Making sense of exoplanets p. 24

JUNE 2017

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Our trillion-galaxy universe

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Vol. 45 • Issue 6

You and Your Shadow... Tele Vue-60

Tele Vue-60 Specifications:

Objective:	APO Air-spaced Doublet
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Max. Visual Field:	4.3° (with 32mm Plössl/24 Panoptic)

Tele Vue-60 OTA shown with optional equipment.

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CFHT/COELUM - J.-C. CUILLANDRE & G. ANSELMI

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One of a trillion galaxies in the cosmos, the nearby face-on spiral IC 342 glistens with stars and gas.

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IN EVERY ISSUE

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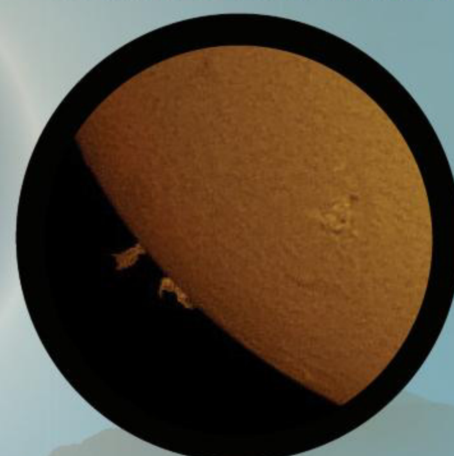

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FROM THE **EDITOR**

BY DAVID J. EICHER

See aurorae in beautiful Norway

The Starmus Festival, which occurs in Trondheim this June, isn't the only astronomical splash happening in Norway this year. From October 10–22, *Astronomy* magazine, along with our tour partner, TravelQuest International, will lead a spectacular trip to see the northern lights over this majestic and captivating country.

If you haven't seen an auroral display from Norway, you've missed out on one of nature's grandest shows. In the Northern Hemisphere, the auroral oval — the region where the northern lights light up brightly — lies straight overhead as seen from Norway.

In addition to aurora watching, *Astronomy*'s Norway: Aurora, Culture, and Scenic Wonders Tour will showcase many amazing places scattered throughout the country, including a rail journey from Oslo to Flåm and Voss through some of Norway's most picturesque landscapes. The trip also includes six nights of cruising through fjords on a majestically outfitted ship, eight nights of dark-sky aurora viewing, a nature safari, and an exploration of Europe's most northerly point, at 71° latitude.

The trip begins at Norway's capital, Oslo. From there, a rail journey carries you to UNESCO-protected fjords along the southern-central part of the country, descending into steep mountain valleys, past dramatic waterfalls, and into 20 tunnels until reaching the shores of the Aurlandsfjord in Flåm. From nearby Voss, the trip continues with cruising on the MS *Polarlys* (which translates to "Polar Light"), one of the famous Hurtigruten ships. In Bergen, you'll see the house of composer Edvard Grieg, the fish market, museums, and funiculars.

Continuing with its cruise, the journey includes shore expeditions to explore the countryside. There's the tiny village of Urke, ringed by snowcapped alps. Lakes, mountains, and valleys accentuate the feast you'll have at Kaiser Wilhelm's favorite vacation spot. Heading on, you'll visit Trondheim, noted for its spectacular Nidaros Cathedral, the largest Gothic structure in Scandinavia. Historic wooden structures, monasteries, bridges, and markets make this city unforgettable.

The ship continues to Bodø, where you'll experience the strongest tidal current on the planet. Crossing the Arctic Circle, the journey moves on toward Tromsø, at the edge of the Arctic Sea. You'll then continue to North Cape, the northernmost point in continental Europe, to see the monument and museum. The trip carries on to Kirkenes, a point near the Norway-Russia border, Karasjok, and Alta, with their ancient, northern cultures.

From there, the journey heads back to Oslo and onward to home. I've been on such a coastal cruise and exploration of Norway, and it is one of the most unforgettable trips I've ever taken. If you decide to go this year, you will have a magnificent time, and probably see the best auroral shows of your life.

For more information on this incredible tour, and for booking details, please see www.astronomy.com/magazine/trips-tours/2017-norway

Yours truly,

David J. Eicher
Editor

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QUANTUM GRAVITY

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

HOT BYTES>>

TRENDING TO THE TOP

EUROPA LANDER
A team of researchers wrote a hypothetical report for a Europa lander to test for life within the ocean on Jupiter's watery moon.

2020 LANDING
Landing sites for NASA's Mars 2020 rover are narrowed down to Northeast Syrtis Major, Jezero Crater, and Gusev Crater.

BLASTOFF
The Trump administration is reportedly mulling putting astronauts on the first flight of the Orion capsule and Space Launch System.

SNAPSHOT

The amazing William Herschel

How a German-British musician became one of astronomy's stars.

A portrait of William Herschel made by British artist Lemuel Francis Abbott in 1785, four years after Herschel discovered the planet Uranus.

HERSCHEL: NATIONAL PORTRAIT GALLERY/WIKIMEDIA COMMONS. TOP FROM LEFT: NASA/JPL-CALTECH (2); NASA

William Herschel was an extraordinary thinker. Born in Hanover, Germany, in 1738 and trained in music, Herschel was a renaissance man, skilled with the oboe, violin, harpsichord, and organ. He was also drawn to the sciences.

After immigrating to Great Britain at age 19, he eventually settled in Bath, England, and explored the heavens with homebuilt reflecting telescopes, aided by his sister Caroline Herschel. In May 1773, he established a regular program of observing in his back garden on New King Street, along with Caroline.

Herschel was a meticulous observer and a careful scientist. Primarily using his 6.2-inch f/13 reflector, he energetically observed hundreds of double stars, and also branched out into observing some of the "fuzzy patches" represented by nebulae.

And then, in his garden on the evening of March 13, 1781, came a momentous event. "In the quartile near Z Tauri the lowest of two is a curious either nebulous star or perhaps a comet," he wrote. "A small star follows the comet at 2/3 of the field's distance."

Herschel had not found a nebula or a comet, but the blue-green glow of Uranus. After being observed for a prolonged period, and aided by the observations and calculations of others, the strange object was confirmed as a major planet. Herschel called the new object the Georgian Star after King George III, but ultimately the name shifted to Uranus, for the Greek god of the sky Ouranos.

The instant celebrity Herschel gained did not go to his head. He remained a productive, obsessed observer for years after the big discovery, finding and cataloging not only hundreds of double stars but thousands of nebulae, many of which would — a century and a half later — turn out to be galaxies.

Herschel reminds us that in an increasingly sophisticated world, many of the greatest stories in the history of science resulted from simple endurance, and a love of nature.
— David J. Eicher

ASTRO**LETTERS**

A misleading title

I teach Earth science and I've used *Astronomy* magazine as a teaching tool for more than 35 years. Thank you for helping me teach and inspire generations of students!

I was excited to read "Explore the impact that killed the dinosaurs" in the December issue (p. 26). As a middle school teacher, it's hard to beat an idea that so elegantly links many scientific disciplines together with such clear and compelling evidence, especially when it involves dinosaurs and a giant explosion that ended their world. The Alvarez hypothesis illustrates the awe and wonder of the scientific method to the minds of 12-year-old students like nothing else.

I was a bit disappointed to find the article was more about a journalist's travel itinerary for a photo-op assignment than it was about astronomy, geology, or physics as I had anticipated. I was hoping to read about how the new drill cores shed light on ideas about crater formation and the effects of large impacts on global ecosystems. My problem is not so much with the article as it is with the misleading, and thus disappointing, headline.
— Steve Dacey, Venice, Florida

Arcs and halos

Just wanted to let you know how much I enjoyed Stephen O'Meara's article "The Sun's crystal horns" in the February issue (p. 18). I've always loved arcs, and I particularly enjoyed learning the relationship between the appearance of the upper tangential arc and the altitude of the Sun. Though I have a couple of books on sky phenomena and arcs, I've never seen this before! It all makes perfect sense, and I can't wait to get out and look for that effect.

O'Meara's choice of subject matter was great for me in that I'd just seen and photographed (just with my iPhone) a circumzenithal arc (CZA) and parts of the 46° and 22° halos near Chattanooga, Tennessee, on December 12. My wife and I

BOB ENGLISH

were there to lead a night hike at a place called Audubon Acres, and we were scouting the trail we planned to use before the hike. About 3:30 P.M., we looked up to see a bright CZA. Beautiful, and I could see pieces of the 46° and 22° halos. I put the Sun behind a tree and made a few shots.

We've gotten into the habit of always looking overhead in the afternoon if we see high cirrus clouds, and checking for halos and arcs. We ended up having a great night hike, and the sky show continued with a bright corona around the Full Moon.

I really felt like I could see more of the arcs with my naked eye than what the camera showed. Maybe this is because the change in the visibility of different parts of the arc makes a visual impression that the camera cannot capture. **— Bob English,** Franklin, Tennessee

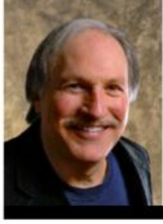
The modest comet hunter

I just finished reading your article "The obsessive comet hunter" in the February issue (p. 54). The idea of being able to discover a comet has always been a dream of mine, loving astronomy as I do. As an amateur, it would be the only thing my name could permanently go on.

Although still possible, I believe this act of discovery has been taken away from us. With today's equipment, the professionals are discovering comets before our modest equipment can see them.

We do not need to know a comet will become visible in a year or two. Let the amateur have a chance to make a discovery first. If not found before becoming a naked-eye object, then let some observatory or satellite place a name on it. Until then, let us try to find them and bring back that excitement of discovery for us.
— Steve Rusnak, Stuart, Florida

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.*

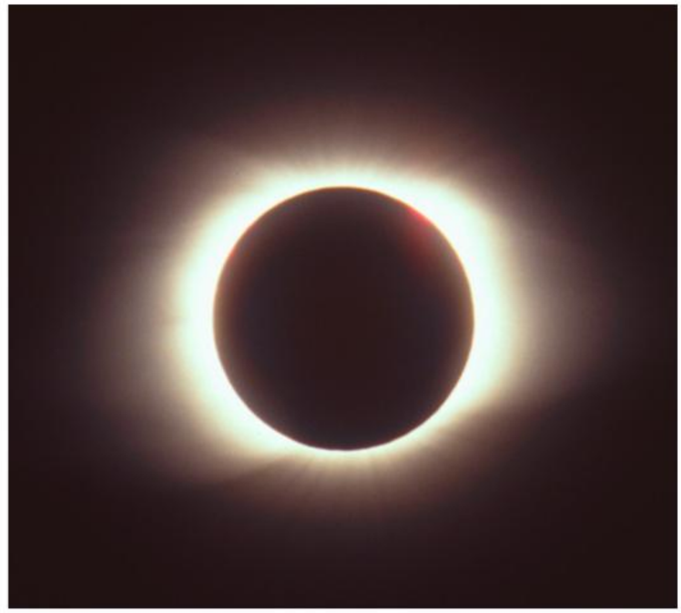


STRANGE**UNIVERSE**

BY BOB BERMAN

Perfect totality

A total solar eclipse like the one coming up is a rarity. Here's how to make the most of the experience.



This total eclipse in 1997 in Russia shows the kind of spectacle that can herald the moment of totality. Fourteen U.S. states will experience totality on August 21, the first total eclipse in the continental United States since the 1970s. NAGOYA TARO

In January, I talked about the August 21 total solar eclipse even though it was a half year in the future. I'm glad I did.

Several readers wrote to say the article had persuaded them to spend the money and travel to see it. I felt honored. So now, though the eclipse is still in the future, let's talk about a bottom-line basic: What should you look for?

I just re-read James Fenimore Cooper's beautiful short story, "The Eclipse." It's worth getting hold of, though it's just 15 pages long. (One option: It's part of a collection of space-based short stories called *The Saturn Above It*.) Cooper, a popular 19th-century author, is famous for *The Last of the Mohicans*. In this wonderful account written in his 40s, he recalls the total solar eclipse he saw as a youth in his hometown of Oswego, New York, in June 1806.

It's fun to see how people lived back then, and to share the author's impressions. Having now led nearly a dozen eclipse expeditions since 1970, and watched the reactions of tour members, I love what totality does to people. What surprised me in Cooper's story was how different the focus was two centuries ago. Back then, everyone was obsessed with how the light faded and then returned, how the stars came out, and how the Moon looked black.

Understandable. We normally perceive the Moon as a white illuminated shape, but during totality, we solely observe its black night hemisphere. It's the only time we can see the New Moon. People of the past loved this aspect of the event.

Watching that black Moon noticeably shift position was another major eclipse wonder back then. The Moon's orbital speed of 1 kilometer per second is dramatic and majestic during eclipses.

The account also revealed what those 19th-century observers ignored. Chief among them was the Sun's corona. So let me say that the outer section of the Sun's atmosphere is one of the greatest wonders of totality. It forms a complex, delicate, stringy structure that streams into space quite far from the Sun. The intricate formation follows the Sun's magnetic field lines. It is a most wondrous thing.

AT TOTALITY, ESPECIALLY THROUGH BINOCULARS OR A SMALL TELESCOPE, LOOK FOR DEEP-PINK PROMINENCES OF NUCLEAR FLAME.

Yet back then, with its nature unknown, it was shrugged off as just some sort of glow.

Same with the diamond ring. Until the New York City totality of January 24, 1925, there was no name for the intense pinpoint of direct sunlight often seen just before or after totality. Because it had no name, no one looked for it. Cooper doesn't give the phenomenon a single word. And yet these days, observers deservedly make a big deal about it.

What else should the newbie look for during totality? Well, first, in the five to 10 minutes before totality, put down your filter and notice how the Sun illuminates the countryside around you. Cars, trees, buildings — the familiar now seems alien. When the Sun has been reduced to a mere crescent, its light comes exclusively from its limb, plus the solar disk is no longer its customary half-degree size. Both these factors dramatically change the quality of sunlight. It's as if we're illuminated by a different kind of star. Colors seem more saturated, contrast is boosted, shadows have strangely sharp edges. Dappled regions like tree and bush shadows contain innumerable bizarre crescents. It's an otherworldly experience.

Then in the one to two minutes before totality, if you are on a white surface or have spread a sheet, you may suddenly see shadow bands. These are shimmering dark lines rippling along the ground. They cannot be photographed. Videos and stills appear with them absent!

The arrival of totality may be heralded by that diamond ring. At totality, especially through binoculars or a small telescope, look for deep-pink prominences of nuclear flame. And that corona, with its stunning beauty. Yes, you can look for stars, but totality does not produce very deep darkness. Your surroundings resemble that of a Full Moon night.

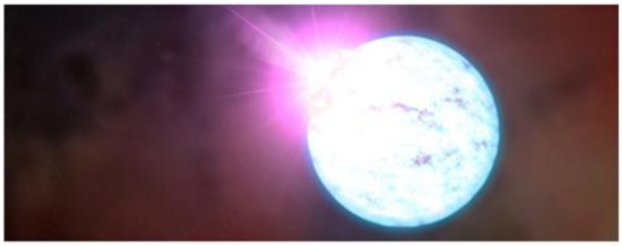
Beyond the science and the aspects lending themselves to verbal description is a feeling, a flavor, a vibe. Totality feels like nothing else in life. Just let it in. I still can't explain it rationally. Something happens when the Sun and the Moon and your spot on Earth form a perfectly straight line. As my ex-wife put it, "It felt like the home of my soul."

Cooper didn't put it that way. It was a different time then. He ended up saying, "I've traveled the world and sailed the seas, but never have I beheld any spectacle which so plainly manifested the majesty of the Creator, or so forcibly taught the lesson of humility, as a total eclipse of the Sun."

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

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

 SPOOKY SOUNDS. Sandia National Laboratories researchers demonstrated a possible explanation for the sounds preceding meteorite strikes. A meteor's light can heat surfaces miles away, which in turn heat the air and create sounds.



EDDINGTON UNLIMITED. ULX-1, in the spiral galaxy NGC 5907, is not a black hole, but rather a neutron star, like the one shown in this artist's impression. ULX-1 appears to be shining at 1,000 times the point at which the photons' pressure should outmatch the force of gravity, known as the Eddington limit. NASA'S GODDARD SPACE FLIGHT CENTER

THE BRIGHTEST, MOST DISTANT PULSAR

Ultraluminous X-ray sources (ULXs) are bright sources of X-rays that aren't associated with a galaxy's central supermassive black hole. Such sources historically have been explained as black holes of 80 to 100,000 solar masses accreting at high rates. Now, one famous ULX has been identified not as a black hole, but as a neutron star less than 1.5 times the mass of our Sun.

Gian Luca Israel of the Italian National Institute for Astrophysics and his colleagues used the X-ray Multi-Mirror Mission (XMM-Newton) and Nuclear Spectroscopic Telescope Array (NuSTAR) space telescopes to explore the inner workings of ULX-1 in the edge-on spiral galaxy NGC 5907, located 40 million light-years away. Their findings were published in the February issue of *Science*.

Israel and his team found periodic variations in ULX-1's X-rays, identifying it as a pulsar (a spinning neutron star). It is both the farthest and brightest X-ray pulsar ever detected. Its intense radiation can be explained only by an extremely strong multipolar magnetic field, such as the type found in magnetars — neutron stars with magnetic fields 1,000 trillion times greater than Earth's.

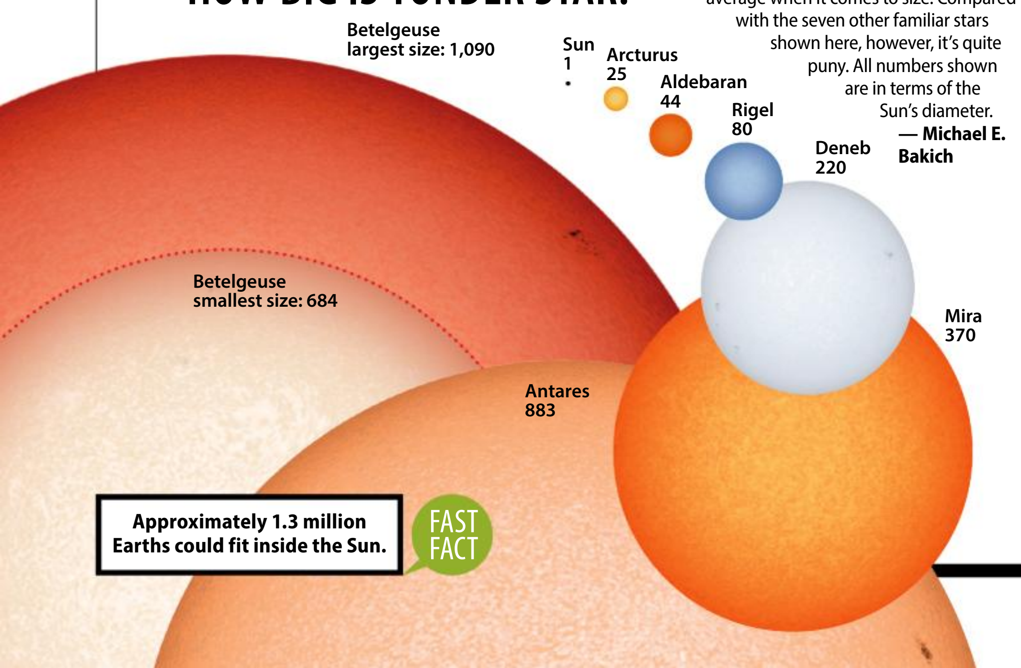
The pulsar Israel's team identified is accreting material at such high rates that it's spinning up, dramatically increasing its speed of rotation. The pulsar's period was 1.43 seconds in 2003, but 2014 observations clocked it at 1.13 seconds. By comparison, that's like a day on Earth decreasing by five hours in just 11 years.

The luminosity of astronomical objects is limited by physics. If an object shines too brightly, its photons will create pressure that outmatches the force of gravity. ULX-1 is shining at 1,000 times this limit for a neutron star, which should blow its accretion disk away, cutting off the very source of its X-rays.

But this limit, called the Eddington limit, assumes an object is radiating equally in all directions. Pulsars emit from only a very small area, sending radiation out into space in coherent beams, like a lighthouse. This beaming effect would lower the true intrinsic luminosity of the source, allowing it to shine brightly without exceeding the Eddington limit. The identification of ULX-1 as a pulsar means that other ULXs may be neutron stars as well, helping to explain these sources' strange properties. — **Alison Klesman**

HOW BIG IS YONDER STAR?

SIZE DOES MATTER. Our Sun is above average when it comes to size. Compared with the seven other familiar stars shown here, however, it's quite puny. All numbers shown are in terms of the Sun's diameter. **— Michael E. Bakich**



ASTRONOMY: ROEN KELLY

Approximately 1.3 million Earths could fit inside the Sun. FAST FACT

BRIEFCASE

TEMPORARILY VARIABLE

The planet HAT-P-2b orbits an F-type star slightly larger than the Sun. Eight times the mass of Jupiter, the planet orbits its sun in just over five days. As it moves, the planet induces seismic waves in the star's surface. HAT-P-2 is right at the boundary of the Delta Scuti instability strip, which causes stars to brighten and dim as Cepheid variables. The planet's presence momentarily pushes the star over this limit every 87 minutes. So far, it isn't understood if there's any abnormal effect from HAT-P-2 on its planet, aside from intense heat thanks to its proximity.

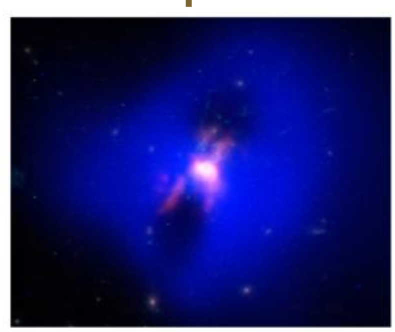
NAMING PLUTO

The International Astronomical Union has accepted the New Horizons team's proposal on naming conventions for surface features in the Pluto system. Themes for Pluto surface names include mythological underworld deities, creatures, and explorers; underworld locations; Kuiper Belt researchers; spacecraft that explored new frontiers; and famous explorers. Charon names include fictional space vessels, destinations, and space travelers, as well as artists and authors associated with space exploration. The naming conventions also include river gods for features on Styx, deities of the night for Nix, mythological or literary dogs for Kerberos, and legendary serpents and dragons for Hydra.

DARK ANDROMEDA

A signal from the center of the Andromeda Galaxy points to the existence of dark matter there. The gamma-ray emissions seem to come from several point sources in a tight clump at the galaxy's center, rather than distributed throughout, as in the Milky Way. Researchers believe the cause could be either an accumulation of pulsars or clumps of dark matter in the galaxy's center. By comparing these signals with our own galaxy's, astronomers may be able to piece together the mechanism responsible. **— John Wenz**

Black hole spews star fuel



FROM THE ASHES. Astronomers studying the Phoenix Cluster of galaxies with the Atacama Large Millimeter/submillimeter Array discovered filaments of cold molecular gas (pink) in the ionized gas (blue) surrounding the cluster's massive central galaxy. This area should be too hot for gas to condense, but the filaments appear along the edges of dark "bubbles" blown by jets associated with a supermassive black hole. There is enough gas in the 82,000-light-year-long filaments to build 10 billion stars, each with the mass of our Sun. **— A. K.**

ALMA (ESO/NAOJ/NRAO) H. RUSSELL, ET AL.; NASA/ESA HUBBLE; NASA/CXC/MIT/M. MCDONALD ET AL.; B. SAXTON (NRAO/AUI/NSF)

ASTRONEWS **ORGANICS ON CERES.** NASA's Dawn spacecraft has discovered organic molecules on the dwarf planet Ceres. Such material is a component of life on Earth, adding to evidence that Ceres might have been favorable for life in the past.

Seven planets packed in like Jupiter's moons

TRAPPIST-1 has a solar system like no other. The tiny red dwarf is barely big enough to be considered a star, and its radius is just a hair larger than Jupiter. The initial discovery of the system last May seemed groundbreaking: three planets, all habitable.

But now comes even more groundbreaking news: Evidence from NASA's Spitzer Space Telescope revealed the system actually has seven planets. Michaël Gillon, a professor at the University of Liége, and his colleagues published the results of their intensive study February 23 in *Nature*.

The initial discovery of TRAPPIST-1 and its planets was somewhat in error. While planets TRAPPIST-1b and TRAPPIST-1c were easily confirmed, TRAPPIST-1d was not — because it was actually three different planets.

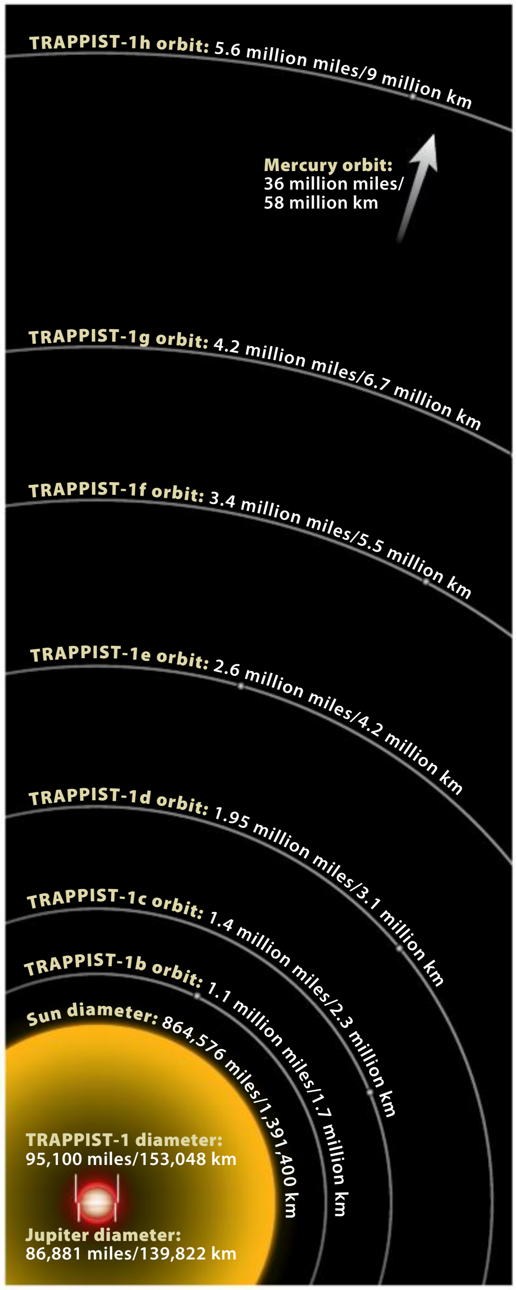
Two transits were witnessed during the first observing campaign, both believed to be the outermost of three worlds. But in actuality, "the first transit and the second transit were coming from different planets," says Gillon, lead author of the paper. "In fact, the second transit was two planets passing at the same time."

The Spitzer telescope helped refine the orbit of those planets, and drew out the presence of two more from the data. TRAPPIST-1b, -1c, -1f, and -1g are all slightly larger than Earth; -1e is slightly smaller than Earth; and -1d and -1h are closer to Mars in size. Of the seven, the researchers believe that -1e, -1f, and -1g are the likeliest to be habitable, based on where they sit in their solar system. TRAPPIST-1b has an orbital period of just 1.5 days and orbits at 1 percent the distance between the Sun and Earth. Because TRAPPIST-1 is so small, though, instead of dooming the planet, its snug orbit could just give it a slightly balmier-than-comfortable climate.

But this doesn't necessarily mean the planets are ripe for life. M-dwarf stars like TRAPPIST-1 tend to start out very active with high-energy flare events. This could strip away any atmosphere of young planets orbiting them.

TRAPPIST-1 and its seven planets are high on the list of targets for the James Webb Telescope to observe after it launches next year.

"We have seven targets that we can study in great depth, and they can give us a completely new insight into planet formation and stellar history," says Julien de Wit, a co-author on the paper. — **J. W.**



TINY SYSTEM. TRAPPIST-1 is an odd planetary system: Its orbital size looks more like Jupiter and its large moons, as opposed to the Sun and its planets. *ASTRONOMY*: ROEN KELLY

Astronomy team releases planet-search data

NASA AMES/JPL-CALTECH/T. PYLE

CALLING ALL AMATEURS. Using HIRES data, citizen scientists can help find exoplanets similar to Kepler-45b, the first Earth-sized world in the habitable zone of a star just like our Sun.

Would you like to help with exoplanet research? Here's your chance.

A team of astronomers, including researchers at the Carnegie Institution for Science and MIT, has publicly released two decades' worth of data, plus a software package and an online tutorial, in the hopes of having fresh eyes examine the observations of more than 1,600 nearby stars within 325 light-years of Earth. The data is from the High Resolution Echelle Spectrometer (HIRES), which is designed to help astronomers determine characteristics of starlight.

HIRES splits incoming light from a star into the light given off by individual elements (most commonly known as spectra), making it easier to accurately determine the composition of the star. This capability can also measure when a star's spectral lines move in a regular pattern over a period of time, indicating a potential exoplanet's orbit.

The HIRES team has highlighted more than 100 stars in the catalog that might host exoplanets. Amateurs can identify targets for follow-up studies by larger observatories, to confirm or deny planet candidates. — **Nicole Kiefert**

QUICK TAKES

FAMILY TREE
Using principles typically applied to living organisms, astronomers have created a "family tree" linking stars into families based on their chemical and kinematic properties.

•

UNIVERSAL RELATION
A research team led by astronomers at Case Western Reserve University found that the distribution of normal matter in galaxies tightly correlates with their gravitational acceleration, which affects galaxy rotation. This result challenges the current picture of dark matter in galaxies.

•

BEYOND THE VEIL
Astronomers used the Arecibo Observatory to look at Comet 45P/Honda-Mrkos-Pajdusakova through its coma of gas and dust. Radar data allows for more precise mapping of its orbit, as well as an improved picture of the comet's size, shape, and rotational properties.

•

APP FOR THAT
Astronomers at the Harvard-Smithsonian Center for Astrophysics recently suggested using a cellphone app to detect fast radio bursts. These powerful but short bursts of radio waves occur at frequencies used by cellphones and wireless networks.

•

BROKEN COMET
Slooh members watched Comet 73P/Schwassmann-Wachmann's nucleus break in two on February 12. Increasing gravitational forces as the comet approached the Sun likely caused the breakup.

•

LONELY NEIGHBORHOOD
A recent study revealed that only about 10 percent of massive stars in the Omega Nebula (M17) open cluster are close-in binaries. This contrasts with the general observation that 70 percent of massive stars occur in binary systems.

•

COMET POLLUTION
The Hubble Space Telescope caught a stellar remnant known as a white dwarf gobbling up a comet-like object 100,000 times larger than Comet 1P/Halley.
— **A. K.**

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

A Dunning-Kruger universe

Everyone, it seems, has a "theory" of how the whole shebang works.

As you gaze into a starry sky, it's easy to draw up your own ideas about how the universe works. But that doesn't make them battle-tested by the scientific method. TONY HALLAS

The other day I got an email from someone claiming to have solved all the outstanding problems in physics and cosmology. Having read a few popular science books, the author insisted that only his brilliant and original perspective could save science from itself. His new "theory" would revolutionize the world!

I've gotten a lot of messages like that over the years, and they always make me smile. Most scientists who are in the public eye have their own collections. I've even received full-fledged manuscripts and autographed, self-published books.

Of course, the problem with these "theories" is that they aren't scientific theories at all. In science, a theory is not just a wild guess. To a scientist, a theory is an idea that is consistent with known facts and makes testable predictions about the world.

Quantum mechanics is a theory that a lot of people never really liked. It made Einstein apoplectic, and some physicists are still trying to strip it of what they see as its philosophically troubling aspects. But quantum mechanics is still around for a simple reason: Even the theory's most bizarre and seemingly preposterous predictions have always turned out to be correct. The same can be said for theories like relativity, the Standard Model of particle physics, the Big Bang, and on down the line.

