star Trek*," says Dodd. "V'ger, V'ger, they always say."

When NASA designed Voyager, they knew that someday it would leave the solar system entirely and might be visible to alien civilizations — if there were any out there to intercept it. In *Star Trek*, the fictional Voyager 6 has encountered a sentient artificially intelligent species that gave the spacecraft the gift of self-awareness. By the time the crew of the Enterprise meet V'ger 6, it's likely the craft had encountered several civilizations.

After the discovery of the parked spacecraft, Spock decides to venture inside and find out more about what exactly V'ger is. As he's flying through the ship, he says, "Curious. I'm seeing images of planets, moons, stars, whole galaxies all stored here, recorded. It could be a representation of V'ger's entire journey. But who or what are we dealing with?" What Spock is seeing is a recorded database of V'ger's encounters. Before the missions had even reached Saturn, people were already looking to Voyager as our future interstellar emissary.

In perhaps the perfect blending of real life and science fiction, *Star Trek*'s Voyager 6 encounter is what scientists had dreamed of when they launched Voyager 1 and 2 into space.

Out there

Star Trek wasn't the only sci-fi hit to jump on the Voyager bandwagon. In a 1994 episode of *The X-Files* titled "Little Green Men," FBI agent Fox Mulder narrates the story of Voyager while visiting the Arecibo Observatory in Puerto Rico. He starts the episode, "On August 20 and September 5, 1977, two spacecraft were launched from the Kennedy Space Flight Center, Florida. They were called Voyager. Each one carries a message. A gold-plated record depicting images, music, and sounds of our planet, arranged so that it may be understood if ever intercepted by a technologically mature extraterrestrial civilization."

Mulder is searching (as always) for evidence of extraterrestrial life, and the Golden Record containing a message from Earth, calling attention to our own existence, is a fitting parallel to his journey. In the episode, a classical music selection from the Golden Record plays while Mulder has a bizarre alien encounter in Arecibo.

The Golden Record in and of itself is a vessel for a mixture of popular culture and general documentation of what it's like to be an earthling. There were musical selections from the likes of Chuck Berry and Beethoven; rights management prevented "Here Comes the Sun" by the Beatles from being placed on the record. (The Fab Four were in favor of the move; their record label, which owned the rights to the recording, was not.) The record also contained 116 photos and images of scientific concepts and daily life worldwide; a "hello" in 55 languages; a recording of human brainwaves; various sounds of our planet, both human and geologic; and countless other time-capsule sights and sounds. Etchings of Earth's position, guided by the position of local pulsars, were included on the outer cover.

Carl Sagan, who was a member of the Voyager imaging team at the time, found the right colleagues to work on the record. Jon Lomberg, an astronomical artist, chose the images. Linda Saltzman-Sagan, a writer and artist, compiled the language greetings; Ann Druyan, an artist, handled the everyday sounds; *Rolling Stone* editor Timothy Ferris lent his particular support on the musical selections; and SETI founder Frank Drake lent to the project his vast knowledge

MISSION WORLD

by Shannon Stirone

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of trying to home in on the best way to communicate with alien species.

Since the 1970s, the symbolism of the record has shown up in TV shows, film, and even clothing. The record even recently became popular again when a Kickstarter campaign to reissue the full Golden Record set received over $1 million in funding from 10,000 people wanting their own copy of history.

The shores of the cosmic ocean

While working on the Voyager mission, Sagan and Druyan created a TV show called *Cosmos*. The PBS show, which debuted in 1980, not only highlighted the beautiful intricacies of Earth, but it gave viewers a perspective about our place in the cosmos, coinciding with the mission's journey toward Saturn. (Sagan and Druyan met while working on the Golden Record and married in 1981.)

The impact of the show on popular culture is so great, it's hard to quantify, though one benefit is that *Cosmos* ultimately inspired an entire generation of scientists. Jim Bell, a planetary scientist at Arizona State University who worked on Voyager at the beginning of his career and would ultimately memorialize the mission in the oral history book *The Interstellar Age*, credits *Cosmos* with inspiring his career path.

"Voyager launched back when I was in high school, and the show *Cosmos* by Carl Sagan was enormously impactful," he says. "It was the first time that science was on TV and being communicated by a real professional communicator who could speak the language of science and translate it."

A mote of dust on a cosmic ocean

Perhaps more than anything else though, the biggest influence the Voyager mission had on popular culture came in the form of a single photo. The "Pale Blue Dot," taken February 14, 1990, by Carolyn Porco and Candy Hansen at Sagan's request, no doubt changed the world and how we saw ourselves. As one of its final images, Voyager 1 pointed its cameras toward Earth and snapped one final shot before the cameras were shut down to save power.

Sagan would later say the dot represented the human experience: "Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every superstar, every supreme leader, every saint and sinner in the history of our species lived there — on a mote of dust suspended in a sunbeam."

As photos of Earth taken from space had done in the 1960s, the Pale Blue Dot put humanity's place in perspective. We weren't just one species uniting for our planet — we also weren't the rulers of the universe, but rather an "insignificant planet of a humdrum star lost in a galaxy tucked away in some forgotten corner of a universe in which there are far more galaxies than people," Sagan says.

"To my mind, there is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world," Sagan says in *Cosmos*. "To me, it underscores our responsibility to deal more kindly and compassionately with one another and to preserve and cherish that pale blue dot, the only home we've ever known."

The photo inspired Sagan's book *Pale Blue Dot*, which, in turn, would go on to inspire short films like *Wanderers* and television shows like *The Expanse* with its grand vision of humans wandering from the cradle of our planet into the wider expanse of our solar system and, eventually, the universe.

The closest thing to the Voyager mission in the modern age may be the New Horizons flyby of Pluto. Today, we can search every major body in the solar system online and find an image of that object, but it wasn't always that way. In 2015, the previously blurry dot we called Pluto became crisp with color, geological features and even a heart-shaped glacier, as the spacecraft undertook a six-month reconnaissance of the distant planet and its moons. Like the Voyagers, New Horizons' discoveries help us understand Earth's place in the cosmos.

"For the first time, we have the power to decide the fate of our planet and ourselves. This is a time of great danger, but our species is young and curious and brave. It shows much promise," Sagan says in the first episode of the original *Cosmos*. "In the last few millennia, we have made the most astonishing and unexpected discoveries about the cosmos and our place within it."

Thanks to the Voyagers and our continued exploration of the solar system, this statement still rings true. We know more about our place in space and can imagine other civilizations having an encounter with an artifact of humanity. Sometime around 2025, both Voyagers will go dormant. But they will always carry a cultural legacy that few robotic missions have before — or may ever again.

Shannon Stirone *is a Bay Area freelance writer who covers NASA, space exploration, and space policy.*

TALK ASTRONOMY with your un-cosmic friends

Here's a concise guide to avoid going over the heads of your science-avoiding peeps.

Text by Michael E. Bakich • Illustrations by Roen Kelly

What's new in astronomy these days? Why does the Moon look bigger when it's near the ground? What star is that?

Such questions are rare when I meet with astronomy hobbyists. When I'm with family, non-science-oriented friends, or the general public, however, these are the only types of questions I get. And now, after more than four decades in astronomy education and popularization, I'm wondering if I've been giving good answers.

I started to think about this subject while I was in Arizona in February 2016 for the fourth annual Tucson Star Party. This event runs from 9 A.M. to 9 P.M. on a Saturday, and it's grown in popularity each year. The East Campus of Pima Community College hosts the gathering, members of the Tucson Amateur Astronomical Association set up telescopes for the public to gaze through, and *Astronomy* publicizes and sponsors it.

After conducting interviews, being the subject of interviews, and making certain everything was ready for the daylong event, I relaxed under the stars with my friend Dave White. He and his wife, Sunni, graciously hosted me for the week.

White is a machinist and a designer of parts for large mining equipment, but his interests lie in other places as well. Like space. As he and I enjoyed Tucson's marvelous warm, clear evenings, he would ask questions about the sky, and I would reply. His follow-up questions clued me in to whether or not he understood my answers, and that made me actually think about them.

