CASSINI'S GRAND FINALE AT SATURN p. 28

SEPTEMBER 2017

Astronomy®

The world's best-selling astronomy magazine

NEW RESEARCH

Solving mysteries of PLUTO

Unique landscapes, geological activity, and — maybe — an underground ocean p. 22

16 times we didn't find E.T. p. 34

HOW Flagstaff is preserving dark skies p. 54

SECRETS of off-season globular clusters p. 50

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 45 • Issue 9

MAJOR IN YOUR PASSION FOR THE STARS.

Whether you're passionate about astronomy or astrophysics, Morehead State will help support your plan for a successful career. With personalized student success programs tailored to your talents and interests, you'll find MSU's commitment to your success starts at enrollment and continues throughout your life.

MSU proudly offers one of the only five space science degrees in the nation and boasts a 21 meter radio telescope, anechoic chamber and far field antenna test range.

SPACE SCIENCE PROGRAMS

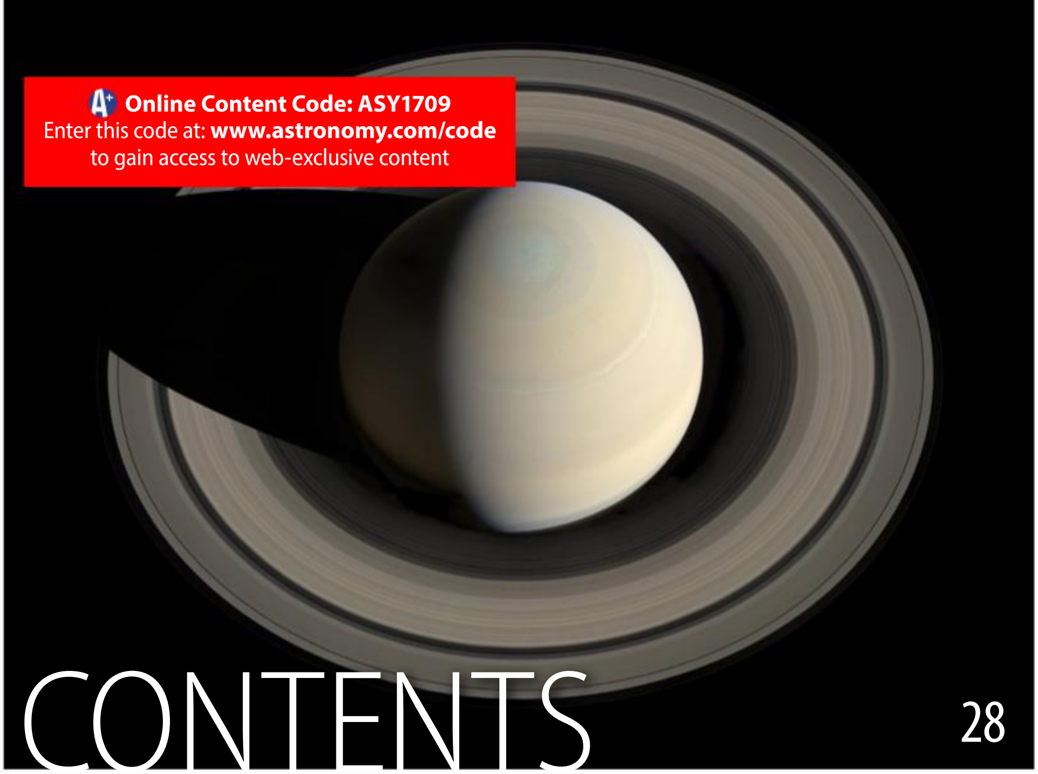
- Master of Science in Space Systems Engineering
- Bachelor of Science in Space Science
- Bachelor of Science in Physics
- Area of Concentration in Astrophysics
- Minor in Astronomy

MOREHEAD STATE UNIVERSITY

MAJOR IN YOU.

www.moreheadstate.edu

MSU is an affirmative action, equal opportunity, educational institution.



Online Content Code: ASY1709
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content

CONTENTS

28

SEPTEMBER 2017

VOL. 45, NO. 9

NASA/JHUAPL/SwRI

ON THE COVER

The huge nitrogen ice glacier Sputnik Planitia on Pluto is one of the many surprising features revealed by New Horizons.

FEATURES

22 COVER STORY

Puzzled by Pluto

Far from the inert ball of ice many scientists expected, this distant world boasts unique landscapes, recent geological activity, and a possible underground ocean. **S. ALAN STERN**

28

Cassini's Grand Finale: 20 years in the making

From grazing Saturn's rings to disappearing into its swirling atmosphere, this spacecraft's final days, hours, and minutes will be fruitful ones. **MICHAEL CARROLL**

34

16 times we didn't find E.T.

For decades, humanity has been searching for aliens. Here are the false alarms. **JOHN WENZ; ILLUSTRATION BY THEO COBB**

36

Sky This Month

An ice giant pinnacle. **MARTIN RATCLIFFE AND ALISTER LING**

38

StarDome and Path of the Planets

RICHARD TALCOTT; ILLUSTRATIONS BY ROEN KELLY

44

Ask Astro

How SETI searches.

46

Phantom planets

The wild and woolly menagerie of ghost worlds that once haunted the halls of astronomical history. **JOHN WENZ**

50

The secrets of off-season globular clusters

Target this list of two dozen beautiful star cities, none of which you'll find in the old standbys of Scorpius, Ophiuchus, or Sagittarius! **F. MICHAEL WITKOSKI**

54

How Flagstaff is preserving dark skies

A star party and world-leading community are keeping the hometown of Lowell Observatory in the dark. **CHRISTIAN LUGINBUHL AND JEFFREY HALL**

60

Fun at America's Darkest Sky Star Party

Several dozen people gathered in a small town under a clear, steady sky — all for the love of astronomy. **MICHAEL E. BAKICH**

COLUMNS

Strange Universe 10
BOB BERMAN

For Your Consideration 16
JEFF HESTER

Secret Sky 20
STEPHEN JAMES O'MEARA

Observing Basics 64
GLENN CHAPLE

Astro Sketching 66
ERIKA RIX

Binocular Universe 68
PHIL HARRINGTON

QUANTUM GRAVITY

Snapshot 8
Astro News 12

IN EVERY ISSUE

From the Editor 6
Astro Letters 11
New Products 69
Advertiser Index 70
Reader Gallery 72
Breakthrough 74

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

ONLINE FAVORITES >>

Go to **www.Astronomy.com** for info on the biggest news and observing events, stunning photos, informative videos, and more.

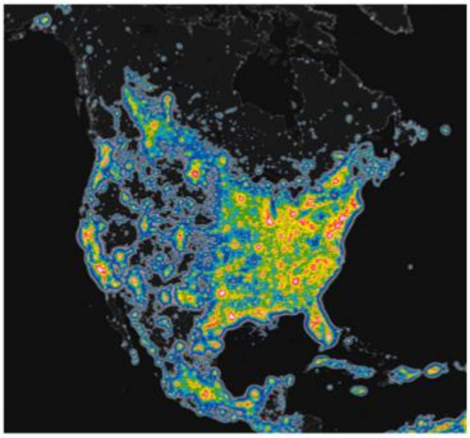
Trips and tours
Travel the world with the staff of *Astronomy*.

My Science Shop
The perfect gift for your favorite science geeks.

News
The latest updates from the science and the hobby.

Sky This Week
A daily digest of celestial events.

BY DAVID J. EICHER



The need for dark skies

A map of the light pollution in North America reveals a bleak outlook for night skies in the eastern half of the United States. The remaining outstanding skies are all out west. SCIENCE/SCIENCE ADVANCES/AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Last year an international team of astronomers led by Fabio Falchi published a stunning new report on the extent of light pollution on Earth. Titled "The New World Atlas of Artificial Night Sky Brightness," the report was published in *Science Advances*.

The bottom line for those who care about the night sky is grave: Some 80 percent of the globe is adversely affected by nighttime light pollution, and the problem in North America is growing worse by 6 percent each year. More than 99 percent of North Americans and Europeans do not see a dark night sky.

By percentage of population, Singapore is the most light-polluted country on Earth, followed by Kuwait, Qatar, and the United Arab Emirates. Africa is home to the top 10 least light-polluted countries. Disturbingly, fully one-third of the world's population cannot see the Milky Way.

As I write this, I've just returned from a conference at Lowell Observatory. On Mars Hill in Flagstaff, Arizona, the dark sky beckons from above. One of the nation's greatest dark-sky advocates, Chris Luginbuhl, is an old friend and a retired astronomer living in Flagstaff. Along with another friend, Lowell Observatory Director Jeff Hall, Chris has written a great story about what communities can do about light pollution. (See p. 54.) I urge you to read this important article and think about what you can do to fight the spread of light pollution in your community. Flagstaff offers a shining example of the right way to handle this scourge.

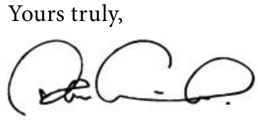
Amateur astronomers need a dark sky. This isn't a hobby you do in your basement. In the continental United States, the only truly dark skies remaining are in the West. The East and Midwest? You can pretty much forget it. That's why a group is offering a place for amateur astronomers to go, called Dark Sky New Mexico. The site near Animas, New Mexico, offers world-class dark skies within a two- to four-hour drive of major southwestern cities: Phoenix and Tucson, Arizona; El Paso, Texas; and Albuquerque and Las Cruces, New Mexico. The group plans to offer remote observing and imaging from this pristine site.

Last spring, Senior Editor Michael E. Bakich and I attended the first "America's Darkest Sky Star Party" in Animas, and we offer a story about the event in this issue. (See p. 60.) We gave several talks and discussed amateur astronomy with attendees before luxuriating in the spectacular darkness.

The group will hold its second star party October 13–14, co-sponsored by the Albuquerque Astronomical Society. Michael and I again will be there to speak and observe.

If you've never spent much time under a truly dark sky, I suggest you attend. It just may change your life.

Yours truly,



David J. Eicher
Editor

Follow the Dave's Universe blog:
www.Astronomy.com/davesuniverse
Follow Dave Eicher on Twitter: **@deicherstar**

Astronomy

Editor David J. Eicher
Art Director LuAnn Williams Belter

EDITORIAL
Managing Editor Kathi Kube
Senior Editors Michael E. Bakich, Richard Talcott
Associate Editors Alison Klesman, John Wenz
Copy Editors Dave Lee, Elisa R. Neckar
Editorial Assistant Nicole Kiefert

ART
Graphic Designer Kelly Katlaps
Illustrator Roen Kelly
Production Specialist Jodi Jeranek

CONTRIBUTING EDITORS
Bob Berman, Adam Block, Glenn F. Chaple, Jr., Martin George, Tony Hallas, Phil Harrington, Korey Haynes, Jeff Hester, Liz Kruesi, Ray Jayawardhana, Alister Ling, Steve Nadis, Stephen James O'Meara, Tom Polakis, Martin Ratcliffe, Mike D. Reynolds, Sheldon Reynolds, Erika Rix, Raymond Shubinski

EDITORIAL ADVISORY BOARD
Buzz Aldrin, Marcia Bartusiak, Timothy Ferris, Alex Filippenko, Adam Frank, John S. Gallagher III, Daniel W. E. Green, William K. Hartmann, Paul Hodge, Anne L. Kinney, Edward Kolb, Stephen P. Maran, Brian May, S. Alan Stern, James Trefil

Kalmbach Publishing Co.
Senior Vice President, Sales & Marketing Daniel R. Lance
Vice President, Content Stephen C. George
Vice President, Consumer Marketing Nicole McGuire
Art and Production Manager Michael Soliday
Corporate Advertising Director Ann E. Smith
Circulation Director Liz Runyon
New Business Manager Cathy Daniels
Retention Manager Kathy Steele
Single Copy Specialist Kim Redmond

ADVERTISING DEPARTMENT
(888) 558-1544
Advertising Sales Manager Steve Meni
Advertising Sales Representative
Dina Johnston, djohnston@kalmbach.com
Ad Services Representative
Christa Burbank, ads@astronomy.com

RETAIL TRADE ORDERS AND INQUIRIES
Selling *Astronomy* magazine or products in your store:
Phone (800) 558-1544
Outside U.S. and Canada (262) 796-8776, ext. 818
Fax (262) 798-6592
Email tss@kalmbach.com
Website www.Retailers.Kalmbach.com

CUSTOMER SALES AND SERVICE
Phone (877) 246-4835
Outside U.S. and Canada (813) 910-3616
Customer Service Astronomy@customersvc.com
Digital Astronomy.Digital@customersvc.com
Back Issues Astronomy.SingleCopy@customersvc.com

SPECIAL EMAIL ADDRESSES
Ad Sales adsales@astronomy.com
Ask Astro askastro@astronomy.com
Books books@astronomy.com
Letters letters@astronomy.com
Products products@astronomy.com
Reader Gallery readergallery@astronomy.com

Follow *Astronomy*

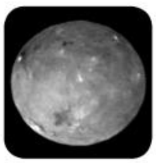
www.twitter.com/AstronomyMag
www.facebook.com/AstronomyMagazine
plus.google.com/+astronomymagazine

QUANTUM GRAVITY

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

HOT BYTES>>

TRENDING TO THE TOP



ROCKY PHOTO OP
NASA captured images of Ceres at opposition, when the Dawn spacecraft was positioned directly between the asteroid and the Sun.

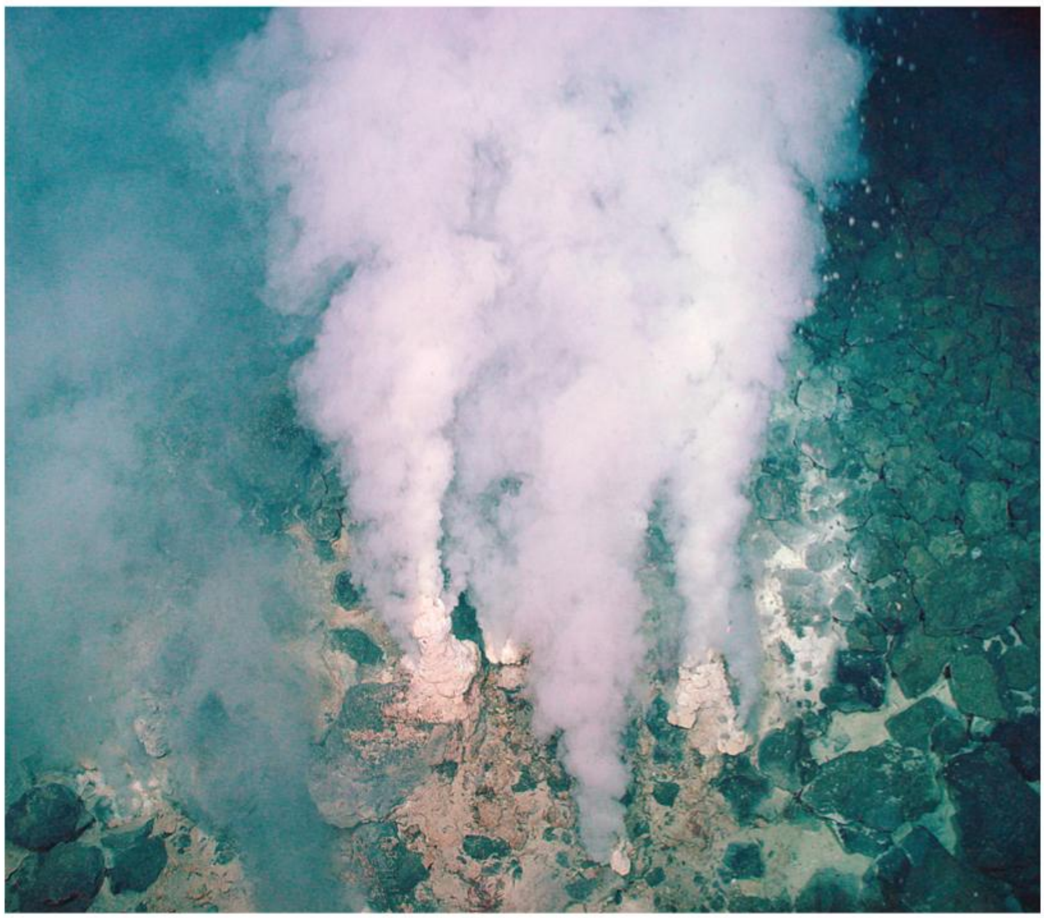
LIGHT IT UP
Ice particles may be responsible for hundreds of mysterious flashes seen between 2015 and 2016 by the DSCOVR craft, which monitors the solar wind.

FERMI MILESTONE
The Fermi Gamma-ray Space Telescope witnessed its billionth gamma ray since its launch in 2008.

SNAPSHOT

Let's hear it for abiogenesis

The origin of life? You can't "magic" it into existence.



Life on Earth may have originated in and around "black smokers" — hydrothermal vents on the ocean floor, like this one emitting carbon dioxide in the Marianas Trench Marine National Monument in the South Pacific.

NOAA; TOP FROM LEFT: NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA; NASA GODDARD; NASA GODDARD

One of the thorniest questions we have is exactly how life originated on Earth. It's been a mystery for a very long time. Scientists call the process abiogenesis — how self-replicating molecules began from nonliving matter such as simple organic compounds. The puzzle of understanding abiogenesis involves multiple sciences including astronomy, physics, biology, chemistry, and paleontology. It attempts to derive a process that occurred nearly 4 billion years ago, on an Earth that was very different from the one we inhabit today.

One of astronomy's most powerful tools, spectroscopy, tells us that chemistry is uniform throughout the universe. So although we don't know exactly when or how life originated, or how its simplest form got going, we do know it was governed by the processes of organic chemistry that we understand well today. As Richard Dawkins has often said, life can't be "magicked" into existence.

The molecular hypothesis of how life started originated in the 1920s, and current ideas build from it. Organic (carbon-containing) molecules are common in the solar system and universe. Going from simple organics to self-replicating RNA and DNA is a big step, but one that is logical given the chemistry of early Earth. We don't yet know what developed first or dominated early: an RNA World, an Iron-Sulfur World, a Protocell World, a Deep Sea Vent World, or a number of others?

It is a highly exciting time for science. Understanding early Earth and its chemistry is taking us closer and closer to comprehending exactly how we got here.
— David J. Eicher

Get set for autumn observing!

2017 Astro SWEEPSTAKES

GRAND PRIZE: NexStar Evolution 6 Wi-Fi Telescope

Celestron's signature telescopes reach a new level with NexStar Evolution 6, the first Schmidt-Cassegrain telescope with a built-in Wi-Fi connection and integrated long-life lithium-ion battery. Leave your hand control behind and slew to all the best celestial objects with a tap of your smartphone or tablet. ***Retail value: $1,299.00***

1ST PRIZE:
Astro Fi 90mm Wi-Fi Refractor Telescope

The Astro Fi 90mm Refractor is a fully featured telescope that can be controlled with your smartphone or tablet using the free Celestron SkyPortal app. The app replaces the traditional telescope hand control for a 100% wireless experience. The Astro Fi 90mm creates its own wireless connection, so it can communicate with your device even in remote locations where Wi-Fi or cellular networks are not available.
Retail value: $399.95

2ND PRIZE:
Inspire 70AZ Refractor Telescope

The Inspire 70AZ is the ultimate telescope for the novice to intermediate astronomer, offers easy transport and storage, and is packed with features never seen before on entry level telescopes. Inspire features fully coated glass optics, a solid altazimuth mount with a unique asymmetrical design, a sturdy steel tripod with integrated fold-up accessory tray, an integrated smartphone adapter, built-in red LED flashlight, and more.
Retail value: $179.95

3RD PRIZE:
Cometron 12x70 Binoculars

Powerful Celestron Cometron 12x70 binoculars feature massive 70mm objective lenses, multi-coated optics, and a large exit pupil for incredible light-gathering capabilities that showcase comets, stars, the craters of the Moon, and even dim nebulae in crisp clarity with high contrast.
Retail value: $89.95

MORE THAN $2,000 IN PRIZES!

4TH PRIZE:
1-Year *Astronomy* Subscription
(5 awarded)

Receive 12 exciting issues of knowledgeable science reporting, insights from top experts, monthly sky charts, spectacular celestial photography, informative equipment reviews, and more. Plus, enjoy all the subscriber-only benefits at Astronomy.com.
Retail value: $42.95 each

Sponsored by:
Astronomy magazine
CELESTRON

ENTER TODAY! Enter Online at Astronomy.com/Sweeps

Hurry! Entries must be transmitted by September 30, 2017. See page 70 for Official Sweepstakes rules.

P30994

STRANGE**UNIVERSE**

BY BOB BERMAN

Finding aliens

The coming decades may bring proof of aliens. But will we know what we're looking at?

The seven new Earth-sized planets around TRAPPIST-1, a red dwarf star 39 light-years away, recently renewed public speculation about extraterrestrials. Sixty years ago, the consensus among astronomers was that life's earthly genesis was so convoluted and unlikely that we may be alone in the universe. For some physicists like Enrico Fermi, negative results from the Search for Extraterrestrial Intelligence (SETI) reinforced that pessimism. But these days, very few astronomers feel that way. The current groupthink is that the universe probably teems with life.

Early discovery steps in the near future will include spectroscopic space telescopes studying exoplanet atmospheres, offering the ability to study their composition. Earth's habitable atmosphere exists solely because of photosynthetic plants exchanging carbon dioxide for oxygen. It would therefore be very encouraging if we detected oxygen around another world, as it may point the way toward life.

But what is life? Scientists can't agree on a definition. Are viruses alive? They have no metabolism, they don't feed themselves, and many biologists regard them as inanimate. Yet their RNA coding forces host cells to make lots of viral copies.

And does life begin through chemistry? If certain occurrences cause life to arise from non-living components, we want to know if it happens readily. In other words, is life easy? Or does it require extremely unlikely events?

A good argument for life being "easy" is that earthly life began almost as soon as it was possible. After the molten Earth cooled, there came a long period when asteroids and comets pummeled our surface. This violence stopped some 4 billion years ago. And bingo, the earliest fossils date from right then, within 200 million years of when it was first possible. That's awfully quick.

A good counterargument, which makes the case for life being "hard," is that life-origination or abiogenesis happened only once (that we know of). Every earthly creature is a descendant of that first ancestral organism. We know this because all life, from elephants to bacteria, share remarkable genetic similarities. They're all made of amino acids and sugars with the same kinds of spirals or asymmetries. Amino acids can come with left- or right-handed twists, called chirality. But on Earth, life only uses amino acid molecules with left-handed twists, and is limited to a right-handed direction in all its sugars and DNA — the same as a corkscrew.

BUT WHAT IS LIFE? SCIENTISTS CAN'T AGREE ON A DEFINITION.

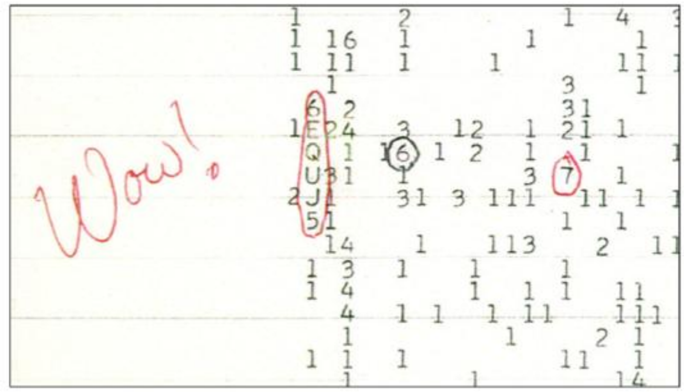
If life started a second time from scratch, it likely would show differences in such chirality. Now, there are at least 6 million species of bacteria (even if only 100,000 have had their genomes sequenced). But every single microbe, plant and animal we've examined is a descendant of that first life creation. The point: Why didn't life start a second time, a third, or a hundredth? Four billion years have passed, and yet life originated only once. This suggests that abiogenesis is not easy, but hard.

So which is it? Fred Hoyle, who coined the term "Big Bang," described an accidental birth of life as akin to a tornado sweeping through a junkyard and creating a jumbo jet. Supporting this, Francis Crick, the co-discoverer of DNA's double helix, described the origin of life as "almost a miracle, so many are the conditions which would have had to have been satisfied to get it going." (He wasn't suggesting a spiritual origin, merely that the process is utterly baffling.) If abiogenesis is really so unlikely, then even given the immense size of the cosmos, it's possible we're the only example.

Of course, this assumes abiogenesis only happens accidentally. But what if advanced aliens are creating life, or if nature has immense innate intelligence? I just saw an amazing nature documentary called *Flying Monsters 3D* by David Attenborough, showing the first flying creatures from millions of years ago. The earliest bird wings had the same shape as modern aircraft. That airfoil configuration is necessary for all flight, and requires a wing's upper surface to be convex. It's hard to see how evolution could have created it. Unlike giraffes' necks, where incremental increases offered survival advantages, a step-by-step process wouldn't work for a wing design. A slightly wrong shape would be useless and confer no benefit. Some 400,000 cells would all have to simultaneously mutate in just the right way to create a properly shaped wing. This defies an evolutionary hypothesis.

Occam's razor might suggest some baked-in, overarching intelligence. I'm not invoking spirituality, merely that the effect of random collisions and mutations is not always a workable answer. So perhaps nature is inherently smart. We cannot visually see this intelligence, just as we cannot see electrical fields; and yes, this is a minority viewpoint. But if true, then the sky's the limit for ETs.

It's guesswork. We know of life on only a single world, so our sample size is one. And when you try to draw a line on a graph but you have just one data point, well, good luck. We'll have no shortcuts when we probe the planetary system of TRAPPIST-1.



While SETI has been around since 1960, it has yet to turn up any conclusive proof of intelligent life. The Wow! signal, pictured above, is one of the more mysterious signals received, but it has never repeated or been conclusively identified. BIG EAR RADIO OBSERVATORY AND NORTH AMERICAN ASTROPHYSICAL OBSERVATORY (NAAPO)

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

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

ASTROLETTERS

The triple sunrise
This is a response to Ryan Hofmann's letter, "An unforgettable sunrise," in the May 2017 issue, about seeing an unusual sunrise while flying into Denver. Not that I have seen crimson beads but I did see a very unusual sunrise while driving on a very cold morning in Omaha, Nebraska, about 15 years ago. It actually looked like three Suns rising together about 15° apart. All three were the same size. I actually got out of the car to make sure it wasn't the glass that was making these additional Sun images. It was so unusual that I turned on the local news radio station, and to my amazement there was no mention of it. Maybe the cold air had something to do with it. This unusual phenomenon lasted about 30 minutes. **— Greg Pappas,** Plymouth, MI

Seeing double
Regarding Stephen James O'Meara's article "Twice-setting stars" in the March 2017 issue: Several times I have witnessed a star (the Sun) set, then rise again, hover for an hour or so, then set again. The trick is in being a fighter pilot stationed in a northern latitude. According to U.S. Air Force rules, if the Sun has set at your home base and you are in the air, you are logging night-flying time regardless of reality (blinding Sun in your face, wearing both sunglasses and solar visor).

Thus, you preflight your F-4C Phantom just as the Sun is setting, taxi to the runway just after sunset, take off, and watch the Sun rise in the west. After leveling off, you then cruise west at 515 knots (600 mph). The Sun appears to just hang there because you are matching the rotation speed of Earth. Then you catch a tanker, slow down for refueling, and observe the Sun gradually sinking. Finally, you turn north for another aspect of your mission, and the Sun finally sets (again) normally, and the sunglasses and visor come off.

At other times, there are "sandwich sunsets," in which you are between flat layers of clouds with the Sun illuminating the upper and lower layers equally.