"Theories" like the one that appeared in my email come nowhere near meeting that standard. For centuries, thousands and thousands of very clever people have spent their lives teasing precious facts out of nature, and building theories that make sense of those facts. Job No. 1 for a new theory is to do no harm; it must account for what is already known. In an established scientific field like cosmology, those facts involve elementary particles, star formation, stellar evolution, galactic structure, general relativity, and so on down a very long list. You just don't get that watching documentaries on cable TV.

I don't want to be harsh. If you are reading this column, you doubtless enjoy the fascinating glimpses of the universe that you find in a magazine like *Astronomy*. You don't have to be an expert to appreciate that beauty. I feel much the same way about things like art and music. It's fun to contemplate the waves you see on the surface of the ocean, even if you don't fully grasp the depths that lie beneath.

I've had a lot of really fun conversations with people who wanted to tell me about their "theories." Most of the time, it is someone who has grappled with what they've read and seen, come up with some idea, and just wants to talk to a scientist about it.

But sometimes talking to someone with a "theory" is anything but fun. Those are the people who are true believers in their own speculations, and they often view scientists with contempt. "The audacity of those scientists! Who are they to pretend that their decades of post-secondary education and research mean anything!"

After all, those self-styled Leonardos are really smart. They are just amazingly smart. They are really just the best and smartest people around. They are so, so much smarter than scientists. And if there is something that they don't know about or that doesn't agree with them, well, it must be wrong and it can't really be all that important, anyway.

Welcome to the Dunning-Kruger effect, named after two Cornell psychologists who gave a large group of people tests and then asked them how they thought they did. Kruger and Dunning were startled by what they found. Almost everyone who took the tests was sure they did much better than average. That was even true for the very worst performers, who wildly overestimated their scores. At the same time, the very best performers typically underestimated how they did.

What Kruger and Dunning found was that if people don't have the skills needed to do well on a test, they don't know enough to assess their own performance. People who know very little can truly believe themselves experts because they can't tell the difference. Meanwhile, experts who fully understand just how difficult and subtle things can be think themselves less competent than they truly are.

British philosopher Bertrand Russell knew about the Dunning-Kruger effect long before it had a name. Quoting Russell: "The whole problem with the world is that fools and fanatics are always so certain of themselves, but wiser people so full of doubts."

I started keeping a file labeled "Dunning-Kruger," where I put things like the "theory" I received in the mail the other day. It joins articles on climate denial, intelligent design, and connections between vaccines and autism, to name a few.

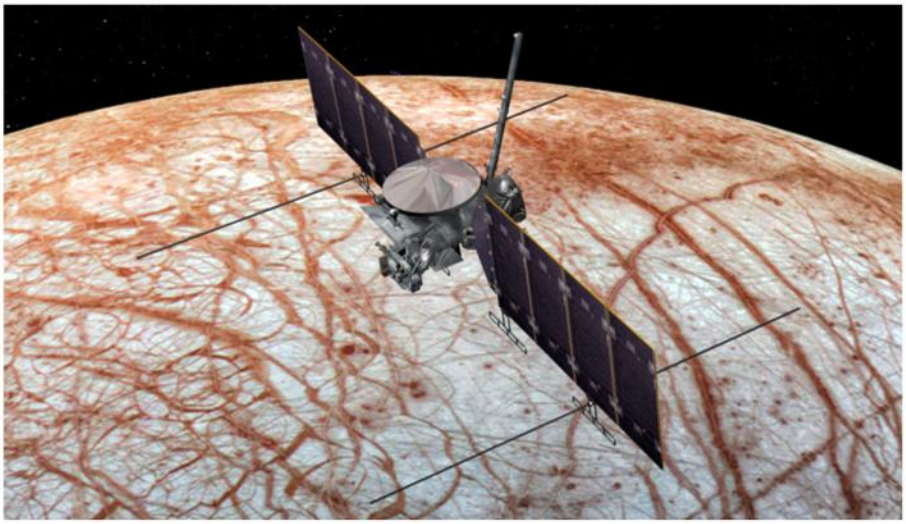
I wonder sometimes just where the Dunning-Kruger effect might lead us. I hate to say it, but that folder is getting thicker and thicker by the day.

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.**

 CLOSE TO HOME. A team of UCLA-led researchers identified a white dwarf star 200 light-years away in the constellation Boötes with an atmosphere rich in life's building blocks: carbon, nitrogen, oxygen, hydrogen, and water.

Europa flyby mission moves into design phase



GIVE ME THE GREEN LIGHT. NASA's Europa spacecraft is in development and expected to launch in the 2020s. The final design may look much different from this artist's rendering from 2016. NASA AMES/JPL-CALTECH/T. PYLE

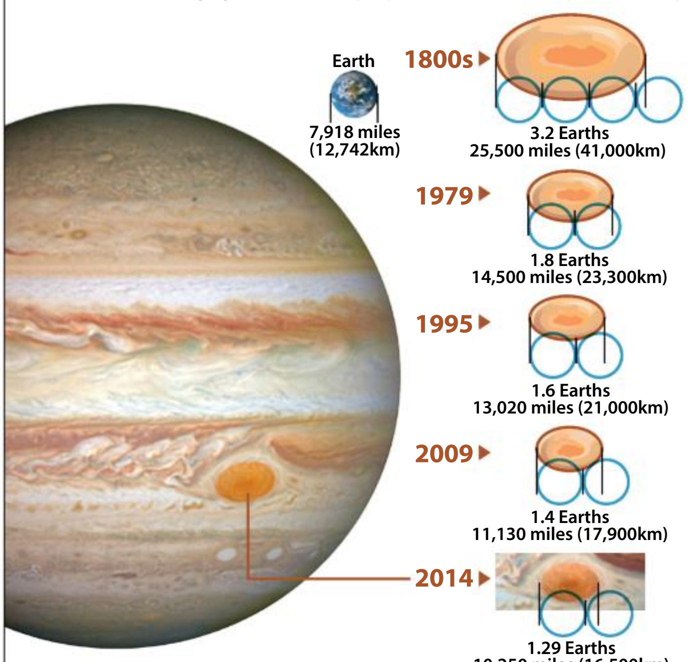
NASA's Europa space exploration mission was given the green light to move on to its design phase after its initial review was successfully completed February 15.

Every NASA mission must pass several stages of review, which demonstrate that the mission meets all the requirements in order to complete the building process and launch. Phase A includes a conceptual study and preliminary analyses of the missions; phase B is preliminary designs; and phases C and D are final designs, creating the spacecraft, testing it, and finally launching it.

Phase A of the Europa mission review involved picking which instruments the team wants to include on the spacecraft to study the potentially habitable jovian moon. The Europa mission team members had already started testing spacecraft components, a step that will continue into phase B.

The current plan is to launch the craft sometime in the 2020s. It will orbit Jupiter as often as every two weeks, completing between 40 and 45 flybys of Europa throughout the mission's duration. In addition to helping researchers study the structure of Europa and learn more about the composition of its ocean, the mission cameras will take thousands of high-resolution images of the icy moon. — **N. K.**

JUPITER'S SHRINKING RED SPOT

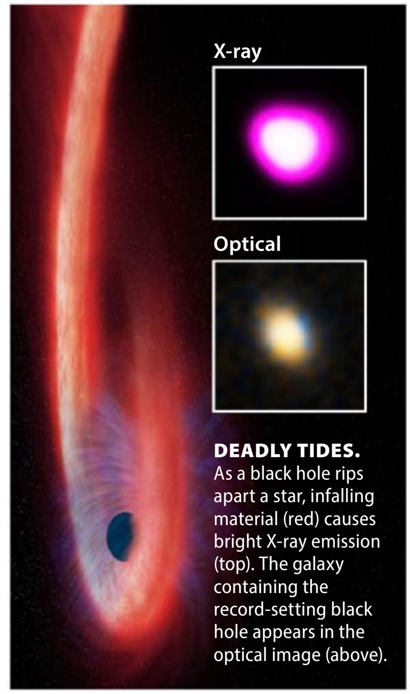


NASA/ESA; *ASTRONOMY*: ROEN KELLY

GOING, GOING ... GONE? The Great Red Spot, a giant storm of Earth-sized proportions, has raged on Jupiter for hundreds of years. But astronomers have seen it steadily shrinking and growing more circular since the 1930s, a trend that continues today. In 2015, it measured just 10,100 miles (16,300km) across. It's unclear whether the storm is coming to an end, or whether it will reverse course and grow again in the future. — **A. K.**

FAST FACT

Earth's largest storms have reached diameters of over 1,300 miles (2,092km); that's still just under 13 percent of the Great Red Spot's current size.



DEADLY TIDES. As a black hole rips apart a star, infalling material (red) causes bright X-ray emission (top). The galaxy containing the record-setting black hole appears in the optical image (above). X-RAY: NASA/CXC/UNH/D. LIN ET AL; OPTICAL: CFHT; ILLUSTRATION: NASA/CXC/M. WEISS

Black hole meal sets new record

A supermassive black hole has been tearing apart and eating a star for so long, it set a new record.

According to researchers, this tidal disruption event (TDE) — when the tidal forces from a black hole's intense gravity destroy an object that gets too close — has lasted 10 times longer than any other known star's death. This either means the black hole is destroying an incredibly large star, or it's meticulously ripping a smaller star apart.

The research team began observing the TDE in July 2005, using NASA's Chandra X-ray Observatory and Swift satellite and the European Space Agency's X-ray Multi-Mirror Mission (XMM-Newton) telescope. The black hole, known as XJ1500+0154, reached peak brightness in June 2008.

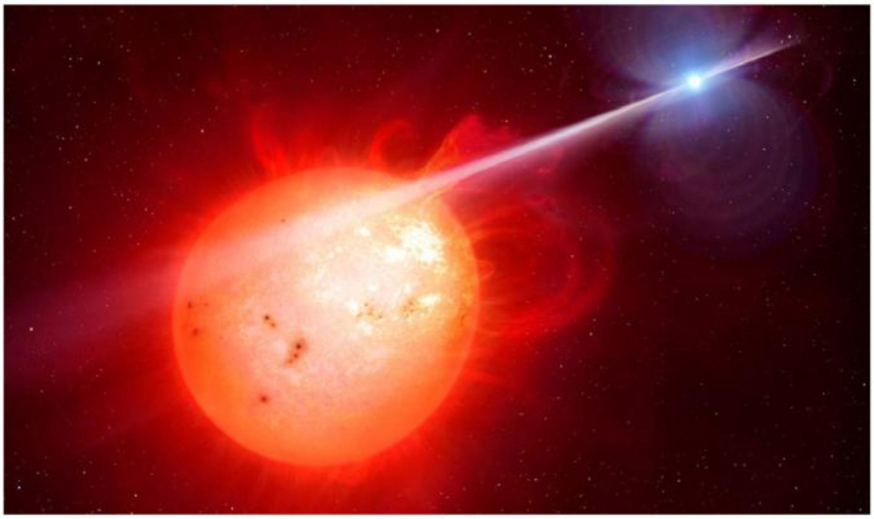
This drawn-out stellar death shows how supermassive black holes grow from cosmic feasts. Supermassive black holes are known to gain mass from swallowing stars, but the exact mechanisms of how are still being worked out.

Researchers say the star will diminish in the next several years and will cause XJ1500+0154 to fade as well. — **N. K.**

17 The number of minor planets (asteroids and other small rocky bodies) granted new names by the International Astronomical Union in February 2017.

MISSING MOUNTAINS. Ceres' lone mountain once may have had other cryovolcano companions that flowed on the early surface like glaciers until they flattened out, according to the Lunar and Planetary Laboratory at the University of Arizona.

White dwarfs can be pulsars, too



M. GARLICK/UNIVERSITY OF WARWICK/ESO

NOT DEAD YET. The AR Scorpii system contains a white dwarf (right) acting as a pulsar. The stellar remnant blasts its red dwarf companion (left) with a beam of high-energy radiation every time it spins.

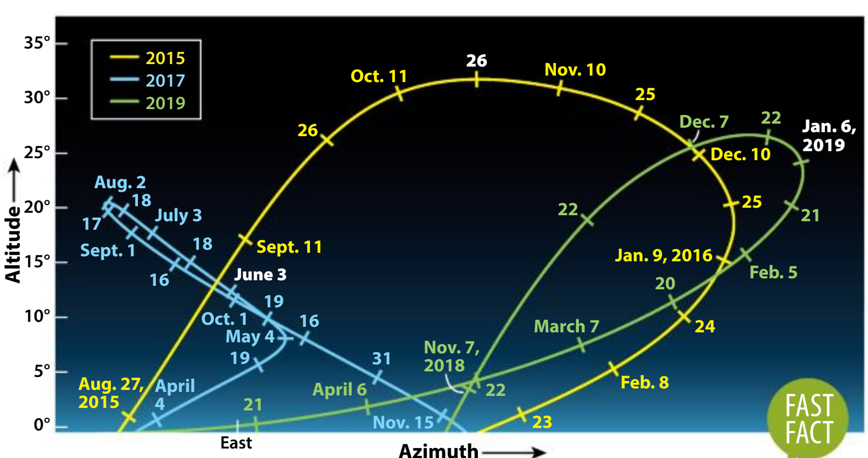
Pulsars are envisioned as spinning neutron stars emitting focused beams of radiation from their poles. Yet astronomers have recently uncovered a pulsar that's not a neutron star at all, but a white dwarf.

Professors Tom Marsh and Boris Gänsicke at the University of Warwick's Astrophysics Group, and David Buckley of the South African Astronomical Observatory published their results in *Nature Astronomy* on February 7. They found that the binary system AR Scorpii (AR Sco), which sits 380 light-years away in the constellation Scorpius, contains a white dwarf acting as a pulsar.

AR Sco's white dwarf and its red dwarf companion orbit each other every 3.6 hours at a distance of about 870,000 miles (1.4 million kilometers), or between three and four times the distance between Earth and the Moon. The white dwarf has an immense magnetic field, 10,000 times stronger than anything it's possible to generate on Earth, and it spins on its axis every two minutes. As the white dwarf rotates, it blasts its companion with a beam of radiation that generates an electric current within the red dwarf. The current produces changes in light that are in turn detectable from Earth.

This makes it "a dead ringer for similar behavior seen from the more traditional neutron star pulsars," Marsh said in a press release. — **A. K.**

VENUS AT DUSK

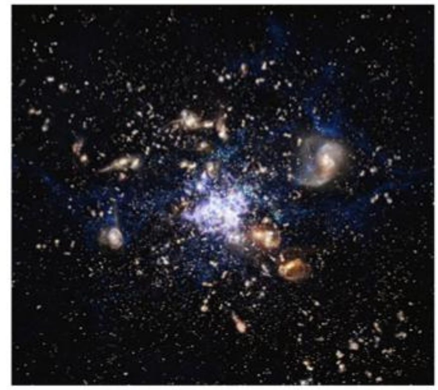


ASTRONOMY: ROEN KELLY

THE "EVENING STAR." How dazzling is Venus? Even on a bad day, it shines nine times brighter than the night sky's brightest star, Sirius. But Venus stands out even more when it blazes against a dark sky, as it will when it reaches peak altitude in January. This chart plots the positions of Venus during its previous, current, and next apparitions for an observer at 40° north latitude an hour after sunset. Notice that the planet's peak altitude often doesn't coincide with its greatest solar elongation (dates highlighted in white). — **Richard Talcott**

FAST FACT

From 40° north latitude, Venus peaks at an altitude of 31° this month. It won't appear any higher in the evening sky until March 2020.



BUILDING A CLUSTER. Protoclusters represent the early stages of formation for modern-universe galaxy clusters. ESO/M. KORNMESSER

Lighting up the cosmic web

Lyman-alpha blobs are large structures of gas that emit light as the hydrogen within them cools. Astronomers have recently discovered one of the largest Lyman-alpha structures to date, but they couldn't immediately discern the source of its glow.

MAMMOTH-1 is an enormous Lyman-alpha nebula, or ELAN for short, 10 billion light-years away. The results of the study that discovered it were published in *The Astrophysical Journal* and authored by Zheng Cai, a Hubble postdoctoral fellow at the University of California, Santa Cruz, and several associates. The ELAN was found using data from the Mapping the Most Massive Overdensities Through Hydrogen survey, or MAMMOTH.

MAMMOTH-1's home is a protocluster of galaxies just 3 billion years after the Big Bang. Protoclusters represent an early step in cosmic evolution; gas flows into them along a "cosmic web" of invisible dark matter to form stars and galaxies. MAMMOTH-1 itself has a filamentary structure, which appears to trace out the cosmic web that's growing the protocluster over time.

"From the distribution of galaxies, we can infer where the filaments of the cosmic web are, and the nebula is perfectly aligned with that structure," Cai says.

All other known ELANs are associated with visible quasars, which provide an obvious heating mechanism for the hydrogen gas. But MAMMOTH-1 is not. Cai and his co-authors speculate that an active supermassive black hole obscured by dust and gas is likely powering MAMMOTH-1's mysterious emission. — **A. K.**

2,200

solar masses

The mass of a possible black hole at the center of 47 Tucanae.

ASTRONEWS **LASER ADVANCEMENTS.** Two recent breakthroughs in laser technology allow the creation of more stable and homogenous beams. Better laser beams could dramatically increase the sensitivity of future gravitational-wave searches.

Juno will stay put for the rest of its mission

NASA's Jupiter orbiter, Juno, which arrived at our solar system's largest planet in July, has now been given new mission parameters: to stay in its 53-day orbit instead of burning its engines to insert itself into a 14-day polar orbit. At perijove (the closest point to the planet) of its current orbit, the spacecraft skims just 2,600 miles (4,184 kilometers) above the top layer of clouds, measuring the planet's weather and magnetic fields. The 14-day orbit would have put it in a roughly circular orbit going from the north pole to the south pole.

However, a planned thruster firing in August that would have shrunk the orbit down (with a second burn bringing the spacecraft closer to the roughly circular polar orbit) went awry. Faulty helium valves thwarted another attempt in October, leading the team to skip a third attempt in October at perijove.

NASA says it will be able to gain "bonus science" from the mission by keeping the 53-day orbit, including determining the effects of the powerful radiation belts moving outward from the planet.

This will also allow the team to perform an extended mission, which wasn't a prospect under the initial mission parameters. If NASA approves an extended mission, Juno would continue to gather science on the planet and add to the body of evidence needed to determine whether the core of Jupiter is a fluid or a solid in nature. Initially, after its mission was complete in 2018, the craft was going to plunge into Jupiter for a final view. — **J. W.**

BEST-LAID PLANS. Juno arrived at Jupiter in July 2016, setting itself in a 53-day orbit around the planet. The probe was intended to eventually fall into a 14-day orbit skimming just above the clouds, but malfunctioning booster rockets derailed that plan. NASA/JPL-CALTECH

Our trillion-galaxy universe

Astronomers have learned that their previous estimate of the number of galaxies in the cosmos was slightly off — by more than 1 trillion.

by Christopher J. Conselice

HOW MANY GALAXIES EXIST IN THE UNIVERSE? No one knows, but for a generation, astronomers have believed 100 billion was the answer. Now, we've discovered the number is likely much higher.

It's a perplexing puzzle to take on, because the universe is so large and has evolved so much over its 13.8 billion-year history. For many of us, it's a problem that at first may seem as difficult as counting all the grains of sand on all the beaches on our planet. Like many others before and since, when I was growing up near the coast of Florida, I would often sit on the beach and admire the vast amount of sand before me. I would naturally ask myself, "How many grains of sand are

Ten thousand colorful galaxies at wavelengths spanning the near-infrared to the far-ultraviolet populate this image from the Ultraviolet Coverage of the Hubble Ultra Deep Field (UVUDF) project. The UVUDF campaign has compiled the most comprehensive image of our universe to date. NASA, ESA, H. TEPLITZ AND M. RAFELSKI (IPAC/CALTECH), A. KOEKEMOER (STScI), R. WINDHORST (ARIZONA STATE UNIVERSITY), AND Z. LEVAY (STScI)

Shredded by interaction with a more compact galaxy, UGC 10214 — the "Tadpole" — sits against a colorful backdrop of distant galaxies. With an exposure time just 1⁄12 of the Hubble Deep Field's, it still reveals galaxies from the very early universe. NASA, HOLLAND FORD (JHU), THE ACS SCIENCE TEAM AND ESA

Most everything else in the universe is within a galaxy, so knowing how many exist is a fundamental property from which the counts of all other things must follow.

there on this beach?" The number seemed almost infinite, or at least incalculable to a young child. When I considered that there were similar beaches all around the world, the number of grains seemed indeed immeasurable.

In fact, this relates to a famous question that the Greek astronomer Archimedes answered. Archimedes, however, didn't limit himself to Earth, but wanted to answer the question of how many grains of sand would fill the entire universe. Of course, Archimedes believed in a much smaller universe than we do today — only a few light-years in diameter. He concluded in "The Sand Reckoner," one of the earliest examples of a research paper, that you would need approximately 10^{62} grains of sand to fill his universe.

Our interests do not change. Ever since Archimedes' time, it is clear that counting things fascinates people. We always want to know "how many" or "how much." And perhaps the most fundamental astronomical counting question is, "How many galaxies are there in the universe?" This is because galaxies are basic units of the universe's matter, and in a real sense they fill the universe, neatly corresponding to Archimedes' grains of sand. Most everything else in the universe is within a galaxy, so knowing how many exist is a fundamental property from which the counts of all other things must follow.

Answering this question further sheds light on many aspects of the universe, such as its cosmological makeup, the nature of the evolution of its structure, and other questions about dark matter and the light from the background sky. The answer also reveals whether galaxies started small and became larger, or whether they formed with masses similar to those we have in the modern universe.

To answer these questions, astronomers must not only determine how to measure the number of galaxies, but also what exactly this measurement means.

Nearly 3,000 galaxies at varying distances appeared in the original Hubble Deep Field, obtained in 1995 over the course of 10 days. This image gave astronomers their first glimpse at the numerous small, irregular galaxies that filled the young universe. R. WILLIAMS (STScI), THE HUBBLE DEEP FIELD TEAM AND NASA/ESA

How do I count thee?

So, how do astronomers measure the number of galaxies in the observable universe? Simple — by counting them. Of course, we have to probe very deeply, going back in time to see the first galaxies and then observing everything in between, which is not as easy as it may sound. The best instrument for this has been, and still remains, the Hubble Space Telescope.

No other telescope in the past 30 years has changed our view of the universe like the Hubble Space Telescope. This is especially true for the study of galaxies, and how they have formed and evolved since the early universe. Because of this ability, Hubble also plays a key role in our story of determining how many galaxies exist in the universe.

The only way to get to these first galaxies, and therefore to count them, is to take very deep exposures. This idea was always part of the Hubble project. In the early days of the telescope, however, astronomers thought that taking a deep picture of a blank field would be a waste of time. They reasoned that the idea behind galaxy formation, based on our current understanding of cosmology, predicts that galaxies should form very late in the universe, near our own epoch of time. If that were true, then a deep picture would come up mostly blank, simply because there would be no galaxies to detect.

Luckily, this did not deter Robert Williams. As the director of the Space Telescope Science Institute, he used his discretionary time in 1995 to carry out a deep pointing of a single area of the sky over two weeks. The result of this was a deep field image, appropriately called the Hubble Deep Field, which probed the universe to a much greater extent than we could ever see before.

To understand why this image is so valuable, think of looking up at the sky to count how many stars are visible. From a dark location, this may seem like a huge number to some people — perhaps millions or even billions. Of course, the answer is actually much smaller. In fact, the number of stars you can see from even the darkest site by eye is only a few thousand. This is similar to the number of McDonald's restaurants on the West Coast of the United States, which may either seem like not so much, or way too many!

Take a telescope to that dark location, however, and the number of stars we can see increases. Telescopes can gather much more light than the human eye, dramatically increasing the number of stars visible. This concept is similar to the result obtained by the Hubble Deep Field. By pointing a telescope better than any on Earth at a "blank" piece of sky, astronomers discovered many more galaxies than had ever been seen before.

The total area of the Hubble Deep Field is, however, very small, just a few arcminutes on a side in the constellation Ursa Major, near the Big Dipper. Still, this deep exposure revealed several thousand galaxies. That may not sound like many, but extrapolating this result over the entire sky gives us the total number of galaxies we could observe — 100 to 200 billion.

Even at that time, astronomers suspected this was an underestimate. If we were to go deeper, we knew we likely would see even more galaxies.

Adding other wavelengths

Over the next 15 years, deeper and wider surveys obtained better data that increased the total number of galaxies by only a small amount. This was because it was hard to expose longer than the Hubble Deep Field. However, one thing had changed. Astronauts on servicing missions using the space shuttle installed better cameras on Hubble, capable of wide-area, near-infrared imaging. This let us probe in more detail how many galaxies of different masses existed all the way back to when the universe was only a billion years old.

In 2009, astronauts installed the Wide Field Camera 3 (WFC3) during the fifth and final Hubble servicing mission. WFC3, the most advanced camera ever on Hubble, takes very deep pictures of the universe over relatively large areas of the sky at infrared wavelengths. This addition to our astronomical toolkit allowed us to determine the distribution of galaxy masses and answer the questions: Are there more low-mass or high-mass galaxies in the universe? Does this distribution change over cosmic time?

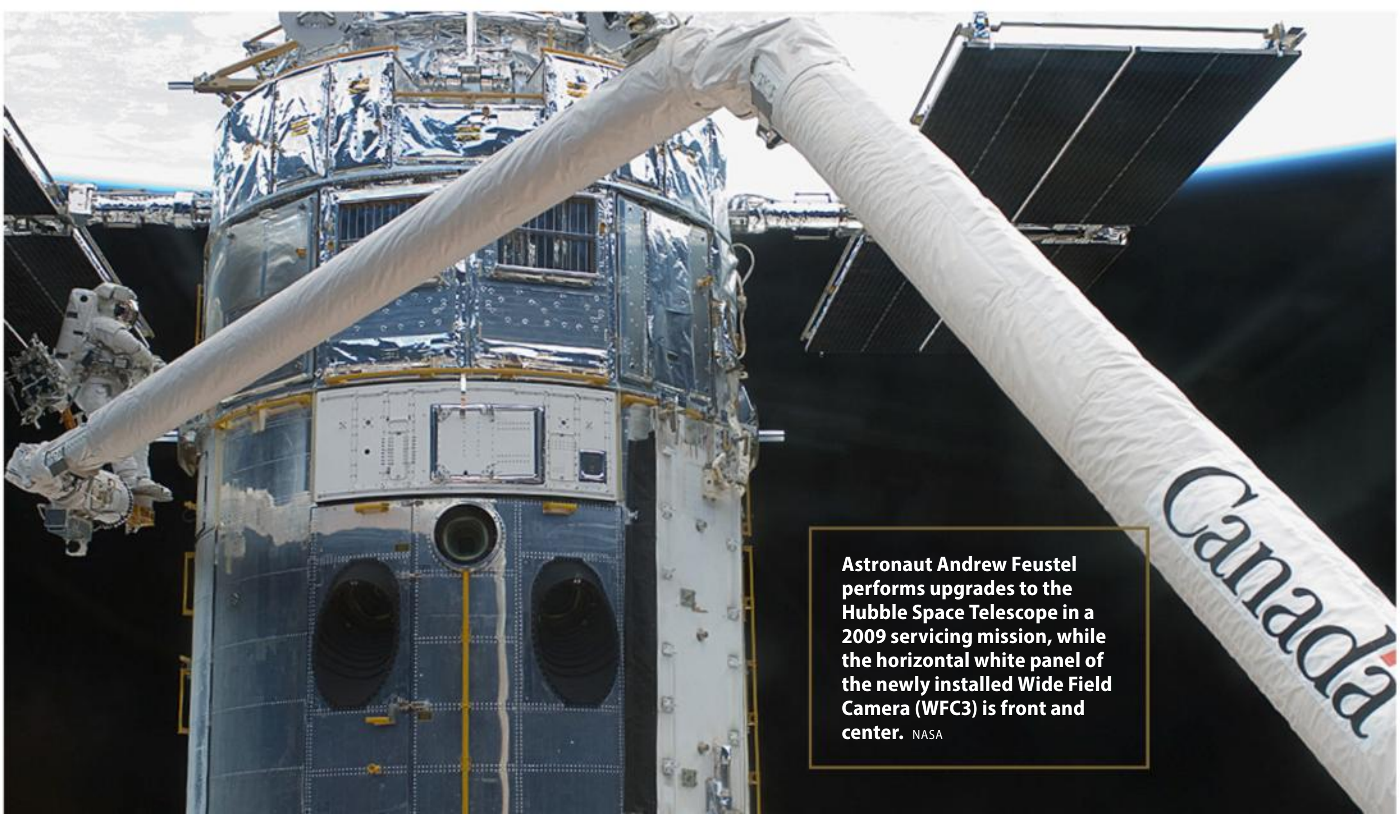
What we get from imaging the cosmos, however, is a 2-D picture of distant galaxies that doesn't show their distribution in time or space. What we need to know is how massive these galaxies are and where in space each one is located.

We can determine this by observing galaxies at many wavelengths. Various types of stars emit light in different parts of the spectrum, so by

UNDERSTANDING PHOTOMETRIC REDSHIFT

The photometric redshift method can be understood quite simply by taking the example of a single hot star that emits as a perfect blackbody. The temperature of the star determines the shape of this blackbody and where the peak of emission is located. Hotter stars have shorter wavelength peak emission. If this star were placed at a greater distance and thus was part of the expanding universe, the peak of the emission would appear to shift to redder and redder wavelengths as it got more distant, due to the Doppler effect.

Measuring photometric redshifts works the same way, where with many different fluxes at different wavelengths, we can figure out the intrinsic spectrum of a galaxy. Then, by comparing the true spectrum with the actual viewed spectrum, we can determine how much it has been shifted, and thus measure the galaxy's radial velocity and distance. — *C. C.*



Astronaut Andrew Feustel performs upgrades to the Hubble Space Telescope in a 2009 servicing mission, while the horizontal white panel of the newly installed Wide Field Camera (WFC3) is front and center. NASA examining the light from a galaxy at each wavelength throughout its spectrum, we can measure the stellar populations within the galaxy. Additionally, the properties of the light can reveal a galaxy's distance. This distance information comes from the fact that the universe is expanding, which produces a Doppler shift in the spectrum of the galaxy. Combining this effect with Hubble's Law, which states galaxies at greater distances appear to be moving away from us at a faster rate, allows astronomers to calculate the galaxy's distance. Using the shape of the spectrum to determine this distance is known as measuring the "photometric redshift."

The process of determining photometric redshifts requires extensive data at different wavelengths. Fortunately, data exist that can be used to calculate these masses and redshifts within the deep Hubble pointings. These data come from multiple telescopes, including additional deep imaging performed with the Subaru Telescope, the two 10-meter Keck Observatory telescopes, and the Hubble Space Telescope.

However, even with our deepest images, we still are not reaching the faintest galaxies at the most distant cosmic times — or at least not all of them. The question then becomes, How many galaxies are we on the cusp of discovering?

Galaxy mass distribution

The answer lies in the distribution of galaxy masses — i.e., how many galaxies there are at a given stellar mass within a volume of space. It turns out that galaxies have a regular distribution — that is, there are not just random numbers of galaxies at different masses. What we know and have known for some time is that many more low-mass galaxies exist than high-mass galaxies.

At high masses, the distribution of galaxies is "normal" or Gaussian, but at low masses, the distribution is a power-law. The slope of this power-law describes for the most part how many galaxies exist.

Astronomers want to characterize the distribution of galaxy luminosities and masses over time. They do this with what is called the Schechter function, which combines the power-law and normal distributions we see.

This distribution holds very well throughout the universe — in all environments. In fact, the observed distribution of masses is predicted using computer simulations of galaxy formation based on our current cosmological models.

The amazing thing is that as we look further back in time, at higher and higher redshifts, the slope of the Schechter function becomes steeper and steeper. This means that the further back in time we look, the more low-mass galaxies exist. In other words, the early universe was full of tiny galaxies. Larger galaxies didn't exist in abundance until later cosmic times, after numerous small galaxies merged into bigger ones. In fact, for every one galaxy that exists today, there were approximately 10 times as many galaxies when the universe was just a billion years old.