Does that sound funny? Who gives an answer without thinking about it? Often, it's an expert — someone who has dealt with a

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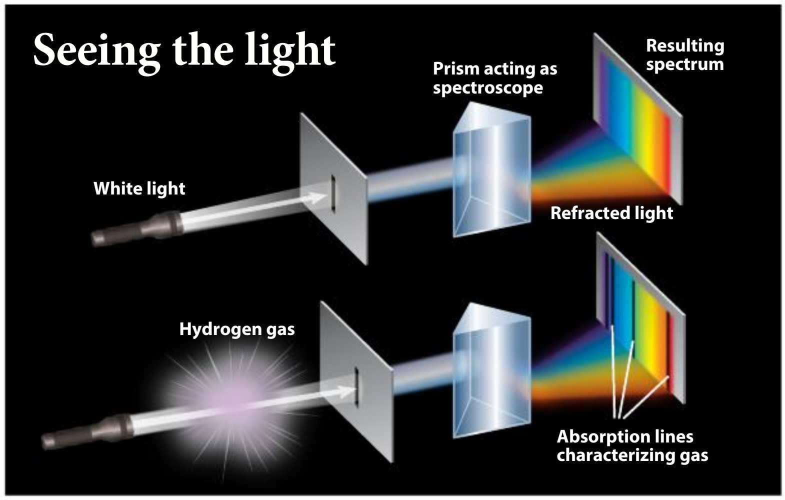
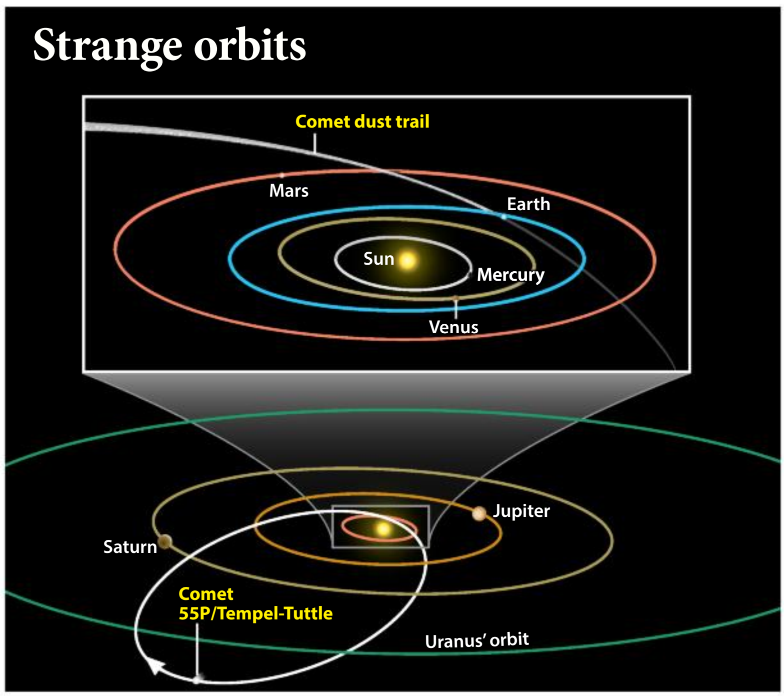
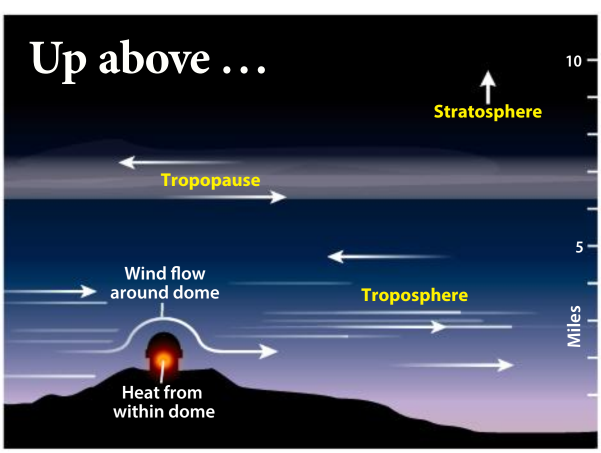


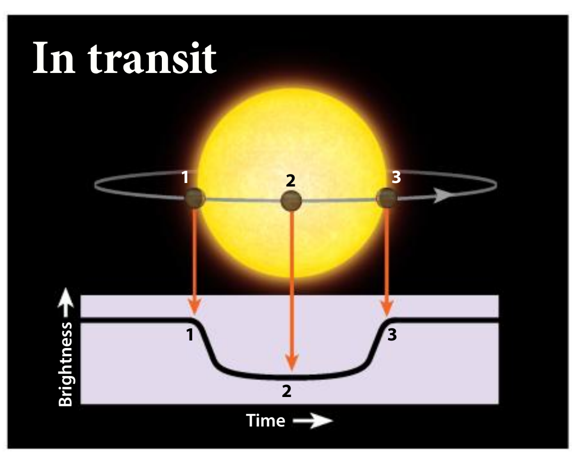
Spectroscopy is the most important tool used by astronomers. Our job is to find a simple way to explain what they discover with it.



A simple way to describe how meteor showers work is to explain that passing comets leave dust trails that Earth runs into around the same time each year.



"Why do stars twinkle?" is one of the most common questions asked by newcomers to amateur astronomy. This illustration demonstrates a few atmospheric reasons.



This simple diagram illustrates how planets are often found, as the light we receive from a star dips when an exoplanet passes in front of it.

One easy jargon-buster is clarifying the difference between meteoroids, meteors, and meteorites.

particular subject matter for a long time. Unfortunately, most experts answer questions the same way no matter who is asking them. Years of dealing with their chosen subject offer little versatility in the replies they give.

In my opinion, many credentialed experts make three mistakes: They give too much information, they provide no examples, and they liberally use jargon.

Too much information

The dreaded "TMI" usually occurs in social situations (the kind that often emerges in childhood or in a comment about my bathroom habits), but it's equally possible when an amateur astronomer talks to friends. Except in such cases, the "too much" is factual in nature rather than personal.

Often, then, a simple question like, "Why does the Moon have phases?" morphs into a full-blown discussion of planetary motion. And you know what? It doesn't have to. You can show how the Moon's phases work with three rocks — or preferably two rocks and a flashlight.

The key here is to focus on the question and not to stray too far afield. It's tough — believe me. Often I keep talking about a subject because I have subconsciously made the judgment that the other person should be as interested about it as I am. It's worse, however, if other experts are present. Then what would be a simple explanation often transforms into a knowledge competition. In the meantime, I've lost my target audience.

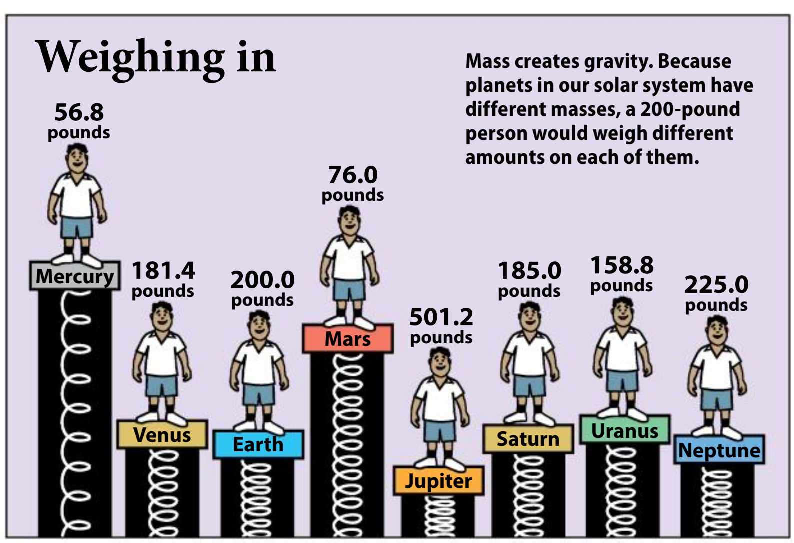
Lack of examples

Consider the question (asked in a way a non-astronomer would phrase it), "How do you know the power of a telescope?" Most of us in the know would reply that anyone can calculate the magnification of a telescope/eyepiece combo by simply dividing the focal length of the telescope by the focal length of the eyepiece.