Flying allows for a variety of special experiences, if you just pay attention.
— Phil LaZeir, Sacramento, CA

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*


ASTRONOMICAL INSTITUTE, ACADEMY OF SCIENCES OF THE CZECH REPUBLIC

The deserving astrophysicist
I can't ever read about Jocelyn Bell Burnell, as I did in May 2017 issue, without being outraged that she was denied a Nobel Prize. A lot of deserving women were denied recognition in the past in astronomy, but hopefully times have changed, and in some cases like Ms. Burnell's, it could be corrected.
— Bill Frazer, Gold Canyon, AZ

A fond memory
The April 2017 issue brought back a very interesting event that happened in July 1996. I was selected to attend a one-month astronomy educator workshop at Northern Arizona University by the National Science Foundation. We were able to visit the U.S. Naval Observatory and Lowell Observatory, and do some scientific work at the mesa south of Flagstaff. But that was not the "event" that sets aside the time for me.

I have built two telescopes, an 8-inch f/8 Dobsonian and a 6-inch f/4 Dobsonian. I took my 6-inch telescope with me to Flagstaff. On my first night at NAU, I took my telescope up to the parking lot on Mars Hill and did some observing. It was a thrill to be able to do that with my own telescope. It just so happened that Hale-Bopp was in the sky. Alas, Mars was not visible then. And even though Pluto was not reachable with my telescope, it was just about due south! **— Dan Goins,** Martinsville, IN

Correction
The "Venus at Dusk" graphic on p. 16 of the June 2017 issue describes Venus' evening appearance while the graphic depicts the planet's morning appearance. We apologize for the confusion.

THAT'S SO METAL. Hot temperatures on exoplanet HAT-P-7b ionize metals in its atmosphere, tying the planet's magnetic field to its winds. This effect allows researchers to study exoplanet magnetic fields.

DETAILS ARRIVE ON TRAPPIST-1'S OUTERMOST PLANET

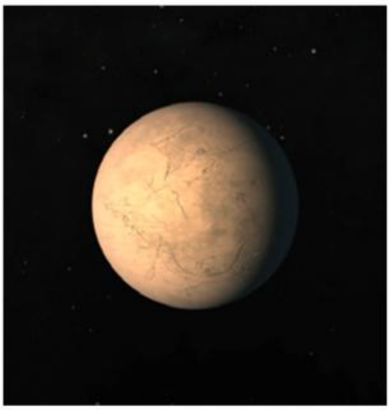
Ever since NASA announced in February that the TRAPPIST-1 system has seven planets instead of three, scientists have been interested in learning more about the unusual system. After further research, they have pinned down orbital details about TRAPPIST-1h, the system's most distant and mysterious planet.

Using data from the Kepler spacecraft, scientists studying the exoplanets have confirmed that the outermost planet, which is about 6 million miles (9.6 million kilometers) from TRAPPIST-1, orbits its host star every 19 days.

Reviewing data from the Spitzer Space Telescope, the team noticed a predictable pattern, also called an orbital resonance, among the first six planets in the system. An orbital resonance occurs when orbiting bodies show a consistent gravitational influence on each other, like how Jupiter's moon Ganymede orbits twice in the same length of time Europa takes to complete four orbits.

Orbital resonances essentially lock objects into specific periods over time; if an object in the system is perturbed, the resonance will eventually bring it back into a stable orbit.

The team calculated six potential resonant periods for TRAPPIST-1h based on this principle. After gathering more data with Spitzer and ground-based telescopes, only one of those potential periods — 19 days — remained plausible. The other five would have shown up clearly in the new observations.

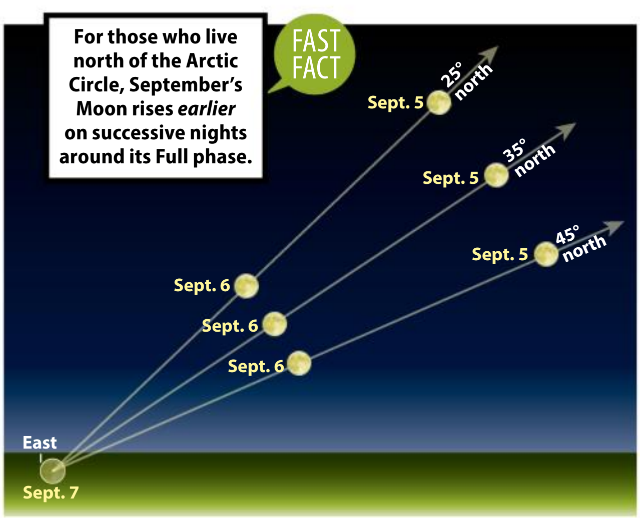


PINNED DOWN. This artist's depiction shows what TRAPPIST-1h, the farthest planet from the TRAPPIST-1 star, may look like. NASA/JPL-CALTECH

NASA has kept its eye on the seven-planet system, which orbits the ultracool dwarf star TRAPPIST-1, since December 2016. The system is anywhere between 3 billion and 8 billion years old. Researchers originally thought that the system had three planets, until Spitzer data recently revealed the four additional planets.

NASA's Hubble Space Telescope is looking for more information about the planets' atmospheres. When the James Webb Space Telescope launches in October 2018, it will join the search for information about the TRAPPIST-1 system. **— Nicole Kiefert**

WHEN THE MOON CAN'T WAIT



ASTRONOMY: ROEN KELLY

MOONDANCE. On average, the Moon rises about 50 minutes later each night. But at the Full Moon in September, the delay shrinks to only about 30 minutes for those at mid-northern latitudes. That's because our satellite orbits close to the ecliptic (the Sun's path through the sky), and, on autumn evenings, the ecliptic makes a shallow angle to the eastern horizon around sunset. But the angle changes depending on latitude, so those who live farther north don't have to wait as long. This year's Full Moon arrives the night of September 5/6 — see how much later it rises on the following nights. **— Richard Talcott**

BRIEFCASE

NOT SO DARK

Energetic gamma rays emitted from our galaxy's center are often attributed by astronomers to dark matter. But a recent study has turned up a different source: pulsars, the dense spinning cores of stars sometimes left behind after supernovae. The study, performed with the Large Area Telescope on NASA's Fermi Gamma-ray Space Telescope, looked at the center of the Milky Way, where researchers expect dark matter to be abundant. Instead of the diffuse glow that should be produced by dark matter interactions, the source of the gamma rays appears "speckled," or composed of many small sources. Pulsars not only make up the majority of small gamma-ray sources in the Milky Way, but the characteristics of the gamma rays coming from the galaxy's center match those from other known pulsars as well. That makes it more likely these objects are largely responsible for the emission.

•

SOLAR SYSTEM ANALOGUE

NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) took a closer look at a nearby planetary system just 10.5 light-years away around the star Epsilon (ε) Eridani. The star hosts a Jupiter-sized planet that lies about the same distance as Jupiter from our Sun, as well as a debris disk of rock and dust, which is left over after planets form. Using SOFIA's instruments, astronomers were able to determine that Epsilon Eridani's debris disk is composed of two distinct asteroid beltlike rings. This finding also indicates the star likely hosts a planetary-mass body in its outer solar system responsible for shaping the second belt. The results were published in *The Astronomical Journal* on April 25.

•

THAT'S NO STAR

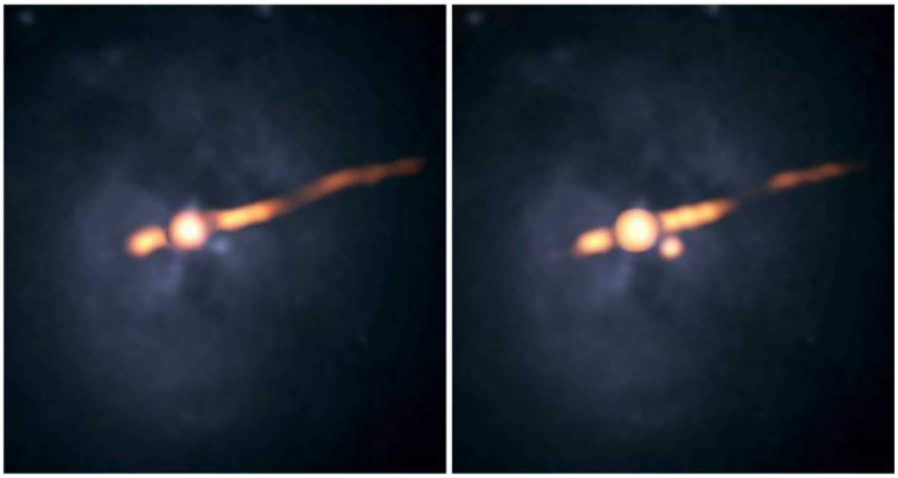
A team of researchers led by Jonathan Gagné of the Carnegie Institution for Science recently discovered that SIMP J013656.5+093347 (SIMP0136 for short), once thought to be a nearby brown dwarf, is in fact much more planet-like than star-like. Brown dwarfs are too small to support the hydrogen fusion that defines stars; instead, they burn deuterium (a hydrogen isotope) briefly, then cool over time, with temperatures that overlap those observed in some planets. The team found that SIMP0136's mass is roughly 13 times that of Jupiter, indicating it's a free-floating planet-like object associated with a young group of stars called Carina-Near. **— Alison Klesman**

0.7 light-year

The extent of the jet of energy launched into space by the brown dwarf Mayrit 1701117.

ASTRO**NEWS**

IN PLAIN SIGHT. JPL researchers modeled galaxy mergers and found that the gas resulting from two black holes merging may become obscured by dust kicked up during this process.



TWO FOR ONE. Cygnus A's previously identified central supermassive black hole appears in these composite radio (orange) and optical (blue) images as a large, bright, circular source. The image on the left is from 1989; the image on the right was taken in 2015. A new bright radio source has appeared since 1989; astronomers believe this second source is also a supermassive black hole. PERLEY ET AL., NRAO/AUI/NSF, NASA

Second black hole spotted in famous galaxy

Cygnus A is an elliptical galaxy nearly 800 million light-years away. Its center hosts a supermassive black hole at least 1 billion times the mass of our Sun, but this well-known galaxy also contains a surprise: a second supermassive black hole, destined to merge with the first.

Upgrades to the National Science Foundation's Jansky Very Large Array (VLA) radio telescope in 2012 prompted observers to return to this famous galaxy in 2015. Cygnus A had not been observed in radio wavelengths since 1996. "To our surprise, we found a prominent new feature near the galaxy's nucleus that did not appear in any previously published images," Rick Perley of the National Radio Astronomy Observatory (NRAO) said in a press release. "This new feature is bright enough that we definitely would have seen it in the earlier images if nothing had changed. That means it must have turned on sometime between 1996 and now."

The astronomers who made the discovery include Perley and his son, Daniel Perley of the Astrophysics Research Institute at Liverpool John Moores University in the U.K., as well as NRAO researchers Vivek Dhawan and Chris Carilli. The results will be published in *The Astrophysical Journal*.

The object lies within 1,500 light-years of the galaxy's other supermassive black hole. Astronomers originally thought its emission represented a dense group of stars, based on infrared images. But the fact that the object has grown brighter in radio wavelengths has prompted new consideration.

Now, "we think we've found a second supermassive black hole in this galaxy, indicating that it has merged with another galaxy in the astronomically recent past," said Carilli. "These two would be one of the closest pairs of supermassive black holes ever discovered, likely themselves to merge in the future."

Although previously quiescent, the second supermassive black hole may have turned on after encountering a new source of fuel, likely stars and dust in the galaxy. Now that it's visible, Daniel Perley said, "This new object may have much to tell us about the history of this galaxy." **— A. K.**

The Perseus cluster is experiencing giant waves of gas

NASA/CXC/GSFC/S. A. WALKER, ET AL.

STIRRED UP. Scientists found a wave of incredibly hot gas in the Perseus galaxy cluster, more than 200 million light-years away. The wave is about 200,000 light-years across, which is twice the size of the Milky Way. The study, which was published in the June issue of *Monthly Notices of the Royal Astronomical Society,* used 10.4 days' worth of high-resolution data and 8.5 days' worth of wide-field observations from NASA's Chandra X-ray Observatory to create an X-ray image of the rolling gas cloud. Scientists estimate that it took 2.5 billion years for the gas in the center of the Perseus cluster, which burns at about 54 million degrees F (30 million degrees C), to expand a distance of 500,000 light-years. As the smaller galaxy cluster flies by, it disrupts the gas and causes rolling waves. The researchers say this wave is a much bigger version of a Kelvin-Helmholtz wave, which is caused by two fluids moving at different speeds past each other. A simple earthly example of this type of behavior is wind causing rippling waves across bodies of water. **— N. K.**

QUICK TAKES

SHINE ON
Caltech chemical engineer Konstantinos Giapis discovered that comets make molecular oxygen when surface ices are sublimated by sunlight.

THE ELDER ONES
A Neptune-sized planet called HAT-P-26b seems to have retained its primordial atmosphere. It has an atmosphere and density much like Saturn's.

ON THE RUN
NASA researchers discovered a 1 billion-solar-mass black hole being kicked out of its galaxy after two black holes merged.

CONNECT THE DOTS
Astronomers discovered a faint "bridge" magnetic field between the Milky Way and two of its satellite galaxies, the Small and Large Magellanic Clouds.

BUCKETS OF RAIN
Early Mars may have had rain strong enough to permanently change the planet's surface, according to research published in *Icarus*.

PUFFED UP
The planet KELT-11b has the density of Styrofoam because of the heat from its home star, researchers at Lehigh University discovered.

BLOW UP
Amateurs on Zooniverse.org discovered a 960 million-year-old supernova event named SN 2017dxh.

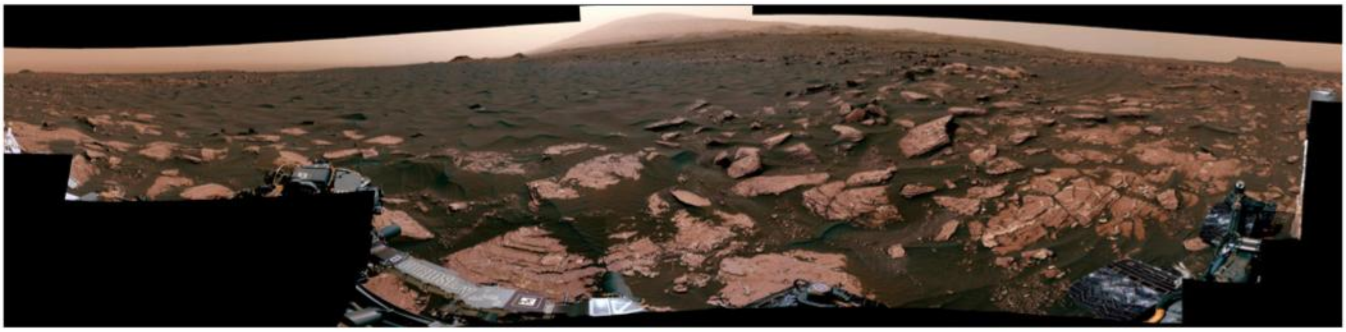
EARLIER LAUNCH
The launch for NASA's Psyche mission has been moved up to 2022 to allow a faster trip to the protoplanet core.

BUT WITH A WHIMPER
The giant star N6946-BH1 seemed to begin going supernova before it disappeared instead, likely collapsing directly into a black hole.

TRICKSTER GOD
A transit of Europa across Io helped astronomers identify lava movements in Loki Patera, the largest volcanic crater on the latter moon. **— John Wenz**

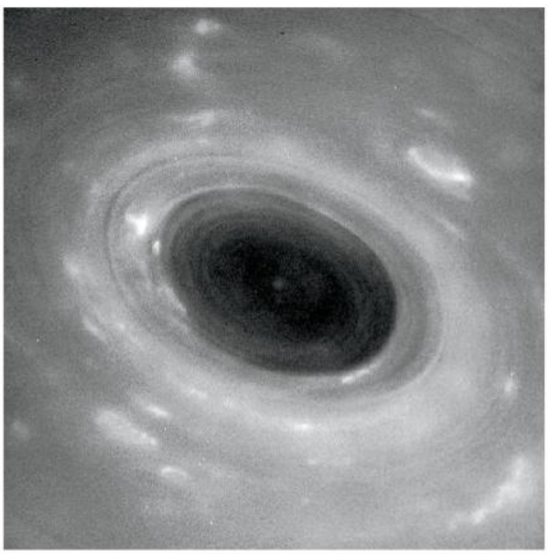
AN OPPORTUNITY TO PERSEVERE. Mars rover Opportunity reached Perseverance Valley, an area carved by some form of erosion, in May. The rover will study if wind or water was the culprit.

Curiosity spies active dunes on Mars



NASA/JPL-CALTECH/MSSS NASA/JPL-CALTECH/MSSS

DUNE BUGGY. Mount Sharp rises in the distance as NASA's Curiosity Mars rover looks out over the Bagnold Dunes in this 360-degree mosaic, taken with the Mast Camera on March 24 and 25. The rover is completing the second part of a two-phase study — the first close-up non-terrestrial investigation of active dunes in the solar system. Between February and April, Curiosity sampled four sites near a linear dune on the northwestern side of Mount Sharp. These samples provide a comparison for samples of crescent dunes taken in 2015 and 2016 from a site about 1 mile (1.6km) downhill. The study aims to compare how Mars' winds shape dunes into different patterns. Curiosity also nabbed a small sample of sand from both types of dunes to image over time and observe whether martian winds preferentially sort different grains with varying mineral contents. — **A. K.**



GET A LITTLE CLOSER. Cassini's first dive on April 26 brought us this image of Saturn's atmosphere. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

An up-close view of Saturn's atmosphere

After 20 years, Cassini is working through its final chapter and is in the process of completing 22 dives through the space between Saturn and its rings before plunging to its death in September. During the first dive, the team was prepared to use Cassini's round antenna as a shield, but surprisingly did not need to use it. Scientists were amazed by how little dust the craft encountered in the 1,200-mile-wide (2,000km) area, but they counted it as a lucky break that Cassini wouldn't have to endure the treacherous conditions for which they had prepared.

Images from Cassini's first dive on April 26 were stitched into a movie to get a better look at what the spacecraft saw as it passed through. The video, which can be viewed at www.nasa.gov/feature/jpl/new-movie-shows-cassinis-first-dive-over-saturn, shows a closer look at the vortex at Saturn's north pole and its hexagon-shaped jet stream.

"I was surprised to see so many sharp edges along the hexagon's outer boundary and the eye-wall of the polar vortex," said Kunio Sayanagi, an associate of the Cassini imaging team. "Something must be keeping different latitudes from mixing to maintain those edges."

The video also notes Cassini's altitude above the clouds, dropping from 45,000 miles (72,400km) to 4,200 miles (6,700km).

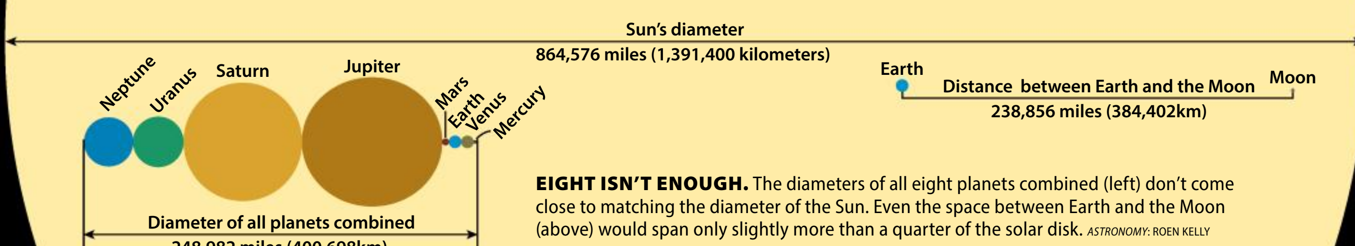
Now that the team knows what to expect from the atmosphere and the space that Cassini will travel through, they plan to adjust camera settings for better results on a similar opportunity June 29.

Cassini is just under half-finished with its dives through the rings and is scheduled to take its death plunge on September 15, 2017. — **N. K.**

THE AMAZING COLOSSAL SUN

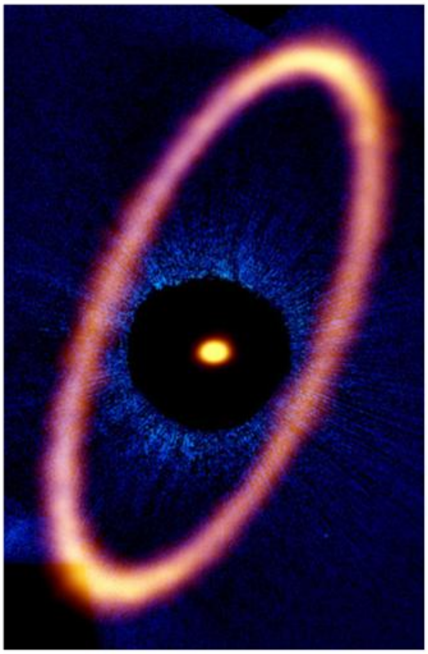
Compared to each of us as an individual, Earth is big. Really big. But even in the setting of our planetary system — to say nothing of the universe as a whole — Earth is quite tiny. Take the word *solar*, as in *solar system*. It comes from *sol*, the Latin name for the Sun. And when we consider our star and its system of planets, moons, asteroids, and comets, nothing comes close to matching the size of the Sun in any way. — **Michael E. Bakich**

FAST FACT The Sun's mass accounts for 99.86 percent of all mass in the solar system.



EIGHT ISN'T ENOUGH. The diameters of all eight planets combined (left) don't come close to matching the diameter of the Sun. Even the space between Earth and the Moon (above) would span only slightly more than a quarter of the solar disk. *ASTRONOMY*: ROEN KELLY

ASTRONEWS



ALMA (ESO/NAOJ/NRAO), M. MACGREGOR; NASA/ESA HUBBLE, P. KALAS; B. SAXTON (NRAO/AUI/NSF)

THE COMPLETE PICTURE. This image combines ALMA data (orange) with optical data from Hubble (blue). The dark region filters the star's brilliant light.

ALMA images a star's icy ring

Fomalhaut, a young star 25 light-years away, is famous for its debris disk; it is one of very few stars around which astronomers have directly imaged planets. This image combines comprehensive millimeter-wavelength data from the Atacama Large Millimeter/submillimeter Array (orange) and the Hubble Space Telescope (blue). Excess light from the star itself is blocked in the center (black) using an instrumental mask. A bright band surrounds the star at a distance of 12 billion miles (20 billion km). The band is likely composed of icy dust resulting from interactions between comets and planetesimals in the system, and it has been narrowed through gravitational influences exerted by Fomalhaut's planets. The increased brightness observed at the disk's most distant points is caused by dust particles "bunching up" as they orbit more slowly when they're farther from their star, then speeding up and spreading out again as they get near the closest point to their sun in their orbit. — **A. K.**

40 to 50
light-years

The distance at which a supernova could fry all life on Earth.

FOR**YOUR**CONSIDERATION

BY JEFF HESTER

Cassandra smiling

Science, politics, and a march in the rain.

On April 22, I was one of 40,000 people who gathered near the Washington Monument for the March for Science. The weather that day was rainy and cold, a good match for the concerns that had brought us together. Even so, spirits were amazingly upbeat. It felt more like a party than a protest. Not even the occasional heckler promising eternal damnation could provoke much other than a smile and a wave.

Hand-drawn signs were as nerdy as they were ubiquitous. I think my personal favorite was, "At the start of every disaster movie, there's a scientist being ignored." Marching down Constitution Avenue toward the Capitol, people joined voices in call and response to a drummer's cadence. "What do we need?" "Evidence-based policy!" "When do we need it?" "After peer review!"

Hardly a pithy political slogan, I know. What can I say? Political activism isn't really our gig, and to be honest, scientists aren't very good at it. It's nowhere near as cool as the stuff going on in the lab! But more and more scientists are discovering that even they have their limits. When it sinks in that the White House prefers "alternative facts" to the real thing, and will fervently declare that 2 + 2 = 4 is "fake news" if they want it to equal 5 instead, a scientist's head is likely to explode. When that happens, the next question is what to do about it.

Some scientists wring their hands about not politicizing science. "If we just stay above the fray and explain ourselves calmly and clearly," they insist, "people will flock to our oh-so-well-reasoned arguments." Really? You've been trying that for a while now. How's that working out for you? Ummm … didn't think so.

Scientists pride themselves on their ability to see reality as it is, regardless of how they would like it to be. Here is one of those realities: People aren't rational. There is a lot of really cool research supporting that statement. Daniel Kahneman won the 2002 Nobel Memorial Prize in Economics for showing that the whole notion of "rational man" is a bunch of hooey. We base our judgments and decisions far less on reason than we do on how they feel.

That statement is as true for scientists as it is for anybody else. Scientists search for real answers because we are emotionally invested in knowing what those answers are. Of course we look at all of the data! Of course we challenge our ideas! Evidence and reason matter!

Or at least they matter to us. We feel those emotions as strongly as any preacher in a pulpit. What we fail to realize is that most people don't.

The human brain evolved to help us survive. Period. In our evolutionary past, things like power, influence, and acceptance by a group mattered far more than devotion to careful review of the evidence. Today it's not that people are incapable of understanding something like global warming. They just aren't as emotionally attached to the whole evidence thing as scientists are. Confronted with a conflict between evidence and higher emotional priorities, most people will eighty-six reality in a heartbeat, and in the next heartbeat rationalize it all away.

The author spends a rainy day in Washington, D.C., with 40,000 like-minded friends near the west portico of the U.S. Capitol. JEFF HESTER

Which brings us to why the March for Science was such an uplifting event.

There we were, standing in the rain with our T-shirts and our signs, protesting against policies that promise dire consequences for the nation and human civilization as a whole. Today's scientists are the descendants of Cassandra, seeing the devastation that always comes from ignoring reality, but frustrated that our voices are not being heard.

Yet our spirits were joyous! Scientists are reality junkies. We get high on knowledge, and on the adventure of pulling back the curtain to discover how the universe works. There was an emotional bond spanning the globe that day. Crowds gathered to declare their common support not for one issue or another, but for something they all held sacred — seeing the world as it is.

There are things that an experienced political organizer might criticize about the March for Science, but most would agree that it was pretty amazing for an international event that started just a few months earlier as a conversation on social media. When I look at the March for Science, what I see is hope.

Science is powerful, and the world desperately needs scientists to raise our voices and demand to be heard. The March provided scientists with a taste of what it is like to set aside differences and join together, arm in arm, in defense of reason. Such camaraderie feels good to us naked apes. The March also sent many onto the battlefield upon which hearts and minds are won and lost. Those battles are emotional, they are strategic, and they are political. It is unscientific to pretend otherwise.

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

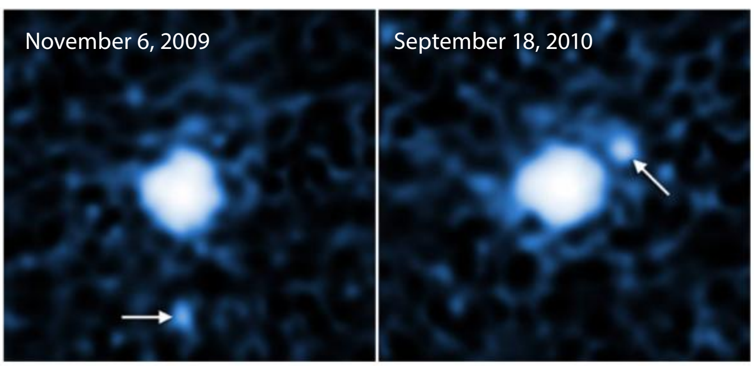
BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

HOT DOUGHNUT. When planets or planetesimals collide, they may create an object called a synestia, a doughnut-shaped mass of molten material that eventually reforms into a solid mass.