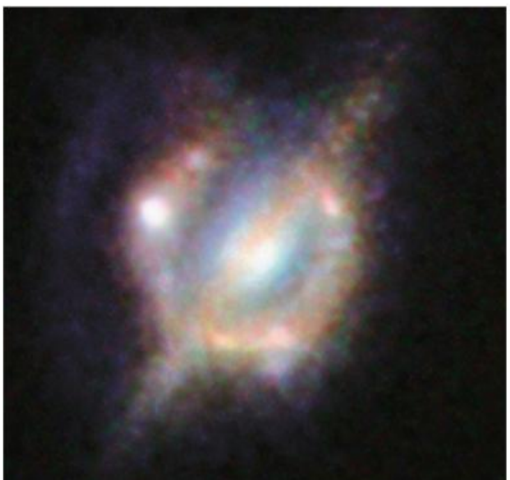
Moreover, we see that the high number density of galaxies in the early universe declines until it

GAUSSIAN AND POWER-LAW DISTRIBUTIONS

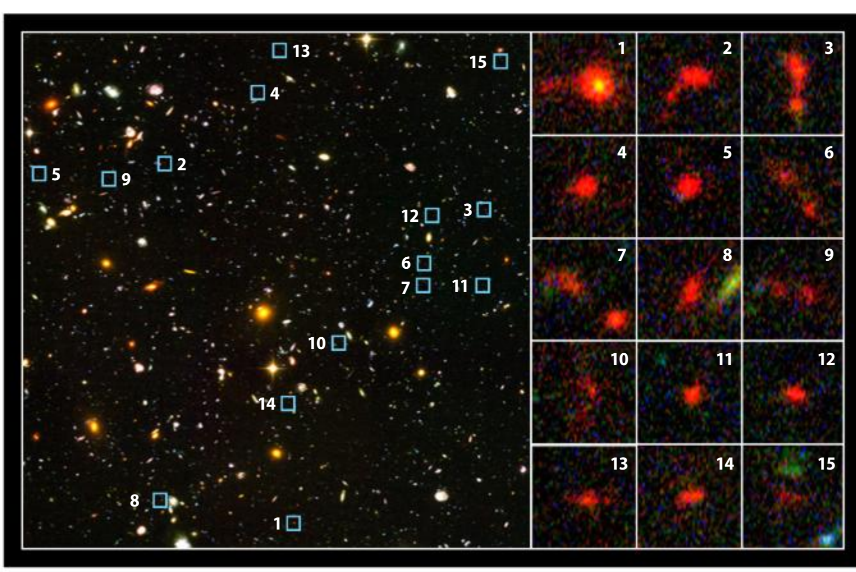
In a Gaussian distribution, also called a normal distribution, the most common values occur around a single value (the mean), with no bias toward higher or lower values. Examples of normal distributions include the heights of people in a group or students' grades on a test. When a Gaussian distribution is graphed, it has a central "bump" at the mean and edges that trail off symmetrically in either direction. Because this curve is shaped like a bell, it's often called a bell curve.

Power-law distributions describe situations in which some probabilities are much more likely than others. When comparing two quantities that show a power-law relationship, a change in one quantity results in a change in the other quantity as a fixed power of the first. A power-law distribution looks like a steeply curved line when graphed. Power-law distributions occur frequently in physics, as well as economics and biology.

— Alison Klesman



A distant galaxy merger is seen through a gravitational lens. The lensing galaxy is an edge-on spiral, which appears as a diagonal "line" in the image. Behind it lies the distorted image of a galaxy merger similar in appearance to the closer Antennae Galaxies, but which occurred when the universe was just 7 billion years old. NASA/ESA/ESO/W. M. KECK OBSERVATORY



These tiny, irregular red galaxies, singled out from just a portion of the Hubble Ultra Deep Field, are among the most distant — and youngest — ever seen. Existing at a time when the universe was less than a billion years old, these galaxies merged over time to form the more massive galaxies we see today. NASA, ESA, R. BOUWENS AND G. ILLINGWORTH (UNIVERSITY OF CALIFORNIA, SANTA CRUZ, USA) reaches the number we find today. This can only happen by galaxy destruction. That is, small galaxies merged over time to form not only fewer galaxies, but also galaxies that are much more massive than they were in the early universe.

These are important conclusions. When we count the galaxies throughout the whole history of the universe, we arrive at a total of 2 trillion. This is at least a factor of 10 higher than we previously thought.

It's important to note that this discovery hasn't changed the amount of matter in the universe, only the number of galaxies containing that matter. Because the universe we see now is the result of mergers, the greater number of galaxies in the past doesn't add mass — it simply moves it into a greater number of smaller units than are around today.

The meaning of 2 trillion

These results have a few important implications. First, galaxy evolution must have occurred through mergers. There's no other way the number of galaxies in a given volume of the universe can decline by such an amount.

Second, consider Olbers' Paradox, which addresses why the night sky is dark. The paradox states that if the universe is infinite in time and space, then stars should occupy every point in the night sky, making it light. However, this is not the case, and for at least the last few hundred years, astronomers have been asking why.

These results for the number of galaxies show that there is an alternate interpretation to this problem. Because so many galaxies exist, every point in the sky should be occupied by a galaxy. However, we do not see most of these galaxies because the human eye can only detect light with wavelengths less than about 700 nanometers. The optical light from distant galaxies is not visible at these wavelengths because the Doppler effect shifts this light to wavelengths longer than 700nm.

Based on this effect, the light that should be visible from such faraway galaxies would have to originate in the ultraviolet portion of the spectrum in order to become lengthened into visible light by the time it reaches Earth. However, such UV wavelengths are easily absorbed by hydrogen within the host galaxy itself, as well as in the intergalactic medium.

This is why astronomers required near-infrared observations to discover these galaxies, and why the WFC3 was the critical instrument for this discovery. In the next year, the James Webb Space Telescope will launch. This successor to Hubble will probe much more deeply than its predecessor, not only examining fainter galaxies at the distances we can now study, but also expanding our knowledge of galaxies to even farther distances as well. This will increase our understanding even more, and undoubtedly refine our knowledge of how many galaxies exist in the universe and the implications of this number for cosmology and galaxy formation.

The Antennae Galaxies are a famous pair of spiral galaxies in the middle of a merger that's been going on for the past several hundred million years. When the merger is complete, a single large galaxy will be left in their place. ESA/HUBBLE AND NASA

Astronomers are tasked with piecing together the complete picture of our universe, from its earliest days to the present epoch. Our ability to detect fainter, younger objects is continually increasing. As deeper data emerge, we're able to better fit the observations we make to the models we've developed to describe the universe — a universe, we now know, that contains not billions, but trillions of galaxies.

Armed with this information, astronomers now have a better understanding of how our current universe evolved, and can more accurately predict where it's headed.

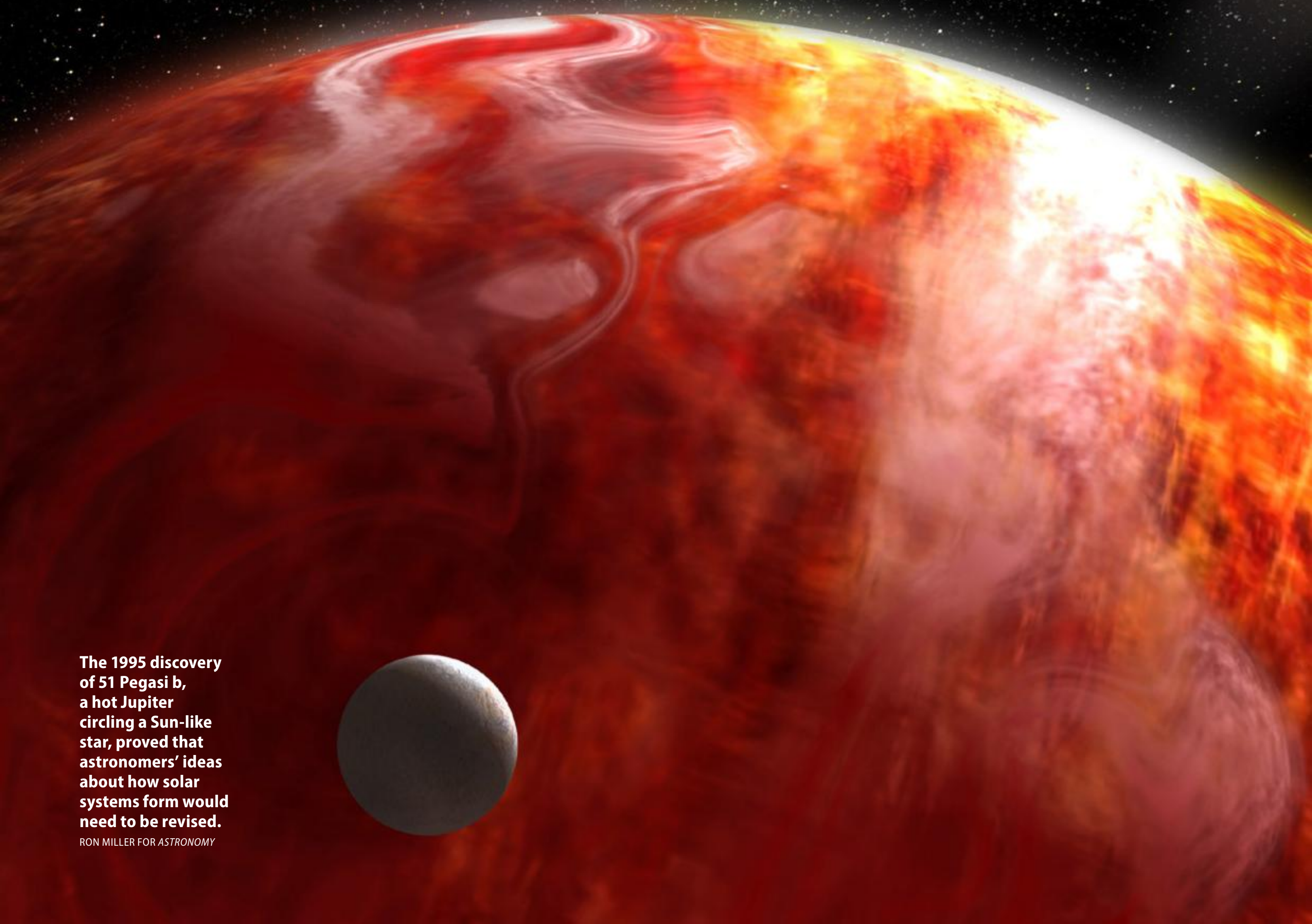
When we count the galaxies throughout the whole history of the universe, we arrive at a total of 2 trillion. This is at least a factor of 10 higher than we previously thought.

Christopher J. Conselice *is a professor of astrophysics at the University of Nottingham, where he studies galaxy evolution and formation.*

Making sense of the
exoplanetary zoo

Astronomers see a menagerie of planetary systems orbiting other stars, but they're just beginning to figure out how these structures arise.

by Robert Naeye



The 1995 discovery of 51 Pegasi b, a hot Jupiter circling a Sun-like star, proved that astronomers' ideas about how solar systems form would need to be revised.
RON MILLER FOR *ASTRONOMY*

Exoplanets have continually defied astronomers' expectations ever since the initial discoveries in the 1990s. The first planets were found where they were least expected: around a pulsar. The next batch were Jupiter-mass leviathans orbiting their host stars in extremely tight, circular orbits or marauding through what was supposed to be the terrestrial planet region in highly elongated orbits. More recently, NASA's Kepler spacecraft has found numerous systems packed with "super-Earths," planets not much bigger than our home world.

Almost none of this was predicted. Before the initial discoveries, astronomers based their expectations largely on our solar system's grand architecture, with small, rocky worlds close in and gaseous behemoths farther out. Computer models based on how planets should form inside disks of gas and dust assumed the same rules would apply elsewhere, so other systems would be variations on a theme.

But the first known exoplanets quickly consigned those models to the dustbin of history. Although the field of exoplanet research is still young, the discovery of more than 3,600 planets makes it crystal clear there's no such thing as a "typical" planetary system, and that systems sharing our solar system's basic architecture are relatively rare. To put it succinctly: Exoplanetary systems are all over the map.

"It ain't what you don't know that gets you into trouble. It's what you know for sure that just ain't so." — Mark Twain

Most of the known exoplanets fall into several broad categories. Hot Jupiters reside in tight circular orbits and are found around only 1 percent of solar-type stars. Warm Jupiters, found around 5 to 10 percent of stars, follow more elongated orbits averaging roughly 0.3 to 3 astronomical units from their stars. (An astronomical unit is the average Earth-Sun distance.) Super-Earths exist around at least half of Sun-like stars, often in multiple-planet systems. Many of these worlds orbit close to their host stars. Surprisingly, long-term radial-velocity surveys show that only about 3 percent of stars like the Sun harbor giant planets orbiting at distances comparable to those of Jupiter and Saturn.

Planet-formation theories alone simply cannot explain the diversity and range of systems. The most important lesson of the exoplanet revolution is that it's not just a matter of how planets form. To understand the panoply of planets in our galaxy, astronomers need to disentangle the deep mystery and complexity of how planetary systems evolve.

The pre-1990s models were naive because they were missing a vital ingredient: migration. Planets gravitationally interact with their formative disks, with other planets, with billions of planetesimals, or with companion stars. They move in and out and shift between circular and elongated orbits. We even see evidence that migration occurred in our solar system.

"We have learned a lot of astrophysics since the 1990s," says Marc Kuchner of NASA's Goddard Space Flight Center. "We have

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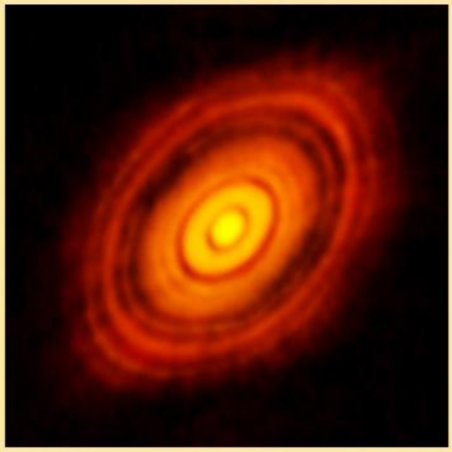
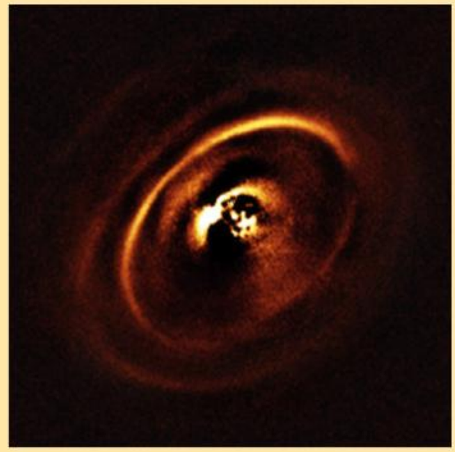
Robert Naeye *was an editor at* Astronomy *from 1995 to 2000. He served as editor-in-chief of* Sky & Telescope *from 2008 to 2014, and he is currently a freelance writer in south-central Pennsylvania.*

The Atacama Large Millimeter/submillimeter Array (ALMA) discovered spiral arms in the outer part of the protoplanetary disk surrounding Elias 2–27. A flattened disk that likely harbors developing planets lies closer to the young star. B. SAXTON (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO)



The protoplanetary disk around HL Tauri shows up beautifully to the probing antennas of ALMA. Astronomers suspect that gaps in the disk represent regions where budding planets have swept up nearby gas and dust. ALMA (ESO/NAOJ/NRAO)



Astronomers captured the planetary disk surrounding the young star RX J1615 with the European Southern Observatory's Very Large Telescope. The camera they used blocks light from this sun to reveal a complex system of concentric rings that resemble a giant version of Saturn's rings. ESO/J. DE BOER ET AL.

learned about planet migration and other processes. Planets are like toddlers. They don't stay in their chairs; they get up and wobble around."

The birth of planets

Surprisingly, the long-standing picture of how planets form inside swirling disks has survived the revolution relatively intact. Observations conclusively show that disks consisting of mostly gas and a smattering of dust are a natural consequence of star birth. Protoplanetary disks range in mass from roughly 1 to 10 percent of the host star's mass, and they vary considerably in their gas-to-dust ratios and chemical compositions. Over time, the disks dissipate as planets sweep up the material and stellar winds blow the gas away.

Astronomers still think small, rocky bodies collide and stick together inside these disks, gradually building themselves up into terrestrial-size bodies. "The general idea remains that planetesimals form quickly in disks and then assemble into planets," says Yale University astrophysicist Greg Laughlin.

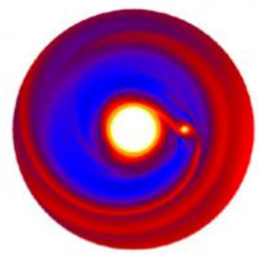
Even the conventional "core accretion" theory of how giant planets form has survived relatively unscathed. In this picture, ice-rock cores build up far from the star, eventually attaining sufficient mass (5 to 10 Earths) to gravitationally sweep up surrounding gas to form worlds ranging from mini-Neptunes to super-Jupiters. Despite the existence of hot Jupiters, most astronomers still think gas giants generally develop far from their host stars, beyond "ice lines" where more massive cores can form, and where there is plentiful gas.

But recent studies of meteorites show that our solar system's terrestrial planets arose more quickly than previously thought — in a few tens of millions of years instead of 100 million years. And observations of stars of various ages demonstrate that protoplanetary disks (and particularly the gas) can survive much longer, giving the processes of planetary formation and evolution more time to do their work.

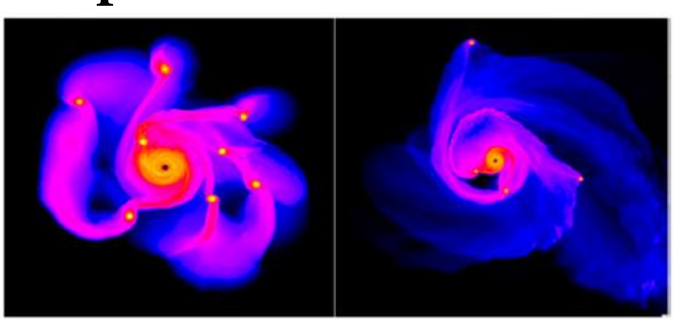
"The birth environment probably plays an important role, but it's not yet certain what that role is," Laughlin says. In the centers of dense clusters, massive stars emit torrents of ionizing radiation that evaporate nearby disks, perhaps truncating them quickly before ice-rock cores can sweep up enough gas to form Jupiters. A star passing nearby could stir up the planet-forming region of a disk or wreck a system. A nearby supernova (as probably happened in our solar system) can also jostle newborn systems in ways that astronomers don't yet understand very well.

A disk's specific composition plays a vital but not yet fully understood role. In general, disks track with their host star's

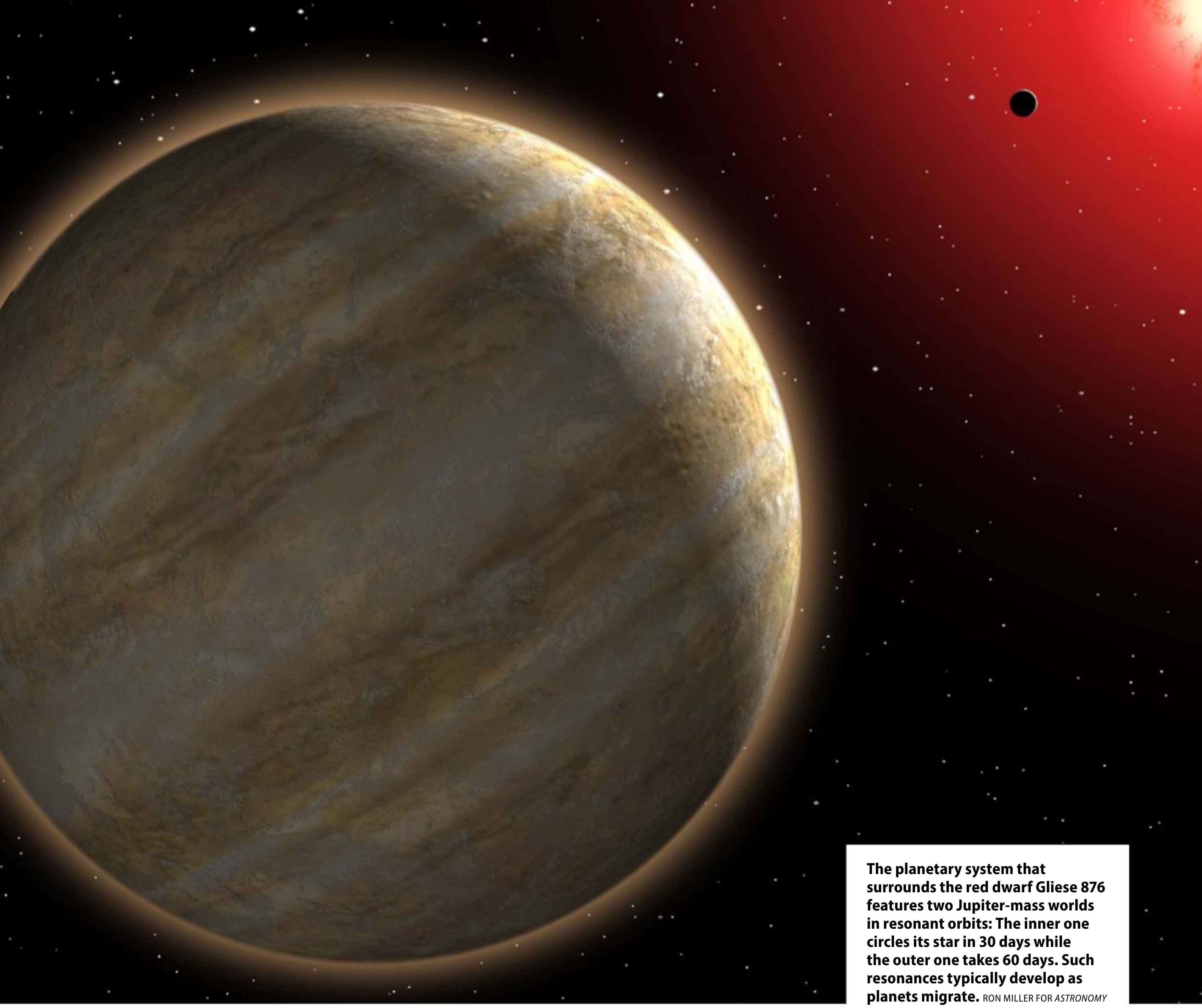
How Jupiter-like planets form



Some astronomers think large planets initially form a large core that pulls in surrounding gas. This simulation shows a 10 Jupiter-mass planet opening a gap in the protoplanetary disk. J. SZULAGYI, JUPITER CODE



Other researchers think some giant worlds form through gravitational instability, in which a protoplanetary disk has so much mass that gravity creates spiral arms. Clumps inside the arms then collapse directly into large planets. This simulation shows the process at an early and late stage. LUCIO MAYER & T. QUINN, ChaNGa CODE



The planetary system that surrounds the red dwarf Gliese 876 features two Jupiter-mass worlds in resonant orbits: The inner one circles its star in 30 days while the outer one takes 60 days. Such resonances typically develop as planets migrate. RON MILLER FOR *ASTRONOMY*

mass and heavy element content. Giant planets are more common around stars with a high concentration of heavy elements, and stars with higher mass in general, while low-mass stars harbor a plethora of low-mass planets.

"Nature produces planetary systems that are extremely different from each other," notes Penn State University astrophysicist Eric Ford. "The problem is that it's very complicated; we're not trying to explain a single repeating pattern. With a rich array of planetary systems, we need a rich array of planetary formation theories."

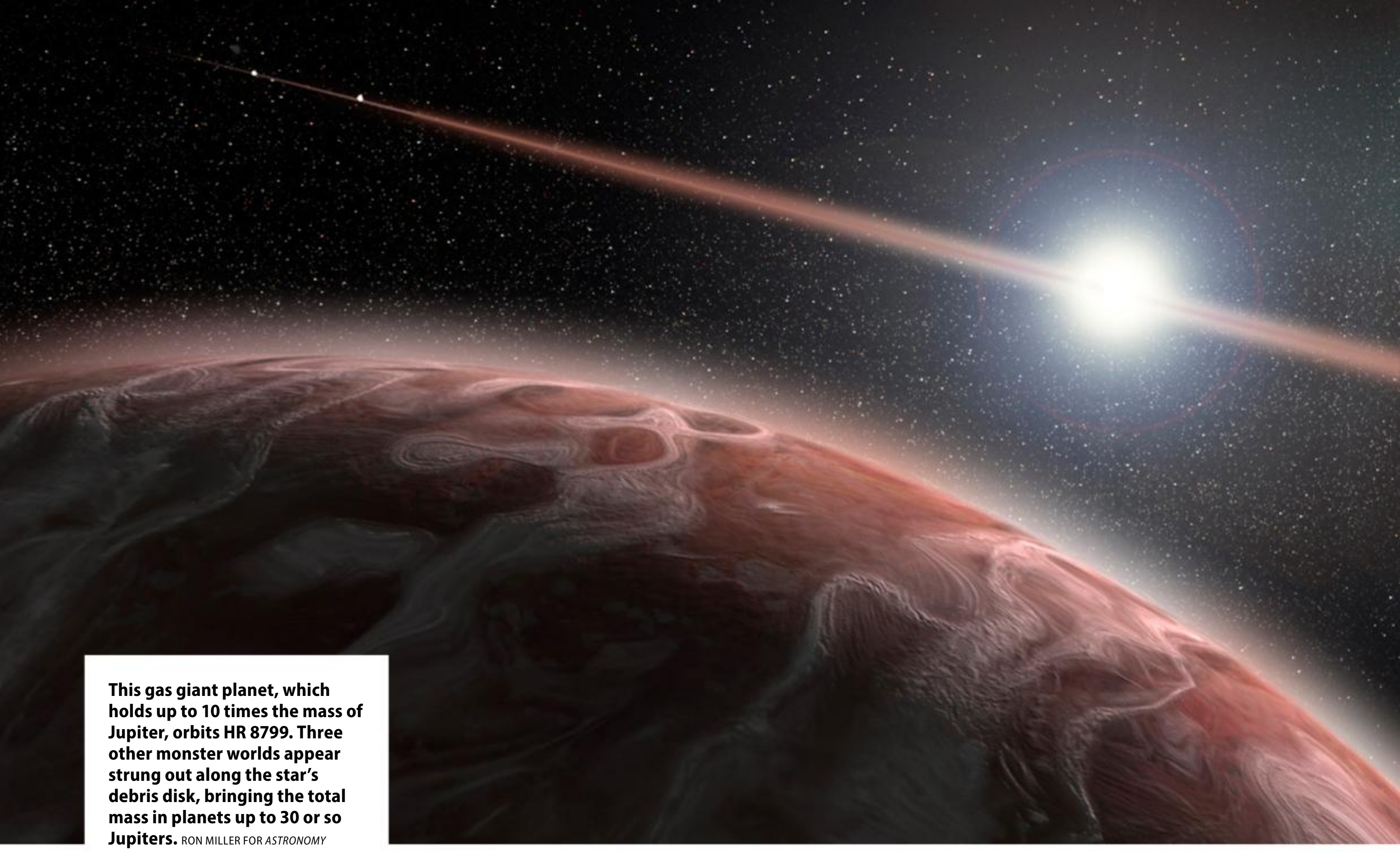
Gentle migration

Even before the 1990s, some theorists realized that planets orbiting within a disk would cause material to bunch up in wakes, and those mass concentrations would, in turn, pull on the planet. Because particles exterior to a planet orbit more slowly, they bunch up behind the planet. The wakes tug back, decelerating the planet and dragging it inward. Particles interior to the planet do the exact opposite, forming wakes that push the planet outward. The net mass difference between the two wakes determines whether a planet spirals inward or outward.

"In an average scenario, exterior material has the upper hand, driving inward migration. So inward migration is thought to be dominant," explains Laughlin.

An inwardly spiraling planetesimal or planet can grow more massive by sweeping up material. And disk-driven migration is relatively gentle, preserving a planet's orbital inclination and direction. So, disk-driven inward migration solves the mystery of how large planets can form beyond an ice line but wind up in fiery, close-in orbits. In particular, it provides a natural explanation for about half of the hot Jupiters — specifically, those that orbit in the plane of their star's equator and in the same direction as the star rotates.

But computer simulations show that disk-driven migration can work fast — sometimes too fast. In many cases, a planet should spiral all the way into its parent star within just a few thousand years. Some disks might create multiple generations of planets. It's even possible that the early solar system harbored super-Earths



This gas giant planet, which holds up to 10 times the mass of Jupiter, orbits HR 8799. Three other monster worlds appear strung out along the star's debris disk, bringing the total mass in planets up to 30 or so Jupiters. RON MILLER FOR *ASTRONOMY*

that fell into the Sun, and that Mercury, Venus, Earth, and Mars formed from leftover material. A key unanswered question is why the hot Jupiters and the close-in super-Earths we do observe were left stranded in orbits lasting just a few days to weeks.

The situation becomes extremely complicated when a disk forms multiple planets, as is usually the case. Multiple wakes form in the disk, driving some planets inward and others outward. As Kuchner explains, "It's hard to tell one simple story when there are so many different things going on. It's like a game of bumper cars."

"Planets are like toddlers. They don't stay in their chairs; they get up and wobble around." — Marc Kuchner

Although astronomers don't yet have the ability to watch planets migrate inward and outward in real time, they can see the aftereffects. A classic example is found around the red dwarf Gliese 876. Two Jupiter-mass worlds are locked securely in a 2:1 resonance: The inner planet goes around the star every 30 days, while the outer one takes 60 days. It's extremely unlikely that the planets formed in this resonance; it's much more likely that both planets migrated inward some undetermined distance until they gravitationally locked onto each other and continued to migrate together. The resonance thus preserves a memory of disk-driven migration from long ago.

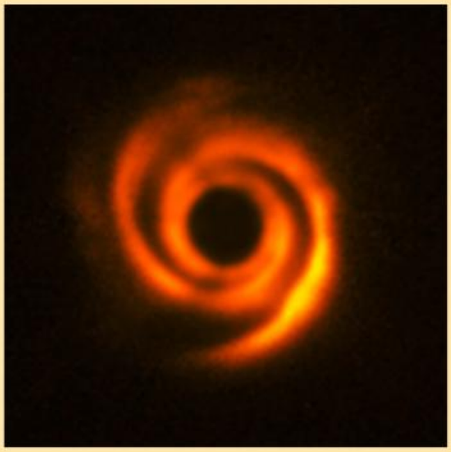
Another piece of evidence comes from the recently discovered TRAPPIST-1 system. Michaël Gillon of the University of Liège in Belgium and colleagues announced in February that they had found a total of seven close-in planets with masses and sizes similar to Earth orbiting a red dwarf with just 8 percent of the Sun's mass. All of them lie in or near the star's habitable zone, and the inner six appear to be in near-resonance. Most astronomers suspect migration played a role here, too, though they debate whether the planets formed farther out and migrated inward or if the rocky material that later would build the planets migrated toward the star, piling up where the worlds formed.

In some regions of a protoplanetary disk, the net torque will drag planets inward, and in other places it will push planets outward. Planets will end up where the migration is slow — planet traps. "The traps can move in or out, and there can be multiple traps in the disk," says Ford. "Maybe the final architecture of a planetary system preserves a memory of where the traps were. But it's just a theory."