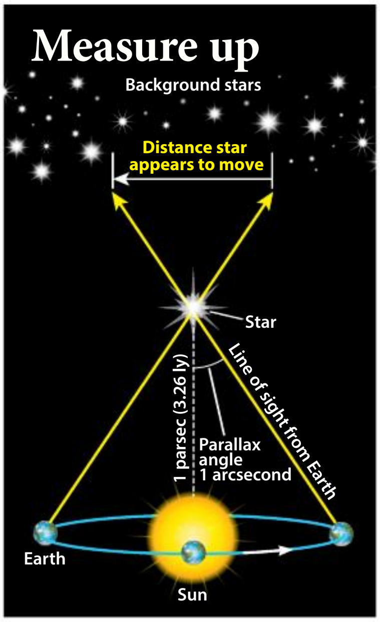
Simply?

Even if we take the time to carefully explain what focal length is, it's kind of an abstract concept. I suggest that we offer more. Provide the listener with an example. If you're just chatting and no telescope is around, have the questioner imagine one with a focal length of 100 millimeters. Then say, "If we put a 25mm eyepiece in, the power would be 4 (100 divided by 25)." You could even continue by asking, "What would happen if we swapped the 25mm eyepiece out for a 10mm one?" In such a case, the power would increase to 10 (100 divided by 10).

If, on the other hand, a telescope

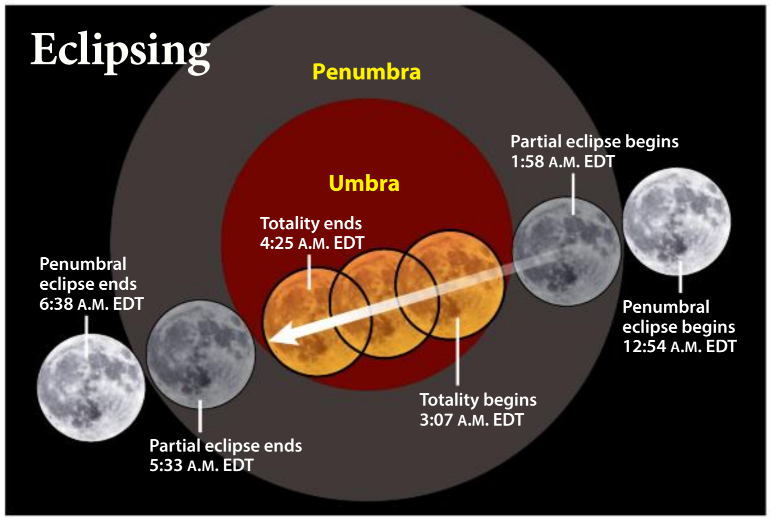


Michael E. Bakich *is a Senior Editor at* Astronomy.



When someone asks you, "How do astronomers know how far away stars are?" you'll have to introduce them to tiny angles and the word *parallax*.

Light pollution can be easier to explain once you're familiar with the different types of shielding that manufacturers make for lights.



This chart demonstrates how lunar eclipses occur in an easy-to-follow format.

is present, use its focal length and that of the eyepiece currently in it to figure out the power. That will bring home the concept in a more concrete way.

An illustration explaining magnification could start with the statement, "A power of X is like being X times closer to something." Explain that 7x binoculars make objects appear seven times closer. Then pick an object. Select a big one but not an immense one. So, pick a car but not a building, a bush but not a giant sequoia. Stand next to your chosen thing and — with your friend — pace out 10 steps and turn around. Gauge the apparent size of the object. Then pace out five steps toward the object and examine it again. Boom! You've just doubled the magnification.

Jargon

Newcomers to our hobby aren't alone in dealing with a huge number of strange terms. A person could be listening to an economist talk about game theory, a computer specialist praise the latest GUI, or an amateur astronomer detail his mirror's Strehl ratio. In all these examples, a better than average chance exists that a word or two will slip by undefined.

Try this: Pretend you're talking to a non-astronomy-savvy friend who just asked you to define right ascension (probably because you used it in a sentence without thinking about it). How much detail would you go into?

Would you point out that astronomers usually measure right ascension in hours, minutes, and seconds? That it's one of the two spherical coordinates used to measure the positions of objects in the sky? That John Flamsteed, the Astronomer Royal of England, first used this coordinate in a star catalog? That 0 hours marks the spot of the vernal equinox? That precession causes the right ascensions of celestial objects to change in a roughly 26,000-year cycle?

Merriam-Webster defines jargon several ways. My two favorites are "confused unintelligible language" and "obscure and often pretentious language marked by circumlocutions and long words." Here at the magazine, we try to avoid jargon, or, if we must use strange terminology, we'll provide definitions, often in the same sentence.

Oh, and in case you're wondering, after many years of confusing people with definitions, here's how I'd define right ascension to a newbie now: It's a coordinate system just like longitude on Earth, but it moves with the stars.

In the early 1960s, American social scientist and Nobel laureate Herbert Alexander Simon wrote that something is simple or complex depending on the way we choose to describe it. As a group of hobbyists who desire to grow our field of interest, let's err on the side of simplicity. And we'll all have lots of chances quite soon. The astronomical event of our lives — the great American total solar eclipse on August 21, 2017 — just took place. If you weren't barraged with questions about it, it's probably because people don't know you're an amateur astronomer. Tell 'em.

Always spectacular in backyard telescopes, Jupiter shows its cloud bands, Great Red Spot, and other features explored in such depth by Voyager. CHRISTOPHER GO

Memories from a BACKYARD OBSERVER

Decades-old observing journals recall a time when Voyager utterly transformed what we know about the outer planets.

by Raymond Shubinski

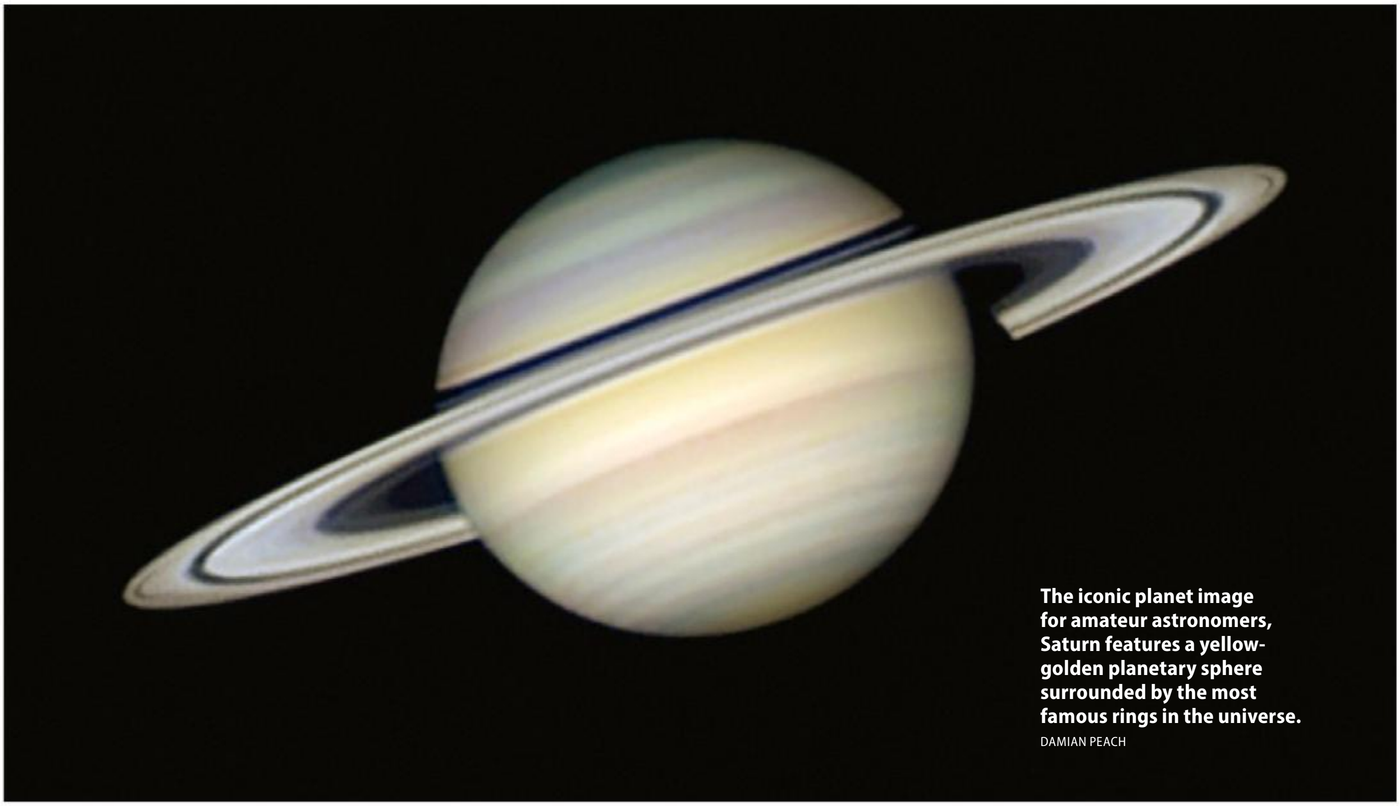
ON Valentine's Day 1990, Voyager 1 sent a loving and last portrait of the solar system it had begun to explore 13 years earlier. Its camera was turned backward to catch a final glimpse of a home now billions of miles away. For nearly a decade and a half, the cameras of Voyager 1 and 2 had looked outward, delivering images of the outer solar system as never seen before.