NASA, ESA, NRAO/AUI/NSF AND G. DUBNER (UNIVERSITY OF BUENOS AIRES)

A new look at the Crab Nebula

A COLORFUL SIGHT. Scientists combined data from five telescopes to produce a new, stunning image of the Crab Nebula: the Karl G. Jansky Very Large Array (radio) in red, the Spitzer Space Telescope (infrared) in yellow, the Hubble Space Telescope (visible) in green, the XMM-Newton Observatory (ultraviolet) in blue, and the Chandra X-ray Observatory (X-ray) in purple. The data from the telescopes span the entire electromagnetic spectrum to provide an incredibly detailed picture. About 6,500 light-years from Earth, the Crab Nebula is a magnitude 8.4 supernova remnant in the constellation Taurus. A superdense neutron star lives in its center, emitting radio pulses as it rotates every 33 milliseconds. A team of scientists led by Gloria Dubner of the Institute of Astronomy and Physics, the National Council of Scientific Research, and the University of Buenos Aires studied the newly found details in the image to better understand the physics of the nebula and are reporting their results to *The Astrophysical Journal*. "Comparing these new images, made at different wavelengths, is providing us with a wealth of new detail about the Crab Nebula," Dubner said. "Though the Crab has been studied extensively for years, we still have much to learn about it." — **N. K.**



I SEE YOU. Hubble images between 2009 and 2010 drew out a previously unseen moon around 2007 OR_{10}. NASA/STScI

Nameless rock has another rock around it

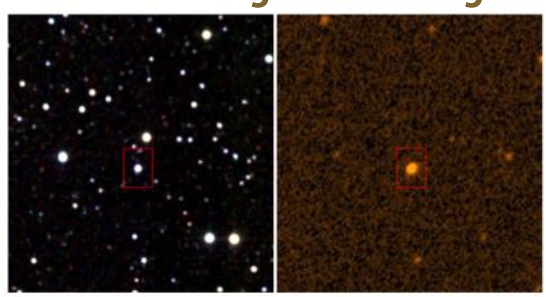
Astronomers recently discovered that dwarf planet 2007 OR_{10}, the largest known body in the solar system with no common name, has a moon. 2007 OR_{10} was discovered in 2007 by Meg Schwamb, a graduate student who was working with planetary scientist Mike Brown at the time. With a diameter between 800 and 950 miles (1,290–1,528km), it's the third- or fourth-largest object known in the Kuiper Belt after Pluto, Eris, and Makemake.

There is some debate about its size. Brown lists it as the fourth-largest, while other estimates place it above Makemake in diameter. It is a red, icy world that swings from 33 to 101 astronomical units in its orbit. (An AU is the distance between Earth and the Sun; Neptune is at 30 AU.)

OR_{10} has a slow rotation rate, which hid the moon in plain sight from Hubble for quite some time. The moon is large for OR_{10}'s size, estimated at 150–250 miles (240–400km) in diameter. The higher estimate would place the moon at the lower limit of dwarf planet status, if it orbited the Sun on its own. A body is considered a dwarf planet if it can attain a round shape and is only in orbit around the Sun and not another body. The moon is about one-quarter the size of OR_{10}, a ratio similar to the Earth-Moon system.

Maybe this large moon will boost the case for giving the dwarf planet a real name. — **J. W.**

Weirdest star gets weird again



WHAT'S THAT? The bizarre dimming of Tabby's Star (KIC 8462852) has excited and confused both the astronomy community and the public since it was discovered in Kepler data in 2015. IPAC/NASA

A star 1,300 light-years away exhibits some of the strangest behavior ever seen: Something dims its light by 20 percent, and that something is much bigger than a planet. It's called KIC 8462852, but most people shorten it to Tabby's Star or Boyajian's Star, for its discoverer, Tabetha Boyajian. In May, it started dimming again, leading to a feverish search for the cause.

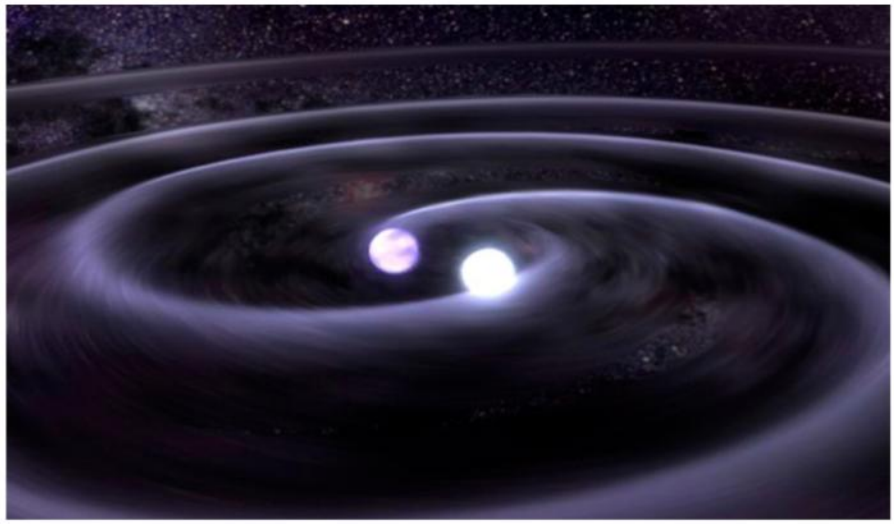
No one knows what causes the dimming. It could be a massive fleet of comets or the spread-out debris of a planet. Boyajian and co-investigator Jason Wright put out the alert, hoping that at least one telescope could grab a spectrum from the star to see what is causing the dimming.

One strange hypothesis — a sort of "all other avenues have been exhausted" — is a giant Dyson Swarm of machines built by an alien megacivilization meant to harness the star's power. Gathering spectra could help rule out or bolster the case for that scenario.

Professional and amateur astronomers participated in a worldwide campaign to observe Tabby's Star. Now we just have to wait for the results. — **J. W.**

 MOON RIVER. River channels on Saturn's moon Titan resemble those seen on Mars rather than Earth. Titan and Mars both show stream formation without influence from plate tectonics.

White dwarf mergers seen as antimatter source



MAKING POSITRONS. The merger of two white dwarfs, depicted here as they spiral toward each other, could provide a major source of positrons in the Milky Way's center. NASA/TOD STROHMAYER (GSFC)/DANA BERRY (CHANDRA X-RAY OBSERVATORY)

Antimatter is matter's opposite. For each particle of "normal" matter, there is an antimatter particle with an opposite charge; for example, positrons are the antimatter equivalent of electrons. When matter and antimatter meet, they annihilate each other, giving off gamma rays in the process.

Astronomers have observed such gamma rays in the center of our galaxy since the 1970s. Despite extensive follow-up, researchers today are still looking for the exact source (or sources) of this emission. It could run the gamut from the mundane — natural processes in a star's life — to the exotic, such as dark matter (see p. 12).

In a paper published May 22 in *Nature Astronomy*, lead author Roland M. Crocker of the Research School of Astronomy and Astrophysics at Australian National University and his co-authors suggest that positrons resulting from white dwarf mergers could contribute significantly to the observed gamma-ray signal.

White dwarfs are left behind after a Sun-like star runs out of fuel. If two low-mass stars (about 1.4 to twice the mass of our Sun) circle each other closely in a binary system, they can interact via mass transfer, a process in which gas from the stars is exchanged. The end result is two white dwarfs that may eventually merge. That merger can produce radioactive isotopes that decay into positrons.

The current resolution of instruments used to study this emission is not high enough to see individual sources, such as single supernova remnants. Thus, more precise measurements and computer simulations will be needed to determine the positron production rates from such events. Such information will also shed light on the processes that shaped the young Milky Way. — **A. K.**

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

The color purple

There's wonderful stuff at one end of the rainbow.

Although our limited eyes cannot detect purple stars, the color purple is nevertheless part of a skywatcher's vocabulary. It becomes especially noticeable when we deal with atmospheric aberrations, lensing effects, and the scattering of light.

Examples of the last include the violet flash at sunset, the purple light of twilight, the indigo bands of a rainbow, or the face of New Moon during a total solar eclipse. All these are fantastically purple, yet the opportunities to see them are generally uncommon.

Even simultaneous color-contrast illusions combined with a nervous atmosphere can trick us into believing we can see the color purple in some stars. The 19th-century English astronomer William Henry Smyth was a master of simultaneous color-contrast perception. He noted, for example, that double star Eta (η) Cassiopeiae has a bright white primary with a lilac secondary.

Back to nature

Nevertheless, although the color purple is a rarity in the sky, I wonder how much of its light escapes our gaze. This could be because we either do not consciously look for it, or perhaps we do not know how to use our eyes efficiently enough to perceive it. I don't know the answer, but I have seen something that makes me ponder.

Occasionally I write about how we can train our eyes to perceive light and color more effectively in the open air by observing the world around us during the day or in the twilight (dawn and dusk). Doing so helps us to learn how our eyes react under certain lighting conditions.

For instance, one misty morning last April (in the Southern Hemisphere) I was walking outside in a gray and cloudy dawn when my eyes caught the sight of a black house spider's web in a tree. When I looked directly at the dense and messy web, which was about 50 feet (15.2 meters) away, it looked white.

As I passed by it, I saw out of the corner of my eye a beautiful patch of lavender light in the direction of the web. When I stopped and studied the web, I noticed that its thinner sections did have a slight aqua sheen when seen with direct vision, which turned purple when I used peripheral vision.

Later I matched my visual impression to a spectrum of light, and I estimated that the light I perceived from the spiderweb with averted vision had a wavelength of about 440 nanometers, putting it in the blue-violet region. This differed from my estimate of about 480nm — in the green-blue region — that I saw using direct vision. That's quite a spectral shift toward the violet! And this was on a gray morning with little (if any) blue in the sky.

Color mixing?

In bright twilight, the eyes' night-sensitive rod cells are still active and can affect color appearance by desaturating long wavelengths of light in our peripheral vision. In addition, the cone cells that line the eye's periphery are dominated by short-wavelength S cones, which are most sensitive to blue-violet wavelengths at around 445nm.

Furthermore, S cones in the human eye are more than four times less sensitive than light shining directly into the center of the eye. Because of this decreased sensitivity, they act like a filter of sorts: They cut down on intrusive glare while enhancing our perception of blue-violet light.

Just as no two fingerprints are the same, our visual experiences are highly subjective (in fact, unique). By sharing my experiences with you, all I can hope to do is inspire you to have your own. As always, send your thoughts to sjomeara31@gmail.com.

Compare the two views of the web of a black house spider, which the author encountered last April. The one at the top, viewed directly, shows hints of green, albeit ever so faintly. When viewed obliquely (bottom image), the strands take on a definite purple cast. STEPHEN JAMES O'MEARA

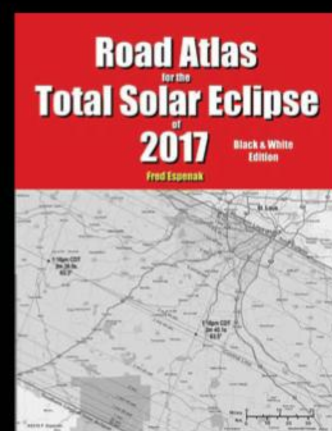
Stephen James O'Meara is a globe-trotting observer who is always looking for the next great celestial event.

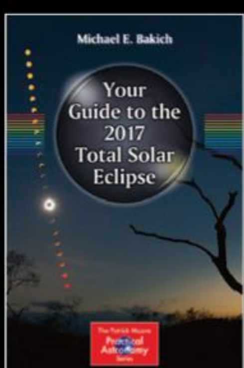
BROWSE THE "SECRET SKY" ARCHIVE AT **www.Astronomy.com/OMeara.**

Get Ready for the 2017 Solar Eclipse!

Prepare for totality with these eclipse-ready products from MyScienceShop.com. You'll be all set to find the best viewing location and safely observe the total solar eclipse of August 21, 2017.

81039



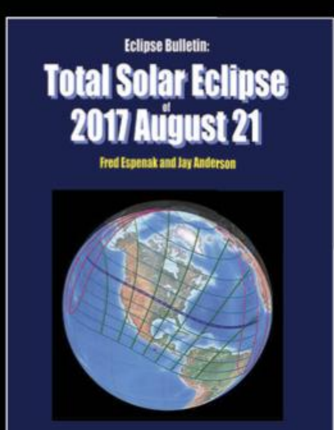


81054

81037

5 PACK ECLIPSE GLASSES

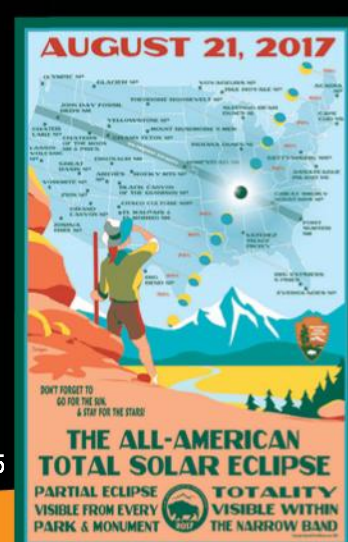
81070



81038

81058

82015



Order Now at MyScienceShop.com/SolarEclipse

Sales tax where applicable

P30696

Pluto displays a rich geological diversity that few planetary scientists expected before New Horizons flew past the distant world in July 2015. In this enhanced color view, ancient, heavily cratered terrains coexist with a nitrogen ice glacier no more than 10 million years old.
ALL IMAGES: NASA/JHUAPL/SwRI

Far from the inert ball of ice some scientists expected, this distant world boasts unique landscapes, recent geological activity, and a possible underground ocean. **by S. Alan Stern**

The exploration of Pluto by NASA's New Horizons spacecraft revolutionized our knowledge of this small planet and its system of five moons. But it also did much more. The encounter showed us again that there is no substitute for going to the planets to learn about them, and it proved once more how first flybys thoroughly shatter scientific paradigms.

Every time we used the cameras, spectrometers, and other onboard sensors on New Horizons, we made discoveries about the Pluto system. We found that the planet's four small moons — Nix, Hydra, Kerberos, and Styx — are as old as Pluto itself, and all are covered in water ice that somehow is kept clean or is eternally refreshed to produce astonishingly high surface reflectivities. We also learned that these satellites surprisingly rotate much faster than they orbit Pluto, and that they are not accompanied by still more small moons as many of us had expected.

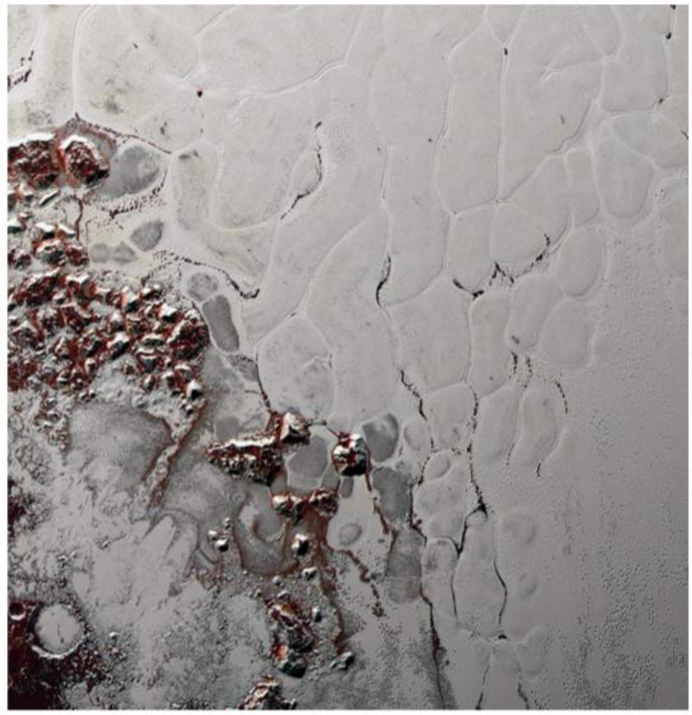
Pluto's giant moon, Charon — the other member of the binary planet at the heart of the Pluto system — also surprised us. It displays an old surface sporting a dark, red northern polar cap unlike anything seen elsewhere in the solar system, flooded plains of water ice, and vast extensional tectonic features — which form under stress as the moon's surface spreads apart. Charon even shows evidence of a possible internal ocean in its youth.

And then there is Pluto — geologically alive on a vast scale and displaying a range of landforms that rivals Mars, the solar system's other red planet. No one really expected any of these big-ticket Pluto surprises. And few anticipated the complexity we see in Pluto's suspended haze layers, the blue color of its sky, the almost 1,000-times lower atmospheric escape rate than predicted, or the evidence seen on the surface that Pluto's atmospheric pressure has been, apparently, sometimes tens to thousands of times higher than what we see today. Yet we found all of this, and much, much more.

The entire data set from New Horizons is now on Earth, and is archived in the open-access NASA Planetary Data System. Researchers on our science team have examined all of the 400-plus observations made by our seven scientific instruments and written over 50 technical papers detailing early findings. But there is much more to do to understand Pluto, and to extend those findings to a better understanding of the other small planets in the Kuiper Belt.

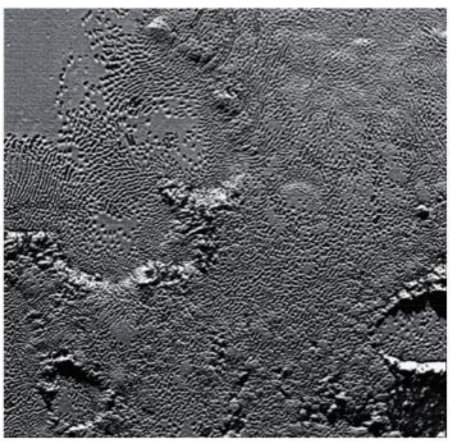
In *Astronomy*'s May 2016 issue, I wrote "Hot results from a cool planet," detailing many of the initial findings we made as the Pluto system data began raining down from the Kuiper Belt. Here, I will supplement those early findings with four

PUZZLED BY PLUTO



Above: The nitrogen ice glacier Sputnik Planitia covers some 400,000 square miles (1 million square kilometers) of Pluto's surface. It is the largest glacier known beyond Earth and appears devoid of craters, implying that some process continuously renews it. (All feature names in this story are informal.)

Right: The cellular patterns seen in western Sputnik Planitia suggest that convective motions within the ice constantly renew the surface by replacing older ice with fresher material from below.



Hundreds of sublimation pits dot the "coastline" of Sputnik Planitia. Scientists think these pits form when nitrogen ice turns directly into gas. New Horizons captured this high-resolution view just 13 minutes before closest approach.

overarching results that stand out from the first exploration of Pluto.

Unique landforms

One of the biggest surprises in the imagery that New Horizons returned is the many new kinds of landforms seen on Pluto's surface. Yes, Pluto displays heavily cratered terrains, polar deposits, canyons, glacial channels, mountain ranges, and even chaotic mountain blocks like those seen on Mars and on Jupiter's moon Europa, and we didn't expect to see so many of these landform types. But even more surprising are the exotic new types of landforms on Pluto.

The star of this show is the vast, 400,000-square-mile (1 million square kilometers) nitrogen glacier informally called Sputnik Planitia (SP), which forms the western lobe of Pluto's "heart." No nitrogen glacier has been seen elsewhere in the solar system, and no glacier of this extent has been seen anywhere beyond Earth.

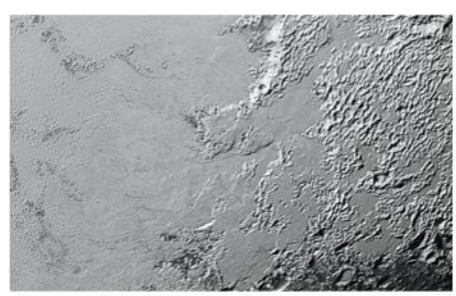
Several features within SP enhance its exotic nature, including cellular structures on its surface (which indicate convective motions in the ice), recharge zones found along its edge, hundreds of mile-wide sublimation pits formed where nitrogen ice has turned directly into a gas, and clear evidence of glacial flow against the surrounding mountains near the northwestern shoreline. Also surprising is the complete lack of craters on SP, indicating that this gargantuan feature renews itself continuously despite a temperature of just 40 kelvins (72° F above absolute zero)! More on that later.

Another completely unique landform on Pluto is the widespread "bladed terrains" of the region informally called Tartarus Dorsa. These long, 1,000-foot-high (300 meters) linear ridges made of methane ice are unlike anything seen elsewhere in our solar system. Moreover, the bladed terrains appear to extend far beyond Tartarus Dorsa and cover wide expanses of the low latitudes on the far-side hemisphere that we imaged only at low resolution. The bladed terrains may even be one of the dominant landform types on Pluto. What causes this terrain? Some scientists suggest that these structures may be penitentes — blades of ice that form in high deserts under sunlight-driven sublimation. Others suggest that they may be the result of wind sculpting or glaciation. There are several ideas, but no clear favorite yet.

New Horizons also discovered unique terrain types on Charon. Although this moon has much the same size, density, and surface composition as some of the mid-sized icy satellites of the giant planets, it shows two types of surface features not seen elsewhere. One is the dark, red polar stain I mentioned earlier. The best theory is that it formed when gases escaped from Pluto, condensed onto Charon's cold poles, and then were chemically altered by solar radiation. Charon's other unique feature is a handful of "moated mountains," each surrounded by a quasi-circular trench. The cause of these structures remains a mystery.

Clinching the giant impact

It has been more than 30 years since planetary scientists like Bill McKinnon first suggested the Pluto-Charon binary formed in a giant impact. In this scenario, a collision between Pluto and another small planet



Nitrogen ice flows from the highland region on the right side of this image onto the frozen plains of Sputnik Planitia through narrow valleys just 2 to 5 miles (3 to 8km) wide.

New Horizons helped clinch the case that Pluto's satellite system formed as a result of a giant collision between a rogue Kuiper Belt object and the young Pluto. Debris from the impact formed a disk around the battered Pluto that eventually coalesced into Charon and its cohort of four much smaller moons. RON MILLER FOR *ASTRONOMY*

launched material into orbit around Pluto that then accumulated to form Charon.

Early clues supporting this formation hypothesis included the large mass of Charon relative to Pluto and the off-the-charts specific angular momentum (the angular momentum per mass) of the binary. Further evidence arrived in the 1990s with the discovery of the Kuiper Belt, which provided a source population for the necessary impactors, and the Hubble Space Telescope's discovery of Pluto's four small moons all in the same orbital plane as Charon.

New Horizons data add to the case for a giant impact origin in three significant ways. First, the spacecraft revealed the compositions of Nix and Hydra for the first time, showing they are covered in water ice. This is exactly what numerical simulations had predicted a giant impact would produce. Second, New Horizons images more precisely determined Charon's volume and thus refined this large moon's density. The improved density measurement indicates Charon is more icy and thus less rocky than Pluto, which is just what you would expect from a giant impact on a Pluto differentiated into a core, mantle, and crust.

Scientists have seen nothing like the so-called bladed terrains of Pluto's Tartarus Dorsa region elsewhere in the solar system. These ridges rise some 1,000 feet (300 meters) above their surroundings in this enhanced color view.

Finally, New Horizons imaged Nix and Hydra in sufficient detail to allow scientists to count craters on their surfaces and thus estimate their ages. (A surface accumulates more craters over time.) This let us compare the surface ages of Nix and Hydra to the age of Charon, similarly derived from New Horizons images. When our science team completed these studies last year, we found that all of these objects are equally old — providing yet another link to their common origin. Together, these latest clues make it all but impossible to imagine any other formation scenario for the Pluto system than a giant impact.

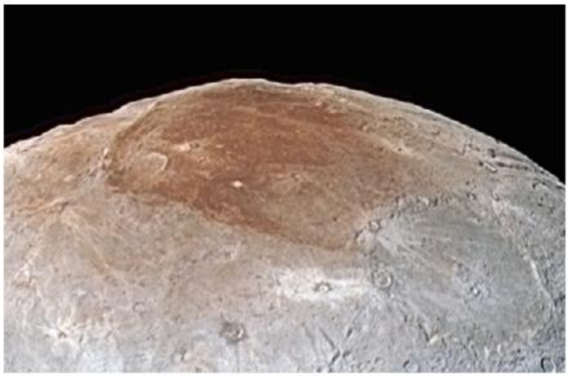
Time-variable Pluto

Another big surprise we found on Pluto is widespread evidence for temporal changes

Pluto's small moons, including Nix (pictured) and Hydra, bolster the case that a giant impact created the entire satellite system. New Horizons showed that water ice covers both moons, and both are the same age as the large moon, Charon — exactly what you would expect from a giant impact origin.

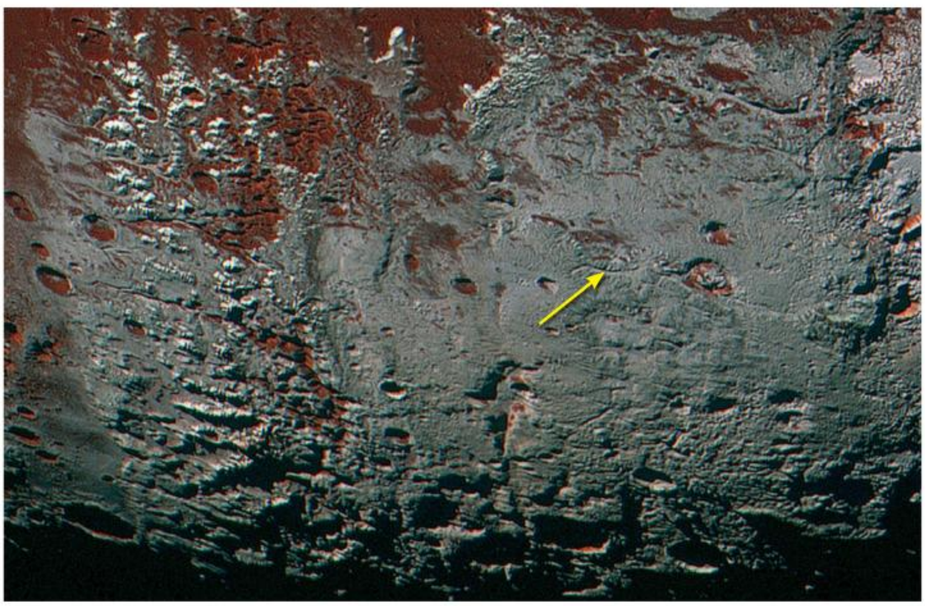
on its surface. This evidence comes in several forms.

SP provides some of the best examples. As I noted earlier, it has no detectable craters on its surface and cannot be older than perhaps 10 to 30 million years. This means it either was created recently or, more likely, continuously renews itself. The cellular patterns of ice convection may be an indication

Above: Pluto's large moon, Charon, also possesses some unique landforms. The dark, red stain that covers the satellite's north polar region appears to be material that originated in Pluto's atmosphere and then condensed on Charon's cold polar terrains. Exposure to solar radiation then darkened and reddened the material.

Left: Charon's other unique landforms are several "moated mountains" like the one seen at the top left. In these features, a quasi-circular trench some 0.6 to 2 miles (1 to 3km) deep surrounds the mountain.



Valley networks that appear to have been cut by flowing liquids or ices provide some of Pluto's best evidence for temporal changes. The one here (arrow) lies south of the equatorial band Cthulhu Regio.

of this renewal process. But the evidence for temporal change on SP goes well beyond that. In fact, we see signs for both glacial recharge in the form of recent flows down the slopes of the surrounding mountains and for currents in SP's nitrogen ice. The currents themselves are a form of temporal change as the ice moves and possibly slides under some of the mountains that SP abuts.