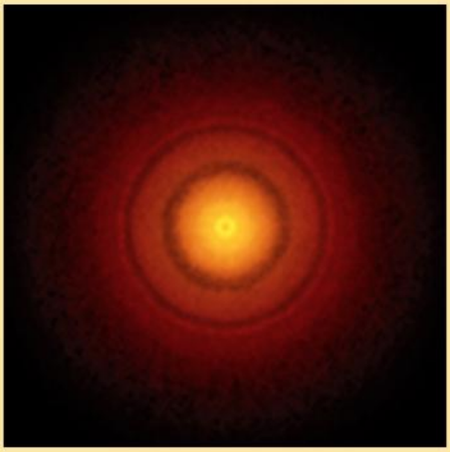
It remains unclear whether close-in super-Earths in packed systems formed *in situ* from a particularly massive disk, or whether they assembled farther out and accumulated mass as they migrated inward. Some of these worlds have extremely thick atmospheres, which points to past migration. "Superpuffy planets may have formed beyond the ice line," says Penn State astronomer Rebekah Dawson.

Planetary pinball

When multiple large planets form in a disk, or if planets develop in a binary system with a nearby stellar companion, migration is inevitable and decidedly non-gentle. Planets will violently tug on one another, forcing worlds to change orbits. Some worlds will move inward or outward, and the survivors will often have their original circular orbits yanked into highly elongated paths. The big brutes generally win, with the losers driven to a fiery death inside their host star or occasionally ejected into the frigid depths of interstellar space.



A camera attached to one of the 8.2-meter telescopes of the European Southern Observatory's Very Large Telescope masks the light from the young star HD 135344B, revealing a disk molded into spiral arms. Scientists think one or more massive protoplanets created these structures. ESO/T. STOLKER ET AL.



The Atacama Large Millimeter/submillimeter Array (ALMA) recorded the sharpest view yet of a protoplanetary disk. This one circles TW Hydrae, a star astronomers estimate to be only 10 million years old. The gaps in the rings mark the sites where planets may be forming. S. ANDREWS (HARVARD-SMITHSONIAN CfA); B. SAXTON (NRAO/AUI/NSF); ALMA (ESO/NAOJ/NRAO)

The concentric rings around HD 163296 represent leftover material in the protoplanetary disk. Observations with ALMA discovered three gaps depleted of dust; the two outer gaps also show less gas than elsewhere. Astronomers interpret these as evidence for newly formed planets. ESO/ALMA (ESO/NAOJ/NRAO)/A. ISELLA/B. SAXTON (NRAO/AUI/NSF)

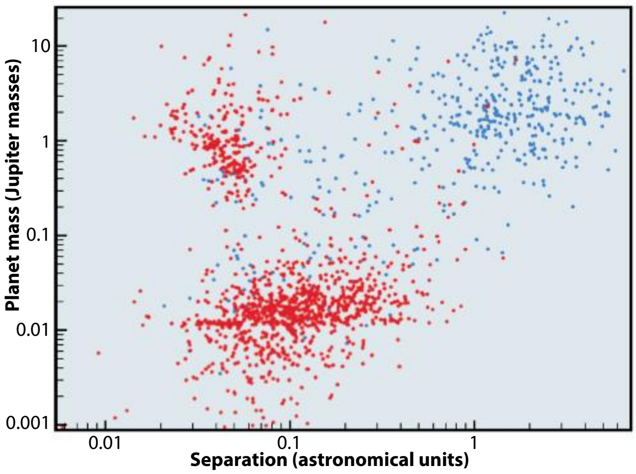
And even if the strongest interactions occur between giant planets that form far from the star, the effects can still disrupt or destroy the inner region. "Planet scattering in an outer planetary system can propagate inward and affect an entire system," notes Ford.

Evidence of scattering among planets abounds in exoplanet systems. For example, about half of hot Jupiters have orbits that are highly inclined to the host star's equator. Some even go around their stars the wrong way. These worlds almost certainly suffered powerful dynamical interactions with other planets or a companion star. Such interactions are particularly strong in binary systems where a planet orbits its host star in a plane highly offset from the orbital plane of the two stars. Complex, long-term interactions will leave a planet stranded in a tight, elongated orbit that will slowly circularize through tidal interactions with its host star.

Scattering also provides a natural explanation for the warm Jupiters. In these systems, the planet ended up in a moderate- to high-eccentricity orbit that plows right through the star's habitable zone. Any pre-existing terrestrial worlds either were destroyed in collisions or, more likely, were gravitationally kicked out of the system. As Laughlin says, "Most exo-Jupiters have substantial eccentricities. They initiated cascades in their inner systems that probably emptied them out."

Given the presence of two massive planets, our solar system appears to have narrowly averted this unpleasant fate, enabling life on Earth to get started and have sufficient time to evolve creatures capable of understanding their past. "We see lower eccentricities in our solar system, which is very boring. This suggests we have had a less dynamic history than other systems," says astronomer Carol Grady of NASA Goddard.

Size matters in exoplanets

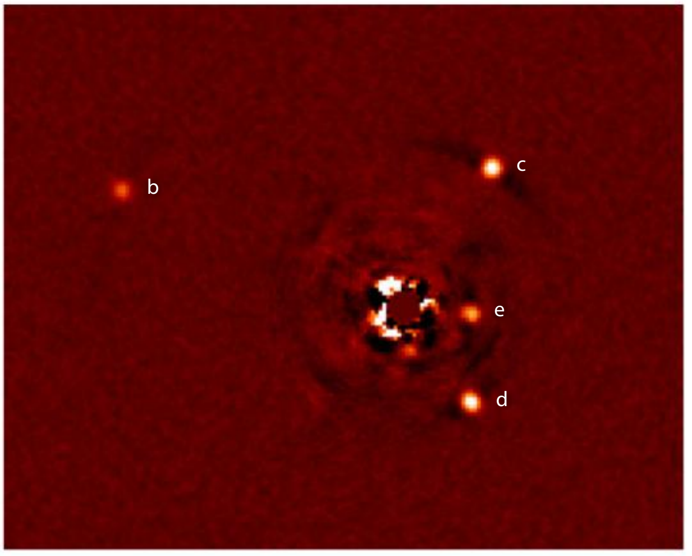


Astronomers so far have found mostly large planets in fairly tight orbits around their host stars. This plot shows a planet's mass against its orbital distance and reveals that most exoplanets fall into a few categories: Hot Jupiters lie toward the upper left, warm Jupiters to the upper right, and close-in planets with fairly low masses at the bottom. The blue dots indicate planets found via radial velocity; red dots indicate those found with the transit method, most of them with the Kepler spacecraft. *ASTRONOMY*: ROEN KELLY, AFTER EXOPLANETS.ORG/JASON WRIGHT (PSU)

Shooting gallery

Even after extended periods of planetary chaos, and after all the gas has disappeared from a protoplanetary disk, migration isn't necessarily complete. The planet formation process is messy and inefficient, and it almost always will leave behind trillions of planetesimals that never came together to join the planet club. As planets move about in their orbits and shift orbits, they will both affect and be affected by these little guys.

Neptune's 3:2 resonance with Pluto is clear evidence that planetesimal-driven migration occurred in our solar system. Both Neptune and the Kuiper Belt probably formed closer to the Sun than their current distances. Gravitational interactions among the four giant planets likely drove Neptune into the Kuiper Belt, where it gravitationally scattered huge numbers of Kuiper Belt objects (KBOs). Neptune handily won these battles, but each interaction



Astronomers have found an oddball system of four massive planets orbiting the young star HR 8799. The four worlds — named HR 8799 b, c, d, and e in order of their discovery — show clearly in this view from the Large Binocular Telescope in Arizona. A.-L. MAIRE/LBTO

subtly changed Neptune's orbit. The cumulative effect was the expansion of the planet's orbit. As Neptune moved outward, its gravity swept up Pluto and many other KBOs, trapping them in 2:1, 3:2, and other resonances.

As KBOs were flung around the solar system, these interactions gradually circularized the orbits of the four giant planets. In fact, this might have been the last gasp of the planet-formation process, leaving the solar system's planets in their current configuration.

If scattering occurred here, it certainly occurs elsewhere. Many of the known multiplanet systems — particularly those with super-Earths discovered by Kepler — feature worlds that just barely miss orbiting in resonance. It remains unclear whether these planets formed more or less *in situ* from a particularly massive disk, or if they formed farther out and accumulated mass as they migrated inward.

"Perhaps early planet formation throws planets into resonances when the gas is still there. But later, those resonances are broken after the gas goes away and the planets scatter planetesimals," says Ford. "This can put planets out of resonances, but not by a lot because there is less mass in planetesimals than in the gas. To me, that smells like the right direction to understand the Kepler planetary systems."

Not like the others

And then there are the oddballs: the many worlds that don't fit into any general pattern, and whose characteristics show how much astronomers have left to learn.

Among the most perplexing are the four giant planets that have been directly imaged orbiting at large distances from the star HR 8799. Based on their infrared glow and estimated age of 30 million years, the planets range in mass from about 5 to 10 Jupiters. This system contains a whopping 30 or so Jupiter masses bound up in planets. No other known exoplanet system contains more than a dozen or so Jupiter masses. How could a disk convert so much mass into planets?

"The HR 8799 planets orbit a massive star, and they appear to be outliers. They were found because they were easy to find," notes Laughlin, who suspects that these big brutes formed through disk instability. In this process, first described in the 1990s, particularly dense regions of disks can suddenly collapse gravitationally to create gas giants.

Ford suggests an alternative. "Either the HR 8799 planets formed in a humongously massive disk, or there was a highly efficient way to convert mass into planets," he says. "Maybe the planets migrated outward and found a resonance when they were at a lower mass, and that caused them to accrete mass at a higher rate. But it still feels like something is missing as to why they grew to be so massive."

Putting it all together

Clearly, many different processes shape the architecture of planetary systems, and they work in tandem or in competition to lead to wildly different outcomes. And the timing of events, such as when the gas disappears, is probably ultra-critical. The difficult task at hand is to figure out which processes predominate.

"There is no consensus on what is the dominant process that determines where planets end up," says Dawson. "We're still piecing all of this together. But clearly, there are a lot of important processes happening after planets form."

It's not even obvious which is more important: initial conditions or random luck. Imagine two protoplanetary disks with almost equal mass and composition orbiting almost identical stars in nearly identical stellar neighborhoods. Tiny initial differences in the disks will amplify through the planet-formation and migration processes to produce two completely different outcomes.

Laughlin agrees. "It's probably a little of both, but the random nature probably has the upper hand. We can't look at a disk and deterministically predict what kind of planetary system it will produce," he says.

A major challenge is the fact that we can capture only snapshots of many different systems at different stages in their evolution. But upcoming satellites and ground-based surveys will help. NASA's Transiting Exoplanet Survey Satellite will find more transiting planets in our solar neighborhood. Radial velocity, microlensing, and direct imaging surveys will reveal more planets in wide orbits, a region where our current knowledge is limited. Studies of disks from ALMA and other telescopes — which are already revealing gaps, spiral arms, rings, and warps that may be related to planets — will teach us much more about the planet-formation environment. NASA's James Webb Space Telescope and Wide Field Infrared Survey Telescope satellites, along with the European Space Agency's Characterising Exoplanet Satellite (CHEOPS) and Planetary Transits and Oscillations of stars (PLATO) missions, also will provide key pieces to the puzzle.

"It's hard to tell one simple story when there are so many different things going on. It's like a game of bumper cars." — Marc Kuchner

Despite the extraordinary progress of the past 20 years, astronomers are still a long way from having a complete understanding of how planetary systems are assembled. As Ford explains, "The final stages of planetary formation are highly chaotic, and this erases various markers of how they form. There might be some processes that are the most important, but it will be hard to tease them out. We don't even know what are the most important questions we need to be asking. Teasing that out will be a multidecade task."

The Gaia probe floats at a Lagrangian point beyond the Earth-Moon system. Its orbit is called L2, and like all Lagrangian points, it marks a relatively stable orbit balanced between Earth and the Sun.
ESA–D. DUCROS, 2013

Mapping the galaxy one star at a time

The astronomy community is preparing for the big one: a spectacular, 3-D map of the entire galaxy. **by Korey Haynes**

Astronomy is often called the oldest branch of science. Since ancient times, humans have stared at the sky, cataloged its residents, marked new arrivals, and charted the constant stars and wandering planets.

Over millennia, huge advances have been made in astronomy, but some surprisingly basic questions remain: Where exactly are the stars? Where, in the grand scheme of things, is Earth? What is the shape and structure of our home galaxy?

We've come a long way from thinking of the stars as a two-dimensional projection on the sky, but measuring a star's distance remains quite tricky. And even tracking a star's motion across the sky in two dimensions is difficult without years of data.

In 1989, the European Space Agency (ESA) launched the Hipparcos satellite to measure the positions of 2.5 million stars, a catalog that wasn't released in full until 2000. In 2013, ESA launched Gaia, which will return even higher-precision data on over a billion stars. Gaia was a Greek goddess who was regarded as a sort of Mother Earth. The ESA mission originally stood for "Global Astrometric Interferometer for Astrophysics." Though many of the parameters changed, ESA kept the name for mission continuity.

Gaia won't complete its mission until 2019, and the final data analysis won't be available until years afterward. But in September 2015, the Gaia science team released a first round of data from 14 months of observing, and welcomed scientists around the globe to jump in. The results are already changing astronomers' perspective of our galaxy.

By the numbers

Gaia's mission statement is to "map a billion stars," but even this bold promise undersells the space observatory's true abilities. Gaia, orbiting around 932,000 miles (1.5 million kilometers) away and mapping the whole sky, carries three instruments. Its astrometric instrument charts positions and motions of stars with pinpoint precision by observing how they appear to move over the course of Gaia's five-year mission. Its photometric camera measures the brightness of stars at both red and blue wavelengths, producing data about their temperatures and compositions. Finally, the spectrometer measures the Doppler shift of particular chemical signatures to reveal whether stars are moving toward or away from Earth. (For an in-depth overview of Gaia's design and mission, check out *Astronomy*'s December 2014 story, "How Gaia will map a billion stars.")

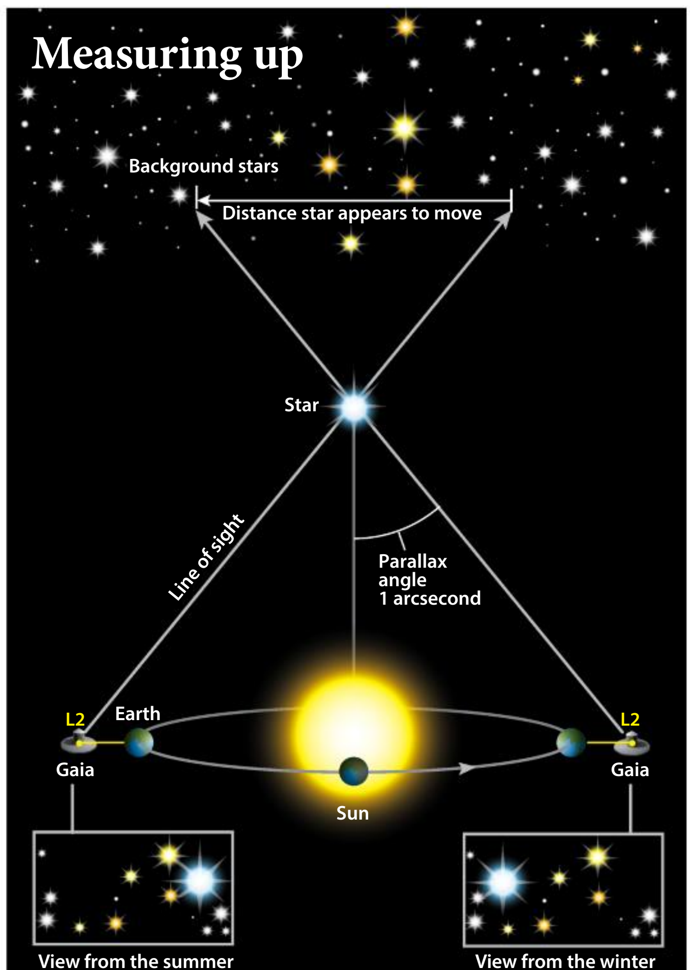
Eventually, Gaia's goal is to plot the distance of 100 million stars to better than 10 percent accuracy. For 10 million objects, its margin of error will be less than 1 percent. It will measure the positions and motions of more than 1 billion stars across the whole sky, down to 20th magnitude, with an accuracy of a few millionths of an arcsecond, crushing previous surveys.

For this first data release, though, Gaia needed some help. Gaia measures the motions of stars to determine their distance. From only the first year of data, it's impossible to untangle the motion of the stars from the telescope's own motion as it follows Earth's orbit around the Sun. But the Hipparcos satellite has already done this work once, for millions of Gaia's target stars. The Hipparcos catalog knows where these stars were 20 years ago, and Gaia knows where they are now, to even better precision. That extended timeline was just what Gaia needed.

So the Gaia team combined the final Hipparcos catalog, called Hipparcos-Tycho 2, with Gaia's data thus far. The Tycho-Gaia Astrometric Solution (TGAS) is the first step in an updated map that will eventually contain a star's position in 3-D, plus its motion, more accurately than ever before. For now, it contains 2 million stars, measured twice as precisely as by Hipparcos alone. By the end of Gaia's mission, the Hipparcos data will be superseded by Gaia's more precise measurements. But in the meantime, Hipparcos — and a few other surprising sources — are lending Gaia a helping hand.

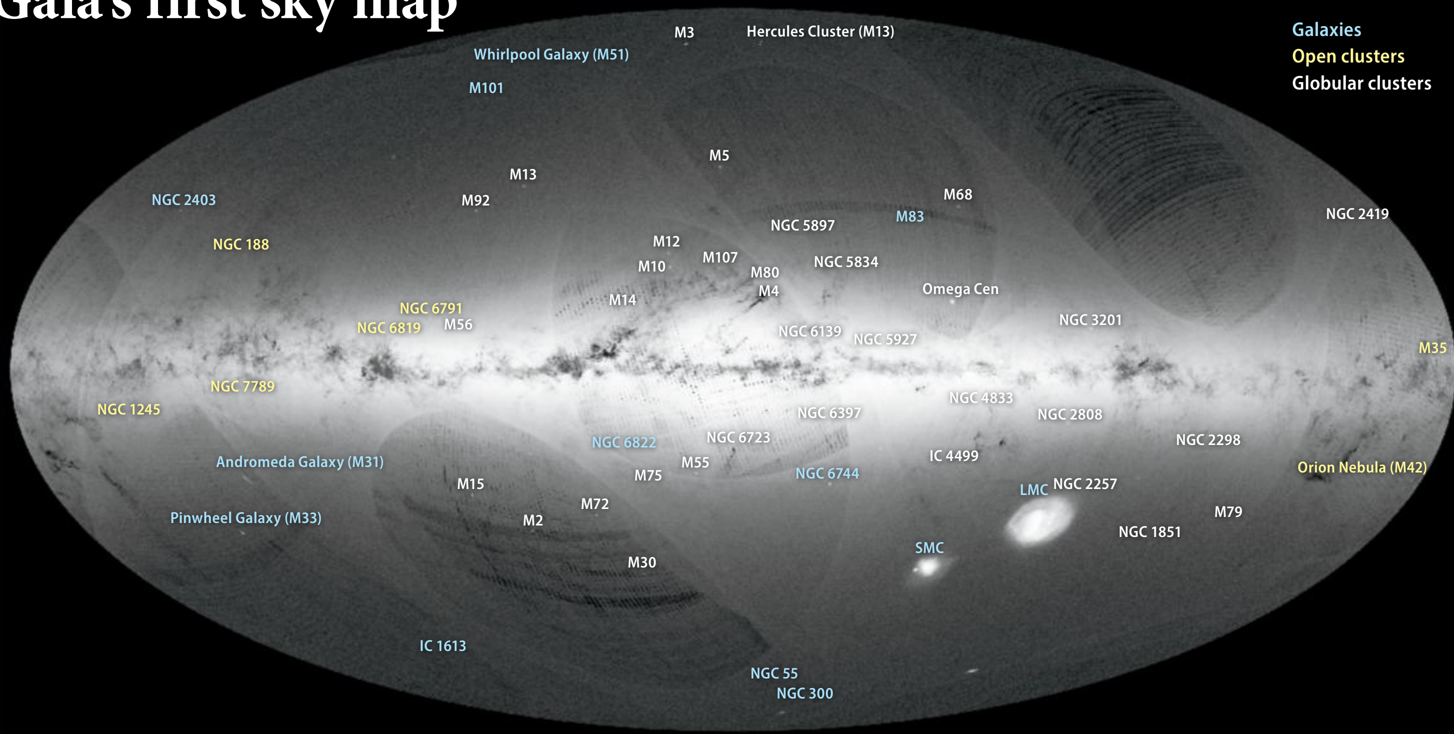
Ladder of the stars

One of Gaia's big tasks is calibrating the cosmic distance scale, which requires some stellar tools. Astronomers use two types of variable stars, called Cepheid variables and RR Lyrae stars, which brighten and fade on regular timescales. The time they take to brighten and fade scales in an orderly fashion with how intrinsically bright they are. So if two Cepheids have the same period, but one appears fainter, then that star must be farther away. Astronomers can determine its distance by observing its period and brightness.



To understand the distances between stars, astronomers rely on a method called parallax. By measuring the distances stars appear to move relative to other stars, astronomers can gauge how far away they are from us and from each other. *ASTRONOMY*: ROEN KELLY

Gaia's first sky map



In July 2014, Gaia began making its first map of the Milky Way and surrounding galaxies. By September 2015, it had completed the map above. Darker areas are dense clouds of interstellar dust. ESA/GAIA/DPAC

For this system to work, though, astronomers must have a solid understanding of the period-luminosity relationship. To calibrate it, they need to know the distance to some of these variable stars. Gaia will measure the closer stars using parallax, or the apparent change in position of a star due to Earth's orbital motion around the Sun. A nearby star will appear in front of different background stars during summer, when Earth (and Gaia, orbiting at a stable point behind our planet) is on one side of the solar system, than in winter, when Earth has changed its own position by 2 astronomical units (an astronomical unit is the average Earth-Sun distance).

> Some 400 million of Gaia's finds are new to human catalogs, as it resolves objects we previously saw as single points of light into multiple stars.

You can simulate this technique simply by holding a finger in front of your face and looking at it with just your left eye, and then your right. Your finger will appear to change position relative to background objects. So in astronomy, nearby stars have a greater apparent change in position than more distant stars, and this change in apparent position reveals their true distance from Earth. This independent distance measurement enables astronomers to calibrate the period-luminosity relationship of variable stars.

By the end of Gaia's mission, the correlation should be razor-sharp. Accurately measuring the distance to nearby variable stars and tightening the period-luminosity relationship will enable astronomers to extend this distance ladder to more distant stars, thereby deriving precise distances to faraway variable stars.

First steps

What can astronomers do with a partial Gaia survey? Plenty.

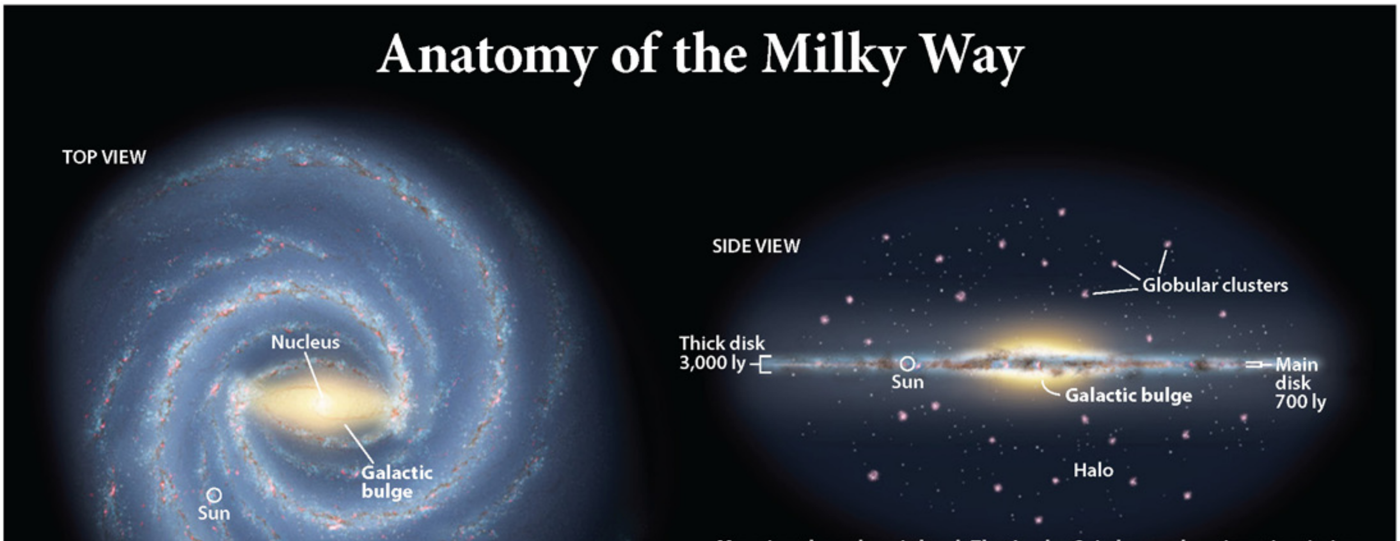
One of Gaia's goals is to provide an updated map of the Milky Way. Some 400 million of Gaia's finds are new to human catalogs, as it resolves objects previously seen as single points of light into multiple stars.

Also, by using the TGAS, astronomers can better understand how stars move, thereby showing them the structure of our galaxy — and some of its neighbors.

One early surprise Gaia delivered was a stunning image of the Milky Way. "I had asked for this image to be made, but it was much better than I expected," says Anthony Brown, a member of Gaia's science team. Brown is also chair of Gaia's Data Processing and Analysis Consortium, the group that makes Gaia's reams of data comprehensible to the science community. The image's clarity and sheer number of targets also suggests that the Milky Way is bigger than previous estimates, though exact numbers will probably wait until later data releases.

More definitively, the Large Magellanic Cloud next door is also bigger than expected. Researchers can study this miniature galaxy from the outside, and Gaia revealed that more stars than expected are tied to its motion across the cosmos. Gisella Clementini, a Gaia team member from Italy, explains, "We're looking in detail with much more powerful instruments than we had before. … Even if they're just behind the corner, because they're close, you find things."

One of Gaia's showier tests was its production of a color-magnitude diagram; plotting stars' color versus their brightness and where they fall on the diagram tells astronomers about their types and evolutionary stages. Most often, these diagrams are created from astrophysical models of stars rather than real data. But Gaia's keen vision and measurements have already provided enough data to build a rough diagram, and its full catalog should allow researchers to build a shockingly clear diagram based entirely on data, allowing theorists to hone their models.



Mapping the galaxy is hard. That's why Gaia has such a gigantic mission to undertake. But it's not just the stars in the disk Gaia is mapping — it's also globular clusters and other objects nearby. The Milky Way itself is 100,000 light-years across and 700 light-years high in the main disk, with some areas stretching as high as 3,000 light-years, thanks to the presence of diffuse older stars. LEFT: NASA/JPL-CALTECH; RIGHT: ESA; LAYOUT: ESA/ATG MEDIALAB

Gaia also identified within the Milky Way 1,394 variable stars, which change in brightness over set periods of time. Of these, 386 have not been observed in previous studies. These variable stars are the first wave of targets that will help Gaia with one of its other primary goals.

Surprise events

Even before the first data release, Gaia shared some stellar surprises with the greater community. The data processing team flagged objects of interest meriting quicker investigation, such as erupting stars, black holes, or supernova explosions. Such objects might have quieted down by the time of a formal data release, robbing researchers of the chance to follow up with other telescopes.

In September 2014, Gaia announced a supernova named Gaia14aaa. Gaia saw the host galaxy grow dramatically brighter between one month and the next, and astronomers quickly followed up with two ground-based telescopes. By studying the spectrum, or light signature, of the galaxy, they determined that the bright light represented a type Ia supernova, when a white dwarf is goaded by a companion star into blowing itself apart.

Another surprising source, named Gaia14aae, flared bright in Gaia's vision in August 2014. Astronomers eventually determined it was a cataclysmic variable, or a system of two stars cannibalizing each other. The uneven gobbling of material can cause energetic outbursts of light. Both professional and amateur astronomers followed up and discovered that the stars lacked any signature of hydrogen, which forms the bulk of most stars in the universe. Both stars are old and have consumed all their usable hydrogen, putting them in a rare class of cataclysmic variables called AM Canum Venaticorum stars, named for the first system of this type found.

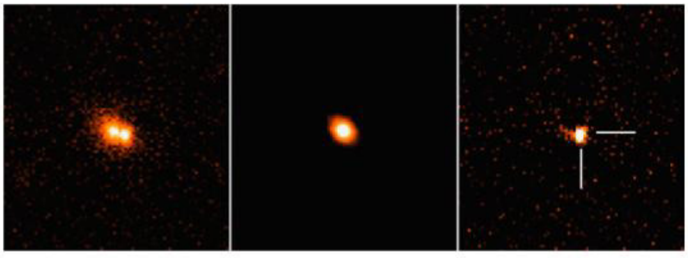
With Gaia's whole-sky gaze, the survey will continue to turn up transient sources — a few to 10 per day, filtered down from roughly a million potential objects leaping out of a first pass through the data — that the general astronomy community can pursue between data releases.

Freedom of information

It took ESA years to release the Hipparcos catalog, waiting until its entire survey was complete and fully analyzed. With Gaia, they're throwing the doors open early. While the survey isn't yet complete, the science team believes there's great value in letting in the science community at the beginning of the process.

David Hogg, a researcher at New York University and a proponent of open access in science, couldn't be more thrilled. He's been organizing "hack days" at astronomy conferences for a few years now and has even expanded them to "hack weeks." In line with more traditional computer programming, hack days — which are more about building things quickly rather than any kind of cyberattack — are designed around the idea that if you put enough smart people into a room to work on focused projects, brilliant ideas and solid results will follow.

Only a month after the first data release, Hogg and some colleagues held a Gaia "sprint" in New York. "It's obvious to me that a huge amount of science is going to come out of the sprint," Hogg says. Multiple papers already are available either online or circulating through his and other researchers' inboxes as they gather comments before publication. All represent, in his opinion, publishable science. In attendance were Brown and Alcione Mora, another



Even though Gaia is tasked with mapping the Milky Way, most of the sky is in its sights. As a result, Gaia captured this image of Gaia14aaa, a supernova in a galaxy 500 million light-years away. The middle image of the triptych was taken by the Sloan Digital Sky Survey. M. FRASER/S. HODGKIN/L. WYRZYKOWSKI/H. CAMPBELL/N. BLAGORODNOVA/Z. KOSTRZEWA-RUTKOWSKA/LIVERPOOL TELESCOPE/SDSS

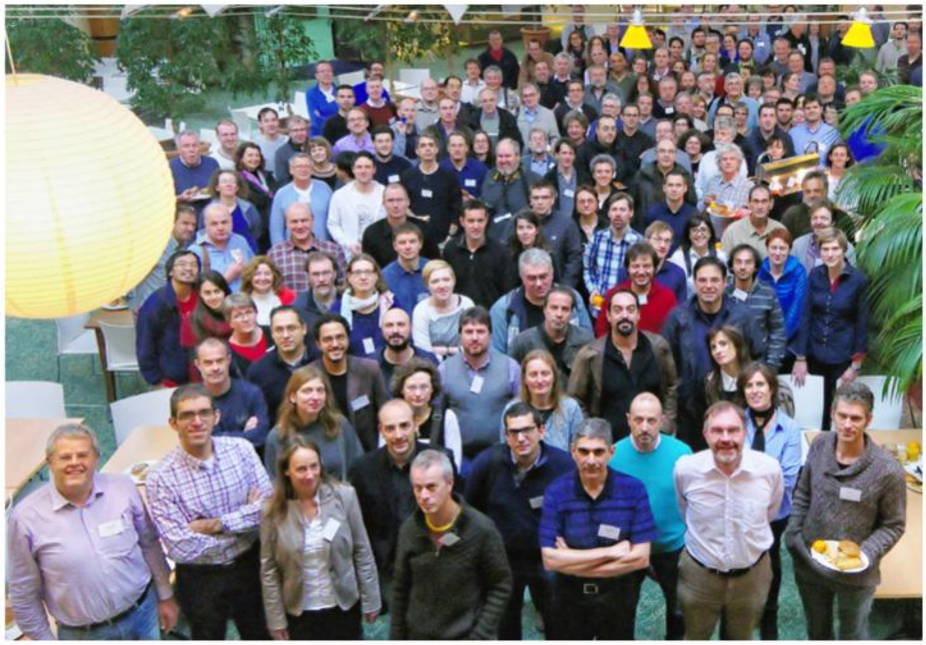
THE PLEIADES ARE PROBABLY STILL WHERE WE THOUGHT

Astronomers have many ways of estimating the distances to stars, especially bright and well-studied systems.