Voyager 2 launched August 20, 1977, and its sister, Voyager 1, departed 16 days later. By mid-1979, both spacecraft had made close approaches to the giant of the solar system, Jupiter, and then journeyed on to worlds so distant, our minds fail to comprehend the immensity of that space. For all of us sitting back on Earth, this was an incredible time of discovery only dreamed of a few years earlier.

A few months after the Voyagers left Earth, I was working with current *Astronomy* Senior Editor Michael E. Bakich at a small planetarium in Lafayette, Louisiana. We delivered program after program on the Voyager mission. Schoolchildren and the public alike were thrilled with every detail of this unfolding adventure. We also ventured out every possible night to observe the targets of all this excitement: Jupiter, Saturn, Uranus, and Neptune.

Blast from the past

Recently I rediscovered some of those memories in my observing notes and journals. An early morning rendezvous with Jupiter and Saturn, for example, on October 21, 1978, recalls that both planets were well placed in the east an hour or so before sunrise. We were observing with a 6-inch refractor mounted on an old surveyor's tripod. My drawings show one cloud band of Jupiter as



The iconic planet image for amateur astronomers, Saturn features a yellow-golden planetary sphere surrounded by the most famous rings in the universe. DAMIAN PEACH

dark and a bit ragged on the upper edge with a hint of a "bulge" on the lower section. The other band was fainter, and we could see little detail on the cloud tops of Jupiter. Europa and Callisto appeared as two starlike objects. Saturn was lower in the sky, but was beautiful as always. The rings were not edge-on, but were partly closed. Unsurprisingly, we couldn't make out any cloud details with a scope of this size.

The 6-inch refractor we used that morning in 1978 was pretty typical of the kinds of scopes many amateurs used in the 1960s, '70s, '80s, and beyond. Browse through the ads of any astronomy magazine of the time, and you will see ads for the Criterion Dynascope RV-6 reflector, Unitron 2.4- and 3-inch reflectors, and the orange squat tube of an 8-inch Celestron telescope.

Resetting the solar system

What we didn't appreciate fully quite yet, in 1978, was that all of us who were into amateur astronomy were about to have our proverbial socks blown off as Voyager 1 made its close approach to Jupiter in March 1979 and Voyager 2 in July of the same year. The astounding detail of the images returned by these spacecraft forced us to totally rethink not only what we knew about this giant planet, but the solar system as a whole.

Our proverbial socks were about to be blown off as Voyager 1 made its closest approach to Jupiter.

In the early years of my planetarium career, I used astronomy books written by Isaac Asimov as an authoritative source for school and public programs. One of those was *Jupiter, The Largest Planet*. According to Asimov, Jupiter had 13 moons. The Voyagers added three more moons to the realm of Jupiter. Today we count 51 moons with names, and another 18 that orbit anonymously around the giant planet.

Planetary discoveries were happening even before the spacecraft departed. On March 10, 1977, just months before the Voyagers launched, the world learned that Uranus, like Saturn, has a system of rings. MIT astronomer Jim Elliott made the discovery while watching Uranus occult, or pass in front of, a star, to study the planet's atmosphere and other features. To his surprise, the star faded in and out before it disappeared behind the planet, providing evidence for the rings. Then, in 1979, Voyager 1 revealed that the king of planets, Jupiter, is also surrounded by four thin dust rings.

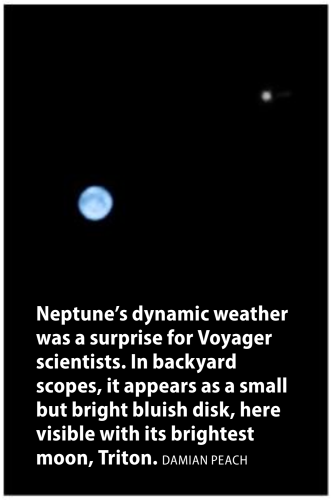
Flipping through my observing journals, I came across an unusual night several years later, on July 17, 1985. I was observing both Jupiter and Saturn. The Voyager rendezvous with these two gas giants was over, and Voyager 1 was on its way out to the edge of the solar system. That night, I was using a Celestron 8-inch telescope and a range of eyepieces. At about 250x, both planets held up well with clear details. I could see at least five bands on Jupiter and the shadow of the moon Io as it progressed across the disk of Jupiter.

Saturn was gorgeous, as always. My drawing shows the rings almost wide open. I noted one cloud band and the Cassini Division as quite clearly visible. As I watched Saturn drift by in my field of view, I thought of all we had learned about the ringed planet during the past few years. In the C8, I could easily see features that had been observed for the past three centuries. Now we knew that Saturn's rings were far more complex than what any ground-based telescope could show. In the high-resolution images returned by Voyager 2, astronomers discovered hundreds of thin rings, some only a few feet thick.

Imaging the outer planets

I have always enjoyed drawing what I see in the eyepiece. Many of my contemporaries, however, have produced images of the outer

Uranus is easy to see as a bluish-green disk, but it is essentially featureless in backyard scopes. DAMIAN PEACH



Neptune's dynamic weather was a surprise for Voyager scientists. In backyard scopes, it appears as a small but bright bluish disk, here visible with its brightest moon, Triton. DAMIAN PEACH

planets using backyard scopes and cameras.

For many years, my go-to book on astrophotography was *Outer Space Photography for the Amateur* by Henry E. Paul, published in 1960. The book still provides a gold mine of information, covering everything from lenses and telescopes to home observatories and sky conditions. Paul recommends using a standard 6-inch f/8 reflector or a 3-inch f/15 refractor, with a preference for the reflector. Obviously, a telescope needs a motor drive to compensate for Earth's rotation. But the revolution in CCD imaging and the use of digital cameras has made the techniques described in this book obsolete. Even films recommended by Paul, such as Kodak's High Contrast Copy Film and Plus-X, have long become extinct.

In the section on planetary photography, Paul says, "The planets are difficult subjects for the amateur photographer because of their small angular size." A number of illustrations in this book show Jupiter, Saturn, Uranus, and Neptune. Paul provides a group of drawings of Saturn next to a few photographs. Every one of the drawings is better and shows more detail than the photos. There is a universal graininess to the photos that was impossible to avoid for ground-based imagers. The Voyager 2 images were astounding compared with any images we could capture from telescopes on Earth.