More evidence for temporal change appears on the flanks of the feature informally called Wright Mons. Wright Mons is a caldera-like structure that likely formed by cryovolcanism — the eruption of water or other volatile liquid. And Wright Mons is huge, rivaling Hawaii's Mauna Loa in scale. But strikingly, its flanks show essentially no evidence of cratering, which implies that either the mountain itself is young or it has been active recently, resurfacing the flanks.

Although the signs of large-scale temporal changes in SP and on Wright Mons are impressive, in my book, the most interesting evidence for such changes on Pluto is something else entirely. Across the surface, we see geological features that strongly resemble sloping valleys and dendritic valley networks on Earth and Mars. On those other two planets, flowing liquids or ices create such structures via erosion. We also see one surface feature, informally called Alcyonia Lacus, that appears to be a frozen lake nestled in a low-lying part of the chaotic mountain blocks that make up the informally named al-Idrisi Mountains. This 19-mile-long (30km) feature is replete with a smooth surface and distinct shorelines.

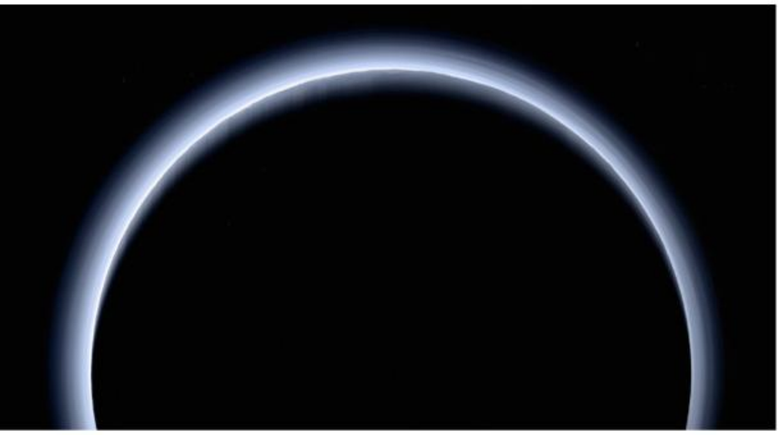
Perhaps the strangest aspect about the possibility that liquids once existed on Pluto's surface is that both the temperature and surface pressure today are far too low to allow liquids. In fact, for liquids to exist on Pluto's surface, temperatures and pressures must exceed the triple point — the conditions under which the solid, liquid, and gas phases of a substance can coexist in equilibrium — of molecular nitrogen, carbon monoxide, or methane. But this in turn requires atmospheric pressures exceeding 100 millibars — about 10,000 times Pluto's current surface pressure of 11 microbars. How can this be?

Scientists discovered in the 1990s that the tilt of Pluto's axis varies by more than 20° every 3 million years. A similar process on Earth, called Milankovitch cycles, causes our own polar tilt to change, but by about 10 times less. Still, even that small shift creates significant climate variations on Earth. In a recent paper in *Icarus* on which I was lead author, we modeled the kind of atmospheric pressure and temperature variations that Pluto's much larger polar tilt variations may cause. We found it is plausible that such cycles caused conditions on Pluto to sometimes exceed the pressures and temperatures of the nitrogen triple point. If further modeling bears us out, this would allow liquids to be stable and even flow on Pluto's surface thousands of times in the past!

Ocean worlds?

At the dawn of the Space Age, Earth was the only known world to have an ocean. Later, increasingly detailed studies of Mars by spacecraft revealed that it almost certainly once had vast seas or oceans of water that have long since disappeared. But to our great surprise, spacecraft also found that many worlds with icy surfaces — including Enceladus, Europa, Ganymede, and Titan — show evidence for internal oceans.

Why should this be so? First, water ice is common to the surfaces and interiors of virtually every solid world in the middle and outer solar system. Second, pressures and temperatures increase with depth, meaning that the water ice often reaches a liquid state in the interiors of these worlds. This typically occurs tens to hundreds of miles below the surface, creating the conditions for global interior oceans with depths



Above: New Horizons found lots of evidence that liquids once existed on Pluto's surface. For this to be so, the atmosphere — seen here as a bluish arc in one of the spacecraft's parting shots — must have been much warmer and denser in the past.

Right: Alcyonia Lacus lies in the mountains just north of Sputnik Planitia. The feature appears to be a frozen, former lake of liquid nitrogen.

The huge tectonic belt that runs along Charon's equator provides dramatic evidence that this moon's interior once held a large water ocean. Scientists think the belt formed from stresses when the water froze and expanded.

and volumes that are, in some cases, even larger than Earth's.

Evidence for these oceans was once only theoretical, coming from computer calculations of interior conditions. But later we found water geysers erupting from the interiors of Enceladus and Europa, and magnetic field variations that suggest electrical currents in salty interior oceans in three of Jupiter's Galilean satellites.

A few years ago, geophysical models indicated that Pluto and Charon might be able to host interior water oceans, or at least to have done so in the past. But when New Horizons arrived, it revealed new evidence that such oceans are actually likely.

The 90-mile-wide (150km) Wright Mons (shown at lower left) appears to be a shield volcano complete with a deep central pit at its summit. The mountain's flanks show no evidence of impact craters, suggesting that it either is young or has recently erupted.

In the case of Charon, a primary sign for an ancient interior ocean is the giant extensional tectonic belt that girdles the moon's equator. Our team suspects the belt originated from stresses created long ago when liquid water in Charon's interior cooled, expanded, and froze after the satellite's violent formation in a giant impact.

The case for an ocean inside Pluto is more nuanced. SP suspiciously lies diametrically opposite to Charon. (Pluto and Charon are tidally locked and thus keep the same faces toward each other.) The odds of this occurring randomly are small. But if there is an interior water ocean that wells up under SP, it would create an excess of mass there because water is denser than water ice. Tidal forces would then naturally reorient SP to just the location we see it — opposite Charon. Of course, this evidence is only circumstantial. If we return someday with an orbiter that can map gravity anomalies, search for magnetic variations, and perhaps even carry a surface-penetrating radar, we can definitively test for this ocean.

The value of exploration

Clyde Tombaugh discovered Pluto 85 years before New Horizons flew past it. During those 85 years, the distant world never appeared as more than a smudgy disk in images. Yes, from afar we learned its basic surface composition, that it has a nitrogen-dominated atmosphere, and that it forms a binary planet with Charon. Yes, from afar we learned Pluto's rotation period and polar tilt, and that it has four small moons. And yes, from afar we learned that the surface is reddish with brighter and darker areas, and that Pluto's interior is made primarily of rock.

But frankly, despite the vast advances in observing capabilities from 1930 to 2015, there wasn't much more we learned about the Pluto system from Earth or Earth orbit. I doubt that if I lived to be 120, we could have learned as much in all those years as we found out in a matter of days while New Horizons zipped by. The lesson of New Horizons is that it took a mission of close-up exploration to really determine Pluto's basic nature.

And so, while I am sure that new tools like the James Webb Space Telescope and the planned 30-meter-class telescopes on the ground will add some detail, I doubt that we will learn much more until we follow up New Horizons with an orbiter or orbiter-lander pair. I also doubt that we'll ever know as much about the other small planets of the Kuiper Belt as we now know about Pluto unless we send probes to fly by them as well. New Horizons re-emphasized the lesson that all those first missions to explore the closer planets in the 1960s, 1970s, and 1980s taught a previous generation of scientists and scientific enthusiasts: There is no substitute for spacecraft exploration.

S. Alan Stern *of the Southwest Research Institute in Boulder, Colorado, is a planetary scientist and the principal investigator on New Horizons.*

Cassini's Grand Finale

20 years in the making

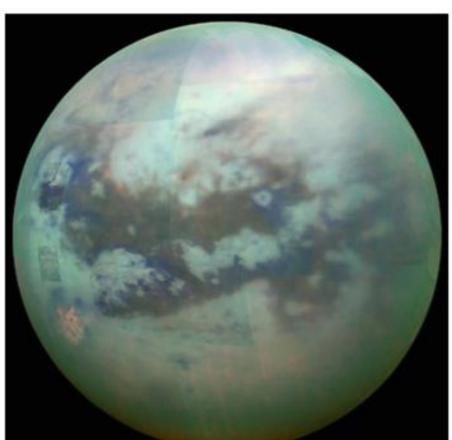
From grazing Saturn's rings to disappearing into its swirling atmosphere, this spacecraft's final days, hours, and minutes will be fruitful ones.

by Michael Carroll

Cassini has offered never-before-seen views of the saturnian system, providing researchers with a more comprehensive picture of the planet's atmosphere, ring system, and moons. This breathtaking portrait created by amateur image processor Gordan Ugarkovic combines 12 images taken by the spacecraft in October 2013. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE/G. UGARKOVIC

IT'S BEEN A WILD RIDE. NASA's Cassini Saturn orbiter has broken just about every record in the planetary encounters book. By the end of its first decade in 2014, the spacecraft had logged 206 orbits, taken 332,000 images, carried out 132 close flybys of Saturn's moons, discovered seven of its 62 moons, and generated 3,039 science papers. Cassini's powerful engines and flexible software enabled flight engineers to redesign the mission to take advantage of unplanned studies at geyser-spouting Enceladus and methane-soaked Titan. And its extended mission has carried those numbers into a second decade of exploration and discovery.

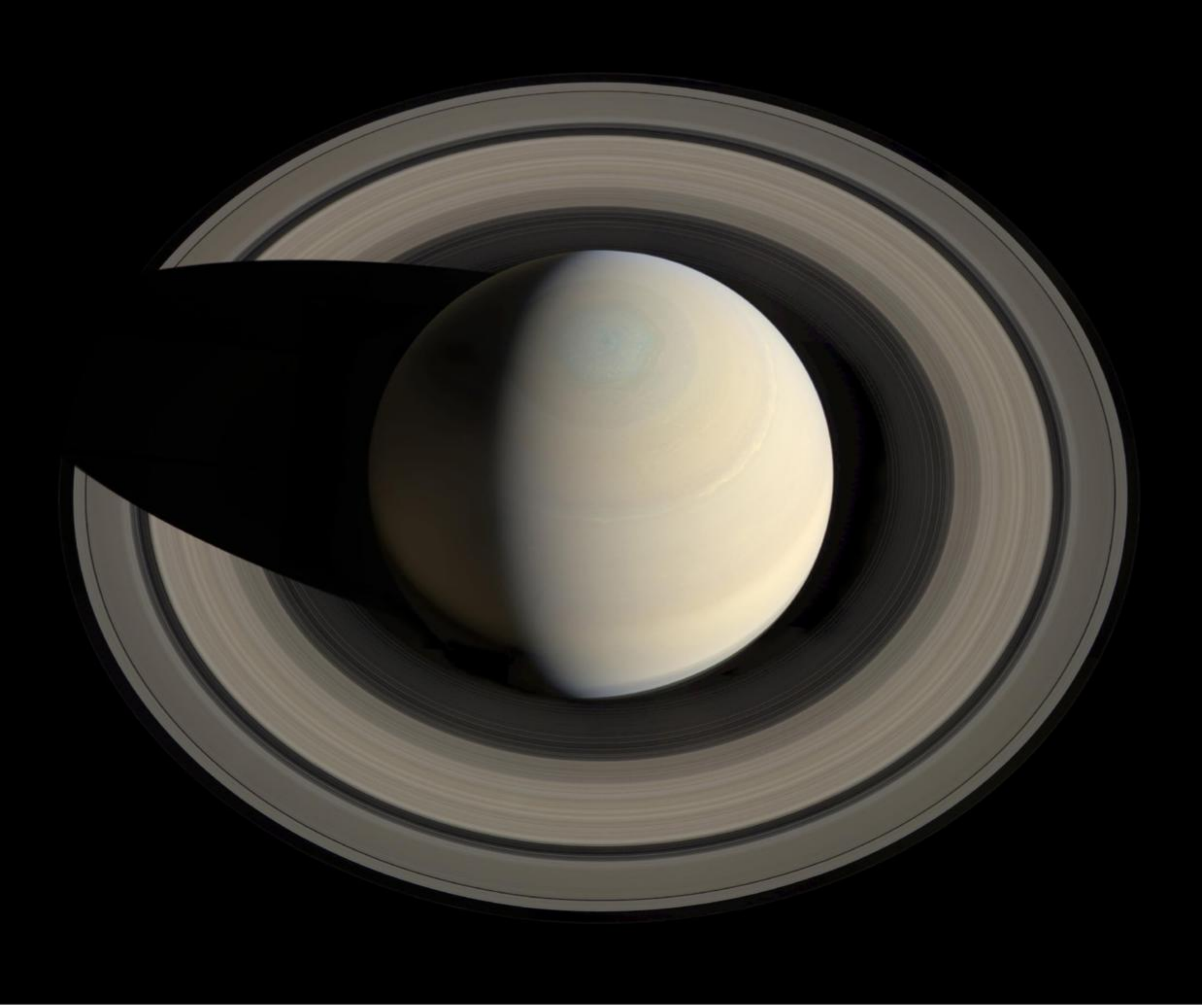
But all good things must come to an end. On September 15, Cassini will meet its doom in a fiery trail through the clouds of



NASA/JPL/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO

CASSINI IMAGING TEAM, SSI, JPL, ESA, NASA

The saturnian moons Titan (left) and Enceladus (right) could support life, whether in their past, present, or future. Cassini's fiery end is a deliberate gesture to prevent unwanted contamination of these worlds with Earth organisms. During its time in orbit around Saturn, Cassini returned unprecedented views of these moons, including the first look beneath Titan's hazy atmosphere at the surprisingly Earth-like terrain below.



Saturn. The valiant explorer's immolation is pre-planned. Flight engineers will control the spacecraft so it will not accidentally make landfall on Enceladus or Titan, moons that present promising sites for exobiology. Enceladus' icy crust, festooned with gossamer curtains of water geysers, hides a global ocean of brine, a potential biome to be protected. Titan's environment may harbor prebiotic conditions similar to those found on primordial Earth.

A new path

Those moons were still largely unknown quantities before Cassini's multiple-encounter mission, says Cassini Imaging Team Lead Carolyn Porco. "Titan was one of our major mission targets. Remember what we didn't know, even after the Voyager flybys. The Voyager cameras' spectral capabilities basically cut out at exactly the place in the electromagnetic spectrum where you could start seeing down to the surface of Titan. All we saw was fog."

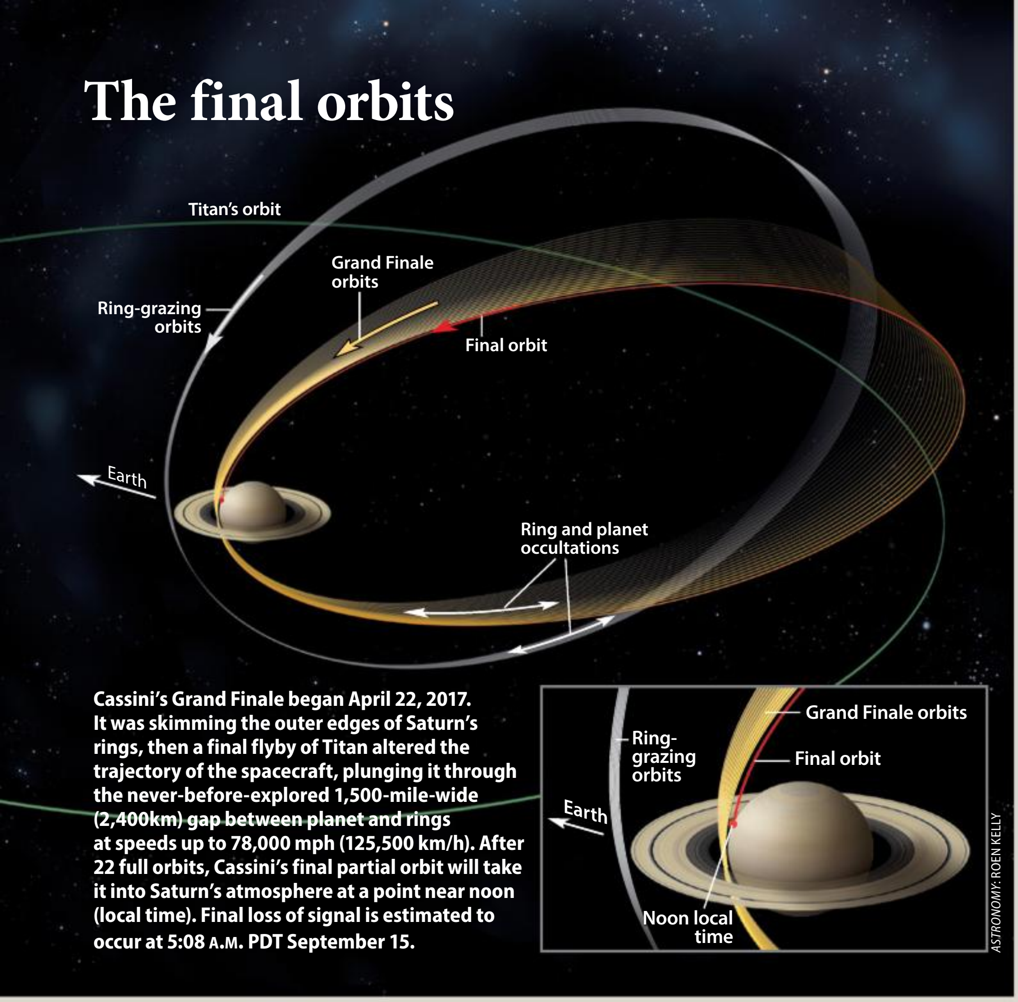
Now that Cassini has peered through that veil, she says, "It's been so enjoyable to find things that look so Earth-like. The dune fields that cover the whole equatorial and mid-latitudes are remarkable. Titan is so geographically and geologically complex, very like the Earth in that respect, and also unlike it at the same time."

Larger than Mercury, Titan supplies gravity that has been an important tool throughout Cassini's reconnaissance. "It has been the body that provided us with the means to tweak the Cassini trajectory around; otherwise it would have required a prohibitive amount of fuel. All the major changes to the orbit were done with flybys of Titan. Programmatically, it's been critical," Porco says.

Titan's gravity also provided mission planners with a way to direct the flight path of the craft inward last November, enabling Cassini to skim the rings at closer range than at any other time in the nearly two-decade mission.

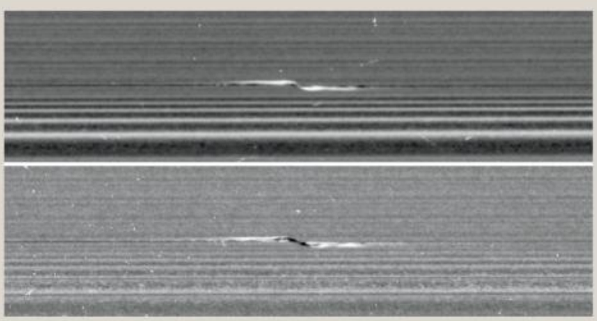
Titan is not the first body to assist in Cassini's flight path. In fact, "gravitational assists" bracket Cassini's journey. The bus-sized spacecraft's arduous seven-year journey from Earth culminated July 1, 2004, as Cassini rocketed into orbit around the lord of the rings. That transit from Earth to Saturn included four planetary flybys: two with Venus (in April 1998 and June 1999),

The final orbits

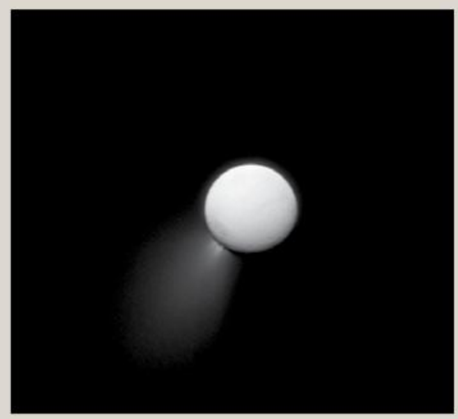


Cassini's Grand Finale began April 22, 2017. It was skimming the outer edges of Saturn's rings, then a final flyby of Titan altered the trajectory of the spacecraft, plunging it through the never-before-explored 1,500-mile-wide (2,400km) gap between planet and rings at speeds up to 78,000 mph (125,500 km/h). After 22 full orbits, Cassini's final partial orbit will take it into Saturn's atmosphere at a point near noon (local time). Final loss of signal is estimated to occur at 5:08 A.M. PDT September 15. *ASTRONOMY*: ROEN KELLY

The Cassini spacecraft, including the Huygens probe destined to punch through Titan's atmosphere to touch down on its surface, sits awaiting launch atop a Titan IVB rocket in 1997. During launch, a payload fairing, or nose cone, protected the craft. NASA



"Propellers" are disturbances in the rings caused by the presence of an often-unseen moon. This propeller in the A ring, nicknamed "Santos-Dumont," had been tracked via less-detailed images for the past 10 years before receiving a close-up on February 21, 2017. Close imaging by Cassini allows researchers to better grasp the effects of the propeller on the broader structure of the ring. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE



Enceladus spews plumes of icy water from its south pole, as seen by Cassini in January 2013. These plumes are part of the case for Enceladus' subsurface ocean, which could also host hydrothermal vents capable of providing heat and nutrients necessary for life. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

one with Earth (August 1999), and a final gravity assist from Jupiter (December 2000), during which the craft imaged the king of worlds and several of its moons. At mission's end, flybys of Titan will carry the spacecraft to its final encounter with Saturn's atmosphere.

Leading up to that end, the craft has reconnoitered moons during dozens of encounters, studied the magnetosphere of Saturn, and scrutinized its clouds. During the final orbits, however, the rings are taking center stage. It's in these last orbits that the mission is trickiest, but promises the greatest return. Cassini Project Scientist Linda Spilker of NASA's Jet Propulsion Laboratory explains, "Starting in November [2016], we began what we call — very appropriately — ring-grazing orbits, where Cassini's periapse [the point lowest in its orbit] was pulled into the closest point ever to the planet."

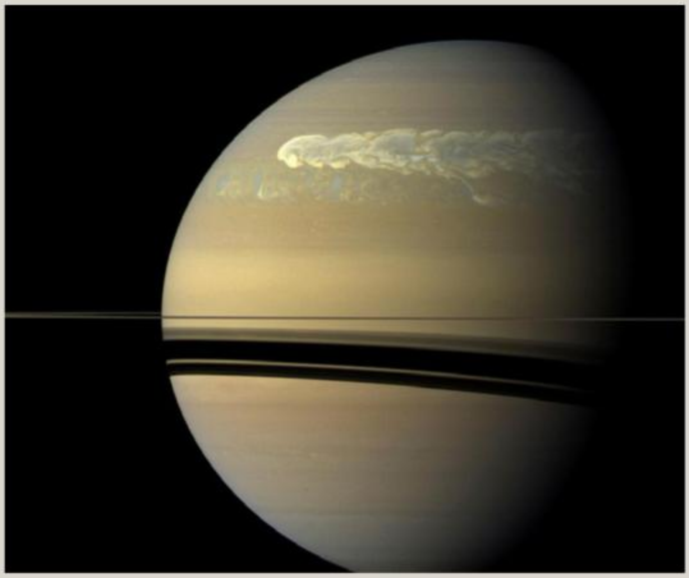
By April, the spacecraft had completed 20 pole-passing circuits. Then Cassini changed its path, now passing inside Saturn's extensive ring system, threading the needle between rings and planet.

The dramatic orbital change was again completed with the help of Titan's gravity. Flight engineers commanded Cassini to fly by the massive moon at just the right angle to kick its orbital path out of the ring plane. The new trajectory sent Cassini high above the planet's north pole, falling inward to just outside of Saturn's F ring. Once Cassini passed by Titan on April 22, flight engineers didn't need any additional burns to change the orbit. Its eventual entry into Saturn's atmosphere was preordained.

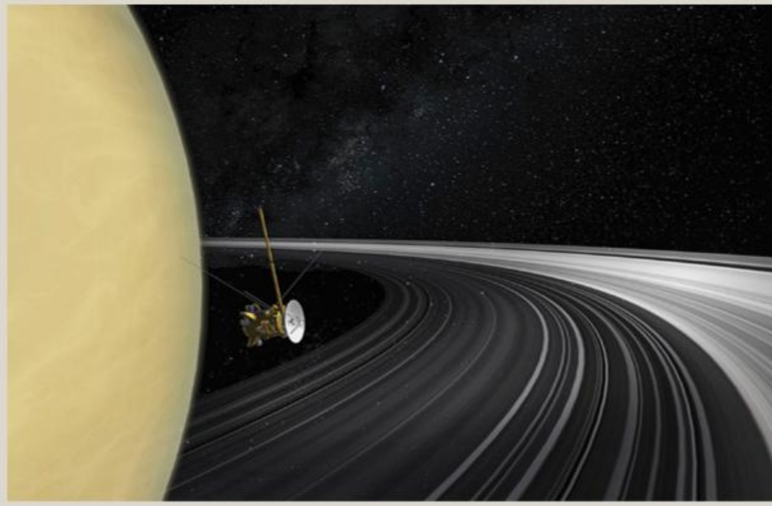
But controllers may nudge the spacecraft with small maneuvers to "dip our toe in the atmosphere" Spilker says. The last five orbits bring Cassini close enough to directly sample *in situ* the composition of Saturn's atmosphere. Like her colleagues, Porco looks forward to the insights it will provide. Onboard instruments "will take measurements all the way down," she says. "It's going to be a new day. It's a lifetime of firsts when you're a planetary explorer."

Still making discoveries

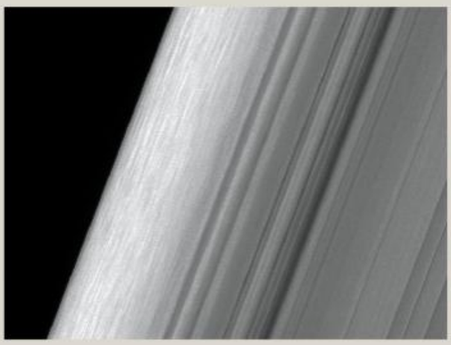
Porco has been with Cassini since its inception. Before that, she served as part of



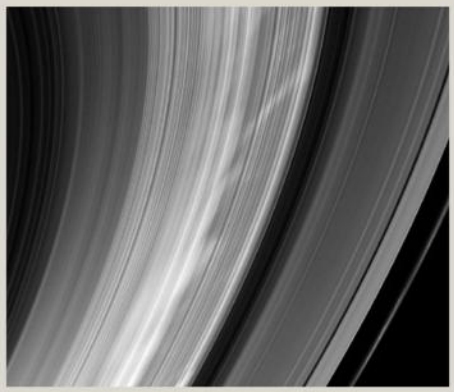
Saturn's atmosphere boasts high winds and monstrous storms, including this planet-encircling system photographed February 25, 2011. By the time Cassini took this image, the storm had been raging for 12 weeks. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE



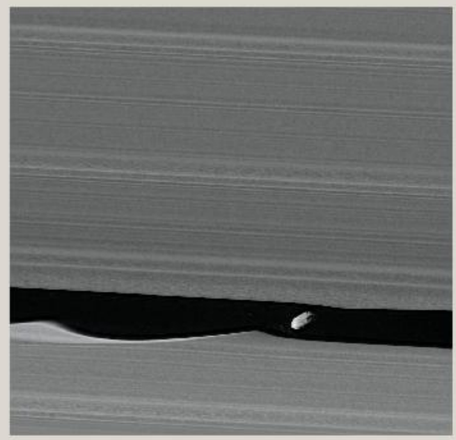
During its Grand Finale, Cassini slips between Saturn and the inner edge of its rings in this artist's concept. This unique vantage point allows the spacecraft to study Saturn's atmosphere, magnetic field, and more with greater precision than previously possible. Not only will these orbits help to pin down the length of Saturn's day, they will also better constrain the mass — and possibly the age — of the rings. NASA JET PROPULSION LABORATORY



During its ring-grazing orbits, Cassini imaged Saturn's B ring at twice the resolution of previous images. Such shots reveal features such as "straw," visible as streaks near the edge of the ring on the left, in greater detail. These structures are actually clumps of ring particles that continued to move during the long exposure, smearing out into elongated shapes that shed light on the motion of ring particles. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE



First observed by Voyager in the 1980s, these radial "spokes" in Saturn's B ring were spotted again by Cassini. This picture, dated February 2, 2009, is just one of many images Cassini took of these features, which are thought to arise from interactions between dust particles and the planet's magnetic field. NASA/JPL/SPACE SCIENCE INSTITUTE



The tiny shepherd moon Daphnis, just 4.8 miles (7.7km) across, creates waves in the edge of the A ring as it orbits within the Keeler Gap. These ripples are visible as shadows across Saturn's face when the Sun and the ring plane align. NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

the Voyager imaging team. For her, some of the greatest insights from the mission involve revelations about Saturn's vast ring system, made possible through a combination of high-resolution imaging and occultations of the rings observed in radio, ultraviolet, and infrared wavelengths. "Between those and our images," Porco says, "we've got a very nice picture. … We know that the particles behave coherently for longer than we thought they would. They seem to clot in ways that we didn't think they would. That's the kind of detail we wanted."