One method uses stellar models to determine a star's true brightness, and therefore derive its distance. Some stars are tougher to measure than others, but when many different studies agree, astronomers trust their results. So, by the mid-1990s, they were pretty confident that the distance to the well-known Pleiades star cluster was roughly 430 light-years.

Hipparcos, Gaia's predecessor, was tasked with Gaia's same job of determining precise positions for a massive number of stars. But Hipparcos found a startlingly closer value for the Pleiades: only 390 light-years. This value remained even after re-reducing the data in 2007, at odds with nearly every other measurement of the Pleiades by other means.

One of Gaia's side quests is to resolve this dispute. And while most of Gaia's first-release data matches Hipparcos' catalog, the Pleiades appear to remain in line with everybody else's distance measurement. Gaia's first release still contains systematic uncertainties and large error bars that keep astronomers from being positive, but the preliminary data points to Hipparcos remaining the outlier. — K. H.



It takes a village to run a spacecraft. Part of that "village" is the Gaia Data Processing and Analysis Consortium, shown here in November 2015. The team takes raw data from the Gaia spacecraft and processes it, helping compile the massive catalog that will come at the end of the mission and be used for decades going forward. ESA/GAIA/DPAC

Gaia team member. But it was the outsiders who put on the show.

Vasily Belokurov from the University of Cambridge pulled an entirely unexpected sub-catalog out of the Gaia release. In the future, Gaia will produce a full catalog of the variable stars that function as priceless tick marks on the cosmic distance scale. So far, this collection is small and confined to a short list that Gaia inventoried early in its mission, but Belokurov says that a much larger catalog is hiding in plain sight.

He used Gaia's photometric uncertainties to prove that stars with higher uncertainties are actually the variable stars astronomers are waiting for. Although these stars are not officially categorized as such by the Gaia team, Belokurov could compare these Gaia sources to past, fully reduced catalogs, to prove they are real. This should allow astronomers to get a jump-start on data they would otherwise have to wait until the next data release, a year or more away, to see.

Jo Bovy, from the University of Toronto, measured the Oort constants "while he was waiting for files to unzip," Hogg says, highlighting the fast-paced nature of a science sprint. The Oort constants, named after the same Jan Oort who predicted the Oort Cloud, are two numbers that determine how the Milky Way rotates. They can be measured by looking at large populations of stars in our home galaxy and studying how they move. With the initial release, Bovy recalculated the numbers in a few minutes. "And he got better values than have ever been measured previously," Hogg says.

While the survey isn't yet complete, the science team believes there's great value in letting in the science community at the beginning of the process.

Hogg himself is digging into how a star's movement relative to the disk of the galaxy is tied to its age. Astronomers have known for a long time that stars gain velocity with age, but the exact relationship has been hard to pin down. This is a common problem with stellar age; humans, after all, don't live long enough to see stars be born and die, and most of astronomers' age measurements are somewhat vague or rely heavily on models. With Gaia's precision and its preliminary results, the next generation of astronomers may have accurate ages for stars based solely on their velocities, Hogg says.

Hogg says Gaia isn't the only massive astronomy project to make its data public. The Kepler mission and the Sloan Digital Sky Survey, among others, made their data publicly accessible, benefiting from outside users turning up hidden gems. When one researcher suggests or requests improvements to how the data is processed or shared, the Gaia mission team can share the benefits with everyone, as well as reap rewards themselves.

But Hogg credits the Gaia mission's leadership, especially Brown and Timo Prusti, for championing open access to the data and for their unflagging partnership with the science community to work through the inevitable questions, even before the survey reaches maturity. The result is a communitywide team effort, and the payoff is more science for everyone.

Hogg is planning future Gaia sprints: this year in Heidelberg, Germany, and in New York again in 2018. Gaia's primary mission won't even complete until 2019. As the catalog matures, Gaia will reveal exoplanets with its radial velocity data, and even sharper views of the Milky Way's structure.

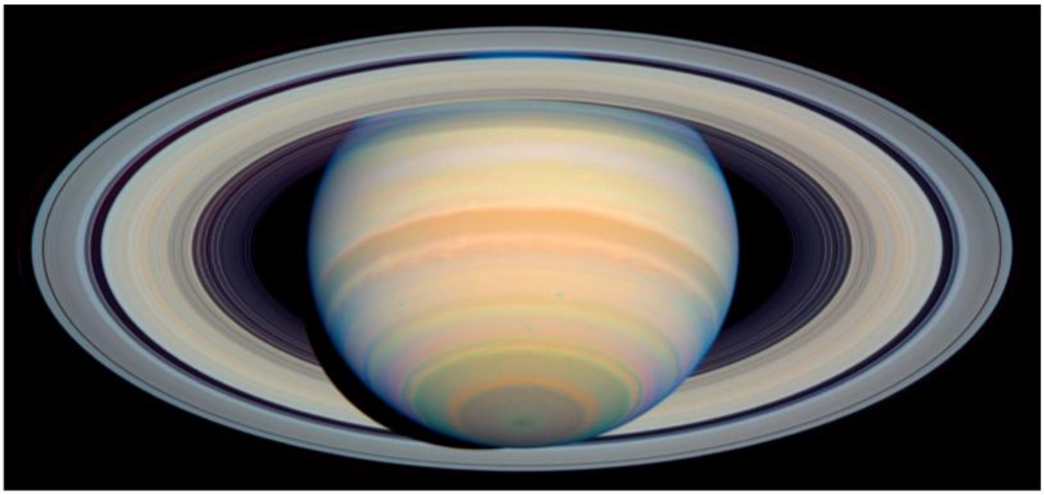
"So far we've seen only the tip of the iceberg," promises Prusti. With this much fresh science from the first release, we can only wait to see what the full and dazzling picture of our Milky Way reveals.

Korey Haynes *is a contributing editor to* 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

June 2017: Peak for the ringed planet

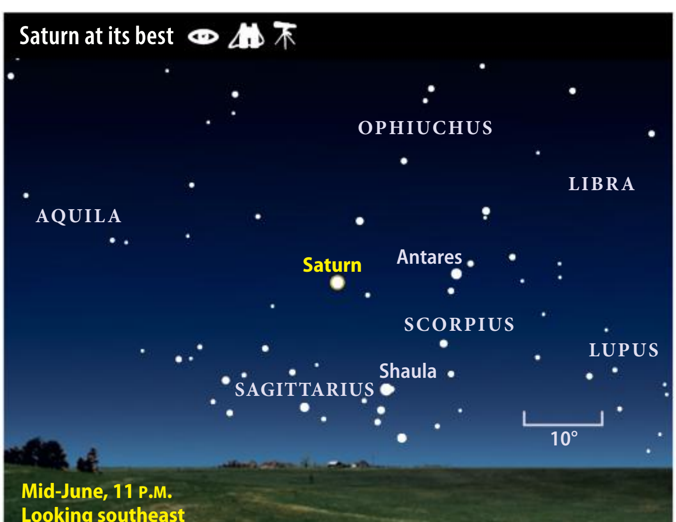


Saturn's rings open wider this year than at any time since 2003. At opposition this month, they tilt 27° to our line of sight and afford observers spectacular views through any telescope. NASA/ESA/E. KARKOSCHKA (UNIVERSITY OF ARIZONA)

Two giant planets adorn the early summer sky. Jupiter shines brilliantly throughout the evening hours, and Saturn remains visible all night as it reaches opposition. Be sure to target the magnificent ringed planet around this time of peak visibility. There's something for early risers, too, as Venus appears stunningly bright in the predawn sky.

Let's kick off our planet viewing this month with a final glimpse of **Mars**. The Red Planet lies low in the west-northwest after sunset in early June. You'll likely need binoculars to spot the magnitude 1.7 object against the twilight glow. Scan for it well below and a little to the right of Gemini's twin stars, Castor and Pollux. Mars becomes lost in the Sun's glare during June's second week and won't return to view until September.

Saturn at its best



The ringed planet reaches its peak June 15, when it lies opposite the Sun in our sky and remains visible all night. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

You'll have no such trouble finding **Jupiter**. The giant world blazes at magnitude –2.2, far brighter than any other evening object except for the Moon. You can compare these two standouts June 3, when the waxing gibbous Moon passes 2° from the planet. The stunning pair stands high in the south after sunset and remains on view until well past midnight.

Jupiter appears nearly stationary against the background stars of Virgo the Maiden during June. It starts the month 3° southeast of 3rd-magnitude Gamma (γ) Virginis. The planet's glacial westward motion comes to a halt the night of June 9/10; it then begins a slow eastward trek that carries it 4° from Gamma by the 30th. The Moon returns to this vicinity that same night, and actually passes in front of Gamma for observers across much of North America.

It's always worth exploring Jupiter through a telescope. Catch it during the evening hours this month — seeing conditions deteriorate when it dips low in the west after midnight. The planet spans 39" at midmonth and offers lots of detail to patient observers. Any instrument should reveal Jupiter's two dark equatorial belts, one on either side of a brighter equatorial zone coinciding with the planet's equator. In moments of good seeing, a series of alternating belts and zones comes into view. And keep an eye out for the Great Red Spot — it shows up clearly as long as it's on the hemisphere facing Earth.

Examining Jupiter is only half the fun, however. Any scope also reveals up to four moons. They shine at 5th and 6th magnitude, bright enough that they would show up to the naked eye under a dark sky if the planet weren't so bright. Io, Europa, Ganymede, and Callisto appear in different positions relative to Jupiter every night. And one or more of these moons frequently crosses the planet's disk (a transit), casts its shadow on the cloud tops, or disappears while passing behind Jupiter or into its shadow.

As darkness falls the night of June 1/2, Io and Europa both lie off the planet's eastern limb. Europa begins its transit at 1:18 A.M. EDT and Io follows 80 minutes later. Europa's shadow appears on the jovian cloud tops starting at 3:31 A.M., with Io's shadow trailing 11 minutes behind.

Io teams with Ganymede's shadow the night of June 3/4. Io strikes first, crossing in front of the planet's eastern

RISING**MOON**

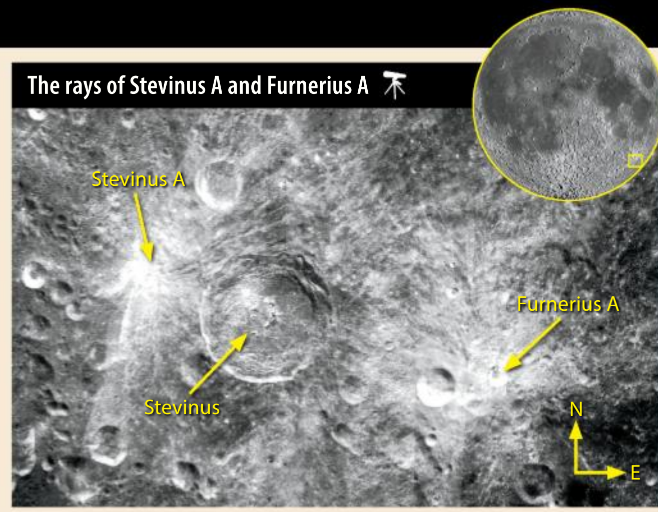
Highlights in the southern highlands

Few lunar features grab more attention near Full phase than the rayed crater Tycho. The impact that gouged out Tycho launched huge quantities of pulverized dust across the Moon's nearside. This material lights up under the Sun's overhead illumination around Full Moon. Because the impact happened quite recently in lunar history, its bright ejecta has not had time to darken under the weak but relentless sandblasting of particles blowing in the solar wind.

Although Tycho may be the brightest rayed crater, it's not the only one. The most conspicuous features near the Full Moon's southeastern limb are two smaller cousins: Stevinus A and Furnerius A.

Zoom in on the area between June 2 and 9 to separate the sources of these white rays. Stevinus A glows brighter than Furnerius A, which lies closer to the lunar limb. Yet Furnerius A is slightly larger — spanning 7.5 miles compared with its neighbor's 5.1-mile diameter. The two straddle the modest 45-mile-wide crater Stevinus. Don't expect to see Stevinus under the high Sun, however. Topographic features show up best when sunlight hits them at a shallow angle.

The rays of Stevinus A and Furnerius A



Bright rays radiate from Stevinus A and Furnerius A, drawing attention to the Full Moon's southeastern limb. NASA/BMDO/NRL/LLNL; INSET: NASA/GSFC/ASU

It's better to look for Stevinus during June's final week.

If the Full Moon's glare is too much for your eyes, try using a Moon filter. Other techniques for dimming the Moon include pumping up the scope's power and putting on sunglasses.

limb at 9:06 P.M. EDT. The moon's shadow appears beginning at 10:10 P.M. Eleven minutes later, Ganymede's large shadow initially falls on the gas giant's north polar region. These shadows dramatically alter Jupiter's appearance all evening. Io's transit ends at 11:16 P.M. Its shadow lifts back into space at 12:21 A.M., and Ganymede's shadow follows 16 minutes later.

Three moons take center stage the night of June 10/11. In eastern North America in the early evening, Ganymede and Io appear against Jupiter's disk. Ganymede exits at the stroke of midnight EDT, five minutes before Io's shadow appears at the opposite limb. Io's transit ends at 1:07 A.M., while its shadow remains on the planet's disk until 2:15 A.M. Ganymede's shadow starts a transit five minutes after that. The night's final event occurs around 3:10 A.M., when Europa emerges from Jupiter's shadow some 30" from Jupiter's eastern limb.

Saturn reaches opposition June 15, when it lies opposite the Sun in our sky and thus remains visible all night. The planet also comes closest to Earth at opposition, so it shines brightest and looms largest when viewed through a telescope. Although you can view the ringed planet any time of night, the best observing comes when it lies high in the south from late evening through early morning.

Saturn lies against the star fields of eastern Ophiuchus,

— Continued on page 42

METEORWATCH

On the hunt for twilight clouds

Although no major meteor showers occur during June, it's worth keeping an eye to the sky for sporadic meteors. These flashes of light arise when tiny dust particles enter Earth's atmosphere and friction with the air vaporizes them. On a dark night, observers typically see a half-dozen or so of these sporadics per hour.

But this fine meteoritic dust also plays a role in creating summer's beautiful noctilucent clouds. These highly reflective, silver-blue clouds develop in the coldest part of Earth's atmosphere, about 50 miles above the surface, where ice crystals form on the dust particles. They appear most often in early summer from latitudes between 50° and 60° north. Look for them during twilight an hour or two after the Sun sets (or before the Sun rises), when our star still illuminates these high-flying clouds but the lower atmosphere is dark.

Delicate noctilucent clouds

During June's extended evening twilight, northern viewers should keep their eyes out for these high-altitude clouds. ALAN C. TOUGH

OBSERVING HIGHLIGHT Venus puts on a brilliant show before dawn as it reaches greatest western elongation June 3. It then shines at magnitude –4.4.

STAR DOME

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

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

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

Planets are shown at midmonth

STAR MAGNITUDES

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

STAR COLORS

A star's color depends on its surface temperature.

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

MAP SYMBOLS

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

JUNE 2017

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

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

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

1 First Quarter Moon occurs at 8:42 A.M. EDT

2 Venus passes 1.8° south of Uranus, 11 A.M. EDT

3 Venus is at greatest western elongation (46°), 9 A.M. EDT

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

5 Dwarf planet Ceres is in conjunction with the Sun, 8 P.M. EDT

8 The Moon is at apogee (252,526 miles from Earth), 6:21 P.M. EDT

9 Full Moon occurs at 9:10 A.M. EDT

The Moon passes 3° north of Saturn, 9 P.M. EDT

10 Jupiter is stationary, 1 A.M. EDT

12 Mercury passes 5° north of Aldebaran, 7 A.M. EDT

15 Saturn is at opposition, 6 A.M. EDT

SPECIAL OBSERVING DATE

15 Saturn reaches its peak, shining at magnitude 0.0 and appearing 18.4" across through a telescope (the rings span 41.7" and tilt 27° to our line of sight).

16 The Moon passes 0.7° south of Neptune, 9 A.M. EDT

Neptune is stationary, 7 P.M. EDT

Asteroid Hebe is at opposition, 11 P.M. EDT

17 Last Quarter Moon occurs at 7:33 A.M. EDT

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

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

21 Summer solstice occurs at 12:24 A.M. EDT

Mercury is in superior conjunction, 10 A.M. EDT

22 The Moon passes 0.5° north of Aldebaran, 11 A.M. EDT

23 The Moon is at perigee (222,412 miles from Earth), 6:52 A.M. EDT

Asteroid Harmonia is at opposition, 7 A.M. EDT

New Moon occurs at 10:31 P.M. EDT

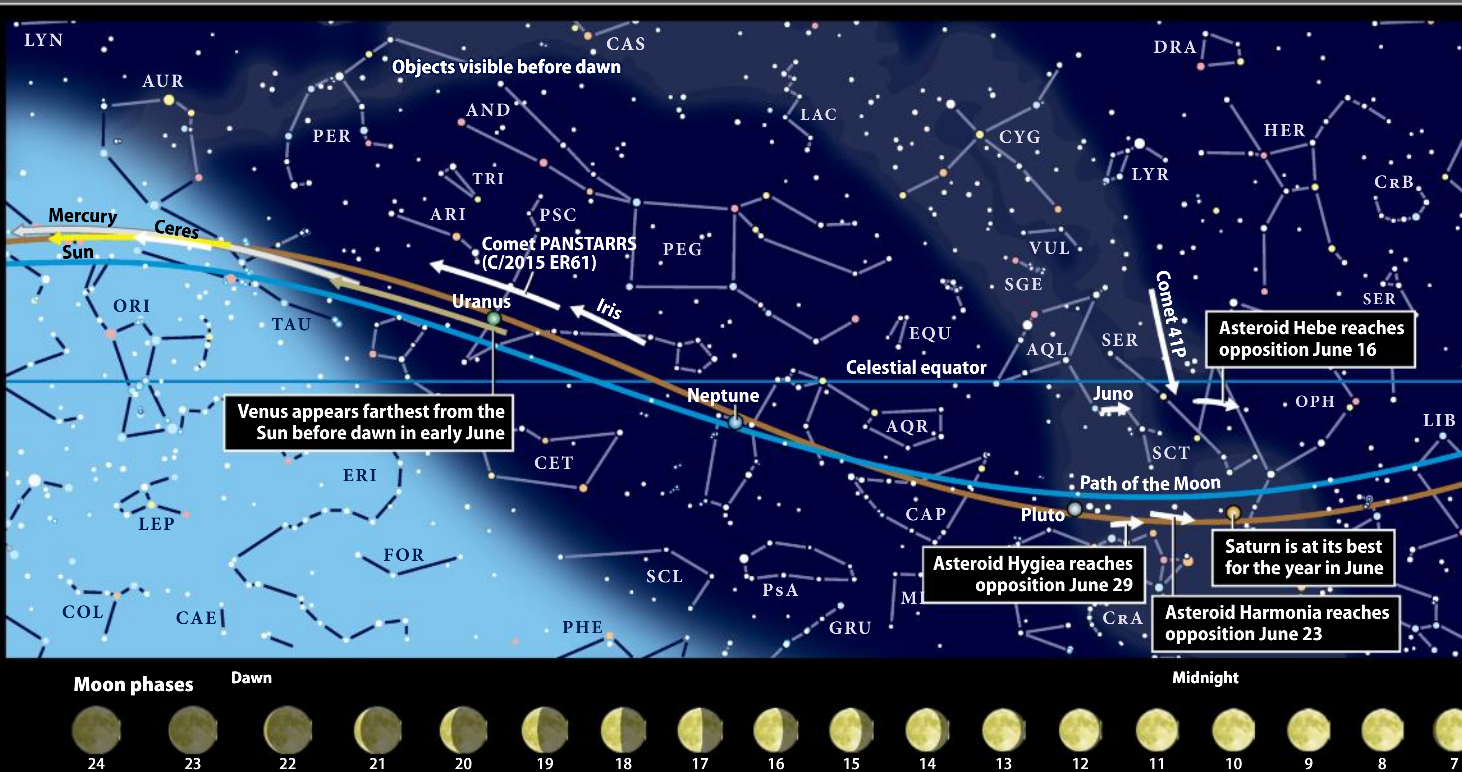
27 The Moon passes 0.03° south of Regulus, 9 P.M. EDT

29 Asteroid Hygiea is at opposition, 3 P.M. EDT

30 First Quarter Moon occurs at 8:51 P.M. EDT

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

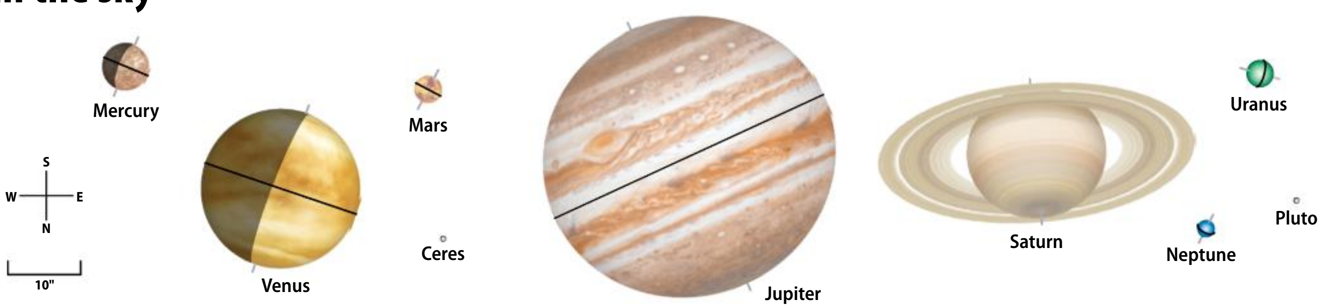
The planets in June 2017



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.

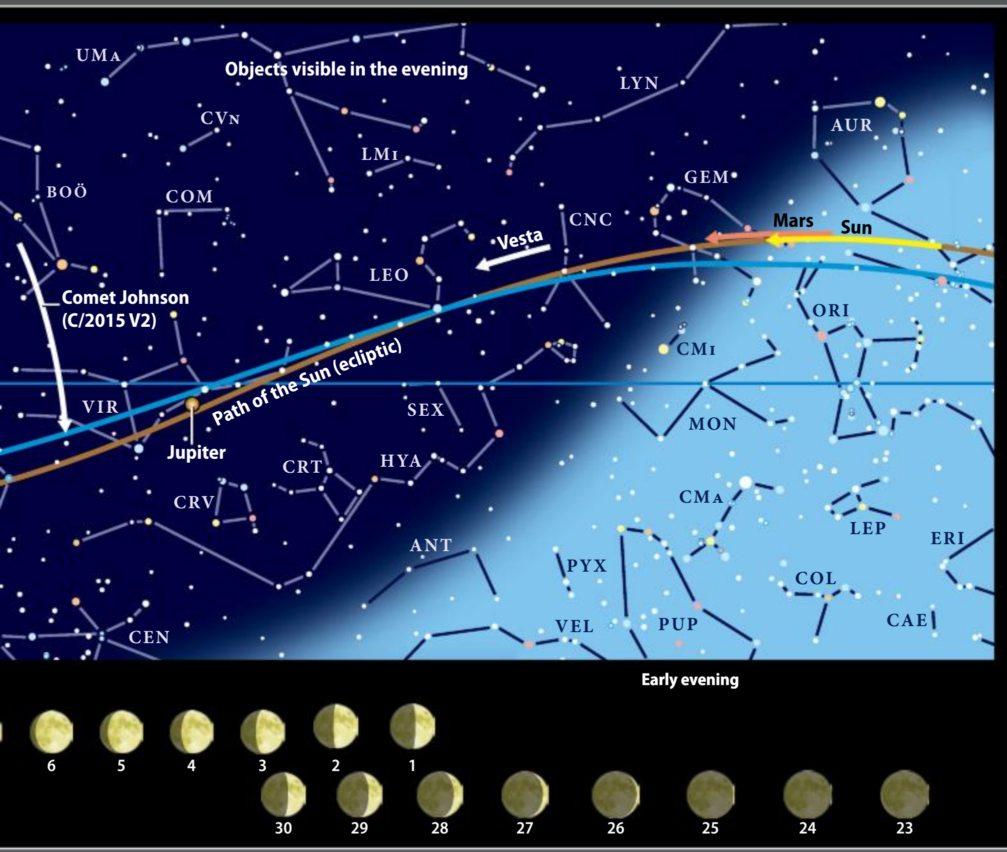
The planets in the sky

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.



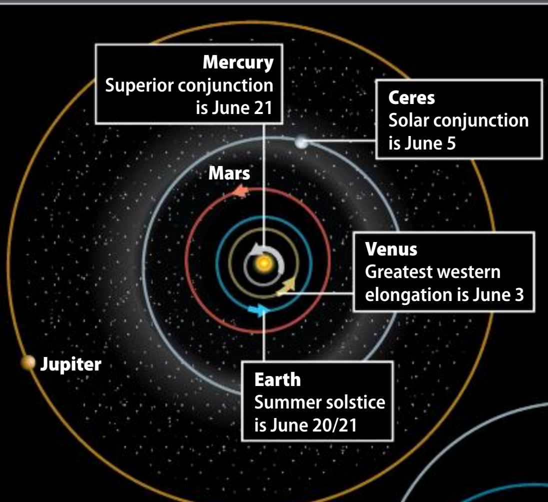
Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	June 1	June 15	June 1	June 15	June 15	June 15	June 15	June 15	June 15
Magnitude	–0.4	–4.3	1.7	8.6	–2.2	0.0	5.9	7.9	14.2
Angular size	6.3"	21.1"	3.7"	0.4"	39.2"	18.4"	3.4"	2.3"	0.1"
Illumination	66%	55%	99%	100%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.069	0.793	2.532	3.713	5.035	9.043	20.466	29.758	32.422
Distance (AU) from Sun	0.384	0.728	1.589	2.703	5.453	10.058	19.924	29.948	33.348
Right ascension (2000.0)	3h11.1m	2h27.9m	5h48.2m	5h12.5m	12h50.0m	17h35.4m	1h42.3m	23h02.5m	19h19.6m
Declination (2000.0)	15°21'	11°49'	24°17'	22°34'	–3°52'	–21°58'	10°00'	–7°07'	–21°22'

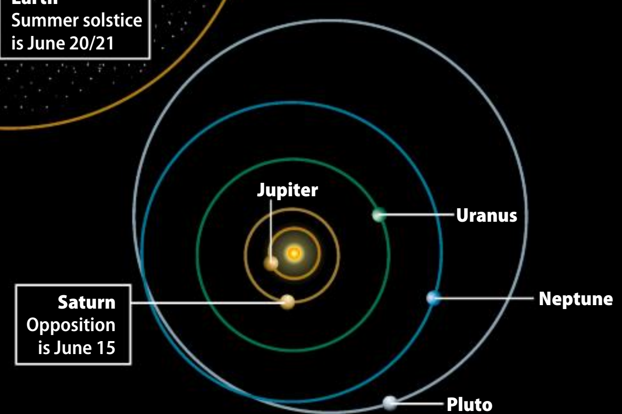
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



The planets in their orbits

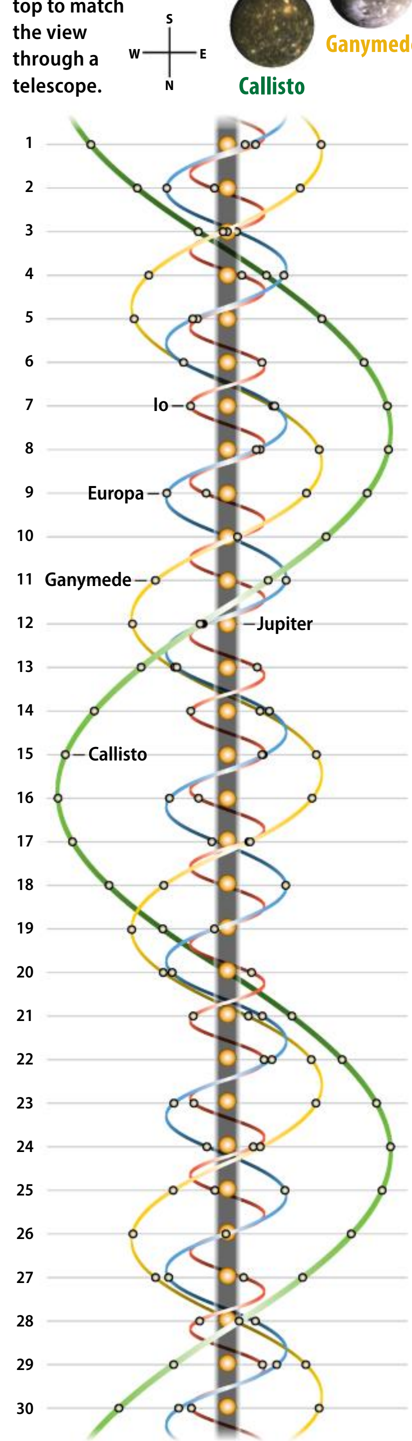
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.





Jupiter's moons

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



ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

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

just over the border from neighboring Sagittarius. Shining at magnitude 0.0 at opposition, the planet appears far brighter than any star in the surrounding constellations.

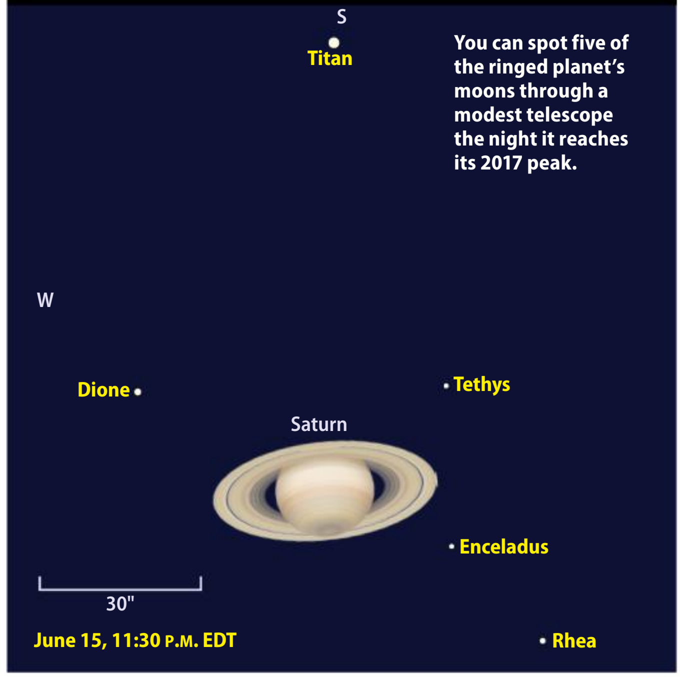
Any telescope delivers spectacular views of Saturn. The planet's disk measures 18" across at midmonth while the rings span 42" and tip 27° to our line of sight. This is their biggest tilt since 2003, and it makes structure easier to see than normal. The Cassini Division — a 3,000-mile-wide gap that separates the outer A ring from the brighter B ring — stands out nicely.