"This is the time when humans have begun to sail the sea of space," wrote Carl Sagan.

In the 1980s, Voyager 2 undertook flybys of Uranus and Neptune, the ice giant planets. My ever-present notebook has an entry for June 9, 1981, featuring an evening search for Uranus. I was using a 4¼-inch rich field telescope, a sheet from *Atlas of the Heavens*, and a finder chart from the Abrams Planetarium *Sky Calendar*. It was easy to spot Uranus' blue-green disk among a number of stars that formed a loose triangle with 41 and Kappa Librae. Needless to say, Uranus appeared as only another bright "star" among this fairly bright group. Even with my 3-inch Unitron and Celestron 8, I could never see any details on this planet. Both Paul's book and the Jupiter book by Asimov have photographs of Uranus and Neptune made with large ground-based telescopes. Because of atmospheric turbulence, no details can be seen in these photos — just a bright, blurry disk with a few of its moons present.

Sharing the excitement of Voyager

By the end of Voyager's Grand Tour, in August 1989, I was director of the Flandrau Planetarium at the University of Arizona, and an excited participant on a television panel of experts talking about Voyager 2's recent close encounter with Neptune. On August 24, Voyager made its closest approach to this distant, shimmering, blue ice giant.

Sitting next to me was Carolyn Porco, a key member of Voyager's imaging team. I felt out of place among the professional astronomers from the university and their years of experience and knowledge they represented. I was, however, the only one at this KUAT public television event who observed the sky with small telescopes and regularly brought these exciting events to the public through planetarium shows.

One of the most exciting discoveries discussed was the existence of massive storms in the upper atmosphere of Neptune. Since the planet is nearly 3 billion miles from the Sun, it was assumed that it'd be far too cold to have any kind of weather. Passing just 3,000 miles (4,800 kilometers) above the planet's cloud tops, Voyager 2 discovered what was dubbed the Great Dark Spot. Voyager also added six new moons, recorded the fastest winds on any planet in the solar system, and uncovered a set of planetary rings.

When the moderator, John McClury, turned to me and asked, "Can the average amateur astronomer expect to see any of these new discoveries in their telescopes?" I had to answer, "None of it." These discoveries are truly beyond not only any amateur equipment, but also the greatest telescopes on Earth. "You may not be able to see these discoveries for yourself, but knowing about them makes your own observations so much more interesting," I said.

Thinking about what the Voyager mission meant to astronomy enthusiasts, I found another old notebook entry. This one was from August 19, 1976. I was observing with the 24-inch Ritchey-Chrétien telescope at Michigan State University with Dave Duzinski, a fellow grad student. We had been taking photographs of Jupiter. After we were done and Dave had gone into the darkroom, I had the scope to myself and began observing the planet visually.

It was about 3:30 A.M., and the sky was steady and clear. The view of Jupiter was one of the best views of the planet I had ever seen. My drawing shows five distinct bands with a few bulges and delicate features. Io's shadow was slowly progressing across the giant's face, and the star field in which it was embedded was beautiful. It turned out that all the photographs Dave and I took were overexposed, and my drawings became the only record of that night.

A unique and epic voyage

All these memories and musings have brought me back to Carl Sagan's book *Cosmos*, published in 1980. The chapter "Travelers' Tales" compares the adventures of the newly launched Voyagers to the early discoveries of the 18th century.

"This is the time when humans have begun to sail the sea of space," Sagan writes. "The modern ships that ply the Keplerian trajectories to the planets are unmanned. They are beautifully constructed semi-intelligent robots exploring unknown worlds. ... We have embarked on epic voyages."

Not only was our understanding of these outer worlds about to change forever, but so was the view in our modest telescopes.

Raymond Shubinski *is a contributing editor of* Astronomy *who has been observing the sky for many decades.*

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Hello, Moon

Our nearest neighbor in space doesn't just shine at night.

Most people associate the Sun with day and the Moon with night — and many mythologies tell us why this is so. But myths are myths, and perhaps they are the reason why some non-astronomers think that something is wrong if they see the Moon during the day.

In fact, the Moon is quite noticeable at various times on most days throughout its monthly cycle (except for about two to three days before or after New Moon).

Scanners

Once the Sun rises, humans seem to be naturally programmed to look (literally) down and out, but not necessarily up. This is mainly a protective mechanism due to the immense brilliance of the solar disk. But up is where you'd have to direct your gaze most of the time to see the daytime Moon.

I tried being a daytime skywatcher for a couple of weeks, noting where my vision takes me naturally throughout the day. What I discovered was, in a sense, biblical: "Let your eyes look straight ahead; fix your gaze directly before you" (Proverbs 4:25). My gaze remained relatively focused forward with occasional sweeps from side to side.

I don't own a smartphone. So, I tend to keep my head level as I walk, so that my field of vision is partly on the ground and partly on the sky.

Research has shown that if we have such a horizontal line of sight, we see (on average) more Earth than sky: roughly 35° below the horizontal (Earth), and about 25° above the horizontal (the sky). My own observations support these figures. We can extend our sky coverage to approximately 50° by simply rolling our eyes up while keeping a level head, but that probably requires a reason to do so, such as when a bird flitters by.

With only a little thought it becomes apparent just how difficult it is to notice the daytime Moon.

When the Moon is 1 percent illuminated, as in this image taken May 26, 2017, only dedicated amateur astronomers will search for it. At this time, our lone natural satellite was a scant 19.2 hours old and appeared only 15° east of the Sun. CHRIS SCHUR

The Moon appears above Grand Canyon National Park in this image taken November 9, 2013. The photographer was backpacking at the time and set up his camera near the Hermit Rapids area of the Colorado River. WOLFGANG GOLSER

Hide-and-seek Moon

The previous figures suggest that as we go about our day, we do not see the Moon unless it happens to be within 25° of the horizon and we happen to be looking in that direction. This usually occurs in the middle to late afternoon after First Quarter and before Full Moon, or in the early to late morning after Full Moon and before Last Quarter.

Around these times, the Moon is also at or near its brightest (between magnitudes –10 and –13), so you're more likely to notice it. Add possible horizon obstructions such as trees and buildings, and the fact that many of us are working or equally occupied for large chunks of the day.

With only a little thought it becomes apparent just how difficult it is to notice the daytime Moon — unless you're specifically looking for it. No wonder it's a surprise when non-astronomers do see it. I once received a call from someone who feared that the Moon was going to collide with Earth because it was near the horizon in the daytime.

See the light

During the night, there is not much of interest on the ground, which under natural conditions is swathed in darkness. So we look up where all manner of celestial lights caress our eyes.

We notice the Moon, mainly because it is the brightest object in the night sky. During the day, however, the Moon hands over its crown to the Sun and then gracefully slips into the background.

If you happen to notice the Moon in a blue sky while you're with other people, ask them if they've noticed it today. Then listen to their replies, and perhaps learn something new about human perception. As always, send your thoughts to sjomeara31@gmail.com.

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

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

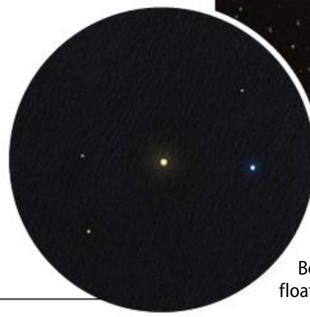
BINOCULARUNIVERSE

BY PHIL HARRINGTON

Exploring Capricornus

Two double stars and a great globular cluster highlight this dim star group.

The dazzling globular star cluster M30 glows at 7th magnitude and is the finest deep-sky object in the constellation Capricornus. DANIEL VERSCHATSE



Beta Capricorni consists of an unequal pair of 3rd- and 6th-magnitude suns that float together in this sketch made with a 6-inch f/8 reflector at 240x. JEREMY PEREZ

Capricornus the Sea Goat is one of the faintest constellations along the ecliptic. With none of its stars shining brighter than 3rd magnitude, many suburban stargazers often bypass it in favor of brighter regions. Yet for those who persevere, Capricornus holds a few hidden gems visible through our binoculars.