Porco asserts that the insights provided by ring research will shed light on the primordial debris disks, known as "accretion disks," that lead to the formation of planets. "The rings are a planetary formation process; we get to see the initial stages. You can predict how smaller ring particles will behave, and you can predict how coherently a bunch of these particles will behave," she says. "It's these insights into the fine-scale behaviors that we've gotten from Cassini."

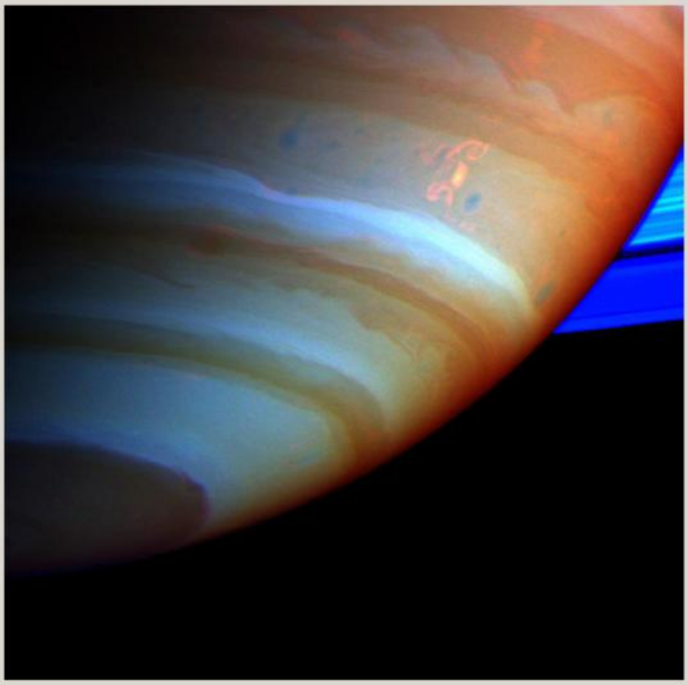
The new orbits also enable Cassini to obtain improved images of the moons nearest the rings. Pandora, Prometheus, and Epimetheus display bizarre grooves and shallow craters filled with material that has slumped down the crater walls, revealing bright outcrops along their rims. Landslides mark long streams of material that has flowed even in these tiny satellites' low gravity. This low-gravity transport of material has researchers reaching for their keyboards to come up with new models.

Other moons shepherd material within the ring system itself. Tiny Daphnis, a favorite of Spilker's, orbits in the Keeler Gap. "It's making waves on the edge of the gap, and it has a little tendril [of ring material] wrapping around it and a ridge around the equator," Spilker says. These ripples had previously led scientists to infer the presence of a moon in the gap, but it was Cassini that first directly spotted Daphnis on May 1, 2005.

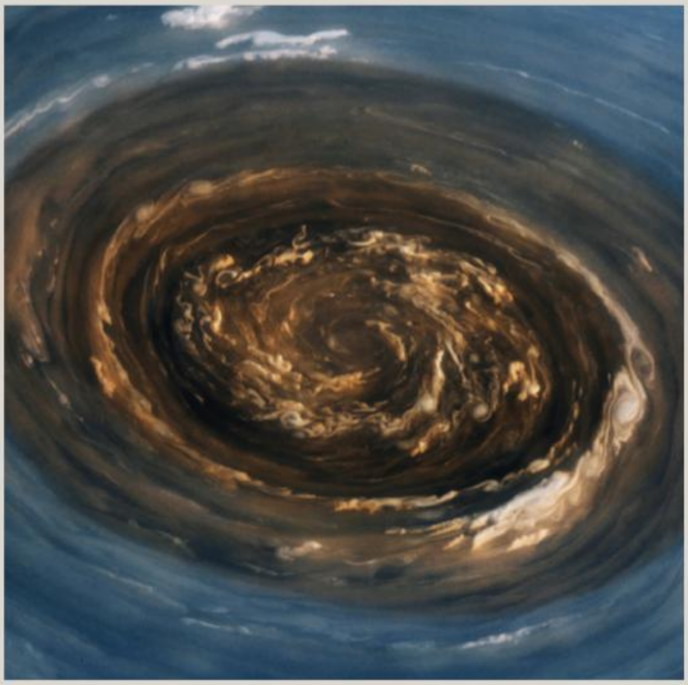
Teasing out answers

On its initial passes through the ring plane, Cassini flew with its antenna facing forward in the direction of flight, using the

Cassini captured this stunning view of a backlit Saturn over the course of three hours on September 15, 2006. Such an image highlights the fine detail of the rings and allowed Cassini to discover two new, faint rings associated with the moons Janus, Epimetheus, and Pallene. NASA/JPL/SPACE SCIENCE INSTITUTE



The Dragon Storm, imaged in near-infrared wavelengths, first appeared in 2004. Curiously, Cassini saw the feature emit intense radio waves only when the planet's rotation took the storm out of direct sunlight and night fell. Planetary scientists believe the emission is linked to electrical activity in the storm, likening it to Earth's thunderstorms. NASA/JPL/SPACE SCIENCE INSTITUTE



This infrared view of the vortex at Saturn's north pole shows a hurricane 1,250 miles (2,000km) across. The vortex sits at the center of a larger hexagonal feature that has been present on the planet for decades.
NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE/ALEXIS TRANCHANDON/SOLARIS

giant dish as a shield from incoming ring debris. But once engineers were confident that ring particles posed little danger to the craft's survivability, they were able to point the antenna back toward Earth. This was important for many experiments, says Spilker: "We want to point the high-gain antenna at Earth so we can get close data, good measurements of Saturn's gravity, and probe how deep the winds might go." Researchers also want to determine if the planet is differentiated — whether it has a rocky core, potentially the size of Earth. "All these things you can learn by going into these close orbits," Spilker says.

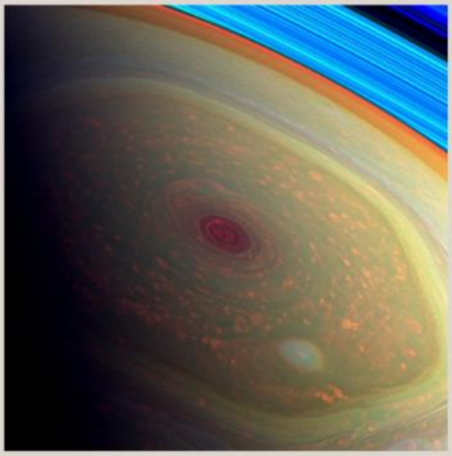
One of the most important numbers researchers want to constrain is the mass of Saturn's rings. Cassini's decade-plus reconnaissance of the system has given researchers an accurate mass for Saturn plus its rings. "But when you hop across the rings [between rings and planet], you get the mass of Saturn alone. You can subtract the two and what you have left is the mass of the rings," Spilker says.

She adds that via indirect measurements of the rings, "there is some other evidence … that the B ring may possibly be much less massive than we were estimating." Investigators believe the rings alone have a mass comparable to Saturn's moon Mimas (8.4×10^{19} pounds [3.8×10^{19} kilograms]). But if the rings are far less massive than this estimate, the data point to young rings, the kind that might be left behind after the death of a comet or the destruction of a moon. Greater mass leaves open the possibility that the rings formed at same time as Saturn. "It doesn't rule out young rings, but it does open up the possibility of old ones," Spilker says. With a direct measurement of the rings, researchers hope to narrow the uncertainty to about 5 percent.

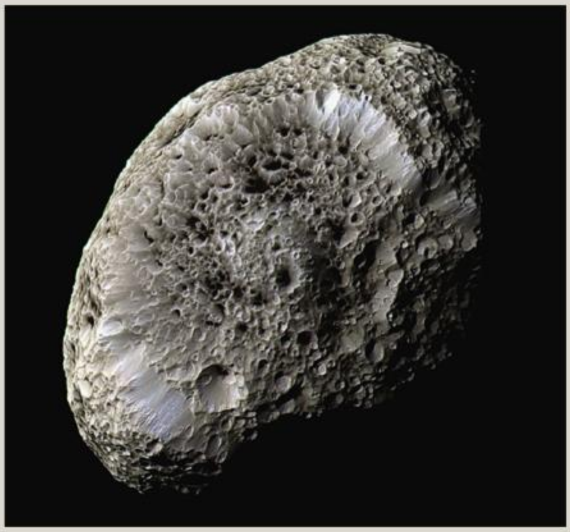
Yet another mystery may be solved through close encounters of the Cassini kind: the length of Saturn's day. In the case of gas and ice giants, no solid surface is visible for plotting a planet's spin rate. Instead, investigators clock the passing of the planet's magnetic fields, slightly offset from the spin axis, to chart the planet's daily turn.

But Saturn's magnetosphere is aligned almost perfectly to its spin axis, so that its

On September 15, Cassini will end its mission as a man-made meteor streaking through Saturn's atmosphere, as imagined in this artist's rendering. NASA/JPL-CALTECH



Cassini snapped this false-color image of Saturn's famous polar hexagon from a distance of 261,000 miles (419,000km). The hexagonal jet stream was first identified by scientists while reviewing data from the Voyager probes. NASA/JPL-CALTECH/SSI



Pandora's entire surface (above) appears coated with fine particles of icy material, which have softened its edges in contrast with other moons, such as Hyperion (left). Like its nearby neighbor Prometheus, Pandora's surface also has peculiar ridges and grooves. ABOVE: NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE; LEFT: NASA/JPL/SPACE SCIENCE INSTITUTE

wobble — if there is any — has been too subtle to see before now. Researchers hope that as Cassini flies through the gap between rings and planet, they'll get high enough resolution in their magnetic field data to tease out any wobble. "If there's even just a tiny angle we can measure, we'll see the length of the day," Spilker says. With this data in hand, researchers will also be able to more precisely measure the relative winds on Saturn, which are some of the strongest in the solar system.

Beginning of the end

Cassini will not go quietly into the night. Its demise will bequeath a last treasure-trove of *in situ* data for investigators, followed by an end that will be both brief and spectacular. Cassini will enter the planet's hydrogen/helium atmosphere at 74,000 mph (119,100 km/h) on the dayside, just a little off noon in Saturn's local time. The vehicle's thrusters will fire constantly, desperately trying to keep the spacecraft antenna pointed toward Earth for a few last data bits. Atmospheric drag from the huge magnetometer boom, which extends to one side, will eventually overcome the attitude thrusters, turning Cassini away from Earth. "Once we lose the signal," says Spilker, "I think things will happen pretty fast."

For Carolyn Porco, the end of the mission will mark one of her life's milestones. "My whole life — and the lives of all of us who were part of this — has been defined by this. These things define your life because they are your life. For me, it's been all consuming. I missed a lot during those years, things that other people take for granted, but in its place I got to do something that not many people get to do."

In those final moments, as the spacecraft begins to glow in Saturn's cloudy skies, most of Cassini's main engine fuel will already have been exhausted. Though it likely won't be visible on the face of the second-largest planet, many earthbound observers will nevertheless watch, waiting for a possible flash as the mission sings its swan song.

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

16 TIMES WE DIDN'T FIND E.T.

For decades, humanity has been searching for aliens. Here are the false alarms. by John Wenz; illustration by Theo Cobb

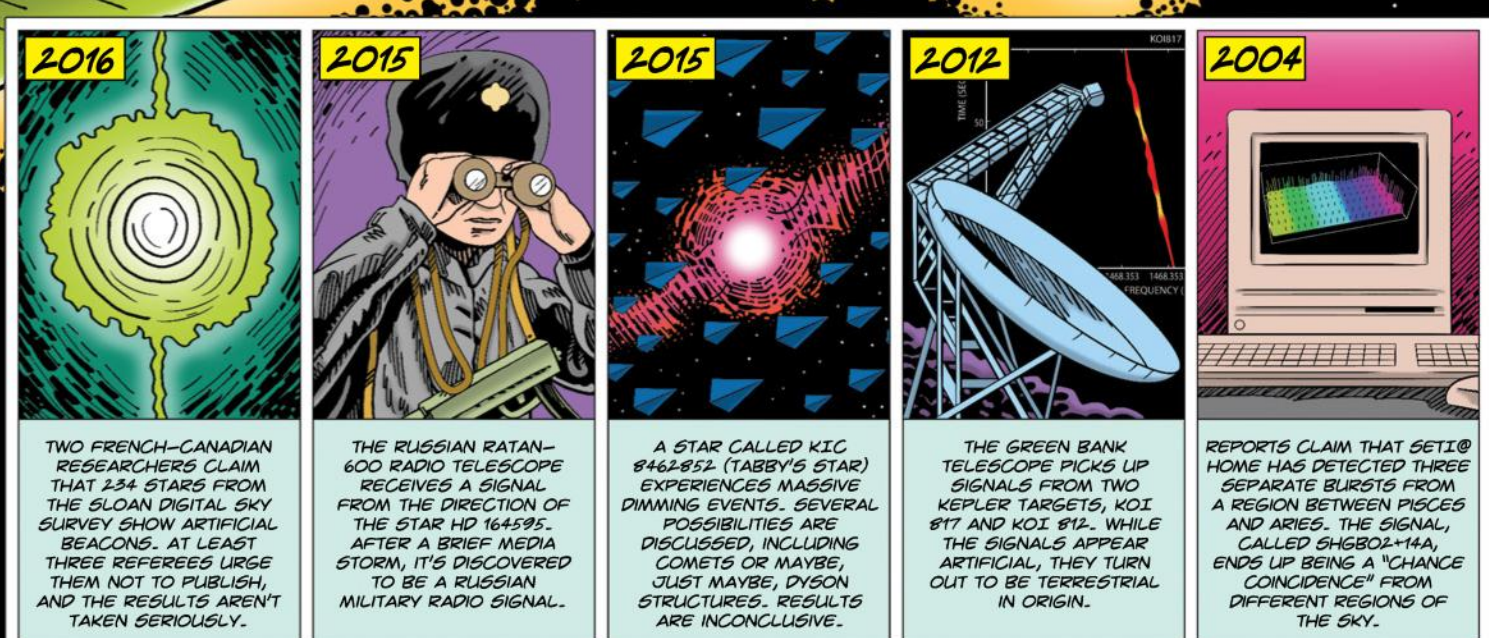
It's never aliens. Until it is.

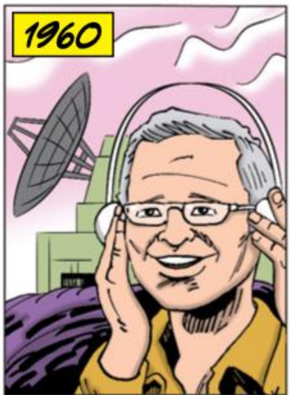
That's been the story for the nearly 60 years the Search for Extraterrestrial Intelligence (SETI) has been officially underway. You can stretch that date back even further if you count a 1924 military campaign to listen for radio signals from Mars as it reached its closest opposition in more than a century. But in all that time, we've come up with nothing.

Thanks to Yuri Milner, a venture capitalist who made billions through big tech investments, more money than ever is going into SETI research. Milner initiated an investment of $10 million a year for a decade in 2015, all with the hopes of finally hearing an alien signal.

That process may involve a few false positives, for which an all-too-earthly cause is ultimately found. They can add themselves to this list: a guide to many of the times we thought maybe, just maybe, we were finally no longer alone in the universe.

John Wenz *is an associate editor of* Astronomy *magazine.*

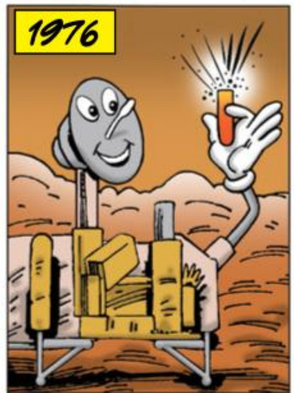




SETI'S FIRST DEDICATED SEARCH, CALLED PROJECT OZMA, BEGINS AN OBSERVING CAMPAIGN OF NEARBY STARS. THE TEAM, INCLUDING FRANK DRAKE, THINKS THEY RECEIVE A SIGNAL FROM EPSILON AURIGAE THAT ENDS UP BEING TERRESTRIAL.

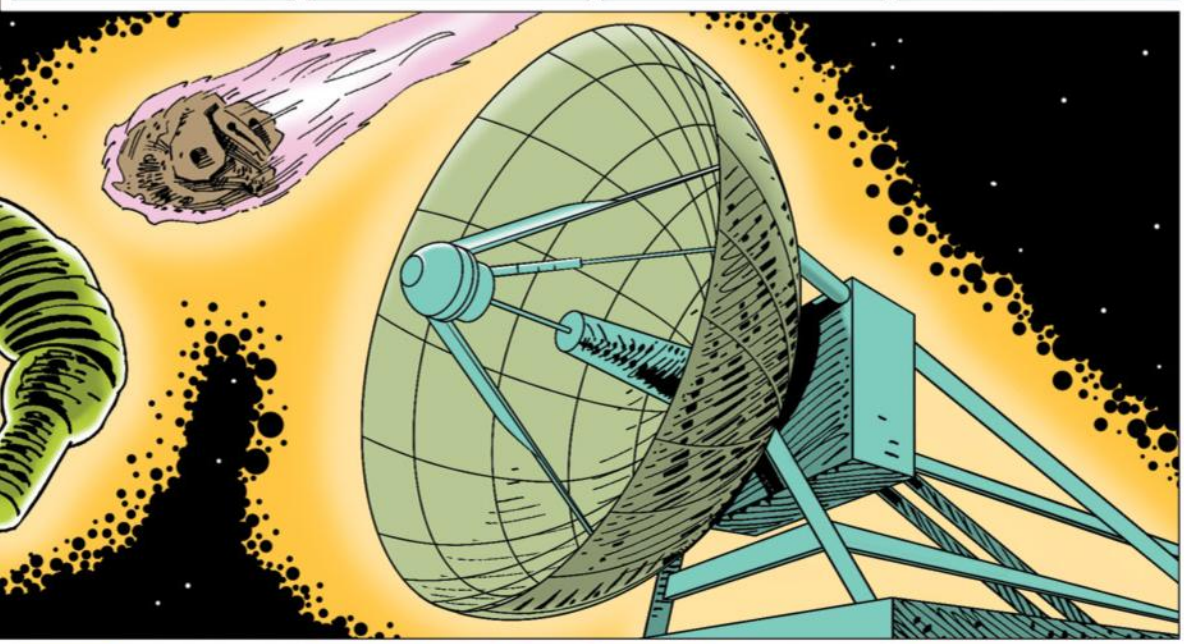
SOVIET ASTROPHYSICISTS NICOLAI KARDASHEV AND IOSIF SHKLOVSKII CLAIM THAT CTA 102 ALMOST ASSUREDLY SHOWS SIGNS OF AN ALIEN CIVILIZATION DUE TO ITS MASSIVE RADIATION OUTPUT. CTA 102 IS LATER FOUND TO BE AN ACTIVE QUASAR.

JOCELYN BELL BURNELL FINDS A RADIO SIGNAL REPEATING EVERY 1.3 SECONDS. AT A LOSS FOR AN EXPLANATION, SHE AND HER PH.D. ADVISER TERM IT LGM-1, SHORT FOR LITTLE GREEN MEN. IN THE END, IT BECOMES THE FIRST DISCOVERED PULSAR.

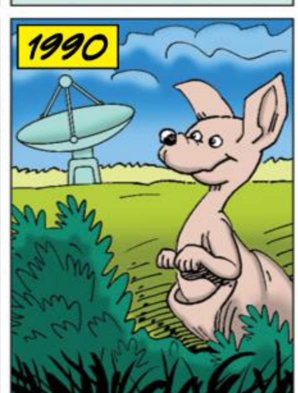


THE VIKING 1 LABELED RELEASE EXPERIMENT OF SOIL ON MARS SHOWS SIGNS OF NUTRIENT METABOLISM IN ONE OF FOUR TESTS FOR MARTIAN LIFE. HOWEVER, TWO OTHER TESTS ARE INCONCLUSIVE, WHILE A FOURTH IS NEGATIVE.

THE BIG EAR OBSERVATORY IN OHIO PICKS UP A SIGNAL THAT CAUSES OHIO STATE UNIVERSITY RESEARCHER JERRY EHMAN TO SCRAWL "WOW!" DUE TO ITS INTENSITY AND FREQUENCY. THE 72-SECOND SIGNAL NEVER REPEATS, LEAVING IT A MYSTERY.



FRENCH ASTRONOMER FRANÇOIS BIRAUD AND SETI PIONEER JILL TARTER DETECT A SIGNAL OVER THE COURSE OF THREE NIGHTS. WHEN THE TELESCOPES ARE RECALIBRATED, IT TURNS OUT TO BE INTERFERENCE FROM THE PARIS AIRPORT.



AUSTRALIAN ASTRONOMERS CATCH A STRONG SIGNAL COMING FROM THE DIRECTION OF HD 157881, A STAR IN OPHIUCHUS. THE SIGNAL GRADUALLY FADES AND NEVER REPEATS.

NASA ANNOUNCES THAT THE MARS METEORITE ALH 84001 APPEARS TO SHOW EVIDENCE OF MICROBIAL FOSSILS. DEBATE RAGES OVER THE STRUCTURES' ORIGIN, BUT THE GENERAL CONSENSUS IS THAT THEY ARE NOT FOSSILIZED MARTIANS.

THE SETI INSTITUTE PICKS UP A NARROW-BAND SIGNAL DURING A TELESCOPE UPGRADE. RATHER THAN ALIENS, IT IS THE SOLAR AND HELIOSPHERIC OBSERVATORY, A SOLAR OBSERVING SATELLITE.

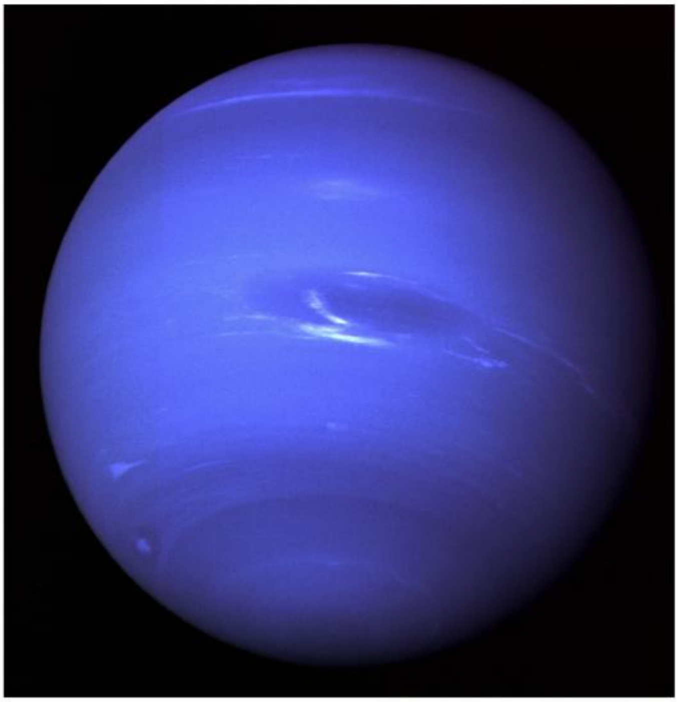
THE ARECIBO OBSERVATORY IN PUERTO RICO DETECTS A SIGNAL FROM THE DIRECTION OF EQ PEGASI. TEN MINUTES LATER, IT REPEATS. BUT A THIRD REPETITION FROM A DIFFERENT AREA OF THE SKY SHOWS IT WAS LIKELY TERRESTRIAL.

A FERMI NATIONAL ACCELERATOR LABORATORY SEARCH FOR THEORIZED ARTIFICIAL STRUCTURES CALLED DYSON SPHERES TURNS UP 23 CANDIDATES, ALL OF WHICH ARE EVENTUALLY IDENTIFIED AS NATURAL SOURCES OF STAR DIMMING.

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

September 2017: An ice giant pinnacle



Neptune's atmosphere displayed wispy clouds and a raging dark storm when Voyager 2 flew past in August 1989. In typical amateur scopes, the distant world shows a small, blue-gray disk. NASA/JPL

Scientists divide the planets into two distinct groups: the smaller, rocky inner planets and the larger, gaseous outer planets. This month's night sky splits these objects along the same lines. September evenings feature excellent views of the four remote worlds. Highlights include seeing Neptune at its annual peak and the opportunity to observe Saturn during the final days of the Cassini mission.

Predawn observers can feast their eyes on Earth's neighbors in the inner solar system. Mercury makes its finest morning appearance of the year in mid-September, coincidentally around the same time that it skims within 1° of Mars. Meanwhile, brilliant Venus rules over its two siblings from higher in the eastern sky. But the highlight of this predawn gathering comes during September's third week, when the waning crescent Moon slides past the three planets.

The first object you'll want to target these autumn nights is **Jupiter**. Although the giant planet has been spectacular all year, its days are numbered. The world hangs low in the west-southwest during evening twilight all month. It sets within two hours of the Sun in early September and less than an hour after sundown late in the month.

Jupiter lies among the background stars of Virgo. It spends most of September within 4° of the Maiden's luminary, 1st-magnitude Spica, passing 3° due north of this star on the 5th. At magnitude –1.7, the planet appears 12 times brighter than the star.

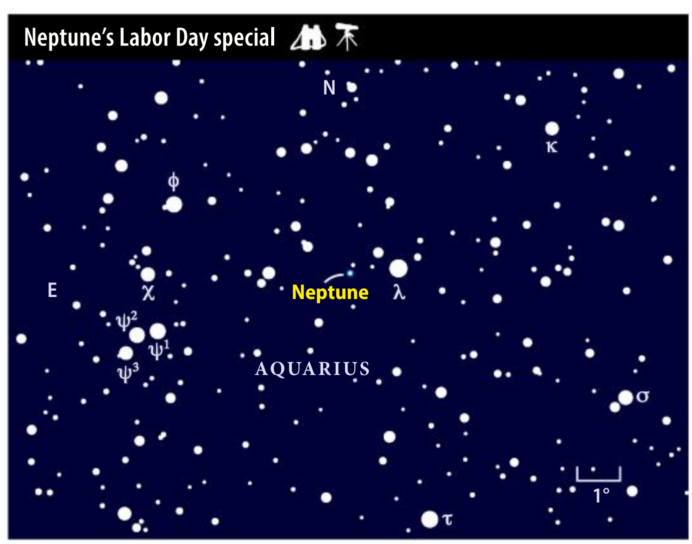
If you plan to target Jupiter through a telescope, do so early in the month when it lies about 10° high 45 minutes after sunset. Because of its low altitude, Jupiter won't show much detail on its 32"-diameter disk. Still, you should see the planet's two dark equatorial belts and up to four bright moons.