Several of these moons are in range of small telescopes. Giant Titan shines at 8th magnitude and appears as the brightest object near Saturn through any instrument. It orbits the planet in 16 days, passing north of the gas giant June 8 and 24 and south of it on the night of opposition, June 15/16. When Titan lies farthest east or west of the planet, it stands 3' away.

Three 10th-magnitude moons lie less than half that distance from Saturn. Tethys, Dione, and Rhea all show up through 4-inch scopes. You'll likely need an 8-inch instrument to see 12th-magnitude Enceladus. This active world — the Cassini probe discovered geysers erupting from its south pole — proves challenging because it orbits close to the glare of Saturn's rings. You can pinpoint these five satellites on the night of opposition with the help of the chart above.

By the time Saturn climbs highest in the south, **Neptune** rises in the east along with the stars of Aquarius. Glowing at magnitude 7.9, it's an easy binocular target in the southeastern sky an hour before twilight begins. Use the western side of the Great Square of Pegasus as a guide.

Saturn's satellites strike an opposition pose



You can spot five of the ringed planet's moons through a modest telescope the night it reaches its 2017 peak.

COMETSEARCH

A trio of tempting targets

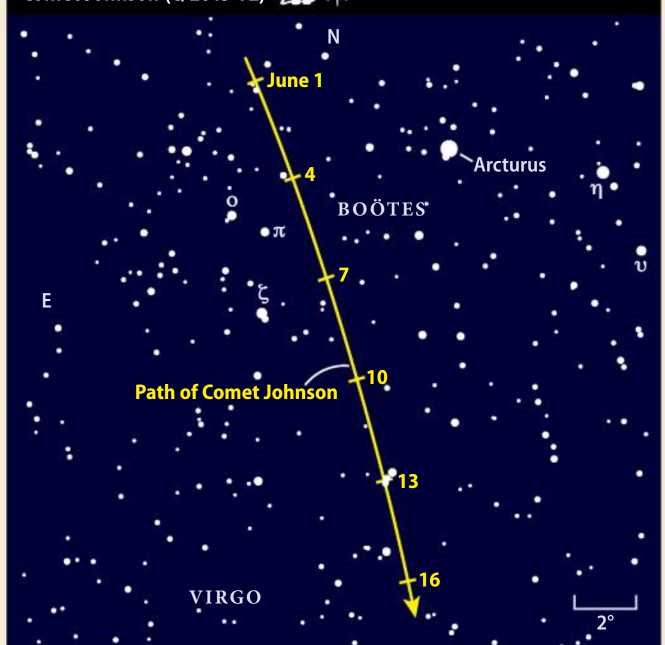
Our current comet cornucopia will last only a couple more months, so take advantage of it while you can. Comet Johnson (C/2015 V2) has been brightening for more than a year and should reach its peak in June. This first-time visitor to the inner solar system makes its closest approach to Earth on the 5th, one week before it passes closest to the Sun. And Johnson also remains visible all night. The 6th-magnitude object moves from Boötes into Virgo this month, passing east of magnitude 0.0 Arcturus on June 3 and 4.

Earth also swings from one side of the comet to the other. Imagine viewing a picture of a classic V-shaped comet taped to a window as you approach a door next to it. The comet transforms into an edge-on knife as you walk through the door and then returns to its V shape once you reach the other side. Comet Johnson appears edge-on May 30 and returns to normal two or three nights later.

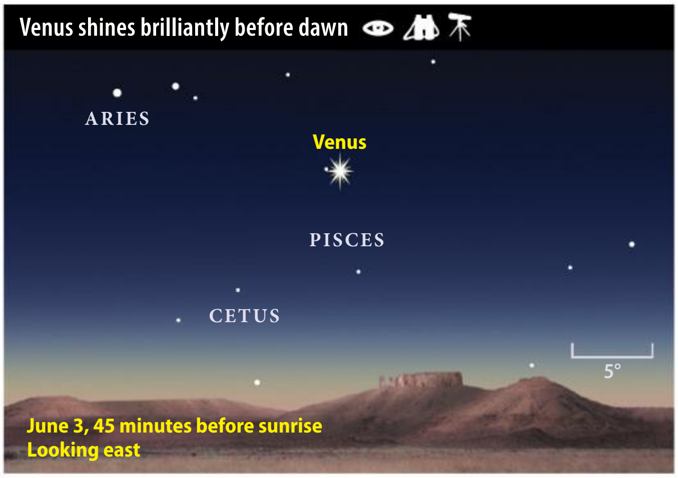
Comet 41P/Tuttle-Giacobini-Kresak also stays out all night. Look for this 9th-magnitude object once the Moon exits the evening sky on the 11th. It's then heading south along the eastern border of Ophiuchus. It skims west of the open star cluster NGC 6633 from June 12–14.

Comet PANSTARRS (C/2015 ER61) rounds out our comet trio. It should reach 7th magnitude in this month's morning sky. The best views come in June's first week as it speeds eastward against the backdrop of Pisces.

Comet Johnson (C/2015 V2)



June's brightest comet should glow at 6th magnitude as it passes south through the starry backdrop of Boötes and Virgo.



Earth's nearest planetary neighbor puts on a stunning predawn show in early June as it reaches its greatest elongation from the Sun.

Extend a line from Beta (β) to Alpha (α) Pegasi to the south about twice the distance between those stars and you'll be in the planet's vicinity.

Neptune lies roughly midway between 4th-magnitude Lambda (λ) and Phi (ϕ) Aquarii. Grab binoculars and locate 6th-magnitude 81 Aqr between them. Neptune lies about 15' east of this star throughout June.

Uranus rises less than two hours after Neptune. In early June, this means near the end of twilight. Brilliant Venus stands near Uranus, however, and serves as a useful guide to finding the distant planet through binoculars. On the 1st, Uranus lies 2.4° northeast of Venus and appears in the same binocular field. As Venus wanders eastward, it passes 1.8° due south of Uranus on the 2nd and remains within 2° of the outer world through the 4th. Target Venus with your binoculars and imagine it as the center of a clock's face. You'll find Uranus just above the 9 o'clock position June 1, at 10 o'clock on the 2nd, at 11 o'clock on the 3rd, and at 12 o'clock on the 4th. You'll need to look carefully to spot magnitude 5.9 Uranus, which glows some 10,000 times fainter than Venus.

Uranus rises earlier and appears against a darker sky as June progresses. Use magnitude 4.3 Omicron (ο) Piscium as a guide during the month's waning days. On the 30th, the planet lies 1° north and a touch west of the star.

Venus reaches greatest elongation June 3, when it lies 46° west of the Sun. The inner planet then rises two hours before our star and climbs more than 10° high in the east an hour before sunup. Venus shines at magnitude –4.4 and appears far brighter than any other morning object. The planet's solar elongation shrinks by a couple of degrees during June, but by month's end, it rises 2.5 hours before the Sun and stands 5° higher than it did early in the month. That's because a line joining Venus and our star makes a steeper angle to the horizon as the month advances.

A majestic vista awaits observers on June 20 and 21, when a waning crescent Moon appears near Venus. Another photogenic scene arrives at month's end. On the 30th, Venus stands 8° to the right of the Pleiades star cluster (M45). The two rise together in a dark sky. As morning twilight starts to paint the sky an hour later, the Hyades star cluster pokes above the horizon.

When viewed through a telescope June 1, Venus shows a 24"-diameter disk that appears slightly less than half-lit. As the planet moves away from us during the month, it shrinks in size while turning more of its sunlit hemisphere in our direction. On the 30th, the planet spans 18" and shows a 62-percent-lit phase.

You might catch a glimpse of **Mercury** before dawn in early June. On the 1st, the innermost planet lies 4° high in the east-northeast a half-hour before sunrise. It shines brightly, however, at magnitude –0.4, and should show up through binoculars if you have an uncluttered horizon. Mercury disappears soon after as it heads toward superior conjunction June 21.

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**

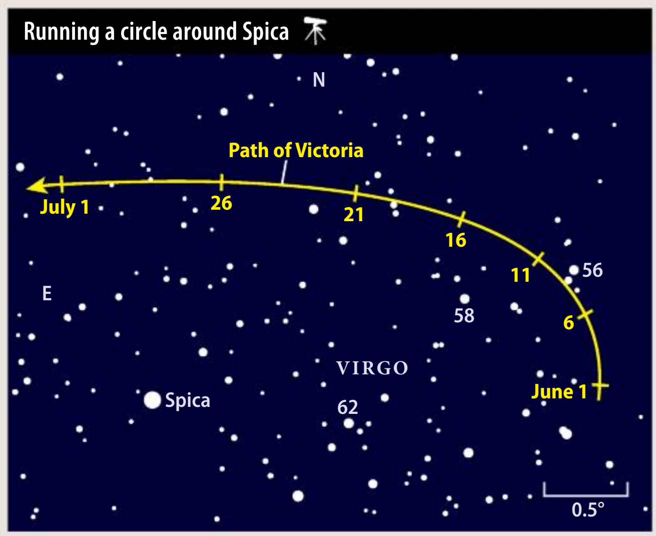
Victory goes to Victoria in June

We usually feature bright asteroids because they tend to be easier to track against the starry background. But brighter is not always better. You'll never get lost looking for 12 Victoria this month because it lies no more than 2.5° from 1st-magnitude Spica, Virgo's blue-white luminary. This area lies high in the southwest once evening twilight fades away.

Still, you'll need to pay close attention to the star patterns to identify this 70-mile-wide minor planet. Victoria dims from magnitude 10.5 to 11.0 this month, and lots of similarly bright stars populate its vicinity.

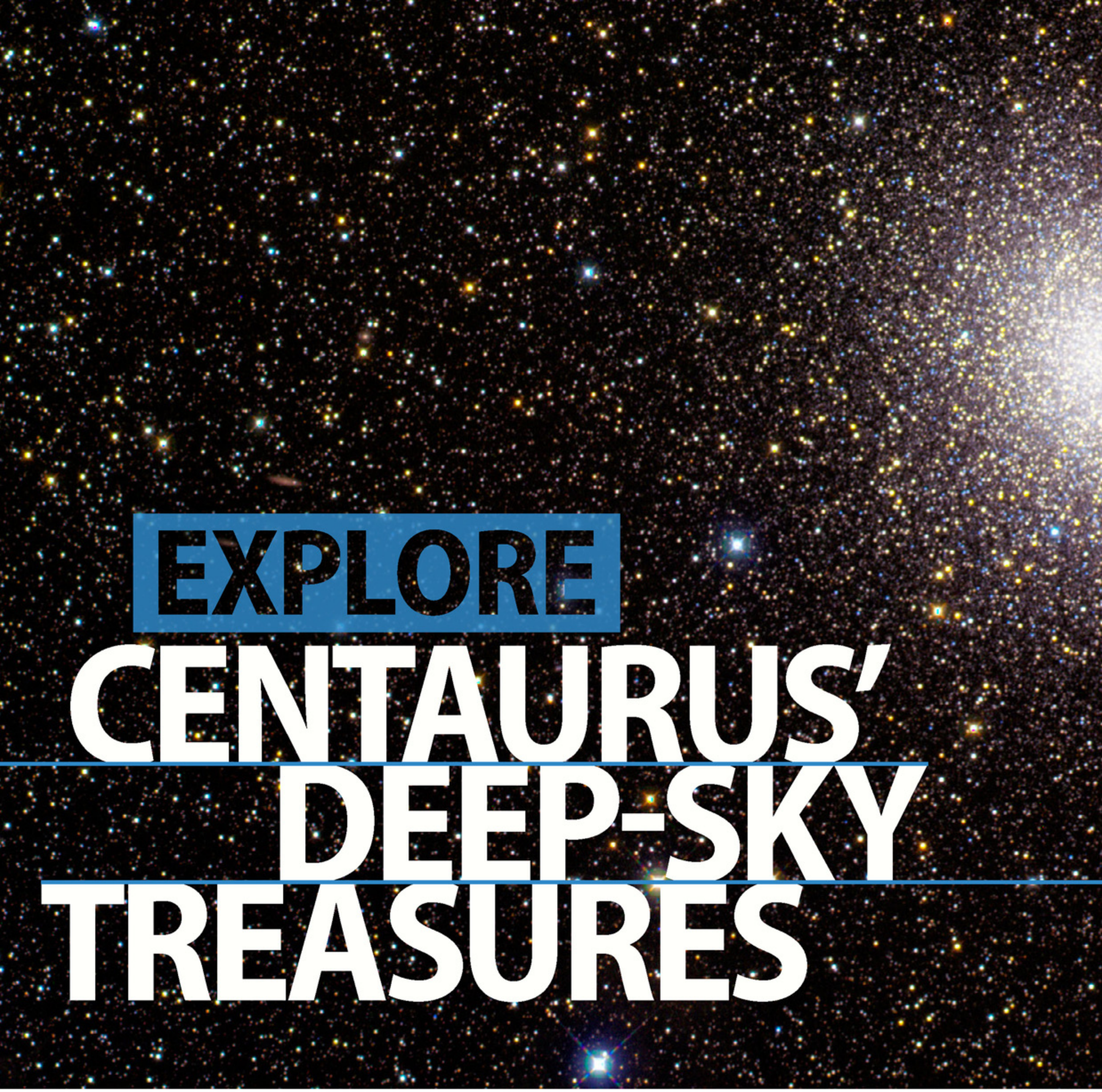
Use the chart below, which shows objects to magnitude 11.0, to home in on the right region. Your best strategy is to notice its movement from night to night against the background lights. Good times to try include June 7 and 8, when Victoria skims east of a triangle of stars that includes 56 Virginis, and June 18–20, when the asteroid slides through a crooked line of stars.

Sketch the field on one night and pencil in the point of light you think is Victoria. By the next night, you should be able to detect Victoria's displacement and thus confirm its identity.



Victoria glows at 11th magnitude as it loops north and then east through Virgo, never straying more than 2.5° from 1st-magnitude Spica.

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



EXPLORE CENTAURUS' DEEP-SKY TREASURES

From stars and star clusters to galaxies and galaxy clusters, this constellation will keep you observing all spring. **by Michael E. Bakich**

For most amateur astronomers in the United States, the constellation Centaurus lies largely hidden below the southern horizon. In fact, you'd have to travel down to 25° north latitude to see the entire Centaurian pattern rise above the ground. That happens from Brownsville, Texas, or Miami. Even from those cities, however, several objects on this list would scarcely be 2° above the horizon at their highest. And Hawaii nets you only an extra 5° in altitude.

Many of us, however, travel to the Southern Hemisphere, either for work or as a vacation

Left: The globular cluster Omega Centauri is the brightest of its kind in Earth's sky, and a moderate-sized telescope reveals more than 1,000 stars within its glowing sphere. GERALD RHEMANN

Below left: The Pearl Cluster, NGC 3766, offers a rich field of bright stars scattered around two prominent orange suns. MICHAEL SIDONIO

Below right: A bright, small planetary nebula in Centaurus, NGC 3918 is visible through small telescopes as a circular glow with high surface brightness. ROBERT RUBIN (NASA AMES RESEARCH CENTER), REGINALD DUFOUR AND MATT BROWNING (RICE UNIVERSITY), PATRICK HARRINGTON (UNIVERSITY OF MARYLAND), AND NASA

destination. If you'll be there during spring in the Northern Hemisphere (which is fall south of the equator), take a small scope and this guide with you and spend a night — or several nights — in Centaurus the Centaur.

To get you started, I've selected 18 objects within the constellation's boundaries that are worth extended looks through your telescope. Some are big and (relatively) bright; others, not so much. I've listed them in order of right ascension.

Our first target, elliptical galaxy **NGC 3557**, lies 2.7° east of magnitude 4.6 Iota (ι) Antliae. It glows at magnitude 10.4 and measures 4' by 3'. This galaxy appears as an oval glow, oriented north-northeast to south-southwest. A thin halo surrounds the wide central region, but you'll need at least a 12-inch scope to glimpse it.

If you spot this object, try for two spiral galaxies nearby. Magnitude 12.2 **NGC 3564** lies 8' east of NGC 3557, and magnitude 12.3 **NGC 3568** floats 11' to its east-northeast.

Now head a bit south. Our next target, open cluster **NGC 3680**, lies 9.1° northeast of magnitude 2.7 Mu (μ) Velorum. It shines at magnitude 7.6 and has a diameter of 7'. Through a

6-inch telescope at 100x, you'll spot more than a dozen stars of magnitude 10.5 and fainter that divide into two groups, oriented north and south, with a dark east-west lane between them.

Head more than 15° farther south to find planetary nebula **NGC 3699**, which lies 0.7° southwest of the magnitude 5.0 double star Omicron (ο) Centauri in a really rich star field. Until recently, astronomers classified NGC 3699 as an HII region. They now recognize it as a bipolar planetary nebula. It glows at magnitude 11.0 and measures 67" across.

If you're using a 12-inch telescope, you can see its double nature. Crank the magnification up to 250x, and the two disks — the brighter one lies to the north — appear mottled. A nebula filter really helps. This planetary isn't huge, but its high surface brightness allows you to use really high power, so reach for your short-focal-length eyepieces.

NGC 4945 is one of the finest Southern Hemisphere dusty galaxies, appearing nearly edge-on to our line of sight. DON GOLDMAN

THROUGH A 4-INCH SCOPE, YOU CAN COUNT 100 STARS, THE BRIGHTEST OF WHICH SHINES AT 7TH MAGNITUDE.

The **Pearl Cluster**, NGC 3766, lies 1.5° north of Lambda (λ) Centauri — and what a sight it is. If you're unfamiliar with it, this is one cluster really worth checking out. It sparkles at magnitude 5.3 across a diameter of 12'.

This object received its common name February 15, 2006, from amateur astronomer Ray Palmer. On that date, he founded the South Celestial Star Light Project to help fine-tune the names of Southern Hemisphere celestial objects. His reasoning is that astronomy must appeal to people, and not be complicated or boring. People — especially young people — will remember and relate to a sky object's popular name more than any of its catalog designations, Palmer believes. I agree, and I'll be calling NGC 3766 the Pearl Cluster from now on.

This cluster is visible without optical aid, but you'll have to work at it because of the rich star field it's in. Binoculars, especially those that magnify 15x or more, will reveal dozens of stars, but the finest view comes through telescopes that magnify between 75x and 100x.

Through a 4-inch scope, you can count 100 stars, the brightest of which shines at 7th magnitude. That number in itself provides a sweet view, but there's more. Riding seemingly in front of a pure-white carpet of diamonds are two pale rubies. One, magnitude 7.5 SAO 251483, lies midway between the cluster's center and its eastern edge. The other, magnitude 7.3 SAO 251470, lies the same distance from the center toward the west. Indeed, the Pearl Cluster is a Southern Hemisphere jewel.

You might figure out on your own how to locate open cluster **Collinder 249** when you hear its common name is the Lambda Centauri Cluster. First, find magnitude 3.1 Lambda Centauri. The line of stars that make up Cr 249 begins with that star and runs toward the southeast throughout this whole area. Its oval shape spans 65' by 40', some three and a half times the area of the Full Moon. But this region contains a lot more than a magnitude 4.0 star cluster. Through a 4-inch telescope from a dark site, you'll spot the HII region **IC 2944** (often called the Running Chicken Nebula) concentrated around Lambda Centauri.

IC 2944 is famous for the dense, opaque dust clouds that South African astronomer Andrew David Thackeray discovered in 1950, now known as Thackeray's Globules. Astronomers find such regions in areas of intense star formation. They appear as shadows against the background nebula, which lies 5,900 light-years away. Ultraviolet radiation from nearby recently formed stars erodes the globules and may ultimately dissipate them.

You won't see Thackeray's Globules visually, but through an 8-inch telescope and a low-power eyepiece equipped with a nebula filter, you can view IC 2944, and it appears bright. Some sources list its magnitude as 4.8. Just 12' southeast of this nebula lies another HII region, **IC 2948**. It appears larger but fainter than IC 2944.

Perhaps the finest and brightest galactic train wreck in the sky, Centaurus A (NGC 5128) appears as a huge sphere bisected by a prominent dust lane. The galaxy is the result of a merger of two smaller galaxies. R. JAY GABANY

The small galaxy NGC 5102, sometimes nicknamed Iota's Ghost, lies a scant 0.3° from the bright star Iota Centauri. CARNEGIE-IRVINE GALAXY SURVEY

For our next object, head about 5° back to the north. There, you'll find **NGC 3918**, sometimes called the Blue Planetary, 3.6° west-northwest of magnitude 2.8 Delta (δ) Crucis. Even small telescopes reveal the planetary's vivid blue, blue-green or greenish-blue hue (depending on your eyes' color sensitivity).

NGC 3918 glows at magnitude 8.2 but measures a tiny 12" in diameter. The disk has incredibly high surface brightness and a sharp edge. Although you can crank up the magnification past 500x on this object, you won't see details other than the color.

Astronomers catalog our next object as the **Centaurus Galaxy Cluster** (Abell 3526), but actually it's two galaxy clusters we see in the same direction. Most of the galaxies belong to the cluster Cen 30. Its brightest member is magnitude 11.9 **NGC 4696**, and it lies 160 million light-years away.

The other cluster, Cen 45, features magnitude 11.1 **NGC 4709** at its center. This much looser cluster is 220 million light-years away.

You'll find this combination object 7.6° southwest of magnitude 2.8 Iota Centauri. Through a 16-inch telescope, you'll spot roughly 20 galaxies in a 2° area. NGC 4696 appears oval, elongated east-west, and measures 4.7' by 3.3'. NGC 4709 lies 15' to the east-southeast and looks nearly circular, 2.3' by 2', with a bright core.

Next, head 8° back to the south for a real treat, **NGC 4945**. This is a huge (23.0' by 5.9'), bright (magnitude 8.8), nearly edge-on barred spiral galaxy oriented northeast to southwest that looks great through any size telescope. You'll find it only 0.3° east of magnitude 4.8 Xi^{1} (ξ^{1}) Centauri.

The galaxy shows even illumination across its surface except at its ends. Of those, the northeastern one glows brighter. Through a 12-inch or larger scope at 300x, look for a dark indentation near that end. A fainter galaxy, magnitude 12.5 **NGC 4945A**, sits 0.3° southeast of NGC 4945.

Depending on the eyepiece in your scope, you may not have to move it to find our next target. Elliptical galaxy **NGC 4976** lies a scant 0.5° east of NGC 4945. Through a 6-inch telescope, you'll see an evenly illuminated magnitude 10.0 oval 80 percent longer than it is wide (5.6' by 3') oriented north-northwest to south-southeast. A larger scope may differentiate the outer halo from the central region, but that's about it.

Our next treat is a long way from NGC 4976, but it's easy to find. **NGC 5102**, sometimes called Iota's Ghost, lies only 0.3° east-northeast of magnitude 2.8 Iota Centauri. This spiral galaxy appears relatively bright (magnitude 9.6) because it is less than 11 million light-years away. Unfortunately, that distance also means it appears fairly large (9.8' by 4'), so its light spreads out quite a bit, and it doesn't show as many details as other similarly sized objects.

Through an 8-inch telescope, look for a bright central region surrounded by a large oval halo twice as long as it is wide. As you might have guessed from this object's common name, you'll get your best views if you move bright Iota Cen out of the field of view.

Seeing **Centaurus A** (NGC 5128) high in the sky is one of the thrills of Southern Hemisphere observing. You'll find it 6.5° south of NGC 5102. Observers call this peculiar galaxy the Hamburger Galaxy because two stellar regions (the bun) surround a dark dusty lane (the burger). Unfortunately, most northern viewers get only a taste of this object's details. For example, from Tucson, Arizona, NGC 5128 climbs to a maximum altitude of 15°. Viewing any object through that much of Earth's atmosphere presents a distorted view. For best results, head farther south.

In 1826, Australian astronomer James Dunlop discovered NGC 5128 and published the observation within a list of 629 objects titled "A catalogue of nebulae and clusters of stars in the southern hemisphere, observed at Parramatta in New South Wales," which appeared in the *Philosophical Transactions of the Royal Society* in 1828.

NGC 5128 glows at magnitude 6.8 and measures 31' by 23', meaning it contains nearly the same area as the Full Moon. Its appearance arises from a galactic collision. The main body of Centaurus A — a giant elliptical galaxy — is absorbing a smaller spiral galaxy. The two objects collided more than 200 million years ago, causing huge bouts of star formation.

Through small telescopes, NGC 5128 appears round with a wide, dark lane cutting the galaxy in half. Use a 12-inch or larger scope, and you'll see a thin wedge of light shining through the lane's western end. That lane widens on both ends.

If you polled most amateur astronomers, they'd say that the biggest draw to Centaurus is the sky's top globular cluster, **Omega Centauri** (NGC 5139). Most observers have no trouble spotting this magnitude 3.9 object, even through moderate light pollution.

NGC 5139 does not have the common name "Omega" because of its shape, as in the case of the Omega Nebula (M17) in Sagittarius. Rather, it appeared as a "star" labeled with the Greek letter Omega (ω) on German cartographer Johann Bayer's 1603 star atlas *Uranometria*. Bayer labeled the brightest stars in constellations with Greek letters. Because Bayer interpreted a historical listing of NGC 5139 as a star, he assigned it Omega.

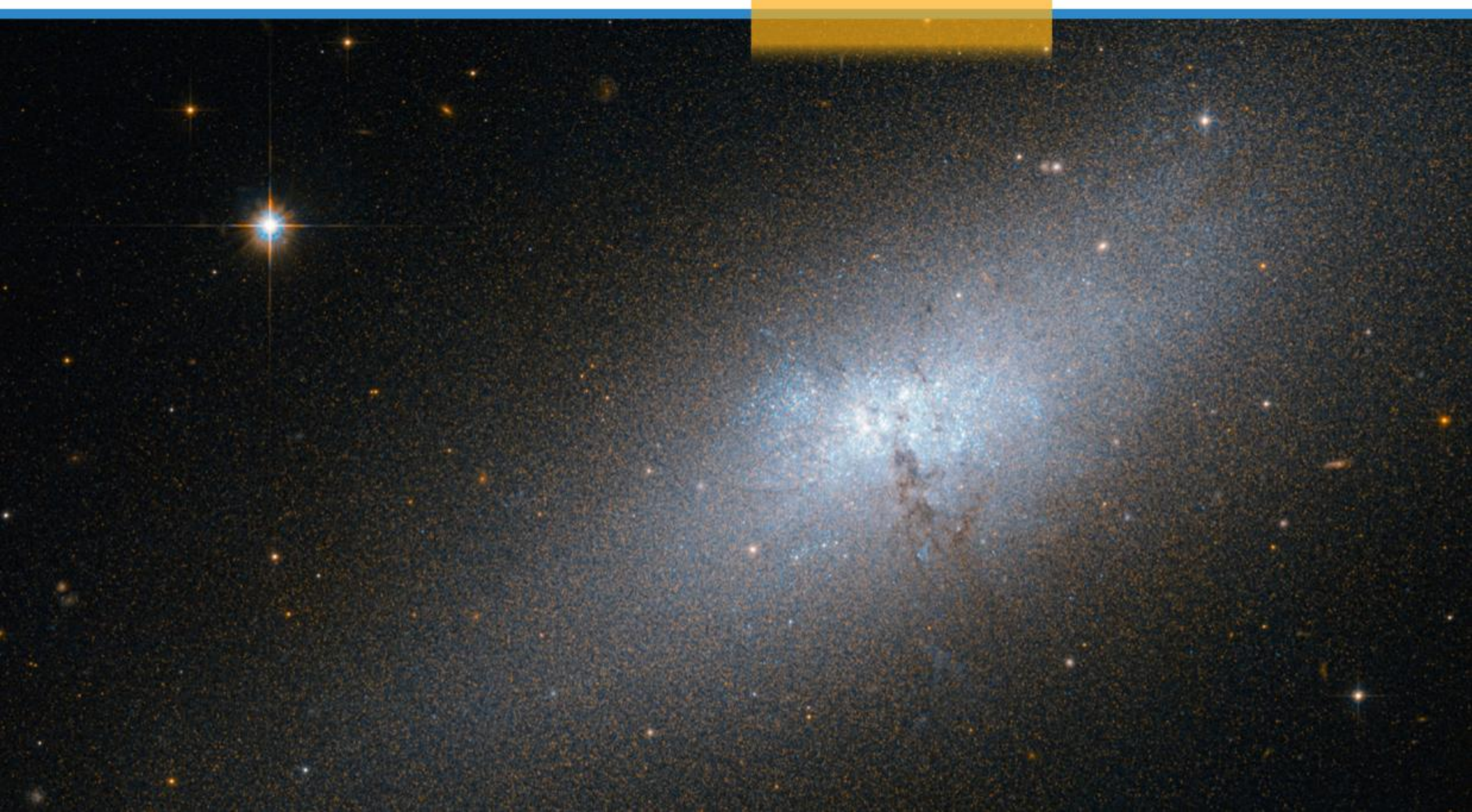
NGC 5139 is a wonder to behold through binoculars or telescopes of any size. With a diameter of 36.3', the cluster appears slightly larger than the Full Moon, and because it's rotating relatively quickly, its shape is slightly out of round.

Through an 8-inch telescope, you'll see 1,000 stars, each a pinprick of light. At high power, the stars appear nearly uniformly distributed across the field of view. Through scopes with apertures larger than 16 inches, crank up the magnification and look for individual red giants within this cluster.

You'll find our next target, the peculiar dwarf galaxy **NGC 5253**, a bit more than 7° northwest of magnitude 2.1 Menkent (Theta [θ] Centauri). It glows at magnitude 10.4 and measures 5.1' by 1.3'. Alternatively, you can locate it by first finding the Southern Whirlpool Galaxy (M83) in Hydra. From that bright object, move 1.9° south-southeast. NGC 5253 lies nearby (11 million light-years), but you won't see many details.

CENTAURUS CONTAINS MANY MORE OBJECTS WORTHY OF MORE THAN JUST A CASUAL GLANCE.

The peculiar dwarf galaxy NGC 5253 is a challenging target for small-telescope observers. ESA/HUBBLE AND NASA



Globular cluster NGC 5286 is a bright ball of stars just 2.3° north-northeast of the star Epsilon Centauri. DANIEL VERSCHATSE

The reflection nebula NGC 5367 appears as a haze surrounding an associated 10th-magnitude star. GERALD RHEMANN

Astronomers believe NGC 5253 may have been a dwarf elliptical galaxy until an ancient encounter with M83. Through an 8-inch telescope, a bright central region dominates the view. A 12-inch scope reveals several tiny bright knots, with the brightest at the northeastern end.

The next stop on our tour, globular cluster **NGC 5286**, lies nearly 20° farther south than NGC 5253, but it's easy to spot because it's only 2.3° north-northeast of magnitude 2.3 Epsilon (ε) Centauri. In addition to the globular, you'll also immediately see the magnitude 4.6 star SAO 241157, also known as M Centauri, which lies only 4' from the cluster's center. Despite the pairing, the star has nothing to do with the cluster, which is 200 times more distant.

At magnitude 7.4 and with a diameter of 9.1', NGC 5286 contains many stars. The brightest ones glow faintly at magnitude 13.5, so you'll have trouble resolving them through telescopes with apertures less than about 14 inches. The cluster's central region appears concentrated, but the outer stars are difficult to see because of the brightness of M Cen.

Now head 11° due south, and you'll spot the **Little Scorpion Cluster** (NGC 5281). This magnitude 5.9 open cluster lies 3.3° southwest of magnitude 0.6 Hadar (Beta [β] Centauri). Its diameter is small, though, at only 5'.

A 4-inch telescope at 100x reveals three dozen stars. The cluster's brightest member is magnitude 6.6 SAO 252442, which lies just north of center. This star forms the top of a slightly curving line of a half-dozen points that arcs gently toward the southwest.

Astronomy Contributing Editor Stephen James O'Meara christened this cluster the Little Scorpion because he saw that animal patterned in its stars, complete with claws and a raised tail. What do you see?