So, what exactly is a Sea Goat, and who concocted that image? Despite its faintness, Capricornus is one of the oldest constellations in the sky, tracing its origin back to ancient Sumeria. As one culture was assimilated into another, Capricornus became associated with Pan, the Greek god of nature who was half goat and half human. In one tale, Pan helped Zeus battle the Titans. During an especially harrowing part of the clash, Pan barely escaped Typhon, the deadliest creature in Greek mythology, by giving himself a fish's tail and jumping into the Nile River.

Alpha Capricorni's twin 4th-magnitude stars are visible in this sketch made with a 6-inch f/8 reflector at 240x. JEREMY PEREZ

In October's evening sky, we find Capricornus fin-deep in the area of sky known as the "wet quarter." There, we see several constellations that are associated with water in one way or another. Besides Capricornus, there's Aquarius the Water-bearer; Piscis Austrinus the Southern Fish; Cetus the Whale; and Pisces the Fish. You may need to travel to a site that is free of light pollution and horizon-hugging haze to make them out, since faint stars comprise nearly all of them.

Binoculars, however, come to our rescue when viewing under less-than-ideal circumstances. Begin by drawing an imaginary line from Vega southeastward to Altair, and then keep going about an equal distance farther. The area may look barren by eye, but aim your binoculars there and you should spot two conspicuous stars separated by about 2°. Both lie at the northwestern corner of Capricornus' triangular form.

Let's first examine the northernmost of those stars, **Algedi**, or Alpha (α) Capricorni. Algedi is made up of two 4th-magnitude suns that are easy to resolve with the smallest pocket binocular, and even with the unaided eye given dark skies. They look like heavenly headlights spaced 6' apart. But looks can be deceiving. It turns out the pair is strictly a chance, line-of-sight coincidence. Algedi is a so-called "optical double," two stars that are actually nowhere near each other in space. The yellow giant southeastern star, known as Alpha^2, is 109 light-years from us, while Alpha^1, a yellow supergiant, is nearly seven times farther away.

The second star, **Dabih** or Beta (β) Capricorni, is just 2° south of Algedi. It easily fits into the same field of view. While Algedi's two stars appear identically bright, Dabih's twosome looks noticeably different. The brighter sun, called Dabih-Major, shines at 3rd magnitude, while its companion, Dabih-Minor, is 16 times fainter at 6th magnitude. Both form a physical system 330 light-years away, with each separated from the other by about a third of a light-year. It takes approximately 700,000 years for the pair to orbit one another.

There is much more to Dabih than meets the eye. Studies show that both stars are themselves accompanied by fainter companions unseen through binoculars. Dabih is at least a quintuple system.

Our final stop within Capricornus is the Sea Goat's sole contribution to the Messier catalog. The 7th-magnitude globular cluster **M30** lies in the constellation's barren southeastern corner. To find it, slowly scan eastward from Algedi along the top side of the Capricornus triangle to Deneb Algedi (Delta [δ] Capricorni) at the triangle's eastern corner. Now, shift 8°, or a little more than a typical binocular field, to the southwest. There you should see 4th-magnitude Zeta (ζ) Capricorni. Center Zeta in your binoculars, and then look toward the eastern edge of the field. A 5th-magnitude star, 41 Capricorni, should just be coming into view. Hold on 41, and then glance just to its west. Can you see a dim, round patch of grayish light surrounding a brighter core? That's M30.

Messier discovered M30 the night of August 3, 1764. Like most globulars in his catalog, it was described as a round nebula free of any stars. How wrong he was. We now know that faint patch is actually a swarm of 100,000 or so individual suns lying an estimated 27,100 light-years away. But unlike most globulars associated with our galaxy, M30 appears to be orbiting through the Milky Way's inner galactic halo backward, or in retrograde. This suggests that, unlike most other globulars, it may have been stolen from a satellite galaxy rather than having been formed from the protogalactic cloud that begat the Milky Way.

Do you have a favorite binocular object? I'd love to hear about it and feature your observations in future columns. Drop me a line through my website, philharrington.net.

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

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

NEW PRODUCTS

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

4mm eyepiece

Orion Telescopes & Binoculars
Watsonville, California

Orion's 4mm LHD 80-Degree Lanthanum Ultra-Wide Eyepiece contains eight fully multicoated elements. The 1¼" eyepiece offers 20 millimeters of eye relief and an 80° apparent field of view. The unit has an aluminum body, and the barrel is threaded to accept 1¼" filters. It weighs 20 ounces (567 grams).

$269.99
800.447.1001
www.telescope.com

8x42 binoculars

Orion Telescopes & Binoculars
Watsonville, California

Orion's ShoreView Pro II 8x42 ED Waterproof Binoculars feature optics made from extra-low dispersion glass. The unit offers a 7.1° field of view and 17 millimeters of eye relief. The company includes tethered objective lens caps, a single-piece eyepiece cap, a neck strap, and a soft carry case.

$179.99
800.447.1001
www.telescope.com

Scope controller

Astrometric Instruments
Westborough, Massachusetts

Astrometric Instruments' PrimeTCS-i telescope controller is for equatorial or alt-az telescopes. It often works with pre-existing motors; alternatively, a variety of motor options are available from the company. The base system includes two drive units, Maestro software for Windows, a versatile hand paddle, and a power supply.

$3,495
508.836.3970
www.astrometric.com

Panning head

Orion Telescopes & Binoculars
Watsonville, California

Orion's Tritech II Compact 3-Way Fluid Pan Head works for observing or photographic applications. The unit features three axes of rotation: 360° in azimuth; 180° in altitude; and a 90° lateral tilt. It can support an 11-pound (5 kilograms) instrument load.

$34.99
800.447.1001
www.telescope.com

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

MARKETPLACE

READER GALLERY

1. COLORFUL SPIRALS
NGC 4151 (left) is a Seyfert galaxy 45 million light-years away. It hosts one of the brightest active galactic nuclei known at X-ray wavelengths. NGC 4145 is a million light-years closer and is considered “anemic” because not much star formation is occurring in it. • ***Mark Hanson***

2. CHROMATIC SPLENDOR
The region around the star Rho (ρ) Ophiuchi is one of the most colorful in the sky. The interstellar clouds of gas here contain both red emission and blue reflection nebulosity. And then there’s the dust, which peppers the region with dark nebulae. • ***Miguel Claro***


3

3. PTOLEMY'S CLUSTER

Open cluster M7 in the constellation Scorpius the Scorpion is the eighth-brightest such object in the sky. Shining at magnitude 3.3, it's an easy catch with naked eyes from a dark site. This object lies about 980 light-years away. It carries the common name "Ptolemy's Cluster," although when that philosopher observed it, he classified it a nebula. • ***Dan Crowson***

4. SUNBEAMS

Crepuscular rays form when sunlight streams through breaks in distant clouds, creating shafts of alternating sunlit and shadowed air. If you trace all the rays back to their origin, you'll arrive at the Sun. The word *crepuscular* comes from the Latin for "twilight," named that because we see them most often at sunset. • ***Jared Bowens***


4

5. SPIN DOCTOR
The Propeller Nebula (DWB 111) is a small part of a much larger emission nebula in the constellation Cygnus. It's also faint. To create this image, the photographer combined 16 hours of exposures. • ***Rodney Pommier***

6. COSMIC BALLOON
Planetary nebula NGC 7094 lies in the constellation Pegasus not far from the famous globular cluster M15. Observers using 11-inch or larger telescopes can see some details in it, along with its 13th-magnitude central star. • ***Warren Spreng***

7. YOU IN?
Irregular galaxy Sextans B lies 4.4 million light-years away. Because of its distance, astronomers are unsure if it belongs to our Local Group. And although it appears as only stars, it contains several planetary nebulae and a large globular cluster. • ***Dan Crowson***