After a quick view of Jupiter, turn your attention toward **Saturn**. The magnitude 0.5 ringed planet stands nearly 30° above the southern horizon soon after sunset. As the sky darkens, look for 1st-magnitude Antares 13° west-southwest of Saturn. The planet's yellow color, which comes from reflected sunlight, contrasts nicely with the intrinsic orange glow of the distant red supergiant star.

Saturn resides in southern Ophiuchus near 4th-magnitude Xi (ξ) Ophiuchi. The planet begins September 0.9° due south of Xi and moves to a position 1.4° southeast of the star by month's end. The pair sets just before 12:30 A.M. local daylight time on the 1st and about a half-hour earlier with each passing week.

Swing a telescope toward Saturn, and you'll immediately see the planet's spectacular rings. They span 38" and tip 26.9° to our line of sight in mid-September. This wide tilt affords earthbound observers with superb views of ring structure. The dark Cassini Division that separates the outer A ring from the brighter B ring shows up clearly through any instrument.

Modest scopes also reveal several of the ringed world's moons. The brightest is 8th-magnitude Titan, an easy target through any scope. It approaches within 1.3' of Saturn when it passes north (September 11 and 27) or south (the 3rd and 19th) of the planet. The moon strays up to 2.9' from the gas giant at greatest eastern and western elongation.



Neptune shines brightest at opposition the night of September 4/5, when it appears against the backdrop of Aquarius. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

Rays of light in a fertile sea

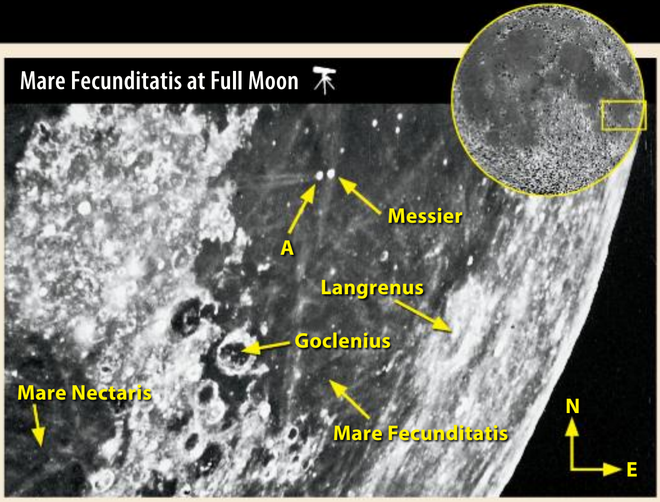
To the eyes of a beginning lunar observer, the terrific ray system radiating from the crater Tycho is perhaps the Full Moon's most impressive feature. These rays — bright material ejected during the relatively recent impact that gouged out Tycho — stand out best within two days of the September 5/6 Full Moon.

Let's follow one of Tycho's prominent rays that angles northeast and eventually cuts across Mare Fecunditatis (Sea of Fertility). This ray first passes through Mare Nectaris (Sea of Nectar), where it nearly pierces the small crater Rosse.

After crossing highland terrain, the ray seems to skip over the crater Goclenius. It then continues across the rest of Mare Fecunditatis. Some scientists suspect that the greater elevations of the highlands and crater rims produced "ray shadows" where Tycho's ejecta could not fall.

Two other ray systems cross the Sea of Fertility. On the eastern shore, numerous short rays spread out from the crater Langrenus like spokes on a bicycle wheel. And in the mare's north-central section, you can't miss the dual rays shooting out of the crater Messier A.

Mare Fecunditatis at Full Moon



Bright rays from the impact that created the large crater Tycho splashed across the distant Sea of Fertility. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

The incessant weathering of the solar wind darkens these lighter streaks over time, but they likely won't fade completely from view for hundreds of millions of years.

While it takes Titan 16 days to orbit Saturn, five dimmer moons complete their circuits in less than five days. Tethys, Dione, and Rhea glow at 10th magnitude and show up through 4-inch scopes on any clear night.

To capture 12th-magnitude Enceladus or 13th-magnitude Mimas, you'll need at least a 6-inch instrument with good optics. The former revolves around Saturn in 33 hours while the latter takes 23 hours. Both lie near the rings' edge and often get lost in the glare. Your best bet is to look for them September 17, when they reach greatest western elongation within two hours of each other.

Coincidentally, the 17th is also the best evening to look for Iapetus, which takes 79 days to orbit Saturn. If you draw a line from Saturn to Titan and then extend it an equal distance, Iapetus will be right there. A 4-inch scope reveals this moon's 11th-magnitude glow.

While you gaze upon the ringed planet this month, the Cassini spacecraft is wrapping up its extraordinary 13-year mission exploring the Saturn system. The probe makes its final two orbits in early September, diving through the 1,500-mile-wide gap between the planet's cloud tops and the inner edge of the

— *Continued on page 42*

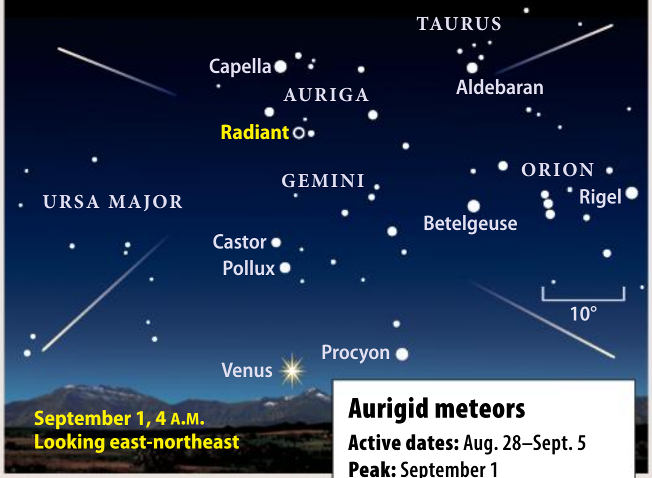
METEORWATCH

Auriga's claim to meteor fame

September is a quiet month on the meteor calendar. The best of the minor showers is the Aurigids, which peaks September 1. Although observers have noticed occasional bursts in the past century, astronomers don't anticipate any this year. The best views should come shortly before dawn, once the waxing gibbous Moon has set and the radiant climbs high. Under a dark sky, observers can expect to see an average of six meteors per hour emanating from the constellation Auriga.

The tiny dust particles that give rise to meteors when they burn up in Earth's atmosphere also permeate the inner solar system. Their combined glow shows up as the zodiacal light in the predawn hours of September's final two weeks. With the Moon then out of the way, viewers at dark sites can see this cone-shaped glow above the eastern horizon. The zodiacal light aligns with the ecliptic, so Venus serves as a guide for finding it.

Aurigid meteor shower



The Moon sets well before dawn September 1, gifting observers with nice views of this month's premier display of "shooting stars."

Aurigid meteors

Active dates: Aug. 28–Sept. 5
Peak: September 1
Moon at peak: Waxing gibbous
Maximum rate at peak: 6 meteors/hour

OBSERVING HIGHLIGHT Neptune reaches its 2017 peak September 4/5, when the planet glows at magnitude 7.8 and spans 2.4" through a telescope.

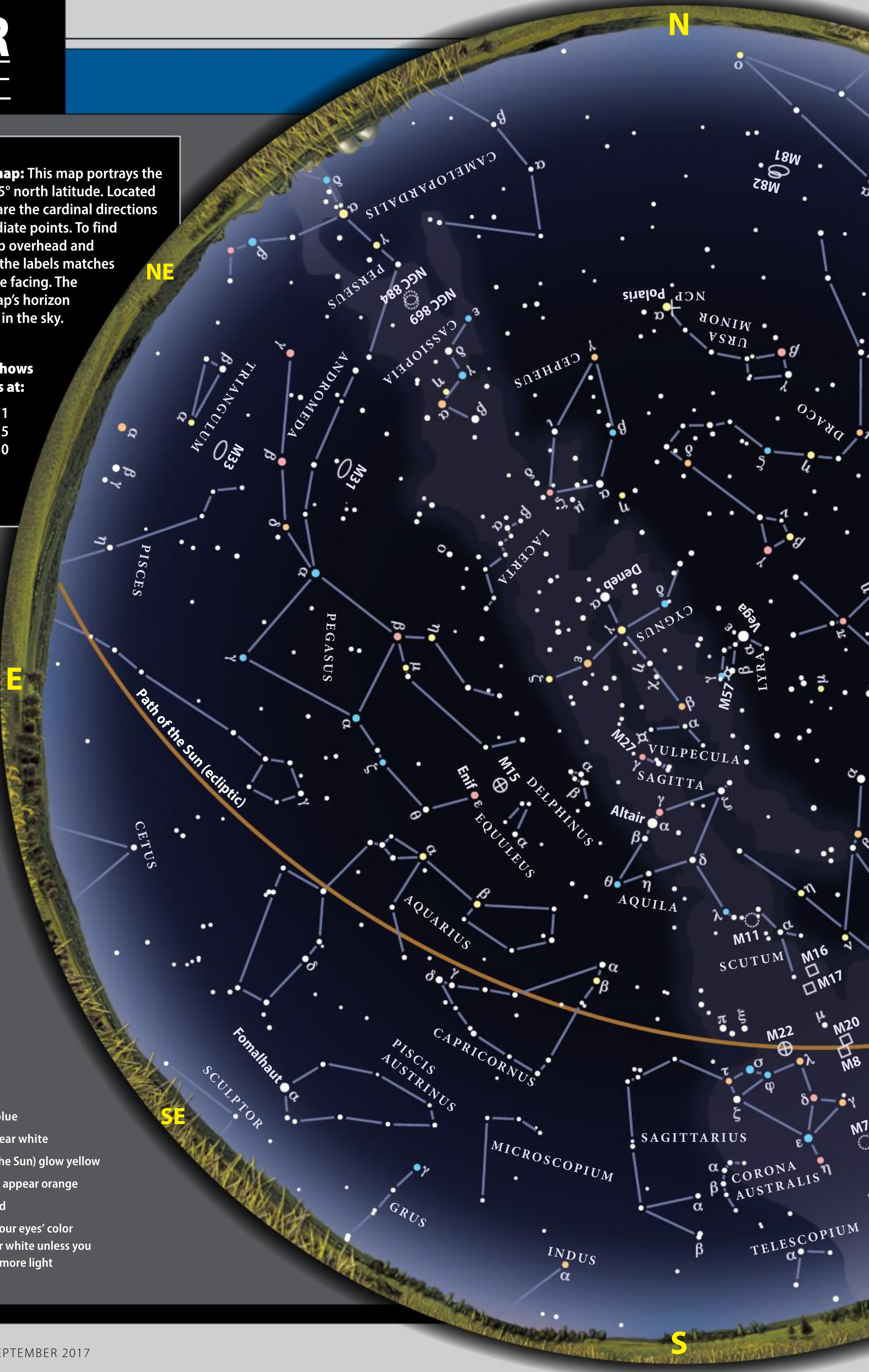
STAR DOME

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

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

10 P.M. September 1
9 P.M. September 15
8 P.M. September 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

SEPTEMBER 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

4 Mercury is stationary, noon EDT

5 Neptune is at opposition, 1 A.M. EDT

Jupiter passes 3° north of Spica, 7 A.M. EDT

6 The Moon passes 0.8° south of Neptune, 1 A.M. EDT

Full Moon occurs at 3:03 A.M. EDT

8 Asteroid Julia is at opposition, 5 P.M. EDT

9 The Moon passes 4° south of Uranus, 6 A.M. EDT

10 Mercury passes 0.6° south of Regulus, 8 A.M. EDT

12 Mercury is at greatest western elongation (18°), 6 A.M. EDT

The Moon passes 0.4° north of Aldebaran, 9 A.M. EDT

SPECIAL OBSERVING DATE

12 Mercury climbs highest before dawn as it puts on its best morning show of the year.

13 Last Quarter Moon occurs at 2:25 A.M. EDT

The Moon is at perigee (229,820 miles from Earth), 12:06 P.M. EDT

16 Mercury passes 0.06° north of Mars, 2 P.M. EDT

17 The Moon passes 0.5° south of Venus, 9 P.M. EDT

18 The Moon passes 0.09° north of Regulus, 1 A.M. EDT

The Moon passes 0.1° north of Mars, 4 P.M. EDT

The Moon passes 0.03° south of Mercury, 7 P.M. EDT

19 Venus passes 0.5° north of Regulus, 7 P.M. EDT

20 New Moon occurs at 1:30 A.M. EDT

22 The Moon passes 4° north of Jupiter, 4 A.M. EDT

Autumnal equinox occurs at 4:02 P.M. EDT

25 Asteroid Pallas is stationary, 7 A.M. EDT

26 The Moon passes 3° north of Saturn, 8 P.M. EDT

27 The Moon is at apogee (251,250 miles from Earth), 2:50 A.M. EDT

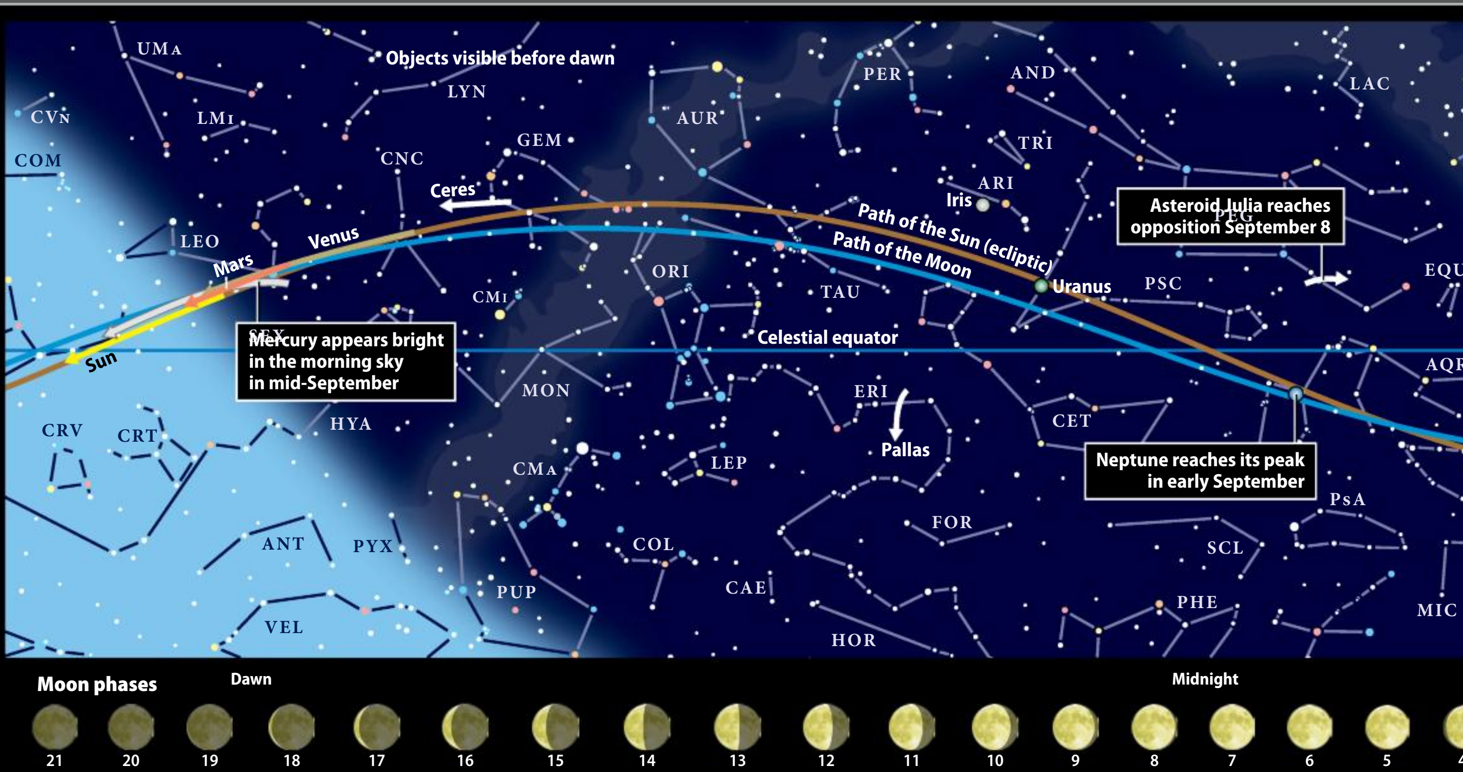
Asteroid Vesta is in conjunction with the Sun, 10 A.M. EDT

First Quarter Moon occurs at 10:54 P.M. EDT

28 Pluto is stationary, 4 A.M. EDT

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

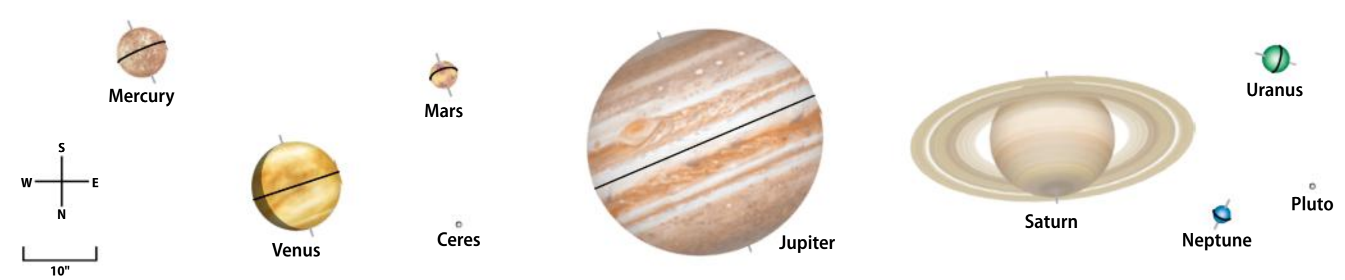
The planets in September 2017



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.

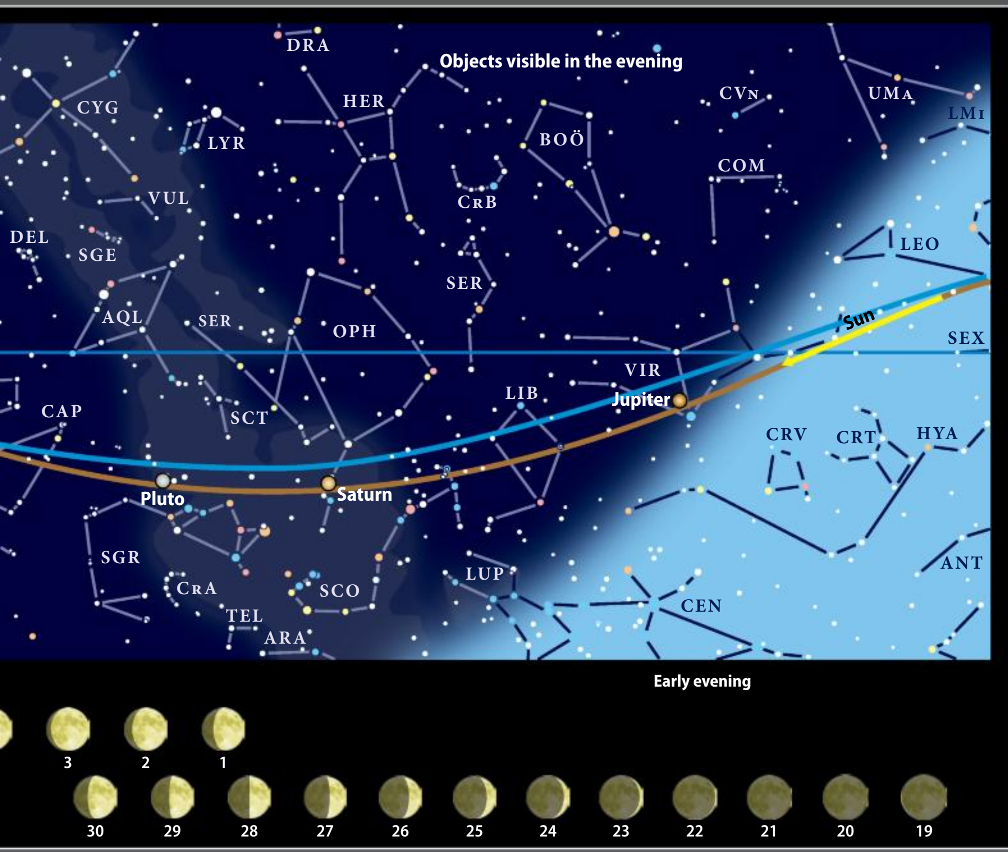
The planets in the sky

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	Sept. 15	Sept. 15	Sept. 30	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15	Sept. 15
Magnitude	–0.7	–3.9	1.8	8.9	–1.7	0.5	5.7	7.8	14.2
Angular size	6.7"	11.8"	3.7"	0.4"	31.4"	16.6"	3.7"	2.4"	0.1"
Illumination	58%	87%	99%	97%	100%	100%	100%	100%	100%
Distance (AU) from Earth	1.010	1.419	2.557	3.069	6.269	10.026	19.087	28.955	32.976
Distance (AU) from Sun	0.308	0.719	1.666	2.637	5.446	10.062	19.914	29.947	33.406
Right ascension (2000.0)	10h27.1m	9h44.7m	11h07.9m	7h56.0m	13h32.1m	17h22.3m	1h43.3m	22h56.3m	19h11.9m
Declination (2000.0)	10°42'	14°20'	6°51'	23°37'	–8°29'	–22°02'	10°03'	–7°48'	–21°46'

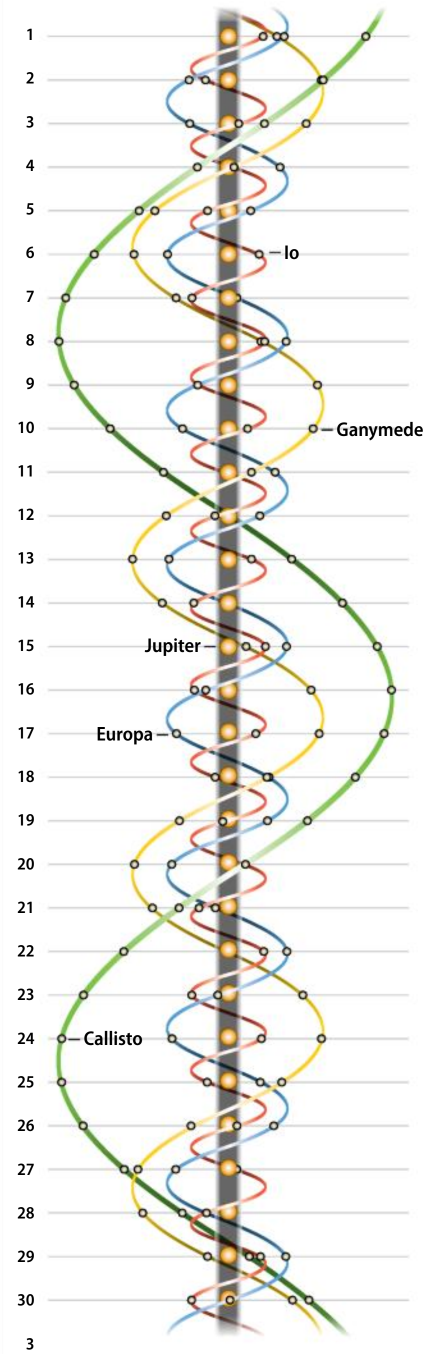
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.



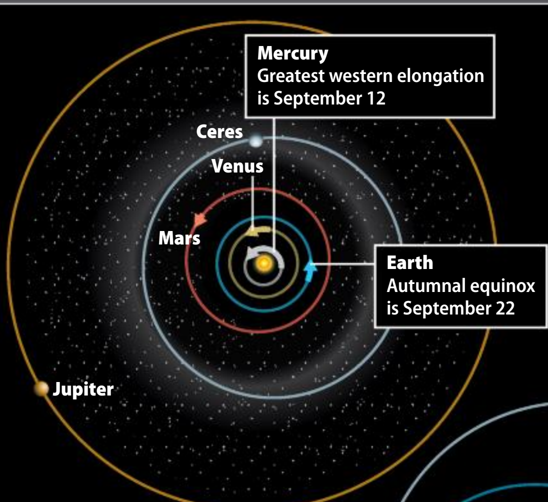
Jupiter's moons

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

S
W E
N

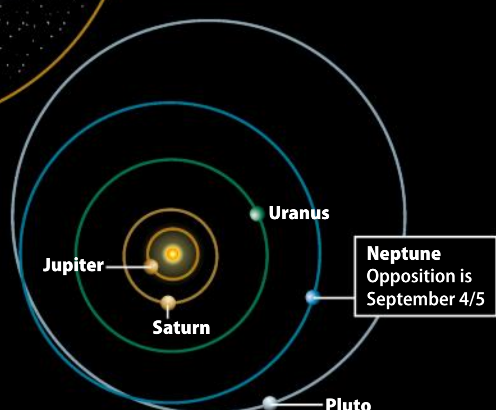


ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY



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.



— *Continued from page 37*

WHEN TO VIEW THE PLANETS

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

rings. The mission comes to an end when the spacecraft plunges into Saturn's atmosphere September 15.

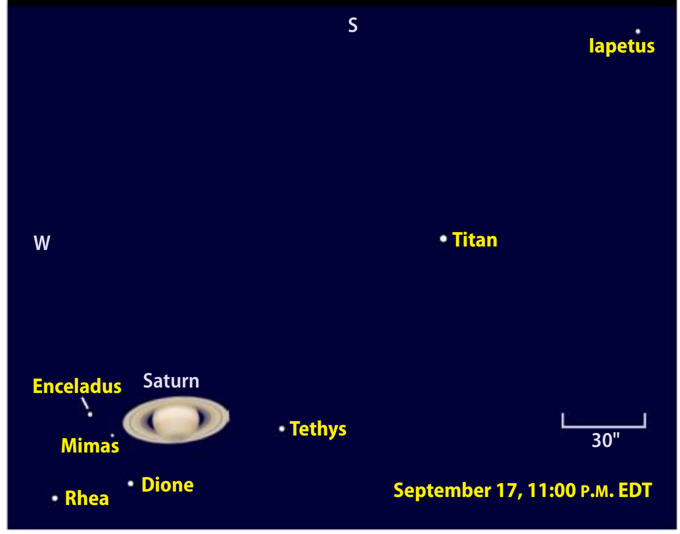
Take your time observing Saturn before turning your attention to **Neptune**. This ice giant world reaches opposition the night of September 4/5, when it lies opposite the Sun in our sky and thus remains visible all night. You can find it climbing in the southeastern sky after darkness falls. It peaks in the south around 1 A.M. local daylight time in early September and by 11 P.M. late in the month.

For an outer planet, opposition typically coincides with best visibility. But on the evenings of the 4th and 5th, the Full Moon lies near Neptune and makes viewing difficult. Fortunately, the planet shines at magnitude 7.8 all month, so you can find it with equal ease on any clear night.

Grab your binoculars and center 4th-magnitude Lambda (λ) Aquarii in your field of view. In early September, Neptune lies 1.2° due east of Lambda. The planet's westward motion brings it 0.7° southeast of the star by month's end.

Neptune passes just 1' south of an 8th-magnitude background star the night of September 18/19. Although the similarly bright objects may be hard to identify through binoculars, a telescope will tell you which is which. Only Neptune shows a distinct disk, which measures 2.4" across and appears blue-gray.