Our next target, open cluster **NGC 5316**, also lies southwest of Hadar, but only 1.9° away. Now, at magnitude 6.0 and with a diameter of 13', this cluster should be visible to observers using just their eyes at a dark site. That's a bit problematic, however, because of the incredibly rich Milky Way star field it lies in.

Through a 4-inch telescope at 150x, you'll see three dozen 9th- and 10th-magnitude stars in NGC 5316. A 10-inch scope at the same magnification brings into view a second tier of fainter stars, raising the total number past 50.

Next, zoom 22° north for the only reflection nebula on our list, **NGC 5367**. You'll find it 2° northwest of magnitude 4.4 Chi (χ) Centauri. Through a 10-inch telescope, an evenly illuminated haze 2.5' across surrounds an associated star that shines at magnitude 9.8. To the northeast lies a detached region 2' across. Don't use a nebula filter on this object because it will simply dim it. A reflection nebula is reflected starlight, which comprises all wavelengths.

Our final stop is the closest star to the Sun, **Proxima Centauri** (Alpha [α] Centauri C). It's also been in the news lately after astronomers discovered a planet orbiting it.

For these factors, I think it easily makes our list despite its magnitude 11.1 faintness. To find Proxima, first center its brilliant companion, magnitude –0.1 Rigil Kentaurus (Alpha Centauri A and B). Alpha Cen C lies a bit more than 2° south-southwest of this pair. At a distance of 4.22 light-years, C lies 0.17 light-year closer to us than its neighbors. However, it glows meekly, so it's easy to miss.

By the way, the word *proxima* comes from the Latin word for near. It's the same root word that gives us the word *proximity*.

Centaurus will keep you transfixed. Beyond what I've described here, as you can imagine, Centaurus contains many more objects worthy of more than just a casual glance through your telescope. The double stars alone will keep you within its boundaries for a week. Still, this list isn't a bad way to start. Good luck!

Michael E. Bakich *is a senior editor of* Astronomy *who is hosting the largest eclipse watch in 2017, at Rosecrans Memorial Airport in St. Joseph, Missouri.*

Moonwalkers and women scientists highlighted at STARMUS IV

The famous festival will take place in Trondheim, Norway, this month, showcasing science, music, and a celebration of life.

text and images by David J. Eicher

What the heck does Starmus mean? Every few weeks, someone asks me that question. It stands for *stars* and *music*, and it's the creation of talented astronomer Garik Israelian of the Institute for Astronomy at Tenerife in the Canary Islands. The Starmus Festival, which brings together the sciences and the arts in a unique way, has taken place three times now. Each of the festivals — in 2011, 2014, and 2016 — has occurred on the paradise-like island of Tenerife, off the northwestern coast of Africa. For the fourth one, festival director Israelian inaugurates a shift to the north.

What will be

Starmus IV, as the organizers are calling it, will take place June 18–23, 2017, in Trondheim, Norway. The beautifully laid out city is home to a spectacular 900-year-old Gothic cathedral and the Norwegian University of Science and Technology (NTNU), which will play host to the festival.

Announcements for upcoming Starmus events will play out over the coming weeks. Thus far, organizers have scheduled two key panels. Three moonwalkers — Buzz Aldrin, Charlie Duke, and Harrison Schmitt — will share the stage to discuss their space exploration experiences. They will participate in an hourlong debate, "To the Moon and Beyond," which will explore the possibilities of a human mission to Mars in the near future.

Also playing prominently in the upcoming Starmus will be a spectacular lineup of scientists, headlined by prominent women. The lineup will include Nobel

Dawn breaks over Trondheim, Norway. The city will play host to Starmus IV, June 18–23.
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1. Stephen Hawking arrives at Starmus III in June 2016, in Tenerife, Canary Islands. Crowds of well-wishers immediately surrounded the great physicist.

2. World-renowned musician Brian Eno delivers his keynote address on science and the arts, how we perceive them, and how they relate to each other.

3. *Astronomy* Editor David J. Eicher catches up with old friend Neil deGrasse Tyson.

4. Astronaut Chris Hadfield sings a tribute to David Bowie with "Life on Mars," accompanied on piano by Rick Wakeman.

5. Carolyn Porco describes to an enraptured audience the spectacular results of the Cassini mission to Saturn.

Prize-winning neuroscientist May-Britt Moser of NTNU, theoretical physicist Lisa Randall of Harvard University, atmospheric scientist Katharine Hayhoe of Texas Tech University, planetary scientist Sara Seager of MIT, Starmus board member and SETI legend Jill Tarter, microbiologist Emmanuelle Charpentier, astrobiologist Nathalie Cabrol, astronaut Sandra Magnus, astrophysicist Priyamvada Natarajan of Yale University, and planetary scientist Carolyn Porco, Imaging Team leader for the Cassini mission to Saturn.

And there will be others speaking, too. Among them will be the great astrophysicist Stephen Hawking, world-famous musician Brian Eno, astrophysicist Martin Rees, planetary scientist Alan Stern, astronaut Terry Virts, astrophysicist Michel Mayor, astrophysicist Robert Williams, and astronaut Walt Cunningham. Also speaking will be several Nobel Prize laureates: Stefan Hell, Edvard Moser, Adam Riess, George Smoot, Susumu Tonegawa, and Robert Wilson.

And I'd like to emphasize this point: There will be more announcements of others to come! Please pay close attention to www.starmus.com for updates and additions to the program, and for information on booking. You can book your tickets at www.starmus.com/product/starmus-entrance.

A FEW OF THE CONFIRMED SPEAKERS AT STARMUS IV

STEPHEN HAWKING

British theoretical physicist, cosmologist, and director of research at the Centre for Theoretical Cosmology at the University of Cambridge. There, he served as Lucasian Professor of Mathematics — a post once held by Isaac Newton — from 1979 until 2009. His most popular book, *A Brief History of Time*, has sold more than 10 million copies. WIKIMEDIA COMMONS

MAY-BRITT MOSER

Professor of neuroscience and founding director of the Centre for Neural Computation at the Norwegian University of Science and Technology in Trondheim. She shared the 2014 Nobel Prize in Physiology or Medicine. HENRIK FJØRTOFT/NTNU KOMM.AVD.

BUZZ ALDRIN

U.S. Air Force pilot (decorated with the Distinguished Flying Cross) and astronaut. During the Gemini 12 mission, Aldrin performed a spacewalk lasting 2 hours and 6 minutes. Along with Neil Armstrong, he was one of the first two humans to set foot on the Moon, landing July 20, 1969. NASA

GEORGE SMOOT

Astrophysicist at the University of California, Berkeley, and senior scientist at the Lawrence Berkeley National Laboratory. Smoot won the 2006 Nobel Prize in Physics for his work on the Cosmic Background Explorer. He is also one of only two contestants to have won the $1 million prize on the television show *Are You Smarter than a 5th Grader?* MICHAEL HOEFNER

ROBERT WILSON

Astronomer who worked for Bell Labs in New Jersey until 1994. While working on a new type of antenna in 1964, he and Arno Penzias discovered the cosmic microwave background radiation, which is the landmark evidence of the Big Bang theory. For this work, he and Penzias were awarded the 1978 Nobel Prize in Physics. VICTOR R. RUIZ

SIR CHRISTOPHER PISSARIDES

School professor of economics and political science and Regius professor of economics at the London School of Economics and chairman of the Council of National Economy of the Republic of Cyprus. He was awarded the 2010 Nobel Prize in Economics for his work on markets where buyers and sellers have difficulty finding each other. MAGNUS REW

Seven astronauts and cosmonauts share the stage for a roundtable on their space flight experiences. From left are Roman Romanenko, Garrett Reisman, Sergey Volkov, Alexei Leonov, Rusty Schweickart, Chris Hadfield, and Claude Nicollier.

A taste of Starmus III

To give you a flavor of what Starmus is all about, let me recount what happened at Starmus III in 2016.

A crowd of 1,000 people showed up in Tenerife last June, and the opening day was incredible, setting the tone for what followed. Last year's theme was a tribute to Stephen Hawking, and our guest of honor was magnificent.

The first afternoon's lectures were hosted by astronomer Jim Al-Khalili, who introduced an opening talk by Adam Riess about the discovery of dark energy. Brian Greene of Columbia University followed with an entertaining romp through the world of string theory and its potential for multiverses. Bob Wilson went next, recounting his discovery, with Arno Penzias, of the cosmic microwave background radiation, which amounted to confirmation of the Big Bang theory.

The talks, about 20 minutes each, sped by. Alf McEwen described the possibilities for life on Mars and Europa, and gave an overview of Mars exploration. Well-known astronomy celebrities Brian Cox and Neil deGrasse Tyson held an informal chat about the state of science communication.

The first evening commenced with talks by Barry Barish (on gravitational waves), Robert Sawyer (on science fiction writing), and Peter Schwartz (on artificial intelligence and the future). Planetary scientist Joel Parker delivered a spellbinding talk on two missions: New Horizons to Pluto and Rosetta to Comet 67P/Churyumov-Gerasimenko. Steve Balbus then spoke of evolution and why fish left the sea, and the evening closed with a great presentation by Eric Betzig on telescopes and microscopy — extreme scales.

Starmus has a way of astounding you and then becoming even better with each passing day. The second day at Starmus III commenced with Nobel Prize laureate Brian Schmidt talking about dark energy and cosmology. Then we were treated to a historic moment when Roger Penrose, famed cosmologist and teacher of Hawking, lectured on the universe, complete with an overhead projector and transparencies.

Chris Rapley delivered a spectacular summary of the science behind climate change — something that anyone corrupted by politics should be forced to sit through. The afternoon brought another highlight as Tyson and SETI pioneer Jill Tarter discussed alien life in the cosmos.

More equally fascinating lectures followed. Eugene Kaspersky spoke about the alarming state of cybersecurity. Edvard Moser delivered a mind-blowing talk about the brain and spatial mapping. Danny Hillis told the crowd about the age of entanglement, in which reality and unreality are becoming increasingly tangled. And Carolyn Porco presented a beautiful summary of Cassini at Saturn.

Next, entertainer David Zambuka gave us a funny and exhilarating session, riffing on Hawking's life and career. And then six astronauts came together to share their experiences of space flight: Alexei Leonov, Rusty Schweickart, Claude Nicollier, Sergey Volkov, Garrett Reisman, and Roman Romanenko. And the session was chaired by Chris Hadfield. Wow!

Starmus' third day brought moments of history. Hawking commenced with "A Brief History of Mine," in which we heard an autobiographical tale of Stephen's life. It was an incredibly moving moment to witness. An all-star lineup followed, beginning with the legendary musician Brian Eno, who delivered a terrific keynote address on the relationship between science and the arts. The Nobel Prize-winning economist Joseph Stiglitz described the economic state of the world and the historic divide between the few richest people and the rest of us. One of my favorite people in the astronomy world followed, Lord Martin Rees, Astronomer Royal, with a marvelous overview lecture on cosmology.

And then came a surprise. MC Hawking, aka Ken Lawrence, gave a great performance overview of "Stephen Hawking's Rap Career." It was hysterical, and it was produced with the insider help of Israelian and friends.

The day just kept going. Elizabeth Blackburn, a Nobel Prize-winning molecular biologist, wowed the audience with an insightful talk on telomeres and the role they play in human aging. My good friend Rusty Schweickart delivered a terrific summary of asteroid-impact dangers and the role that Asteroid Day can play in energizing research. (Please see www.asteroidday.org and support this cause if you do not already.)

6. Biologist Richard Dawkins and astronomer Steve Balbus (not pictured) talk about Darwinian evolution in the cosmos.

7. Eicher backstage with SETI pioneer Jill Tarter.

8. Brian May adds a blistering guitar solo to the final stages of the Sonic Universe concert.

9. Bono and The Edge, two of the founding members of U2, send a video message to the Starmus audience.

10. Sarah Brightman wows the crowd with her incredible voice at the Sonic Universe concert.

Nobel Prize-winning physicist David Gross outlined the challenges that remain for physics. We then heard a discussion between biologist Richard Dawkins and astrophysicist Balbus on Darwinian evolution. Hadfield then described his experiences as an astronaut, entertaining the crowd magnificently. And then astrophysicist and Queen guitarist Brian May, one of Starmus' central figures, introduced the audience to his new OWL Virtual Reality Kit, an essential tool for anyone who wants to see the universe in 3-D. (See www.londonstereo.com/vr-kit.html.)

There's music, too

Just when we thought it was all too much — our minds were on overdrive — the crescendo arrived. Each event features a "Sonic Universe" concert with an array of amazing performers. Remember, we must employ both halves of the mind. Sarah Brightman delivered an orchestral concert that was chilling. Her soaring notes had to be heard to be believed, especially on the emotional closer, "Time to Say Goodbye." A ceremony followed to award the first Hawking medals for science communication, which went to composer Hans Zimmer, Al-Khalili, and the producers of the film *Particle Fever*.

Next, rock group Anathema played a set, closing with Queen's famous song "Who Wants to Live Forever." It was a rousing moment for Starmus. And that wasn't all. We had a video message from Bono and The Edge, and another video from Peter Gabriel and Sting, who sang an electrified "Twinkle, Twinkle, Little Star."

And it just kept going. Hadfield strolled out and was accompanied by the great Rick Wakeman in a rendition of "Space Oddity" and "Starman," paying tribute to the late David Bowie.

Zimmer then led an incredible musical exploration of black holes, explained by the great Kip Thorne. And of course Brian May trotted out to lay down some amazing guitar solos, putting a finish on the whole event.

As it always is, Starmus was an incredible show. And I can tell you that Starmus IV will be the most spectacular version yet.

Astronomy *Editor* **David J. Eicher** *is a member of the Board of Directors of the Starmus Festival.*

25 HOT ECLIPSE PRODUCTS

Viewing the eclipse safely doesn't have to break the bank. **by Phil Harrington**

Psst … have you heard there's going to be a solar eclipse in August?

I ask that question with tongue firmly in cheek because every reader of *Astronomy* has long known that the first total solar eclipse to cross the continental U.S. in 38 years is coming soon.

If you are like me, you've been planning a trip to see totality for years. Because nearby total eclipses are so rare, and totality itself so fleeting, planning ahead is a must. Where are you going to go? What are you going to bring to view nature's great spectacle?

Even if you aren't traveling to the centerline, you can enjoy the partial eclipse. You can view it solo or with a group, perhaps at a public viewing event. Either way, it takes preparation and some equipment to do so safely.

To help you along, I've prepared a list of 25 great products manufacturers have created to help you view the Great American Eclipse. As you'll discover, the well-equipped eclipse chaser has lots of choices for just about every contingency. While it may take some effort now, you'll find the eclipse will be far more enjoyable with a little preparation. Note that all product images came from the manufacturers.

1 SOLAR GLASSES

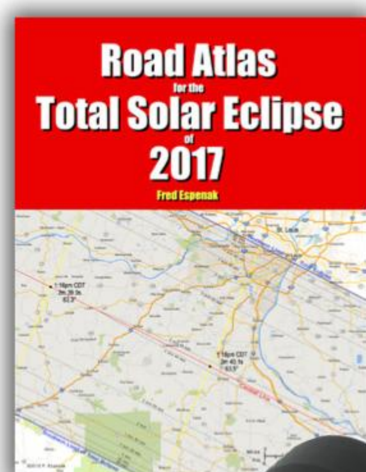
Astronomy magazine has solar glasses for viewing the Sun safely by eye alone. They feature cardboard frames and come in lots of five. The frames carry the magazine's logo, so your friends will know you read *Astronomy*. These glasses use impregnated polymer (referred to as black polymer) filters that turn the Sun yellow-orange. All meet the International Organization for Standardization ISO 12312–2 safety standard for such products. ($9.95 for a five-pack, www.myscienceshop.com)

2 SOLAR FILM

Since its introduction two decades ago, Baader AstroSolar material has become the standard bearer of aluminum-coated safety-film filters. Visually, it produces a neutral (white) Sun, which is the most scientifically accurate image through any filter. The high image contrast helps to bring out subtleties in sunspots. This becomes especially evident at high powers. You can purchase 8-by-10-inch (20-by-25-centimeter) sheets. ($27, www.astrosolar.com/en)

3 SOLAR FILTER

AstroZap solar filters are available in two varieties, either made with a glass element for a yellow-orange image or made of aluminized safety film that yields a white image. The latter uses Baader's AstroSolar material, detailed at right. All AstroZap filters feature aluminum mounting rings custom-sized to fit all popular binocular and telescope sizes. Each is held firmly to the instrument with one or more plastic retaining screws that will not scratch the finish. ($52–$179, www.astrozap.com)



4 ECLIPSE TRAVEL GUIDE

Astropixels' *Road Atlas for the Total Solar Eclipse of 2017* is only one of the eclipse-related publications this company produces. Many of us will hit the road to see the August eclipse. But which road should you take? Eclipse expert Fred Espenak has the answer with this coast-to-coast road atlas featuring the eclipse path. This is a must-have, even if you're flying to a destination, because conditions may require you to get mobile on eclipse day in search of clear skies. ($14.99–$19.99, www.myscienceshop.com)

5 SOLAR BINOCULARS

Celestron designed its EclipSmart 10x42 Solar Binocular specifically for viewing the partial phases of the August eclipse. But thanks to the permanently mounted glass solar filters, these binoculars are sure to make Sun-watching fun on any sunny day for years to come. The multicoated optics deliver high-contrast images that clearly show larger sunspots. ($69.95, www.celestron.com)

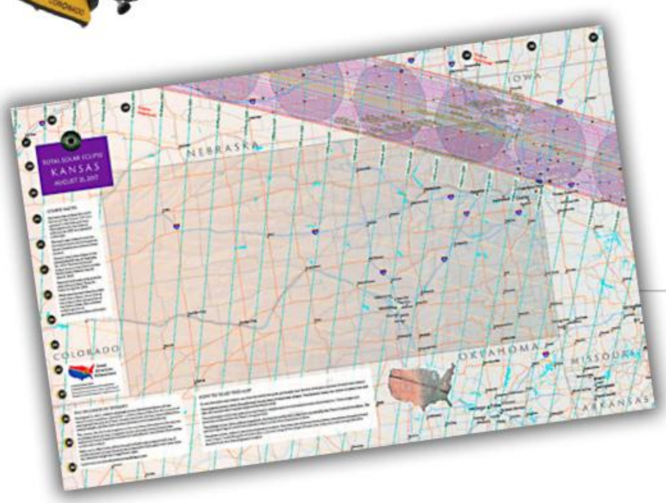
MIKE REYNOLDS

6 SOLAR TRAVEL SCOPE Celestron also offers a special-edition EclipSmart Travel Scope 50 2-inch refractor for those who prefer a telescopic view of the action. Like the EclipSmart solar binoculars, the EclipSmart 50 is a full-time solar scope. The permanently mounted glass filter creates a yellow image of our star, while the included 20mm Kellner eyepiece magnifies the disk 18 times. You can also use any other standard 1¼" eyepiece. Included in the package is a clever "shadow finder" that lets you aim the scope at the Sun safely, as well as a photo tripod to hold the Sun steadily in view. Everything fits neatly into the supplied backpack. ($99.95, www.celestron.com)

7 SOLAR TELESCOPE Coronado's 1.6-inch (40mm) f/10 Personal Solar Telescope (PST for short) has brought the amazing world of Hydrogen-alpha solar viewing to a lot of amateurs. The high-quality construction — including an aluminum tube, fine-adjustment focuser, and integrated finder scope — all belie the PST's low price. One of the most exciting parts of totality will be the beautiful prominences erupting along the limb of the Sun. With the PST, you can watch them every day, along with sunspots and sinuous filaments. A 20mm Kellner eyepiece comes with the telescope, but you'll need to purchase a mount separately. ($699, www.meade.com/products/coronado.html)

8 SOLAR TELESCOPE If the PST has piqued your interest in solar astronomy and if you're looking to climb up to the next level in equipment, Coronado's 2.4-inch (60 millimeters) f/6.6 SolarMax II 60 seems a natural progression. Not only will the larger aperture show finer detail in filaments, granulation, and prominences, its superior construction and narrower bandpass filter (less than 0.7 angstrom versus the PST's, which is specified as less than 1.0 angstrom) means better image contrast as well. ($2,499, www.meade.com/products/coronado.html)

9 SOLAR FILTER Perhaps you own a catadioptric telescope or refractor that you want to use to study the Sun's prominences, filaments, and chromosphere. Daystar Instrument's QUARK filters are for you. Available in both Hydrogen-alpha and Calcium wavelengths, the QUARKs combine adapters and filters into a single assembly that slips into your scope's focuser. ($1,015.75, www.daystarfilters.com)



10 ECLIPSE MAP GreatAmericanEclipse.com sells 2017 path maps that are perfect for planning your road trip to view the eclipse. Maps measure 11 by 17 inches (28 by 43cm) and are available for each state that the eclipse's centerline passes through. ($10, www.greatamericaneclipse.com)

11 SOLAR BINOCULARS

Sunoculars, available from GreatAmericanEclipse.com, are binoculars made specifically for solar viewing. Available in four colors, the 8x32 Sunoculars let you safely view sunspot activity as well as the partial phases of the August eclipse. A mini 6x30 version, which is ideal for children, is also available. ($29.95–$129, www.greatamericaneclipse.com)

12 SOLAR FILTERS

Daystar has produced a single useful product in a number of different sizes. Its Universal Solar Lens Filters conform to the ISO 12312–2 safety standard and transmit only one-thousandth of 1 percent of the Sun's light. Each has a spring-folded shape to hold onto various sizes of camera lenses, binoculars, or telescopes. To use them, you fold the flat pieces into cup-shaped lens filters that then fit over the front (always the front!) end of your optics. ($12.95 to $39.95, www.daystarfilters.com)

13 SOLAR FILTER

J.M.B. Inc. offers three classes of glass solar filters. Class A filters — coated with an alloy of nickel, chromium, and stainless steel — are available for telescopes 2 to 14 inches in aperture. Less expensive Class B filters are identical except for the stainless steel in the alloy (so they're slightly less durable). Class C filters have a lighter density that allows solar photographers to operate their cameras at faster shutter speeds. They are not for visual use. ($57–$263, www.buytelescopes.com)

14 SOLAR FILTER

Orion Telescopes & Binoculars offers glass filters for telescopes with apertures between 2.4 and 12 inches (60 to 305mm). Each uses high-quality machine-polished glass that is triple-coated with a nickel-chromium-stainless steel alloy that creates a yellow-orange image of the Sun. These come mounted in foam-lined aluminum cells with three equidistant thumbscrews for secure attachment. ($80–$160, www.telescope.com)

15 SOLAR FILTER

For observers who want a lighter-weight filter, Orion also sells less expensive safety film filters for the same apertures. Each uses Baader AstroSolar film for a neutral image. Like the company's glass filters, three nylon thumbscrews hold the filter securely to the front of a telescope. ($60–$150, www.telescope.com)

16 WRAPAROUND SOLAR GLASSES

Rainbow Symphony has been making Eclipse Shades glasses from black polymer for years. Like with other filters that use black polymer, the Sun appears yellow-orange. All meet the International Organization for Standardization ISO 12312–2 safety standard for such products. These carry the magazine's logo. ($19.95, www.myscienceshop.com)

17 SOLAR FILTER

Rainbow Symphony also sells full-aperture mounted filters for binoculars, camera lenses, and telescopes. Two series are available, allowing consumers to choose between black polymer (yellow-orange image) or Baader AstroSolar film (white image), although every size of the latter was sold out when I last checked. Both come in felt-lined cells that slip over the front of a telescope. Available sizes range from 2 to 4 inches (50 to 101mm). ($19.95–$29.95, www.rainbowsymphonystore.com)

18 SOLAR VIEWER

Rainbow Symphony's SolarScope is a great way to share the excitement of the eclipse's partial phases safely with a group. The design uses a small eyepiece-less "telescope" and a flat mirror mounted in a clever cardboard hood and base assembly to project the Sun onto the inside of SolarScope's hood. After assembly, simply aim the SolarScope at the Sun by shifting the box left or right and tilting the hood up or down until the image appears inside the hood. ($124.99, www.rainbowsymphonystore.com)

19 SOLAR FILTER

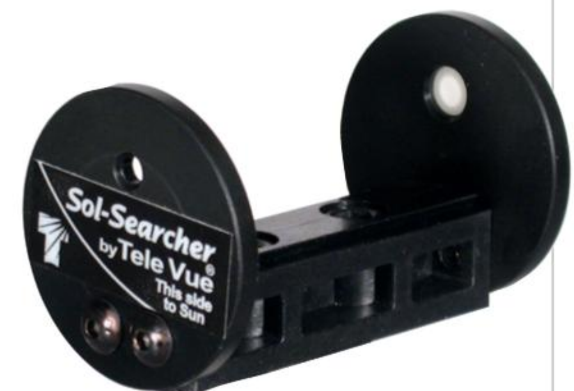
Stellarvue sells glass solar filters for its 80mm to 102mm refractors. Each filter is mounted in a custom, felt-lined metal cell designed to friction-slip over the telescope's dewshield. ($79, www.stellarvue.com)

20 SOLAR FILTER

SeymourSolar offers an assortment of glass and black polymer filters for cameras, binoculars, and telescopes. Both materials produce yellow-orange solar images. The telescope and binocular filters are mounted in slip-on aluminum cells securely attached with nylon thumbscrews. Full-aperture and off-axis glass filters are available for telescopes up to 16 inches (406mm), while polymer filters go up to 7.5 inches (190mm). The company also offers threaded polymer filters for camera lenses from 37mm to 82mm. ($62–$202, www.seymoursolar.com)

21 SOLAR VIEWER

The SunSpotter, by Science First, is a great gadget for groups viewing the Sun, either during the partial eclipse phases or just on any sunny day. Made of finely crafted wood, the SunSpotter uses a 62mm refractor to focus sunlight onto a series of flat mirrors, which then direct the image onto a white projection screen. The resulting image measures 3.25 inches (83mm) across. Like the SolarScope, the SunSpotter is easy to set up and fun to use. ($389.95, shop.sciencefirst.com)

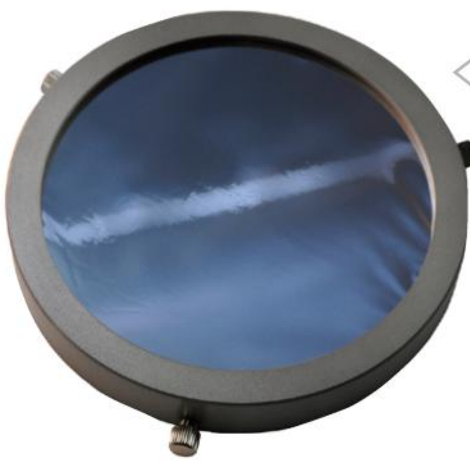


23 SOLAR FILTER

Thousand Oaks Optical, a well-established name in the solar filter field, makes both glass and polymer filters. The Type 2+ filters use glass hand-selected for its flatness, and then coated with the company's proprietary "Solar II Plus" mixture of chrome, stainless steel, and titanium, to produce yellow-orange solar images. Type 2+ filters are available to slip over telescope tubes with outer tube diameters 2 to 6.5 inches (50 to 165mm). ($69–$99, www.thousandoaksoptical.com)

22 SUN FINDER SCOPE

Aiming a telescope at the Sun can be difficult, as you can't use the finder scope. Tele Vue has the answer: the Sol-Searcher. This clever device projects an unmagnified image of the Sun onto a small translucent screen. Once you align it to your telescope, simply move your scope around until the Sun's image is centered on the screen, and it will also appear in the eyepiece's field of view. The Sol-Searcher attaches to the mount ring slot of every Tele Vue telescope. (Prices may vary around $30, www.televue.com)



24 SOLAR FILTER

Vixen StarGuy solar filters come in several sizes to fit telescope tubes with outside diameters 2.6 to 7.6 inches (66 to 194mm). All use thin film for neutral white images and come mounted in an aluminum cell. Thumbscrews securely hold the filter to the front of a camera lens or optical tube. ($70 and up, www.vixenoptics.com)

25 SOLAR FILTER

Thousand Oaks also sells Solarlite black polymer filters for tubes up to 17 inches (432mm) in diameter. Like the Type 2+ glass filters, these generate a yellow-orange image. Filters come mounted in felt-lined aluminum cells that slip over the front of a telescope tube. ($59–$179, www.thousandoaksoptical.com)

Phil Harrington *is an equipment guru as well as an* Astronomy *columnist and contributing editor.*

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

The Sun's 'shimmering' corona

Does our star's outer atmosphere display variations?

It's amazing how often the Sun's delicate outer atmosphere, as seen during a total solar eclipse, is described as the shimmering corona. Taken literally, this means the corona shines with a soft, wavering light. But does it? While the use of "shimmering" appears to be largely a case of poetic license — to make an otherwise tranquil phenomenon seem more animated — is there a glimmer of truth to it?

Near or far?

During the March 9, 2016, total solar eclipse, I was in a fishing boat off the coast of Ternate, Indonesia, watching totality through a substantially large hole in the clouds. Several times I saw the corona waver ever so slightly like a mirage, and I wondered if my eyes were deceiving me.

It is true that the Sun's corona is in a dynamic state. But the Sun is so huge that it would take a light flicker a couple of seconds to cross the corona's brightest parts — not fractions of a second, as occurs with a shimmer.

Therefore, naked-eye coronal shimmering must be a localized phenomenon, with the source being perhaps air turbulence close to the observer, thin atmospheric vapors passing in front of the corona, involuntary motions in the observer's eyes, or a combination of any or all of these. The flickering I saw reminded me of the passing of shadow bands, except that I saw them cross the "white sheet" of the corona. Before delving into this curious phenomenon further, let's look at shadow bands as we traditionally see them.

Shadow bands and totality

Shadow bands (not every total solar eclipse produces them) are long, alternating bands of light and dark that sweep across Earth like moving waves. Shadow bands are an atmospheric effect caused by light from the Sun's narrowing crescent interacting with turbulent bundles of air in our atmosphere. These bundles act like lenses to separate the incoming light into moving patterns of constructive (light) and destructive (dark) strips and patches.

Shadow bands dance across clouds during the July 11, 2010, total solar eclipse. This image may have been the first published that depicts bands on clouds. MIKE REYNOLDS

This Sun's corona never looked better than in this spectacular composite image of the March 9, 2016, total solar eclipse. DON SABERS AND RON ROYER; PROCESSING BY MILOSLAV DRUCKMÜLLER

Today, observers usually look for shadow bands in the minutes leading up to second contact (the start of totality) or immediately after third contact (the end of totality). But in the 19th century, observers occasionally recorded shadow bands during totality.

For instance, as reported in No. 1294 of *Astronomische Nachrichten* (the world's oldest astronomical journal, first published in 1821) during the July 18, 1860, total solar eclipse, Herr C. Haase and Herr Ibach in Valencia, Spain (near the edge of the eclipse's path), independently observed shadow bands on a nearby tower and its rooftop during totality, noting that the corona also appeared to "undulate violently." And during the December 22, 1870, totality, Diamilla Muller reported to the Italian Commission that just after the beginning of totality, he saw "undulating shadow bands … moving rapidly over the front of a house."

Such reports made me wish I had looked down when I saw the corona undulate, to see if shadow bands were visible. But how could they be?

Coronal magic

During the July 11, 2010, total solar eclipse that covered Easter Island, *Astronomy* contributing editor Mike Reynolds imaged shadow bands not on the ground but in thin clouds passing in front of the Sun (though not during totality). Is it possible that shadow bands, hardly noticeable to the eye, could induce the visual wavering of the solar corona as they swept across high, thin clouds?

In his great book *The Nature of Light & Colour in the Open Air*, Marcel Minnaert tells us that the light of Venus shining through a small opening in a window into a darkened room is enough to create shadow bands — "a wispy cloudiness" that passes over a white wall. Then why shouldn't the solar corona (especially its bright inner rim), which has the brightness of the Full Moon, be able to produce them? Guess I know what I'll be looking for come August 21.