8. GASEOUS ERUPTION
The photographer captured this pair of huge prominences dancing above the Sun's surface July 8, 2017. The large one arced some 43,400 miles (70,000 kilometers) above the solar limb. • ***Paco Bellido***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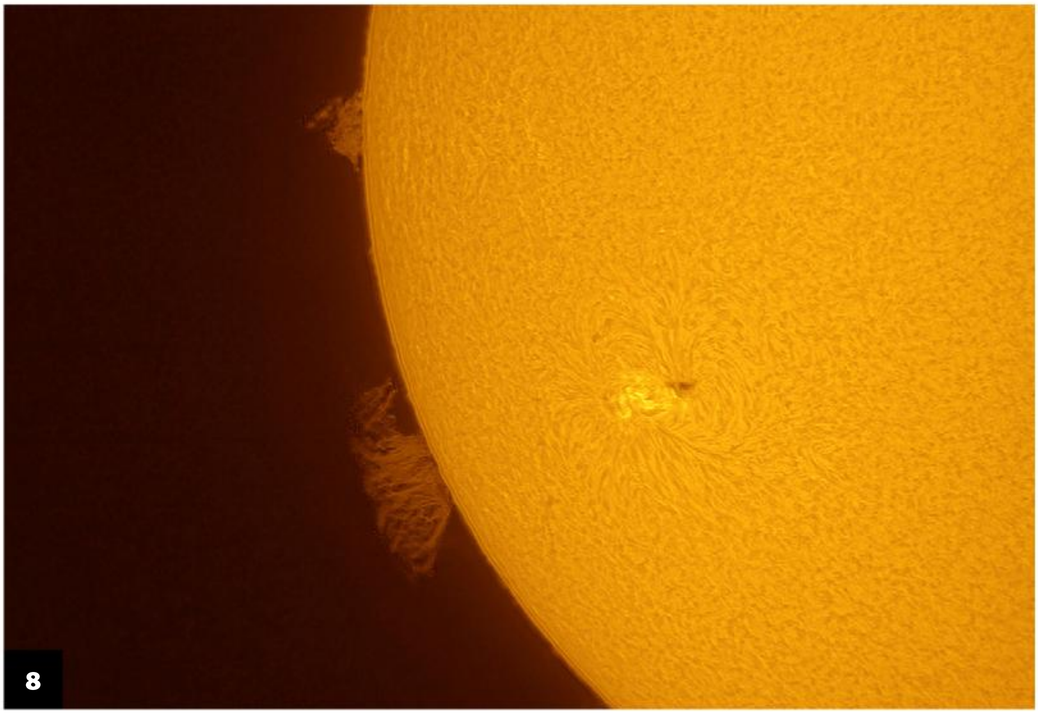
8

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.

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A PURCHASE WILL NOT INCREASE YOUR CHANCE OF WINNING.
VOID WHERE PROHIBITED.

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2. **Sweepstakes Period.** The Sweepstakes begins on June 15, 2017 at 10:00:00 a.m. Central Time, and all entries must be transmitted online no later than Sept. 30, 2017 at 11:59:59 p.m. Central Time.

3. **How to Enter.** To enter, complete the Sweepstakes Official Entry Form online at www.astronomy.com/sweeps with your name, address, city, state or province, and ZIP or postal code, and then click on the SUBMIT MY ENTRY button. You may submit only one entry through the Sweepstakes Online Entry Form during the Sweepstakes Period. However, when you submit your entry online, you will receive a link that you can share on Facebook, Twitter, Google Plus or by email; you will automatically receive three additional entries for each person who enters the Sweepstakes using that link. The online entry form must be filled out completely to be eligible. This Sweepstakes is in no way sponsored, endorsed, administered by, or associated with, Facebook, Twitter or Google Plus. Entries from any person submitting more than the stated number will be disqualified.

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5. **Drawing/Odds/Notification.** A random drawing for all prizes will be held on or around October 5, 2017. Odds of winning depend on the number of entries received. Limit one prize per person. The average total circulation for *Astronomy* magazine is 103,640. Winners will be notified by email on or before October 5, 2017.

6. **Prize Restrictions.** No cash equivalent or prize substitution permitted. All prizes subject to the guarantees/warranties of the manufacturer. Any applicable federal, state, and/or local taxes are the responsibility of the winner. For prizes of $600 or more in value, winner's Taxpayer I.D. will be required to issue a Form 1099-MISC showing prize ARV as income.

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8. **Winners List.** For a list of winners, see the *Astronomy* website (www.astronomy.com) after Nov. 1, 2017, or send a stamped, self-addressed envelope to: 2017 Astro Sweepstakes Winners List, P.O. Box 1612, Waukesha, WI 53187-1612. (Residents of FL, VT, and WA may send a self-addressed envelope without the stamp.) Requests for Winners List must be received by October 31, 2017.

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11. **Sponsor.** Sponsored by Kalmbach Publishing Co., P.O. Box 1612, Waukesha, WI 53187-1612.

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BREAK
THROUGH

A colorful crustacean

The Lobster Nebula (NGC 6357) harbors at least three clusters of hot young stars. In visible-light photos, these clusters often hide inside the dense clouds of gas and dust that gave birth to them. Yet X-rays from the massive suns penetrate the shrouds and reveal these luminaries. In this composite image, X-rays appear purple, infrared radiation glows orange, and visible light shows blue. The purple clouds highlight the youthful clusters and their embedded stars, whose stellar winds and radiation are carving cavities into their surroundings. The Lobster Nebula lies some 8,000 light-years from Earth in the constellation Scorpius. X-RAY: NASA/CXC/PSU/L. TOWNSLEY ET AL.; VISIBLE: UKIRT; INFRARED: NASA/JPL-CALTECH

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

December 2017: Mars and Jupiter rule

December begins with a pair of planets hanging low in the west-southwest during evening twilight. **Mercury** shines at magnitude –0.1 and will be far easier to spot than its sibling, magnitude 0.5 **Saturn**. The innermost planet lies 9° high 45 minutes after sunset on the 1st and appears 3° to the ringed planet's upper left. Mercury reached greatest eastern elongation in the final week of November, but it is now sinking rapidly toward the Sun on the way to its December 13 inferior conjunction. Target it through a telescope in the month's first few days and you'll be rewarded with nice views of an 8"-diameter, crescent-shaped disk.

Because Saturn glows more faintly and stands deeper in the twilight, it is much harder to view. Although binoculars should reveal the pair, you'll be hard-pressed to spot the ringed planet with your naked eye. And a telescope likely won't show much detail because turbulence in Earth's atmosphere distorts the image. Saturn passes on the far side of the Sun on December 21 and won't return to view until January.

You'll need to wait until the other end of the night to see another bright planet. **Mars** rises about two hours before the Sun in early December. Look for its ruddy glow in the eastern sky soon after. If you don't see it right away, first find 1st-magnitude Spica, the blue-white luminary of Virgo. Mars lies 3° below Spica. At magnitude 1.7, the planet glows half as bright as the star.

Mars moves eastward at a good clip relative to the background stars, crossing from Virgo into Libra in late December. It then rises 3.5 hours before the Sun and stands 25° high at the start of twilight. Still, its better position doesn't translate into good views through a telescope. Even on the 31st, the Red Planet shows a featureless disk just 5" in diameter.

Jupiter also resides in the morning sky. It rises 90 minutes before the Sun in early December, when it appears about 15° to Mars' lower right. Unlike Mars, however, Jupiter shines brightly. Gleaming at magnitude –1.7, it's the brightest point of light in the night sky. Jupiter lies in Libra and moves eastward as well, though more slowly than Mars. By the end of December, the two planets have closed to within 3° of each other.

Jupiter still lies fairly low in the sky, so it won't appear supersharp through a telescope. By month's end, however, you should be able to discern its two dark equatorial belts on a disk that spans 33".

Our final planet is none other than **Mercury**. After passing between the Sun and Earth at inferior conjunction, the innermost planet climbs rapidly into the predawn sky by the end of December. On the 31st, it stands 8° high in the east-southeast 45 minutes before sunup. Shining at magnitude –0.3, it should be easy to pick out of the twilight glow. If you don't see the planet right away, binoculars will bring it into view. A telescope reveals a disk that spans 7" and appears slightly more than half-lit.