Spotlight on two-faced Iapetus



Saturn viewers can zero in on Iapetus the evening of September 17, when the dim moon lines up with brighter Titan and the ringed planet.

Uranus tracks across the sky a couple of hours behind Neptune. You can start to look for Uranus once it climbs clear of the eastern horizon in late evening. It glows at magnitude 5.7, making it an easy binocular target and visible to the naked eye under a dark sky.

Uranus resides among the background stars of Pisces, not far from 4th-magnitude Omicron (ο) Piscium. The planet stands 1.0° north of this star September 1 and moves to a point 1.2° northwest of it by the 30th. A telescope reveals Uranus' distinctive blue-green disk, which spans 3.7".

You'll have to wait until early morning to catch sight of the inner planets. **Venus** appears first, rising in a dark

COMETSEARCH

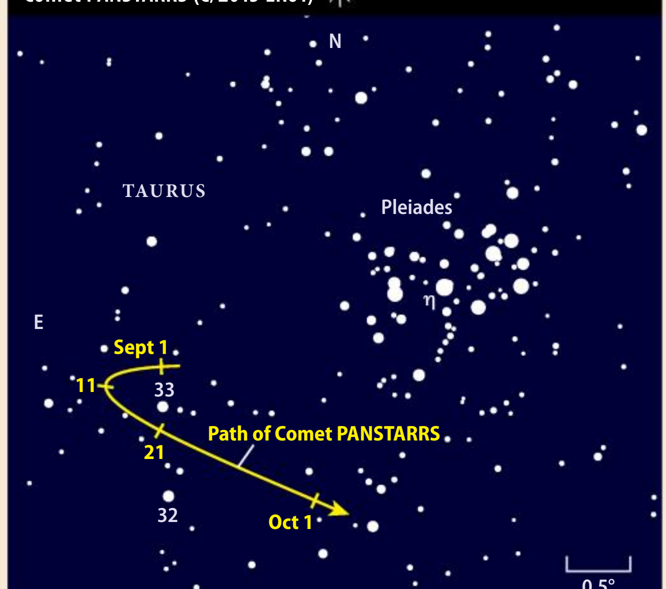
Cruising past the Seven Sisters

Although the brighter comets of spring may be gone, the pleasures of viewing fainter comets from a dark site at this time of year shouldn't be overlooked. First, you get to see the magnificent Milky Way emerge out of the dusk; then, the Cygnus star clouds take over at midnight; and finally, the sparkling stars of winter splash across the sky before daybreak.

Comet PANSTARRS (C/2015 ER61) enjoys the company of one of winter's finest star clusters. The comet remains within 3° of the Pleiades (M45), or Seven Sisters, throughout September. The month begins with a few Moon-free mornings, when the comet and cluster ride high in the southeast. A second window opens once our satellite wanes to a slim crescent in mid-September. For the rest of the month, you can view the comet starting around midnight local daylight time and continuing until it passes nearly overhead before morning twilight begins.

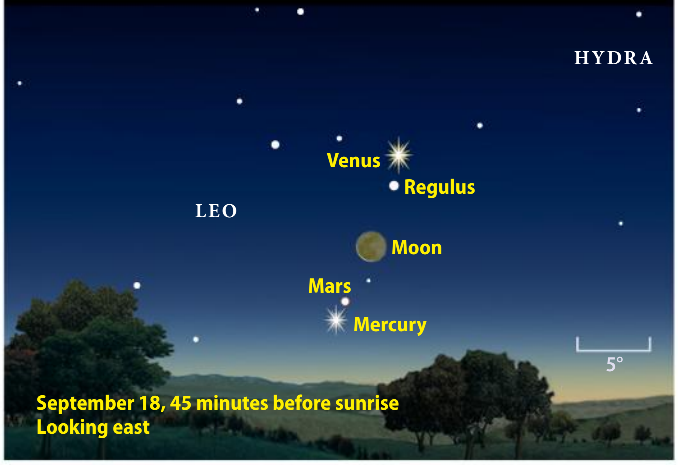
This 10th-magnitude comet shadows the Pleiades all month. It begins September nearly due east of the cluster, then heads slowly east before reversing course and moving more quickly to the south and west. Experienced observers won't have trouble viewing PANSTARRS through a 4-inch telescope, but you might need a 6- or 8-inch instrument to see fine details.

Comet PANSTARRS (C/2015 ER61)



This comet should glow around 10th magnitude during September as it lingers just a few degrees southeast of the Pleiades star cluster.

The Moon crashes a predawn planet party



Leo forms the backdrop when a crescent Moon stands below dazzling Venus and above Mercury and Mars the morning of September 18.

sky more than two hours before the Sun and standing high in the east as dawn breaks. You won't mistake the planet for anything else — at magnitude –3.9, it far outshines every other point of light in the sky. Don't miss Venus passing 1° south of the magnificent Beehive star cluster (M44) the mornings of September 1 and 2. The pair makes a lovely binocular sight and a stunning photographic composition.

On September 10, Venus crosses from Cancer into Leo, where it remains for the rest of the month. The Lion serves as a backdrop for some impressive morning vistas because **Mercury** and **Mars** also reside in this constellation, though they hang closer to the horizon.

Mercury reaches the peak of its best morning appearance of the year September 12. It then lies 18° west of the Sun and stands 11° high in the east a half-hour before sunrise. Shining at magnitude –0.4, it appears conspicuous in morning twilight. Use binoculars to pick out magnitude 1.8 Mars 3° to Mercury's lower left.

These planets pull closer over the next few days. On the 16th, they come within 10' of each other and appear in the same low-power field through a telescope. (Mercury spans 6.4" and is about two-thirds lit; Mars is 3.6" across and full.)

A waning crescent Moon adds to the scene on the 17th. The slim crescent hangs 6° above Venus with Leo's brightest star, magnitude 1.4 Regulus, 3° below the planet. Mars and Mercury huddle 11° below Venus.

The solar system fireworks peak September 18. A wafer-thin crescent Moon then lies below Venus and above the Mercury-Mars pair, with just 1.5° separating the latter two planets. While Venus and Mars shine as brightly as they did earlier in the month, Mercury has improved to magnitude –1.0.

The next two mornings see Venus pass within 1° of Regulus, but that's the last September conjunction. Mercury quickly falls back toward the Sun and disappears from view in the month's final week. Meanwhile, Mars climbs higher before dawn. By the 30th, it approaches within 3° of Venus, setting the stage for a close conjunction in early October.

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**

See an asteroid move while you watch

Except for the Moon and a handful of comets, it's rare to see a reasonably bright object move against the background stars in real time. But occasionally we get lucky and receive advance notice of a 10th-magnitude or brighter near-Earth asteroid destined to whiz across the sky. September's first week gives observers the chance to see such a space rock hurtle across the evening sky.

Asteroid 3122 Florence — named after British nursing pioneer Florence Nightingale — is perfectly placed for evening viewing from the Northern Hemisphere. It comes closest to Earth on September 1, when it sweeps within 4.4 million miles of our planet and appears among the background stars of eastern Delphinus. By the next evening, it has shifted into northern Delphinus. Florence moves at some 9° per day, which translates into 22" per minute. (In comparison, Jupiter currently spans 32".)

Florence glows at 9th magnitude on September's first three nights and dims to 10th magnitude the following three nights. On the 5th, it sweeps 1° west of 2nd-magnitude Gamma (γ) Cygni, the central star of Cygnus the Swan. But by then its motion has slowed to nearly half of what it was at the beginning of the month.

Astronomers classify Florence as an Amor asteroid, which means it comes close to but does not actually cross Earth's orbit. If you scaled our planet's orbit to the size of a dinner plate, Florence would come within 0.2 inch of its outer edge. At its farthest, Florence reaches halfway to Jupiter. The asteroid orbits the Sun once every 2.35 years, but this is its closest approach to Earth since 1890, and it won't be as close again until after 2500.

Catch Florence as it skims past Earth

This fast-moving asteroid peaks at 9th magnitude when it passes within 4.4 million miles of our planet during September's first week.

HOW SETI SEARCHES

The Allen Telescope Array carries out SETI searches at centimeter wavelengths. It currently uses 42 elements in the Cascade Mountains near Lassen Peak in California.

Q: WHAT ARE THE PARAMETERS FOR SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) SEARCHES AND THEIR DIRECTION OF FOCUS? ASSUMING OTHER CIVILIZATIONS CAN SEE EARTH TRANSITING THE SUN, DO WE SEARCH AREAS OF THE SKY IN THE SAME PLANE AS OUR POTENTIAL OBSERVERS?

***Michael Martin,** Gilbert, Arizona*

A: Finding something we've never seen before is hard, so naturally there are numerous parameters for SETI searches. Will a signal arrive today, next year, did it happen during the reign of Julius Caesar, or all three? Will it last for less than a billionth of a second or remain continuously visible? Will its wavelength be in radio, optical, infrared, or not even a photon? A signal could "sound" like a simple tone or a complex, information-rich hiss. Could you see it with your naked eye, or will it require an enormous telescope?

A SETI search tries to cover as much of this "parameter space" as possible. Ideally, we'd observe the whole sky all the time, removing both time and space from the equation. But most of today's high-powered telescopes can't even observe the whole Sun or Moon at once, never mind the entire sky. So, you could choose to stare at one tiny patch of sky all year round, or you could look at half a million patches for just a minute each. But either way, you'd cover only about five millionths of the space dimension — and that's assuming you operated every day of the year!

To deal with this resource limitation, SETI researchers often bias toward targets deemed more likely to yield a detection, such as closer stars, more densely packed areas like the galactic plane, or stars with known orbiting planets. One technique is indeed to look at a star when one of its planets passes in front of (a transit) or behind it (an occultation)

Transits are how we've found most exoplanets to date, so maybe other civilizations are using this to help us know where and when to look for their signal. Occultations are useful because the parent star suddenly hides the planet from us, which might ironically illuminate a pattern in the radiation that we hadn't discerned from the overall cacophony. However, observing an occultation requires preparation and luck for the once per exo-year event!

Eliot Gillum
Director of the Optical SETI Program, SETI Institute, Mountain View, California

Q: WHAT IS THE DIAMETER OF A BODY WITH JUST ENOUGH MASS TO PULL ITSELF INTO A SPHERE? HOW BIG ARE THE SMALLEST SPHERICAL BODIES IN OUR SOLAR SYSTEM?

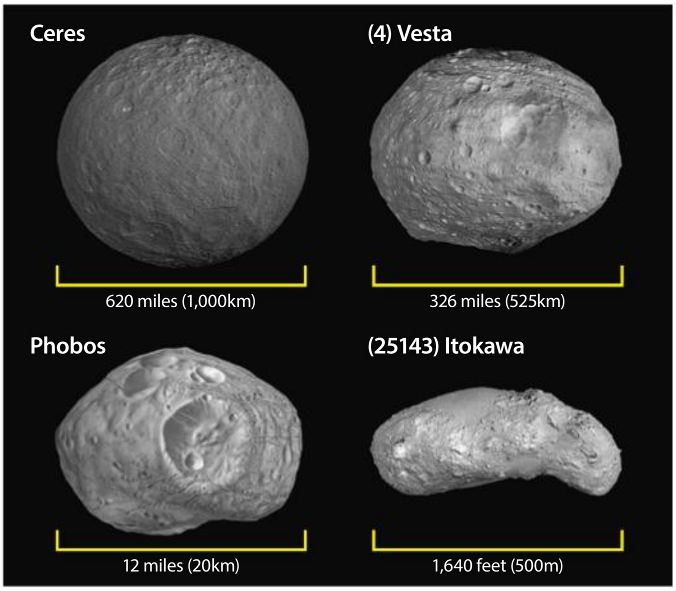
Paul Kendelman
Pennsville, New Jersey

A: The solar system contains hundreds of thousands of small bodies larger than a few kilometers in size. Many are in the main asteroid belt, which contains the fragmentary remnants of planetesimals, small bodies from which the planets formed. A few have survived nearly intact. Most asteroids are irregular in shape; however, Ceres, the main belt's largest body and the smallest dwarf planet, is round. The smallest round bodies may be found among the icy moons of Saturn or in the outer solar system.

Roundness requires hydrostatic equilibrium, which is one of the criteria used by the International Astronomical Union to define a planet or dwarf planet. When subjected to self-gravity, a rotating fluid will relax to a round (ellipsoidal) shape. Solids (rigid bodies) resist changes in shape, but when stresses are large enough, they deform, fracture, and flow. For massive objects, gravitational and rotational forces overcome rigid body forces, resulting in round bodies with low topographic relief.

Planetesimals that formed close to the Sun incorporated little water and condensed largely from silicate grains containing short-lived radionuclides such as aluminum-26, which originated from a nearby supernova. The heat produced by radioactive decay may have been sufficient to melt bodies as small as 62 miles (100 kilometers) in diameter. Imagine a massive, round blob of molten rock — as heating abated, these bodies solidified to form an iron-rich core, silicate mantle, and basaltic crust.

For these igneous planetesimals, the diameter needed to



The dwarf planet Ceres is round due to its size; Vesta once may have been round, but it has since been deformed by impacts. Planetesimals smaller than the size required to reach hydrostatic equilibrium were never round. (Scales are approximate; shape models are available from NASA's Planetary Data System at http://sbn.pds.nasa.gov.)

overcome rigid body forces and become round is about 620 miles (1,000km). The main belt asteroid Vesta is 326 miles (525km) in diameter. In its early history, Vesta's interior was at least partially molten and may at one time have been in hydrostatic equilibrium; however, after cooling, Vesta was battered out of round by large impacts.

Farther from the Sun, ice condensed along with silicate grains to form planetesimals consisting of a fragile mixture of ice and rock. The minimum diameter to achieve hydrostatic equilibrium for an icy body is comparatively small, about 310 miles (500km).

Due to rotational forces, icy Ceres (620 miles [1,000km] in diameter) is an oblate (flattened) spheroid. Some smaller bodies in the outer solar system, such as the trans-Neptunian object Huya (310 miles [500km] in diameter), appear to be round and may also be in hydrostatic equilibrium.

Thomas Prettyman
Senior Scientist, Planetary Science Institute, Albuquerque, New Mexico

Q: DURING THE AUGUST 2017 SOLAR ECLIPSE, I ASSUME I WILL SEE STARS DURING THE DAYTIME. WILL I SEE NEW STARS AND CONSTELLATIONS?

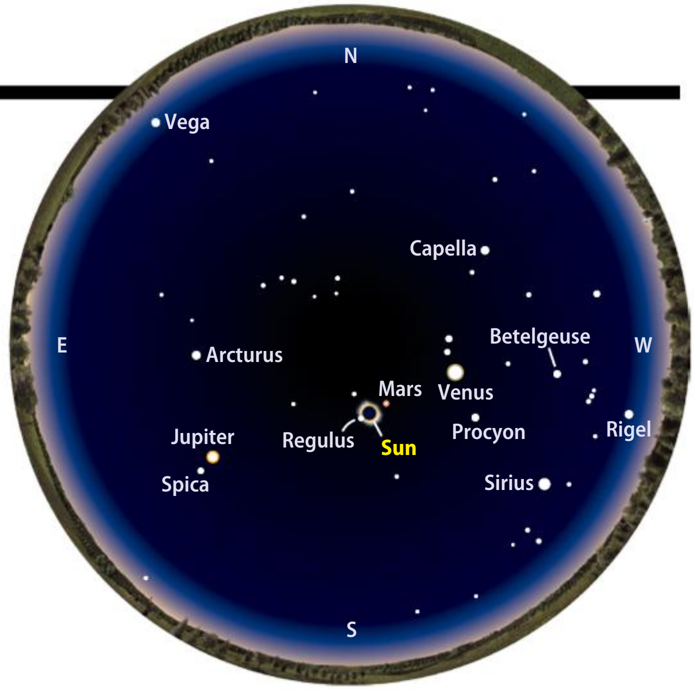
David Pippin
Dearborn, Missouri

A: During totality, and even for a short while before and after, you should be able to see the brightest stars and planets while the Sun is covered by the Moon. At the time of the August eclipse, the stars you may be able to see without optical aid include Sirius, Arcturus, Capella, and Rigel. Visible planets include Venus and Jupiter; although Mercury and Mars will be in the sky, they'll be too faint for the naked eye. I also stress "may" because your location in the United States will affect which objects are visible above your horizon. From your location in Missouri, roughly 25 miles (40km) from where *Astronomy* Senior Editor Michael E. Bakich will be watching the eclipse, Jupiter, Venus, Sirius, and Arcturus should be visible.

While the sky is dark enough to show some constellations during an eclipse, it won't be as dark as a moonless night. Additionally, because totality will last less than three minutes, your eyes won't have time to adjust to the change in light levels necessary to make out more than the brightest objects.

It's also important to note that none of these stars or constellations are necessarily new. When a constellation is not visible in the night sky, it's because those stars rise and set while the Sun is up, which depends on Earth's position in its orbit. This is why the constellations we see change with the seasons. You will get to see stars and planets that are up during the daytime while the Sun is completely covered, but they'll be the same stars and planets you could see at night during other times of the year.

Alison Klesman
Associate Editor



During totality, some stars and planets may become visible in the darkened sky, including Sirius, Arcturus, Capella, Jupiter, and Venus.
ASTRONOMY: RICHARD TALCOTT AND ROEN KELLY

Q: WHAT HAPPENS TO STARS ONCE THEY DIE AND COOL DOWN COMPLETELY? IS THE END RESULT DIFFERENT FOR NEUTRON STARS, PULSARS, AND WHITE DWARFS?

Rich Livitski
Seal Beach, California

A: The discovery of nuclear fusion processes last century was the seed for a detailed picture of the evolution of a star from a protostellar gas cloud through extinction as a white dwarf or death in a supernova. A star's mass largely determines its fate; chemical composition plays a smaller role.

Stars with mass similar to the Sun will end up as white dwarfs — cores of carbon and oxygen with hydrogen- or helium-dominated atmospheres — after their outer layers of gas are lost as stellar superwinds. Ultraviolet radiation from the white dwarf ionizes the ejected gas, forming a planetary nebula. The white dwarf core can burn no additional fuel, and it gradually cools until it no longer emits heat or electromagnetic radiation in the visible spectrum. This stellar remnant is called a black dwarf. No black dwarf has been detected yet, as the cooling time that a white dwarf needs to reach this state is longer than the age of the universe. Stars of a few solar masses also end their life cycles as white dwarfs; however, these objects have a mixture of carbon, oxygen, neon, and magnesium in their cores.

In the final moments of stars more than eight times our Sun's mass, the outer layers fall in at a tenth of the speed of light, bounce off the rigid core, and are ejected in an intense supernova explosion. The core of the star, which contains traces of heavier elements such as iron, is either left as a neutron star or implodes as a black hole. A white dwarf in a binary system can also explode as a supernova, leaving no remnant and expelling iron and other heavier elements generated during the explosion into interstellar space.

Borja Anguiano
Research Associate, Department of Astronomy, University of Virginia, Charlottesville

Send us your questions

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

Phantom planets

The wild and woolly menagerie of ghost worlds that once haunted the halls of astronomical history. by John Wenz

Our galaxy is lousy with planets. NASA's exoplanet archive lists more than 3,400 confirmed planets outside our solar system, with more added every day. Nearly 4,500 planetary candidates from NASA's Kepler spacecraft await confirmation, meaning thousands more could make the list in the near future.

Before 1995, there were only 11 known planets. There were the nine classical planets in our solar system, from Mercury through Pluto (then still a planet), and two bizarre objects that had been found around a distant pulsar.

But in 1995, we discovered 51 Pegasi b, the first confirmed planet around a Sun-like star. It was a weird one. It circled its star every four days and was eight times more massive than Jupiter. At the time, it received a lukewarm reception.

"In 1995, 51 Pegasi b was found, and about 50 percent of the astronomers or fewer believed it was an exoplanet," says Debra Fischer, a professor of astronomy at Yale University.

Why did it take so long to find a world circling another star in the first place?

"You have to picture the size and the mass of the star and then a little planet like the Earth. And if you set them side by side, Earth has a diameter that's 1/100th the size of the Sun and [a fraction of] the mass," Fischer says. Thus, astronomers can't directly see exoplanets, as even at "the edge of [their] solar system, [they] are drowned out by the light of the star." To find planets, astronomers must employ other methods, many of which have only just come into their own.

With that in mind, it was a long road to get to 51 Pegasi b. The right technology had to reach maturity at the right time. But it wasn't the first planetary claim. In fact, the history of claims of planets outside our solar system stretches back more than a century and involves outsized personalities, outright fraudsters, befuddled scientists, brown dwarfs, numerous retractions, bitter back-and-forths, and more.

Here are the tales of the planets that never were.

Thomas Jefferson Jackson See

The grand fraud

Thomas Jefferson Jackson See (1866–1962) was a lot of things. He was a brilliant astronomer — at least, if you asked him. But his peers saw him as something else: arrogant and prone to plagiarism. Thomas J. Sherrill, a Lockheed engineer and astrophysicist, wrote in a 1999 paper published in the *Journal for the History of Astronomy* that few scientists of the early 20th century "inspire a degree of rancour comparable to that evoked" by See.

Sherrill states that although See had a "solid background in celestial mechanics," his latter work "[diverged] from his astronomical colleagues in striking ways."

An 1895 paper published in *The Astronomical Journal* was especially audacious. "Since August 20, when I first announced to you the existence of peculiar anomalies in the motion of the companion of F.70 Ophiuchi, I have succeeded in showing conclusively that the system is perturbed by an unseen body," See said, his arrogance readily apparent.

When an 1899 paper by Forest Moulton challenged the findings — claiming that the three-body problem proposed by See would fling a planet out of the binary star system — See wrote a letter to the journal so vitriolic that most of it was redacted, and he was nearly banned from further publication. (The editors instead said See would be heavily censored in future communications.)

See attempted a second career as a geologist before publishing books about the formation of the solar system, which Sherrill says had a few correct assertions, but "many more were speculations presented with little justification, and others were borrowed from his contemporaries."

See's eventual undoing was a supposed biography written by a journalist who turned out to be See himself, playing up his own brilliance. By the time he had taken to writing bitter letters (a few of which appeared in *The New York Times*) about Albert Einstein's theories, few, if any, members of the science community heard him out.

"See was indeed a most colorful person, and probably quite brilliant, but he seemed to be extremely paranoid and double-dealing," says David DeVorkin, senior curator of astronomy at the Smithsonian National Air and Space Museum.

See was also not the first person to propose a planet around 70 Ophiuchi. William Stephen Jacob of the Madras Observatory put forth the idea in 1855. After See, astronomers Dirk Reuyl and Erik Holberg brought it back in 1943. A. Vibert Douglas wrote in a 1955 article in the *Journal of the Royal Astronomical Society of Canada* that the planet is "more remote from its star than Jupiter from the sun. Jupiter is believed to be wholly incased in ice, so that the likelihood of life on 70 Ophiuchi C is negligible."

But to date, no planet has been confirmed. So why has this binary star system so entranced astronomers?

DeVorkin says it's because 70 Ophiuchi is a "close-by low-mass system that's relatively easy to observe.

"Old ideas die hard," he adds.

The man of wonder

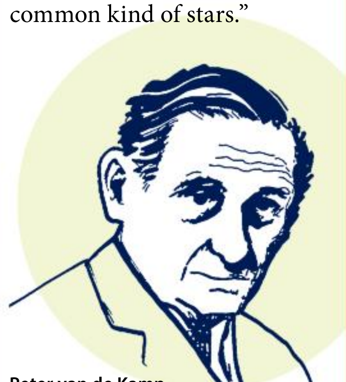
See had no standing left in the astronomical community by 1905. He was eventually, as DeVorkin says, "banished to Mare Island," a small observatory in San Francisco.

Astronomer Peter van de Kamp (1901–1995) was nothing like See. While See was arrogant and unscrupulous, van de Kamp was gregarious and popular. While See failed to make lasting contributions to the field of astrophysics, van de Kamp wrote the book on 20th-century astrometry.

But both had one thing in common: planets that vanished upon further scrutiny.

Van de Kamp was a popular professor known for dynamic lectures, a love of classical music, and his amiable demeanor. As the director of Sproul Observatory at Swarthmore College, van de Kamp became a trusted adviser to several students, teaching them astrometry, a technique that measures the precise position of stars.

"Peter van de Kamp was one of the first to push this work down to much cooler and less massive stars," says Eric Jensen, a professor of astronomy at Swarthmore. "So the work that he and others did at Sproul Observatory over many years, measuring orbits for systems with low-mass stars, was fundamental for our understanding of cool, red stars, which we now know to be by far the most common kind of stars."



Peter van de Kamp

This work led to 61 Cygni. Van de Kamp and his graduate student Kaj Strand first proposed a planet in this binary system in 1942, based on their astrometry measurements. 61 Cygni A and B seemed to wobble slightly as they orbited each other, as if tugged by an unseen object. Van de Kamp added to his planetary claims in 1951, this time announcing a proposed planet around Lalande 21185 with graduate student Sarah Lee Lippincott.

But 1963 saw van de Kamp's most explosive announcement:

Sarah Lee Lippincott

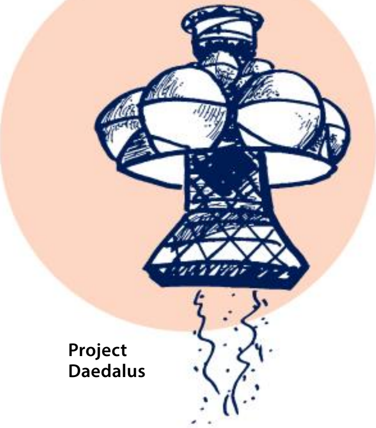
There was a planet around Barnard's Star, an M dwarf just 6 light-years away. It was a cold, inhospitable planet larger than Jupiter, in a 12-year orbit. Later, van de Kamp added a Saturn-sized world in a 20-year orbit, based on further assessment of the star's motions.

"His work was focused on measuring the orbits of stars," Jensen says. "But once you measure an orbit, you get masses for the orbiting object. And he thought he had found, from the orbit he measured for Barnard's Star, that it implied an orbiting companion of planetary mass."

A 1966 paper on interstellar travel focusing on Barnard's Star kicked off what became Project Daedalus, one of the first modern engineering studies into interstellar travel within a human lifetime. A robotic probe would use nuclear explosions to propel a spacecraft toward Barnard's Star at 12 percent the speed of light.

But by 1973, a new view on these planets was emerging: Sproul Observatory's telescope was flawed, and none of the planets actually existed. Specifically, the photographic plates were underexposed, and when the telescope was calibrated a certain way, some stars appeared to move artificially.

ALL ILLUSTRATIONS: *ASTRONOMY*: KELLIE JAEGER



Project Daedalus

"Astrometry, it turns out, is just tough to do from the ground because we're looking through Earth's atmosphere and the stars are twinkling," Fischer says.

One of the flaw's discoverers was the new Sproul Observatory head, Wulff-Dieter Heintz. Another observatory employee, John L. Hershey, published a paper in *The Astronomical Journal* in June 1973. Hershey had studied the tiny M-dwarf star Gliese 793, and as he pored through photographic plates, he noticed something: It had the exact same data discontinuity as Barnard's Star.

But the United States Naval Observatory and Allegheny Observatory at the University of Pittsburgh found no shift in the motion of Barnard's Star.

"When his work was checked over by other observatories using the more powerful plate constant method, his unseen planetary companions to Barnard's Star vanished," DeVorkin says.

That didn't deter van de Kamp, but it did damage his friendships with Heintz and George Gatewood, the astronomer at Allegheny who confirmed the lack of perturbations in the motion of Barnard's Star. As late as the 160th Meeting of the American Astronomical Society, held in Troy, New York, in 1982, van de Kamp was still pushing for his planets.