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.**

BY GLENN CHAPLE

A smartphone lunar atlas

Image the Moon easily with your smartphone camera.

I have covered the topic of basic smartphone astroimaging on two previous occasions ("Cellphone imaging" in November 2011 and "Cellphone digiscoping" in October 2012). I had little choice. Both of those issues were astroimaging-themed, and I was asked to do my part.

It was a daunting task, as my experience with astrophotography was limited to taking 20- to 30-second exposures of constellations with a tripod-mounted, single-lens reflex (SLR) camera and 35mm slide film — and that was back in the late 1970s.

For the first time in my life, I'd be putting camera to telescope. I took a deep breath and gave it a try, and discovered that lunar imaging with a smartphone was a lot easier than taking constellation slides with an SLR camera.

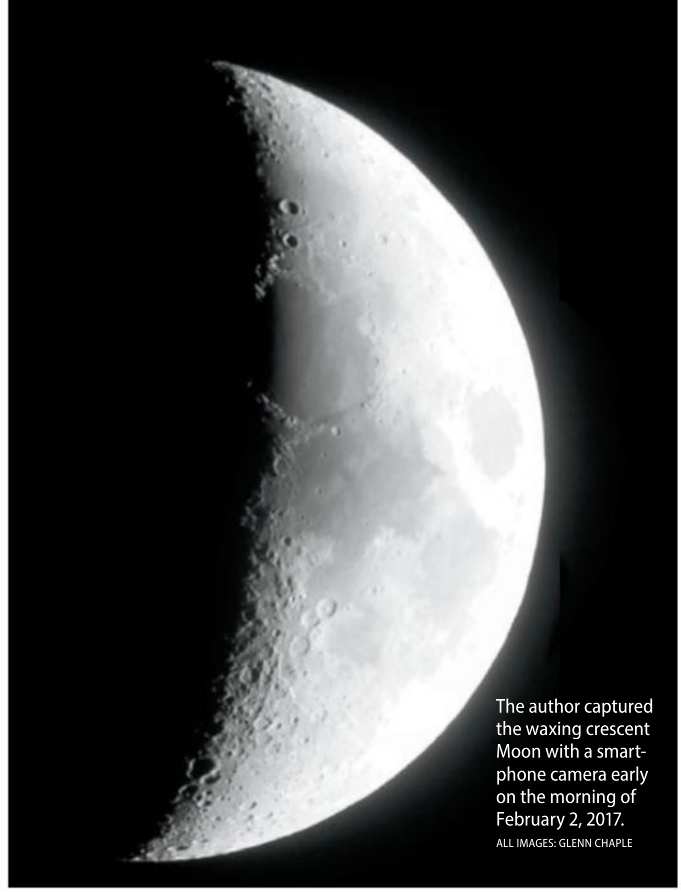
This past winter, I returned to lunar astroimaging in a big way by deciding to put together my own small-scope Moon atlas. Each night (and early morning when the Moon was in its waning phases), I'd trudge outside with my smartphone and a 4.5-inch f/8 reflector rigged with a 16mm wide-field eyepiece, and take a whole Moon snapshot. Setting up the scope, aligning it with the Moon, getting a decent shot with the smartphone, and putting everything away took 15 to 20 minutes.

The hardest part came in finding the "sweet spot," where the smartphone can capture a lunar image from the eyepiece. Not only does the phone have to be positioned precisely both up-and-down and side-to-side, but it also has to be at a 90° angle and the right distance from the eyepiece. The process can be simplified with smartphone adapters, like the ones featured in Tom Trusock's "Turn your smartphone into an astro-camera" article in the March 2017 issue.

Not owning such an adapter, I had to hold my smartphone in my hand and keep it as steady as possible. This took a lot of practice and patience. Fortunately, I could quickly review each shot and delete it if the result was less than satisfactory. My earliest attempts required a dozen or two takes, but eventually I was able to capture a workable image in the first half-dozen tries.

A close-up of the lunar southern hemisphere reveals three prominent craters: Theophilus, Cyrillus, and Catharina (top to bottom).

This part of the lunar northern hemisphere features the craters Aristoteles (top) and Eudoxus north of the Sea of Serenity.



The author captured the waxing crescent Moon with a smartphone camera early on the morning of February 2, 2017. ALL IMAGES: GLENN CHAPLE

Once I got an image I liked, I emailed it to myself. At the computer, I retrieved the image, transferred it to a Word document where I did some fine-tuning, and then ran it through the printer. I referred to a Moon map to label the main features, then slid the sheet into a page protector and placed it in a three-ring binder. I used to curse the Moon for making it difficult to conduct deep-sky observing. Now, I welcome the opportunity to add another page to "Chaple's Small-Scope Lunar Atlas."

Enter the neophytes

If you have a smartphone and have never taken astroimages through a telescope, I urge you to give lunar imaging a try. Even a rank beginner can do it. At a star party for a local elementary school, I brought my 4.5-inch reflector and invited parents with smartphones to try their luck taking an image of the Moon. After a quick demonstration with my smartphone, I put one of the parents in charge of the scope and went to my 10-inch reflector to conduct the main part of the star party.

Eventually, a girl walked up and proudly showed me a stunning lunar image she'd just captured. Here was a person who had likely never even seen the Moon through a telescope, and she was about to go home with an image of it that she had taken herself — from novice to lunar astroimager in less than an hour!

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Why I won't recommend a particular restaurant, movie — or telescope!

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.**

BINOCULARUNIVERSE
BY PHIL HARRINGTON

Great Ursa Major galaxies

The bright spiral M81 is one of the sky's most spectacular galaxies. R. JAY GABANY

As darkness falls, the nighttime curtain over the spring sky reveals myriad galaxies scattered across the expanse of the universe. Although most are too dim to be seen through binoculars, a few noteworthy exceptions beckon us to hunt them down.

Of those, my favorites are a celestial version of *The Odd Couple*: **M81** and **M82** in Ursa Major. Nowhere else in the sky do we find such an unusual pair. On one hand, we have a textbook example of a spiral galaxy. Like Felix Unger, it appears neatly arranged and well groomed. On the other, we have Oscar Madison, an unkempt, disheveled galactic mess.

Like Felix and Oscar, they live right next to each other in space, and have an undue influence on each other's existence — some good, some bad.

The Felix Unger of the pair is M81, a model Sb spiral system. The galactic arms in Sb spirals are wound moderately tightly around their galactic core. Color photographs show a bluish-white tint to those arms due to the many young, scorching stars found within. The core appears yellowish, a telltale sign of more mature stars.

When 18th-century German astronomer Johann Bode, then director of the Berlin Observatory, discovered M81 in 1774, he saw no indication of the galaxy's structure. That structure also eluded Charles Messier when he added it to his catalog five years later. Even William Herschel, gazing through the largest telescope of his day, missed it. Only with the advent of photography did the true nature of M81 become evident.

Through binoculars, M81 looks distinctly oval due to its tilt from our vantage point. Centered within that oval glow lies the galactic core, appearing like a faint, buried star.

Then we have the Oscar Madison of the couple, M82. Bode is also credited with its discovery in 1774. He probably didn't notice it at first, since M82 is about a magnitude fainter than M81. But he eventually glimpsed it, and so can you. Glance about half a degree north of M81. M82 looks long and thin, somewhat like a sausage. With patience, I've spotted it through 7x35 binoculars under suburban skies.

Unlike M81, which flaunts a pronounced core, M82 looks pretty much uniform from end to end visually. Photographs, however, reveal a pair of huge plumes of matter extending from a dark rift that cleaves the galactic center in half. Many believe this upheaval is the end result of a collision between M82 and M81 in the far-distant past. M81's greater mass disrupted M82, triggering tremendous internal turmoil and intense starburst activity.

Nicknamed the Cigar Galaxy for its stogie-like shape, M82 is often cited in books as the quintessential example of an irregular galaxy. But all that changed in a paper titled "The Discovery of Spiral Arms in the Starburst Galaxy M82" in the July 2005 issue of *The Astrophysical Journal*. Examining images of M82 taken at near-infrared wavelengths, authors Y. D. Mayya, L. Carrasco, and A. Luna noted that we are seeing M82 nearly edge-on. That challenging orientation plus the "high disk surface brightness, and the presence of a complex network of dusty filaments in the optical images are responsible for the lack of detection of the arms in previous studies."

Before we close, let's leave intergalactic space and bring it back home for a look at the variable star **R Ursae Majoris**. R UMa, about 4.5° due east of M81, is a long-period variable, like Mira in autumn's constellation Cetus. These pulsating red giants throb with enviable regularity. Over 302 days, R UMa goes from a maximum brightness of about 7th magnitude down to less than 13th, and then back again. Right now, it's on the way up. Maximum brightness is expected to occur in June or early July, so be sure to keep an eye on it.

R UMa forms a narrow triangle with 5th-magnitude SAO 15269 to its northwest and 6th-magnitude SAO 15260 to its southwest. You may notice the two SAO attendants look yellowish, while R UMa is noticeably red, especially near max.

Have a favorite binocular target that you'd like to share with us? I'd love to feature it in a future column. Drop me a line through my website, philharrington.net.

Until next time, don't forget that two eyes are better than one.

Lying near M81, M82 is a peculiar galaxy seen nearly edge-on that is undergoing an intense burst of star formation. KEN CRAWFORD

The soft glows of M81 and M82 are visible in the same field of view through binoculars, forming a spectacular sight. Another galaxy, NGC 3077, is to the left of M81. ROGELIO BERNAL ANDREO

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

ASTRO**SKETCHING**

BY ERIKA RIX

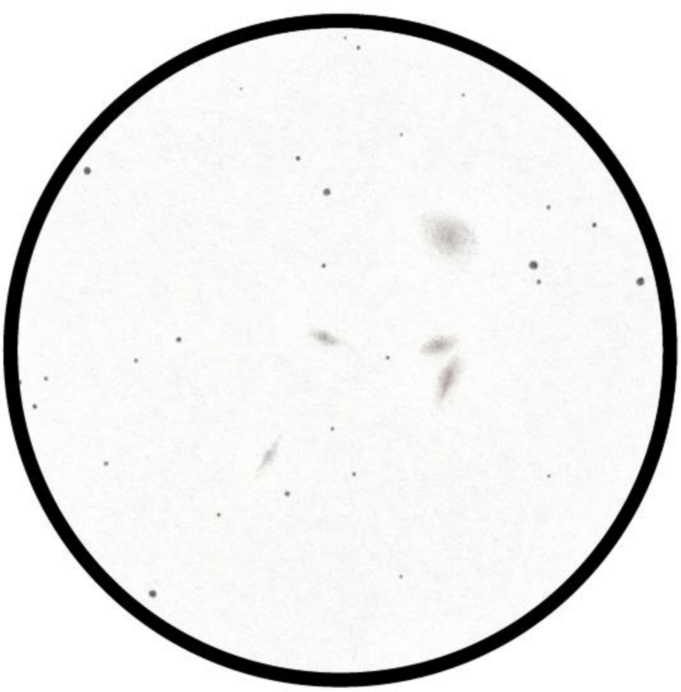
Hickson groups

In 1877, French astronomer Édouard Stephan identified the first compact galaxy group. Astronomers now call it Stephan's Quintet. Nearly two centuries later, Canadian astronomer Paul Hickson compiled a list of 100 such groupings while examining prints created using red-sensitive plates from the Palomar Observatory Sky Survey.

He based each group's inclusion on its population, surface density, and isolation from other galaxies. While these gravitationally bound gems offer researchers opportunities to study galactic evolution, they also provide captivating views for backyard observers with large scopes.

For me, the real fun begins during the sketching process. The brightest members of any group are the easiest to spot, so the challenge is to locate and identify as many of the others as possible. At that point, we can study their unique shapes and draw them within the star field. I'll break down the process with two sketches. The first shows Hickson 68, a tight, five-member group near the eastern border of the constellation Canes Venatici.

To locate Hickson 68, sight your telescope halfway between Nekkar (Beta [β] Boötis) and Cor Caroli (Alpha [α] Canum Venaticorum). The group's brightest member, NGC 5353 (Hickson 68A), glows at magnitude 11.0 and covers an area 1.2' by 1.1'. It forms a close pair with similarly sized NGC 5354 (68B), a magnitude 11.4 object.



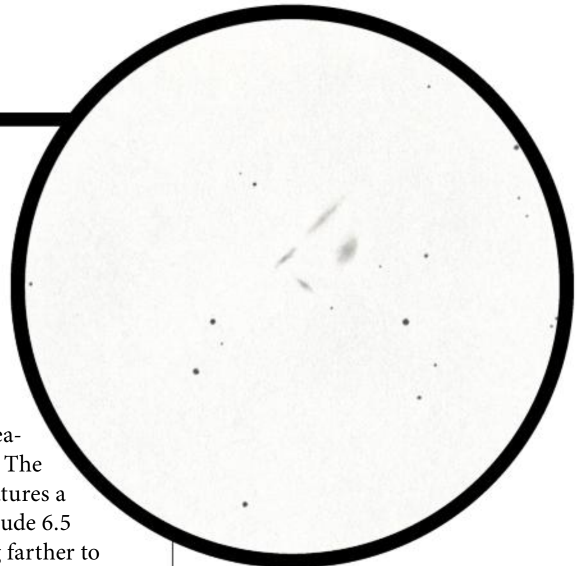
This sketch of the Hickson 68 group shows (clockwise from the top) NGC 5350, NGC 5354, NGC 5353, NGC 5358, and NGC 5355. The author drew both sketches using a 16-inch f/4.5 reflector on a non-tracking Dobsonian mount with a 12mm eyepiece for a magnification of 152x. She used graphite pencils on white paper and a blending stump. After scanning the sketch, she removed the stray markings and cleaned up the stars with Photoshop. BOTH SKETCHES: ERIKA RIX

The largest of the family is NGC 5350 (68C), which glows at magnitude 11.3 and measures 3.2' by 2.3'. The star field also features a beautiful magnitude 6.5 orange star lying farther to the southwest. NGC 5355 (68D) and NGC 5358 (68E) are the faintest, with magnitudes 13.1 and 13.9, respectively. As a bonus, you'll be treated to magnitude 10.6 NGC 5371, a conspicuous galaxy that lies 0.5° northeast of the group.

Notice how I placed the brightest stars near the edge of my sketch. I added those first and used them as markers so that when the star field drifted out of view, I could nudge the telescope back to the exact location.

Once I completed the star field, I tackled the galaxies by marking their locations on the sketch with the tip of a blending stump that I lightly covered in graphite. Then, starting with the brightest of the group, I worked my way outward from its core to build its structure with the blending stump, lightening the pressure as I proceeded to create diffuse edges. Because each subsequent galaxy became fainter, I had to use averted vision to tease out their ghostly details.

For my second example, I chose to sketch the Hickson 61 group, an alluring little quartet that lies 3° west of Gamfma (γ) Comae Berenices. Magnitude 11.7 NGC 4169 (61A) marks the western corner of the box and shines the brightest. NGC 4173 (61B), at magnitude 13.3, is more challenging to see at the northern corner due to its low surface brightness. The remaining galaxies, NGC 4175 (61C, magnitude 13.5) and NGC 4174 (61D, magnitude 13.6), form a nearly 90° angle along the eastern and southern corners.



The author's drawing of the Hickson 61 compact group shows (clockwise from the top) NGC 4173, NGC 4169, NGC 4174, and NGC 4175. Both sketches have north at the top and west to the right.

Unfortunately, few stars were near the field's edge for framing. So instead, I used an imaginary crosshair. Two bright stars floated just below the horizontal line and each a third of the way into the field of view from the western and eastern edges. This placed a moderately bright star at the 2 o'clock position, a double star at 3 o'clock, and a faint star at 9 o'clock. Once I had the stars in their places, I used the blending stump to draw NGC 4174 because it was conveniently placed in the center of the crosshairs. I then included the remaining family members by cross-referencing their positions with other stars or to my imaginary clock face.

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

Erika Rix is co-author of Sketching the Moon: An Astronomical Artist's Guide *(Springer-Verlag, 2011).*

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Santa Fe, New Mexico

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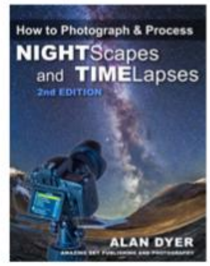

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MARKETPLACE

INDEX *of* ADVERTISERS

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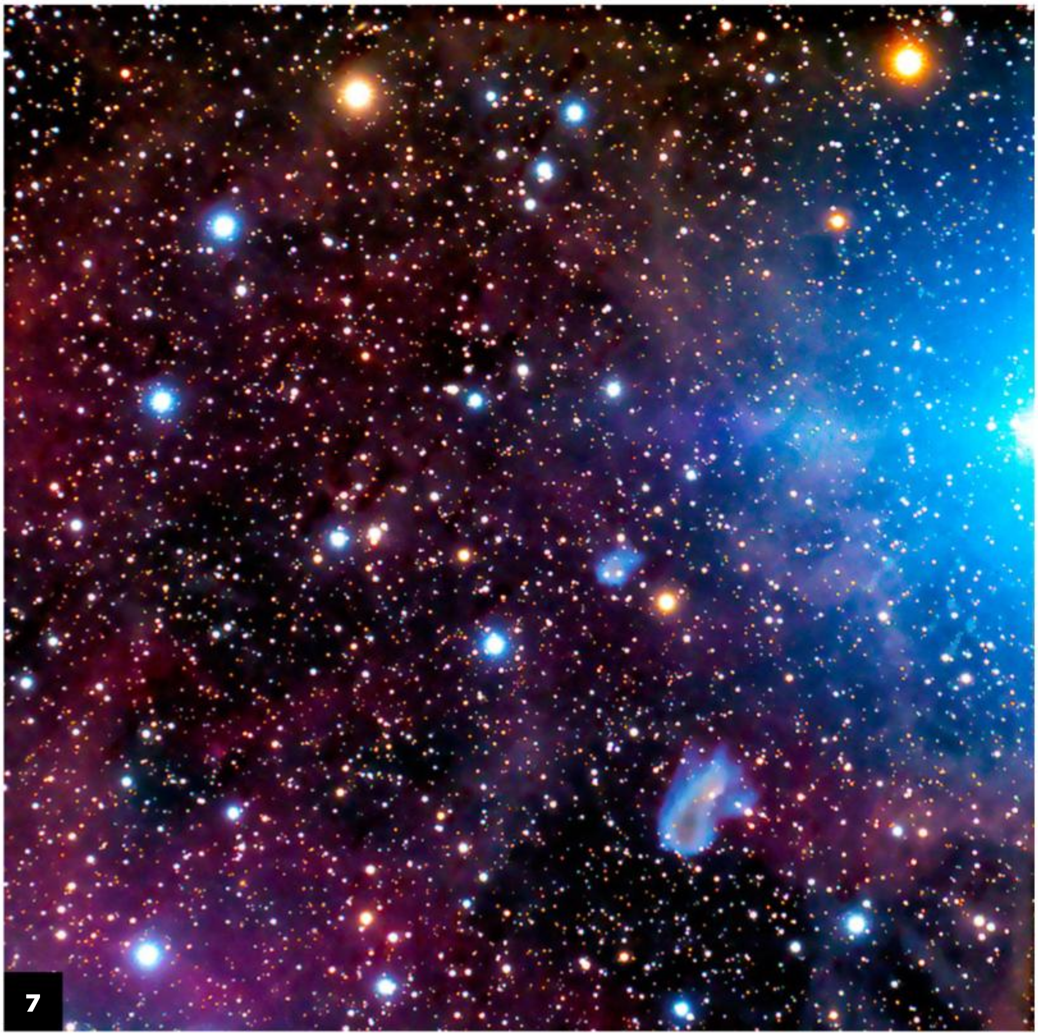
1. LONELY, BUT NOT ALONE
Open cluster M6, which floats just below center in this image, is one of the brightest such objects in the sky. And while a few other clusters lie nearby, it's the vast clouds of emission, reflection, and dark nebulosity that dominate this region of Scorpius.
• Gerald Rhemann

2. WHIRLING DERVISH
In the minds of some astronomers, barred spiral galaxy NGC 134 in Sculptor resembles the Milky Way. It's bigger, though, spanning some 150,000 light-years. NGC 134 lies 60 million light-years away.
• Warren Keller and Steve Mazlin

3. SPHERE OF ILLUMINATION
Globular cluster NGC 3201 may not be as tightly packed with stars as similar objects, but it's still a fine telescopic sight. The cluster, which lies 16,300 light-years away in the constellation Vela, shines at magnitude 6.9.
• Dan Crowson

4. COOKED IN COSMIC FIRE
The Robin's Egg (NGC 1360) is a planetary nebula in the constellation Fornax the Furnace. It glows an attractive shade of blue at magnitude 9.4 from a distance of 1,800 light-years.
• Ted Wolfe



5. UNEARTHLY DUST
The summer Milky Way from Hyalite Canyon near Bozeman, Montana, contains billions of unresolvable stars and vast quantities of interstellar dust. • ***Carlos Eduardo Fairbairn***

6. COSMIC BALLERINA
Barnard 22 is a dark nebula in the constellation Taurus. Near its center you can see the small, bluish, fan-shaped reflection nebula IC 2087, sometimes called the Little Flame. • ***Lynn Hilborn***

7. FRIENDLY GHOSTS
IC 423 and IC 424 are small reflection nebulae in the constellation Orion the Hunter. Because their heads point to Mintaka (Delta [δ] Orionis), astronomers think that's the star whose light is reflecting off the gas making up these objects.
• ***Howard C. Anderson***

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

BREAK
THROUGH

Cosmic cats and crustaceans

Few terrestrial zoos can boast the menagerie found lurking in the sky. Domestic and wild species exist side by side in Scorpius, where you can find the Cat's Paw Nebula (NGC 6334, at upper left) just 2° from the Lobster Nebula (NGC 6357). These glowing clouds of hydrogen prowl the constellation's southern confines, slightly northwest of the Scorpion's stinger. Although they appear to be neighbors, the Cat's Paw lies some 5,500 light-years from Earth while the Lobster resides 8,000 light-years away. Hot, massive stars hidden within the nebulae excite the surrounding hydrogen atoms and cause them to glow. ESO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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

August 2017: Giant worlds rule the night

The Sun's two largest planets ride high in August's early evening sky. Naked-eye observers and those with telescopes will enjoy spectacular views of Jupiter and Saturn all month.

Jupiter rules the western sky as darkness falls. Although it dims from magnitude –1.9 to –1.7 during August, it outshines every other evening planet and star. Virgo's brightest star, 1st-magnitude Spica, stands a few degrees above the planet. The gap between the two objects closes noticeably during the month.

Target Jupiter through a telescope and you'll find a disk that measures 33" across the equator at midmonth, some 2" wider than the polar diameter. This flattening — obvious through any scope — arises because the planet is gaseous and rotates rapidly. Small instruments also reveal an alternating series of bright zones and darker belts running parallel to the equator.

After you've viewed Jupiter, turn your attention to **Saturn**. The ringed planet stands nearly overhead as twilight fades and doesn't set until well past midnight. It glows at magnitude 0.3 in mid-August, far brighter than any of the neighboring stars in southern Ophiuchus. Saturn's slow westward motion relative to the stellar backdrop comes to a halt in late August some 3° north of 3rd-magnitude Theta (θ) Ophiuchi.

Saturn's high early evening altitude makes this the perfect time to scrutinize the planet through a telescope. No other celestial object compares to this magnificent world. Any scope shows the planet's 17"-diameter disk (noticeably flattened like Jupiter's) surrounded by a ring system that spans 40" and tilts 27° to our line of sight. Also look for Saturn's brightest moon, 8th-magnitude Titan.

A third bright planet graces the evening sky, but you'll have to search a bit harder to spot **Mercury**. The innermost planet lies fairly low in the west-northwest as darkness falls in August's first half. On the 1st, it appears nearly 15° high an hour after the Sun sets. Mercury then shines at magnitude 0.4 and stands out nicely in the fading twilight.

The planet reached greatest eastern elongation in late July, so it pulls closer to Earth during August. Through a telescope, it grows larger and turns its sunlit hemisphere away from our view. On the 1st, Mercury appears 8" across and slightly less than half illuminated. By the 15th, the planet spans 10" and shows a crescent that's just 18 percent lit. You'll need good seeing conditions to get a nice view because the planet then glows at 2nd magnitude and lies lower in the twilight sky.

Although August's predawn sky boasts just one planet, you can't miss **Venus**. The inner world shines at magnitude –4.0 — only the Sun and Moon glow brighter. Look for Venus in the northeast as twilight starts to paint the sky. The planet spends most of August in Gemini, passing to the right of that constellation's luminaries, Castor and Pollux, as it enters Cancer late in the month.

Unfortunately, Venus doesn't look like much through a telescope. In mid-August, its disk appears 13" across and about 80 percent lit.

Mars was in conjunction with the Sun in late July and remains lost in our star's glare. It will return to view before dawn in late September.

A **partial lunar eclipse** graces the skies above Australia, New Zealand, the East Indies, and much of Asia and Africa the night of August 7/8. (From Australia and New Zealand, the event occurs on the morning of the 8th.) The Moon enters Earth's dark umbral shadow at 17h22m UT on the 7th and leaves the shadow at 19h19m UT. Maximum eclipse occurs at 18h20m UT, when one-quarter of the Moon's diameter resides in Earth's shadow.

A **total solar eclipse** occurs August 21, but the path of totality lies entirely in the Northern Hemisphere. People in northern South America viewing through safe solar filters can see the Moon cover up to 50 percent of the Sun's diameter.

The starry sky

It's surprising what you can find while sweeping the Milky Way through a telescope. Many years ago, as I was observing in the neighborhood of the prominent star clusters M6 and M7 in Scorpius, I stumbled across an object I hadn't noticed before. Next to the 3rd-magnitude star G Scorpii, which sits roughly midway between M7 and Iota (ι) Sco, I spotted a patch of light that looked like a comet's head.

Of course, it wasn't a comet — I had found globular cluster NGC 6441. It lies so close to G Sco that the two usually appear in the same field of view. The pair passes nearly overhead during the early evening hours of August.

G Sco is an orange giant star with an age of about 3 billion years. It burns helium in its core and shines about 100 times brighter than the Sun. Although our galaxy contains many stars like G Sco, few have such an interesting history.

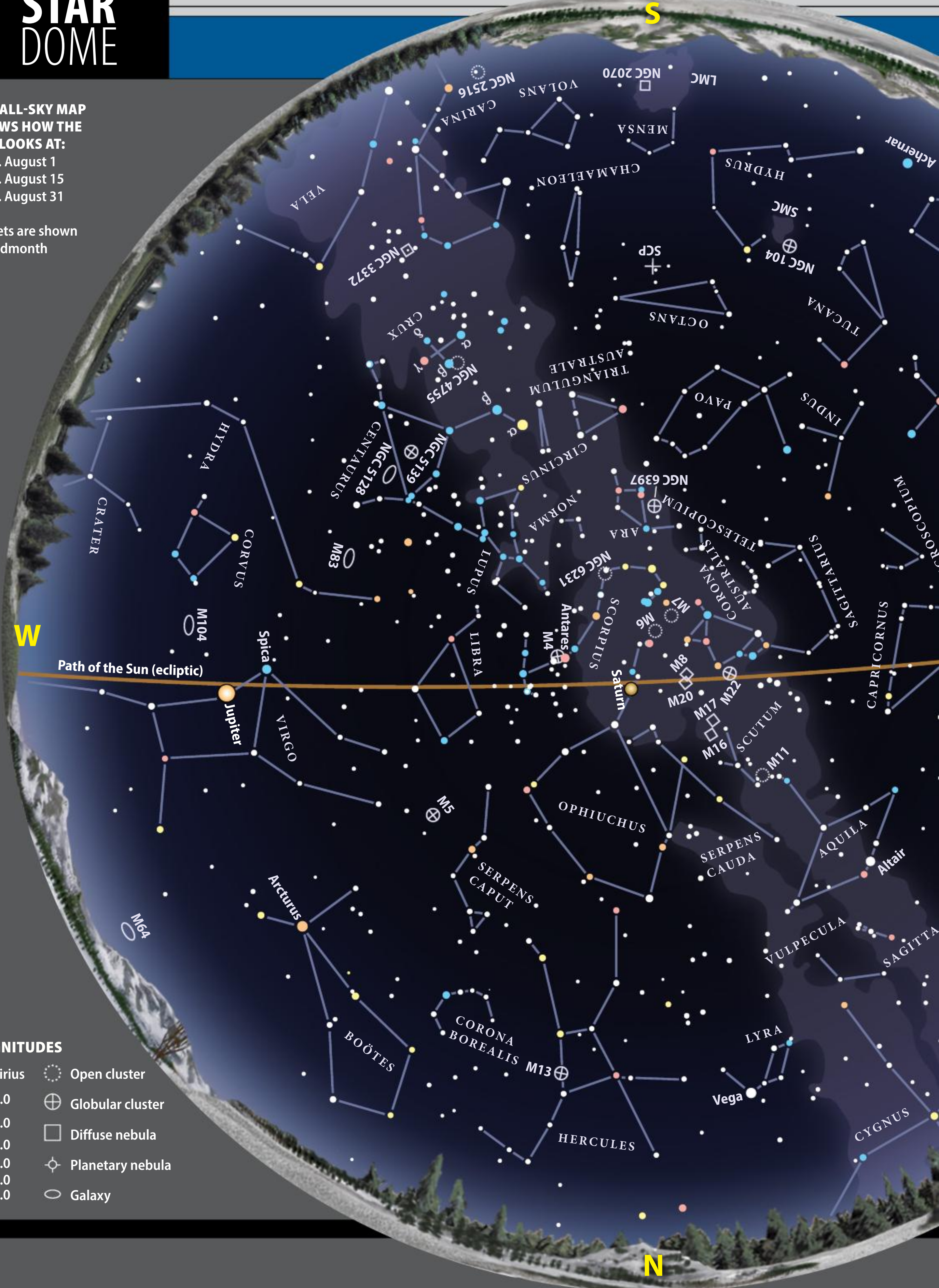
A bit southeast of G Sco lies Telescopium the Telescope, a constellation French astronomer Nicolas Louis de Lacaille introduced in the 18th century. Although the corner of Telescopium lies 10° from G, Lacaille considered it a part of the Telescope and called it Gamma (γ) Telescopii. Eta (η) Sagittarii was another victim of Telescopium's intrusion. Astronomers reduced the Telescope's size in the 19th century, returning these stars to their original constellations.

While you're in the area, take a closer look at NGC 6441. This cluster is one of the most massive in the galaxy and shows up easily through small telescopes despite G Sco's proximity. Its stars concentrate heavily toward the center, however, so you'll need a large aperture to resolve it. NGC 6441 ranks among the Milky Way's most unusual globulars. Not only does it have a relatively high proportion of elements heavier than helium, but it seems to contain two or three distinct populations of stars.

STAR DOME

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

AUGUST 2017

Calendar of events

2 The Moon is at apogee (405,025 kilometers from Earth), 17h55m UT

3 The Moon passes 3° north of Saturn, 7h UT

Uranus is stationary, 10h UT

7 Full Moon occurs at 18h11m UT; partial lunar eclipse

9 The Moon passes 0.9° south of Neptune, 23h UT

12 Mercury is stationary, 6h UT

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

15 Last Quarter Moon occurs at 1h15m UT

16 The Moon passes 0.4° north of Aldebaran, 7h UT

18 The Moon is at perigee (366,121 kilometers from Earth), 13h18m UT

19 The Moon passes 2° south of Venus, 5h UT

21 New Moon occurs at 18h30m UT; total solar eclipse

Venus passes 7° south of Pollux, 19h UT

25 The Moon passes 3° north of Jupiter, 13h UT

Saturn is stationary, 15h UT

26 Asteroid Juno is stationary, 10h UT

Mercury is in inferior conjunction, 21h UT

29 First Quarter Moon occurs at 8h13m UT

30 The Moon is at apogee (404,308 kilometers from Earth), 11h25m UT

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

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