Venus hides in the Sun's glare all month. It will pass on the far side of the Sun in January and return to view in the evening sky in early autumn.

The starry sky

We're all busy in December, whether preparing for the holiday season or attending all of those end-of-the-year parties. With summer's late sunsets upon us and the extra hour of summer time observed in many places, it's a great opportunity to pop outside with binoculars after an evening barbecue to admire the sights of December's night sky. Keep in mind that the lights of the city will make these objects harder to view.

Although many people don't consider the variable star W Orionis spectacular, it's one of my favorite objects. I find this deeply red star quite striking. To locate it, start at 2nd-magnitude Mintaka (Delta [δ] Ori), the westernmost star in Orion's famous belt. Using binoculars, scan westward toward 4th-magnitude Pi^6 (π^6) Ori, the southernmost star in Orion's shield. You'll find W about 80 percent of the way to Pi^6. Visually, W varies between magnitudes 6 and 8 over a period that averages about 200 days.

To find the next group of objects, swing around to the west and zero in on 2nd-magnitude Diphda (Beta [β] Ceti), the brightest star in Cetus. Aim your binoculars 7° south and a bit east of Diphda. (Seven degrees is a typical field of view through 7x50 binoculars.) This carries us across the border into Sculptor, where we find the splendid Silver Coin Galaxy (NGC 253). This almost edge-on spiral is not a difficult binocular object under a dark sky, and you should see it as a short streak of light. Caroline Herschel, William Herschel's sister, discovered this object in 1783.

About 2° southeast of NGC 253 lies globular cluster NGC 288. This loosely concentrated object, discovered by William Herschel in 1785, glows at 8th magnitude.

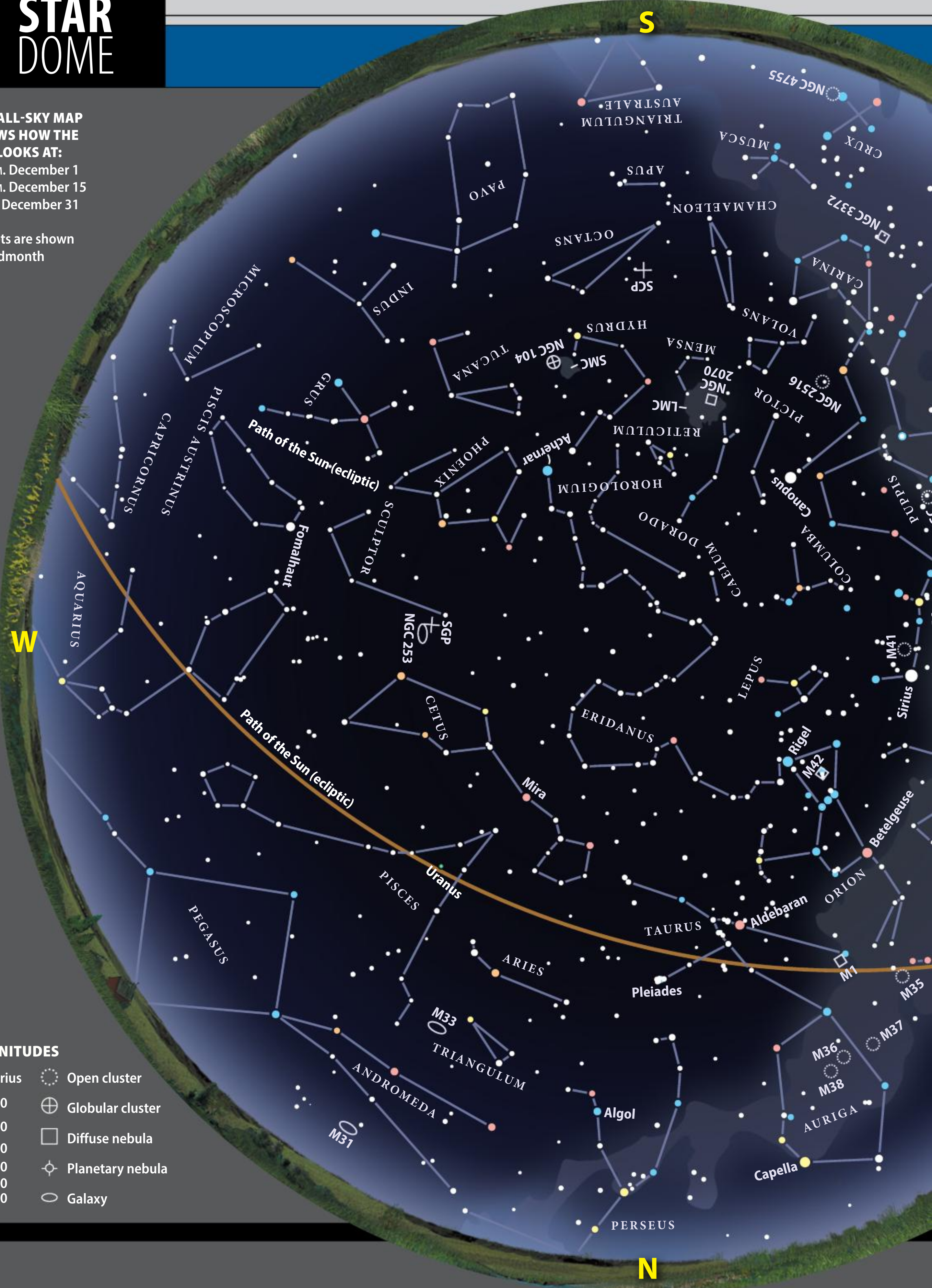
Now shift your gaze 17° farther south to the 2nd-magnitude star Ankaa (Alpha [α] Phoenicis). Scan 4° northwest and see if you can spot NGC 55. This is another edge-on spiral in Sculptor, but it's harder to spot than NGC 253.

The last three objects I mentioned are best suited to dark country skies, so let's wrap up our tour with an easy one. Go back to Orion, trace a line through its belt stars, and then extend this line to the southeast. You'll immediately see brilliant Sirius, Canis Major's luminary and the night sky's brightest star. Scan 4° due south of Sirius and you'll land on the splendid open star cluster M41. If it helps you figure out directions, remember that M41 lies about one-third of the way from Sirius to magnitude 1.5 Adhara (Epsilon [ε] Canis Majoris), the Big Dog's second-brightest star.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
11 P.M. December 1
10 P.M. December 15
9 P.M. December 31

Planets are shown at midmonth



MAGNITUDES

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

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

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

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

Illustrations by *Astronomy*: Roen Kelly

DECEMBER 2017

Calendar of events

1 Asteroid Dembowska is at opposition, 13h UT

3 Mercury is stationary, 8h UT

The Moon passes 0.8° north of Aldebaran, 13h UT

Full Moon occurs at 15h47m UT

4 The Moon is at perigee (357,492 kilometers from Earth), 8h46m UT

8 The Moon passes 0.7° north of Regulus, 23h UT

10 Last Quarter Moon occurs at 7h51m UT

13 Mercury is in inferior conjunction, 2h UT

The Moon passes 4° north of Mars, 16h UT

14 Geminid meteor shower peaks

The Moon passes 4° north of Jupiter, 14h UT

The Moon passes 0.2° south of asteroid Vesta, 19h UT

17 Asteroid Massalia is at opposition, 16h UT

18 New Moon occurs at 6h30m UT

19 The Moon is at apogee (406,603 kilometers from Earth), 1h26m UT

21 Summer solstice occurs at 16h28m UT

Dwarf planet Ceres is stationary, 21h UT

Saturn is in conjunction with the Sun, 21h UT

23 Mercury is stationary, 3h UT

24 Asteroid Pallas is stationary, 6h UT

The Moon passes 1.4° south of Neptune, 13h UT

26 First Quarter Moon occurs at 9h20m UT

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

31 The Moon passes 0.8° north of Aldebaran, 1h UT