"Current analysis for one orbit clearly yields a perturbation with a period of 12 years," his abstract read. "As before, a desirable improvement is made by an additional perturbation with a period of 20 years."

Incidentally, at this same conference, van de Kamp's protégé Lippincott presented the possibility of planetary-mass companions around three other stars. One of those stars, Luyten's Star, has been recently confirmed to host planets. However, Lippincott suggested two long-period gas giants, whereas the planetary companions found in March 2017 were a super-Earth and an Earth-mass planet. These planets don't account for the magnitude of Lippincott's possible detection. Another 1982 paper by Lippincott suggested — but far from asserted — that a planet could cause flare activity on EV Lacertae.

"In general, people have been skeptical about planetary discoveries, often for good reason — [van de Kamp's] is far from the only claim of a planetary discovery that turned out to be incorrect," Jensen says. "And even the initial discoveries of exoplanets in the mid-1990s were met with some skepticism initially, though of course now we have overwhelming evidence of the rich diversity of planets around other stars."

Luyten's Star is the only star in van de Kamp's cadre with a confirmed planetary system. To

date, no planets have been found around Barnard's Star, Lalande 21185, or 61 Cygni.

Gatewood did present a paper in 1996 claiming that he had found several planetary-mass companions around Lalande 21185. This result, too, was based on astrometry. Gatewood's planets also were cast in doubt and remain unconfirmed. A February 2017 paper suggested evidence of a 3.8-Earth-mass planet, though it also remains ambiguous.

Lalande 21185 just can't catch a break.

Still, van de Kamp's work left him "highly respected" at the end of his career, according to DeVorkin. And Sproul Observatory has since been replaced at Swarthmore with a new one: Peter van de Kamp Observatory. As part of the Kilodegree Extremely Little Telescope program, the observatory has turned up planets — this time, real ones.

"Our collaboration has published discoveries of about 15 exoplanets so far, and many of the discovery papers include data from our telescope here," Jensen says. "Although van de Kamp was wrong about Barnard's Star, he made important contributions to astronomy, and I'm pleased that we can honor and remember his work by having his name on our observatory."

Van Biesbroeck 8B

When astronomers discovered an object around van Biesbroeck 8 (vB8) in 1984, they weren't quite sure what they were seeing. *The New York Times* ran the headline "Possible Planet Found Outside the Solar System," with author John Noble Wilford stating, "If this is indeed a planet, the discovery would be a clear breakthrough in the long search for extrasolar planetary systems and the first direct evidence to support a premise underlying theories of possible extraterrestrial life, which is that planetary systems are not unique to the Sun and may even be common in the universe."

But there was a problem with the puff of gas that had been spotted in the infrared: Although it was the size of Jupiter, further studies showed an outsized influence on its parent star. In fact, this is a common problem in the hunt for planets. There are objects that are neither stars nor planets, called brown dwarfs, which can be easily mistaken for planetary companions. Mass estimates on vB8's companion were hard to nail down — somewhere between 30 and 80 Jupiter masses. To several astronomers, this indicated a brown dwarf.

Jill Tarter of the SETI Institute first gave brown dwarfs their name. Brown dwarfs accumulate matter in the same way as stars, but fail to attain enough mass to ignite hydrogen fusion. Stars fuse hydrogen into helium, which can only occur above a certain

MODERN GHOSTS

The early years of planetary detection sparked debate as discoveries accumulated. Of the first 19 planets discovered, half were actually brown dwarfs. The problem persists today, as more accurate mass measurements of hefty planets reveal instead brown dwarfs.

In 2009, the Kepler telescope inundated astronomers with new data. Previous false detections were relabeled candidates, while some candidates became false detections. But only one confirmed Kepler planet has ever been retracted: Kepler-32e, the result of a clerical error.

The Gliese 581 system has seen quite the volley back and forth. In 2010, astronomers found two or three potentially habitable planets: Gliese 581b, c, and e. But the proposed Gliese 581f was soon ruled out, while the status of Gliese 581g, the most potentially habitable planet, has long been cast in doubt.

Alpha Centauri Bb, discovered in 2012, was such a weak detection that it became a high-profile retraction. Many of the planet's discoverers joined the Pale Red Dot team, which successfully found the Earth-mass planet Proxima Centauri b in the same system in 2016. — *J. W.*

temperature and pressure. Objects above that threshold are stars. Brown dwarfs initially produce heat by fusing an isotope of hydrogen called deuterium into helium-3, which can occur at lower temperatures and thus, lower masses.

TRAPPIST-1, an ultra-cool dwarf star, is 84 Jupiter masses. The largest known brown dwarf is 90 Jupiter masses. In other words, the realm of large brown dwarfs and small stars is a bit murky.

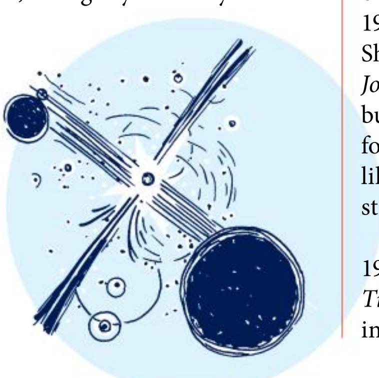
Astronomers discovered the first brown dwarf in 1995, the same year they confirmed the first planet around a Sun-like star. So, what happened to vB8's companion 11 years earlier?

The vB8 discovery sent shock waves through the astronomical community; a conference was convened in 1986 on the topic of brown dwarfs. According to *New Light on Dark Stars* by I. Neill Reid and Suzanne L. Hawley, that very conference torpedoed the case for vB8's companion, as other infrared observations failed to find it. "The only possible conclusion is that the original detection was an observational artefact, probably due to the chromatic effects of atmospheric refraction," they write.

The first planet — or possibly the first brown dwarf — evaporated almost as quickly as it had emerged.

Pulsar planets

In 1992, astronomers officially found the first planetary system when they discovered two (later found to be three) objects around PSR B1257+12, a pulsar 2,300 light-years away. Pulsars — a type of rapidly rotating neutron star — are often too small to be seen in optical light, so the planets' presence was inferred from subtle changes in the normally precise radio signals coming from the pulsar.



Pulsar planets are weird — neutron stars are formed in supernovae or stellar mergers, violent events that tend to consume or sweep away materials from any planet in the vicinity, destroying them. Thus, the scant few pulsar planets discovered to date are likely to have formed after the supernova in a second planetary genesis.

A year earlier, in 1991, there were claims of a planet around PSR B1829–10, a different pulsar 30,000 light-years away.

The progression of papers in the journal *Nature* tells it all. In August 1991, a trio of astronomers published their results: "A planet orbiting the neutron star PSR 1829–10." But a January 1992 paper by two of the three original authors was titled "No planet orbiting PSR 1829–10." The planet detection had been a simple miscalculation created by failing to model Earth's orbit accurately when assessing measurements of the star.

The 1991 claim wasn't even the first possible pulsar planet that never was. In a November 1979 *Nature* letter, Mieczysław Prószyński and Marek Demiański of Warsaw University found timing variations in pulsar PSR 0329+54 suggesting something was affecting the dense star husk. They proposed a change in shape, a change in magnetic fields, or a planet half the mass of Earth (or less) orbiting it. A 1995 article by Tatiana V. Shabanova in *The Astrophysical Journal* tried to bolster the case, but subsequent investigations found the signal variations are likely a consequence of the star's variable rotation rate.

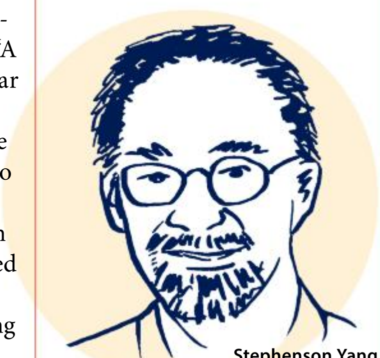
There is also an October 22, 1969, article in *The New York Times* asserting a planet orbiting the Crab pulsar, based on a "wobble" observed in the pulsar that could be like the wobble that occurs in the Sun as the planets orbit. The results were published in *Nature* in 1970, but subsequent papers on the wobble observed in the Crab and Vela pulsars suggested that it was instead caused by stresses and friction in the star's crust, leading to starquakes.

Gamma Cephei

Some planet stories have a happy ending.

Gamma (γ) Cephei A was initially thought to have a planetary-mass companion in 1988, though the evidence was only tentative. At the time, the emerging technology of radial velocity was just barely refined enough to detect planets.

The 1988 data did confirm one thing: Gamma Cephei was a binary star system with a low-mass red dwarf, Gamma Cephei B, circling Gamma Cephei A. Even after accounting for the companion's effects, Stephenson Yang and his associates still saw evidence in their signal for a low-mass, possibly planetary object in the system.



Stephenson Yang

But a 1992 follow-up study cast doubt on the tentative planet. Gamma Cephei B dominated the radial velocity measurements, making the supposed planet's signal scientifically unreliable. "We had a very weak signal, one and a half sigma," says Yang, a professor at the University of Victoria and a principal investigator.

Also, Gamma Cephei A was believed to be much younger than it actually is. "We thought we were looking at a much more variable star than one that was main sequence," Yang says. They chalked up their weak signal to variations in the star and retracted their planetary claim.

Fast-forward to 2003. A planet around Gamma Cephei A was announced with roughly the mass and orbit suggested by the 1988 results. Yang and his compatriots had, in fact, found the first exoplanet. They just hadn't been able to confirm it.

In 1992, Gamma Cephei B wasn't well constrained. By gathering more data, it was possible to extract the signature of the smaller star from the wobbles of Gamma Cephei A. And from that information, a Jupiter-sized world with a 2.5-Earth-year orbit emerged.

"When you look at the radial velocity of the star, you do see a large radial velocity change because it has a companion," Yang says. "If you took out the changes, you see ripples, which [are] caused by the planet."

And thus, a planet called Gamma Cephei Ab was found around a future North Star, based on the small changes it makes to its star's orbit, which had been drowned out by the tug of a much larger star.

"I still remember the first time we looked at the ripple and said, 'Oh wow, it fits so nicely to the orbit,'" Yang says.

So 51 Pegasi b got the glory. But Gamma Cephei Ab was there first. (Fischer also points out HD 114762b, which was discovered in 1989 and confirmed in 2012. Technically it could be considered the second, bumping 51 Pegasi b to third.)

A nearly 150-year hunt had drawn to a close. Now armed with a few confirmed planets, astronomers could begin to build a real catalog of stars with planetary systems. All it took was a handful of phantom planets to get there.

John Wenz *is an associate editor of Astronomy magazine.*

The secrets of off-season glo

Target this list of two dozen beautiful star cities, none of which you'll find in the old standbys Scorpius, Ophiuchus, or Sagittarius! **by F. Michael Witkoski**

When most Northern Hemisphere observers think of globular clusters, they imagine a concentration low in the southern summer sky. The dense nebulae and stellar clouds in that area are bright enough to cast a subtle shadow as they point to the core of our Milky Way.

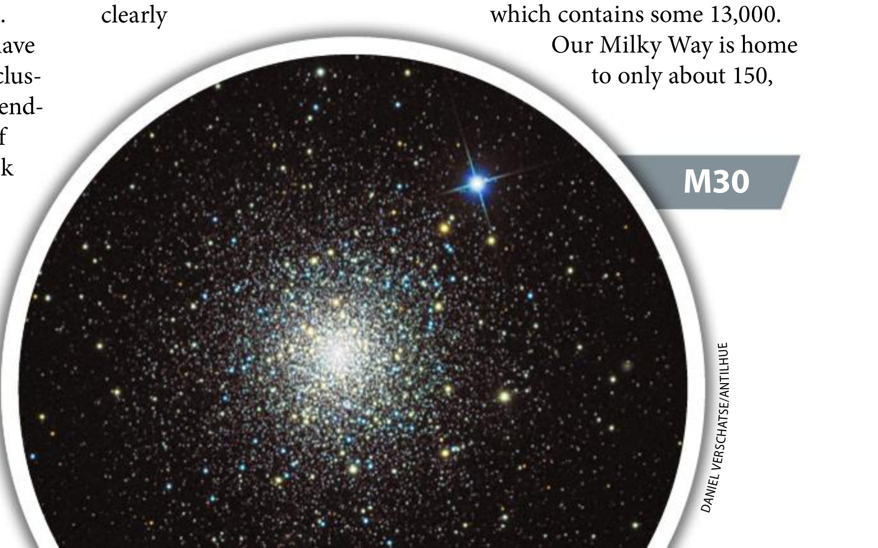
Earth's placement halfway from our galaxy's center governs our perspective much as a suburban view toward a city contrasts sharply with farms and fields in the opposite direction. Reflecting this skewed dispersal is the placement of globular clusters, enormous stellar spheres floating against a seemingly infinite firmament. They contain, on average, several hundred thousand closely packed stars, and their density is a few hundred to a few thousand times greater than that in our Sun's neighborhood.

Sagittarius joins its prominent neighboring constellations Scorpius and Ophiuchus in hosting roughly half of these great stellar metropolises. Analyses over the years have shown that the globular clusters form a large halo extending past the main body of our galaxy. While the disk of the Milky Way is dense, dynamic, and rife with star formation, the halo is relatively calm. The globulars are placid, stable, and nearly as old as the universe itself.

Among Milky Way objects they are distant, and despite their great numbers of stars, they are not conspicuous naked-eye objects. Only two are plainly visible without optical aid (both in the southern sky), and a handful of others hover at the threshold of visibility. Views of other galaxies clearly show their halos of globular clusters, something we cannot observe from within the confines our own system.

Our nearby galactic neighbor, the Andromeda Galaxy (M31), houses about 500 globulars, a pittance compared with the thousands for giant elliptical galaxies such as Virgo's M87, which contains some 13,000.

Our Milky Way is home to only about 150,



M30

DANIEL VERSCHATSE/ANTILHUE

bular clusters

KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF

although it's likely the dense clouds of Sagittarius hide a few dozen more.

While the best and the brightest globular clusters appear more prominently in the summer sky, our focus will be on those often overlooked specimens best viewed during the rest of the year. We will survey both Messier and NGC objects, all discovered by the 1800s and all visible through backyard telescopes.

Autumn

As the more sparsely populated fall sky replaces the jeweled treasures of summer, the number of globular clusters diminishes. The two premier examples are **M2** in Aquarius and **M15** in Pegasus. Elsewhere, we find a sprinkle of other Messier globulars. Greater challenges loom with a handful of NGC globular clusters scattered over this season's sky.

Let's start our tour with a bonus object, in the eastern corridor of Sagittarius. In an overlooked corner of this constellation, away from the bright star clouds and nebulae associated with summer, is **M75**. Within the reach of all but the smallest telescopes, it's fairly tight and consequently not resolvable into individual stars. It more or less typifies the profile of an off-season globular.

Not so for M2 and M15, which are separated by about 13° nearly due north and south. Through a 6-inch telescope, both show as concentrated balls of stars, although M15 is a bit looser and consequently easier to resolve into stars inside its edges. M15, the second-brightest cluster in our survey, is astrophysically noteworthy for two reasons. First, it is one of only four members of its class known to host a planetary nebula: 14th-magnitude Pease 1, discovered spectroscopically in 1927. Lost among thousands of stellar pinpoints, it is next to impossible to identify visually. If Pease 1 is not enough of an oddity, M15 is one of only a few globular clusters that emit X-rays. The X-ray radiation undoubtedly results from stellar material streaming from one star of a pair onto the superdense surface of its companion (be it a neutron star or a black hole), which no optical telescope will reveal.

THE GLOBULARS OF AUTUMN

OBJECT	CON.	R.A.	DEC.	MAG.	SIZE
M2	Aquarius	21h34m	–0°49'	6.6	12.9'
M15	Pegasus	21h30m	12°10'	6.3	12.3'
M75	Sagittarius	20h06m	–21°55'	8.5	6'
M30	Capricornus	21h40m	–23°11'	7.3	11'
M56	Lyra	19h17m	30°11'	8.3	7.1'
M71	Sagitta	19h54m	18°47'	8.0	7.2'
M72	Aquarius	20h54m	–2°32'	9.3	5.9'
NGC 6934	Delphinus	20h34m	7°24'	8.7	5.9'
NGC 7006	Delphinus	21h02m	16°11'	10.5	2.8'
NGC 1466	Hydrus	3h45m	–71°40'	11.6	3.5'
NGC 1841	Mensa	4h45m	–83°59'	11.4	0.9'
NGC 7492	Aquarius	23h08m	–15°37'	11.2	6.2'
NGC 1049	Fornax	2h40m	–34°15'	12.6	0.4'
NGC 288	Sculptor	0h53m	–26°35'	8.1	13.8'

Key: Con. = Constellation; R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude

NGC 6934

DALE NIKSCH/ADAM BLOCK/NOAO/AURA/NSF

NGC 2419

ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

The respectable globular cluster **M30** resides in the constellation Capricornus. It's easy to locate, lying less than 0.5° west of the magnitude 5.2 star 41 Capricorni. Binoculars will reveal it as a fuzzy "star," and any telescope will reveal its true nature.

Lyra is quite different from Capricornus. The small constellation lies just outside the Milky Way mainstream and is rich in inviting targets. It houses Vega (Alpha [α] Lyrae), the fifth-brightest star in the night sky; the famous Ring Nebula (M57); and the celebrated Double-Double, Epsilon (ε) Lyrae. All overshadow the small globular cluster **M56**.

Nearly midway between Sulaphat (Gamma [γ] Lyrae) and Albireo (Beta [β] Cygni), it is a fairly loose cluster but a magnitude dimmer than M30. However, residing farther to the north, it is visible for more of the year than its counterpart.

Across the Milky Way from Lyra is star-rich Sagitta, the third-smallest constellation. Four uniformly bright stars define its prominent "arrow." Between the two easternmost ones lies **M71**, a medium-size cluster with a total brightness similar to that of M56. It is the nearest globular in our survey, and if it were as distant as others we are visiting, it would be beyond the range of most amateur telescopes. Its loose concentration makes it one of the few through which galaxies are visible in Hubble photographs. Most other globulars are so dense in the middle that nothing in the background comes through, and until the 1970s, M71's status as a globular cluster was uncertain.

THE GLOBULARS OF WINTER

OBJECT	CON.	R.A.	DEC.	MAG.	SIZE
M79	Lepus	5h24m	–24°31'	7.8	8.7'
NGC 1851	Columba	5h14m	–40°03'	7.2	11'
NGC 2298	Puppis	6h49m	–36°00'	9.2	6.8'
NGC 2419	Lynx	7h38m	38°53'	10.3	4.1'

Key: Con. = Constellation; R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude

The remaining autumn Messier globular is **M72**, a resident of Aquarius. It is dim, although a 3-inch telescope easily shows it. It is not very concentrated, but its stars stubbornly resist resolution.

Delphinus, a small yet conspicuous constellation just east of Sagitta, houses two diminutive globulars, **NGC 6934**, 4° due south of Epsilon Delphini, and **NGC 7006**, 3.5° due east of the attractive double star Gamma Delphini. NGC 6934 is brighter and much nearer than its counterpart. NGC 7006 is among the most remote globular clusters within range of portable telescopes. It appears as no more than a smudge through instruments with 12-inch apertures. No details are discernible, and being in a field of view consisting of perhaps two dozen faint stars where nothing stands out as a reference, it is an object that truly tests the best telescopes.

Another challenging object is **NGC 1049**, also known as Fornax 3, which is not a member of our Milky Way. It belongs to a satellite galaxy, the Fornax Dwarf. Although it glows at magnitude 12.6, NGC 1049 is visible through an 8-inch scope under good viewing conditions.

In autumn, NGC 7492 is the most challenging globular cluster viewable from the northern sky.

Two other NGC globulars comparably distant are the southern specimens, magnitude 11.6 **NGC 1466** and magnitude 11.4 **NGC 1841**. Neither is a part of the Milky Way, however, but both are associated with the Large Magellanic Cloud, a satellite galaxy of ours. This pair lies at the limit of visibility in small telescopes.

The most challenging globular cluster viewable from the northern sky this season and still belonging to the Milky Way is Aquarius' **NGC 7492**. It is small and glows softly at magnitude 11.2.

Lying 4° east of a relatively bright star, magnitude 3.3 Delta (δ) Aquarii, it is nevertheless easy to overlook. It

The parent galaxy, however, is invisible, being only available photographically. While NGC 1049's southern location poses an obstacle for many northern observers, from a site where it rises far above the horizon, such as the Caribbean area, it shows up in scopes at least as well as NGC 7492.

Our last fall globular is **NGC 288**, a loose cluster in the nondescript southern constellation Sculptor; the south galactic pole lies within its borders. This globular is less than a degree northeast of the pole and is the closest NGC object to it. NGC 288 is visible from northern latitudes for only a few hours per night; late evenings in October and November are best.

Winter

As autumn skies give way to winter, the globulars become scarcer yet. Our first stop is **M79** in Lepus the Hare, the target of the great hunter Orion. This object is far from spectacular but is within easy reach of large binoculars or small telescopes. Its southerly position, however, may limit the view of it for northern observers if sky conditions are less than ideal. Recent research places it within the Canis Major dwarf galaxy, which is a satellite of our Milky Way.

South of Lepus is Columba the Dove, home to the respectable but overlooked globular cluster **NGC 1851**. It is a half-magnitude brighter than M79 and more concentrated. Its placement in an out-of-the-way corner of a little-known southerly constellation adversely affects its popularity, but it's well worth the perseverance needed to find it.

Another challenge awaits us in Puppis, the next constellation east from Columba. Here resides the small and dim globular cluster **NGC 2298**. It is nearly as far south as NGC 1851, but it has less impressive credentials (2 magnitudes fainter) and is much more difficult to find.

Lynx is a small constellation in the northern winter sky and home to few bright stars. Within its borders is an extremely challenging globular, **NGC 2419**, often called the Intergalactic Wanderer, the most remote of its kind in our galaxy visible through a portable telescope. It lies more than twice as far away as NGC 7006. A 4-inch telescope will show it as a hazy "star," and only with much larger instruments does it become apparent that a globular cluster is in view, but at its enormous distance, no details are evident.

Spring

During the final season in our survey, we visit five constellations and seven globular clusters.

Coma Berenices in the northern sky houses an unusual pair visible together through a wide-field eyepiece. **M53** is a fairly bright cluster containing perhaps half a million stars, while its similarly sized neighbor, **NGC 5053**, about 1.5° due east, contains at most several thousand. The two exhibit the most extreme contrast between two nearby globulars anywhere in the sky.

NGC 4147 also lies in Coma Berenices. At magnitude 10.4, it is dim and among the most difficult to spot in our survey. Realistically, 6 inches is the minimum aperture for viewing this specimen. Although its apparent brightness compares with that of NGC 1049, in absolute terms there's no match. NGC 4147 is simply smaller and closer.

Our next object is the respectable globular cluster **M68** in Hydra, the sky's largest constellation. Because this slithering giant contains few bright stars for its size and little outstanding to the naked eye, observers often overlook it. By association, targets within its borders are not among the best known. Compounding this is the southern location of M68.

Virgo, the second-largest constellation in the sky, hosts at least 100 galaxies visible through backyard scopes. Most of them bunch together in this star pattern's western corridor.

Also within Virgo's confines but far east of these galaxies is the globular cluster **NGC 5634**. A humble object, it is nevertheless among the brightest deep-sky objects in Virgo.

While M87, the gravitational nucleus of the extensive Virgo Cluster, is one of the most thoroughly studied of its type, its total apparent brightness trumps the relatively unknown NGC 5634 by less than one magnitude. In fact, that galaxy's thousands of globular clusters, visible as such only photographically, are much more celebrated than our lone globular at the opposite end of the constellation.

Magnitude 9.2 **NGC 5466** in Boötes is a diffuse globular with no immediate reference points, although the spectacular cluster M3 in the adjacent constellation Canes Venatici lies a cozy 5° west. While NGC 5466 is closer to the summer sky than **M3**, which is at the cusp of naked-eye visibility, I included it because it typifies the challenge of off-season globular clusters.

Majority rule

I purposely abbreviated this survey of globular clusters. I could have included more southern sky objects or even explored some non-NGC objects. Because globular clusters within the Milky Way total only about 150 objects, and because many are within the reach of portable telescopes, most observers could view more than half of them within a reasonable timespan. By contrast, how many observers have seen most of the galaxies?

When we observe a globular cluster, we see through our eyepiece an image nearly as old as the universe. And while our Milky Way is in a state of constant flux, the opposite is true for globulars. These objects have long been stable, and because of their distance from the nucleus of our galaxy, they will remain intact for a very long time.

THE GLOBULARS OF SPRING

OBJECT	CON.	R.A.	DEC.	MAG.	SIZE
M53	Coma Berenices	13h13m	18°10'	7.7	12.6'
NGC 5053	Coma Berenices	13h16m	17°42'	9.9	10.5'
NGC 4147	Coma Berenices	12h10m	18°33'	10.4	1.7'
M68	Hydra	12h40m	–26°45'	7.6	12'
NGC 5634	Virgo	14h30m	–5°59'	9.5	5.5'
NGC 5466	Boötes	14h06m	28°32'	9.0	11'
M3	Canes Venatici	13h42m	28°23'	6.2	16.2'

Key: Con. = Constellation; R.A. = Right ascension (2000.0); Dec. = Declination (2000.0); Mag. = Magnitude


BERNHARD HUBL

M53 and NGC 5053

F. Michael Witkoski *has been a deep-sky observer for many years. He has previously contributed to* Astronomy *and other publications.*

Partygoers and telescope hosts share a star-filled sky near Flagstaff, Arizona, during the city's annual star party. FLAGSTAFF DARK SKIES COALITION

How FLAGSTAFF is preserving DARK SKIES

A star party and world-leading community are keeping the hometown of Lowell Observatory in the dark.

by Christian Luginbuhl and Jeffrey Hall

FLAGSTAFF, ARIZONA, WRAPS picturesquely around the base of the San Francisco Peaks, the state's highest mountain range. At an elevation of 7,000 feet (2,130 meters), the air is thin, and nights are chilly even in summer. The bracing environment, however, doesn't stop thousands of people from coming every September to Buffalo Park, a large open space right in the middle of the city, to peer into the cosmos.

Here at the Flagstaff Star Party, rows of telescopes are hosted by the area's many amateur astronomers, as well as by professionals from Flagstaff's two major observatories: Lowell Observatory and the United States Naval Observatory (USNO). Despite the location less than 2 miles from City Hall, the sky is spectacular. The astronomers trace constellations and stars fainter than 6th magnitude for the partygoers, and the autumn Milky Way rises from the looming peak of nearby Elden Mountain, arcs through the zenith, and dives into the southwestern horizon directly over the center of the city. Even the splendid Sagittarius star clouds find little competition from the sky glow.

The Flagstaff Star Party bills itself as "The World's Most Accessible Dark Sky Star Party," a unique event providing easily accessible viewing under unexpectedly dark skies, within a 10-minute drive of restaurants, hotels, and all the amenities of a college town of 70,000 inhabitants. To the quantitatively inclined, the event boasts Bortle class 4 skies, a zenith sky brightness fainter than 21.2 magnitudes per square arcsecond, and a zenith limiting magnitude of 6.5 or fainter. (The Bortle scale is a nine-level scale of sky darkness created by astronomer John Bortle in 2001. Bortle 9 is a terrible, urban sky, and Bortle 1 is a perfect sky with no terrestrial lights.)

All of this stems from a 59-year tradition of dark-sky preservation in Flagstaff, which in 2001 was given the first "International Dark-Sky City" designation by the International Dark-Sky Association (IDA). Flagstaff shows in brilliant highlights just what can be achieved.

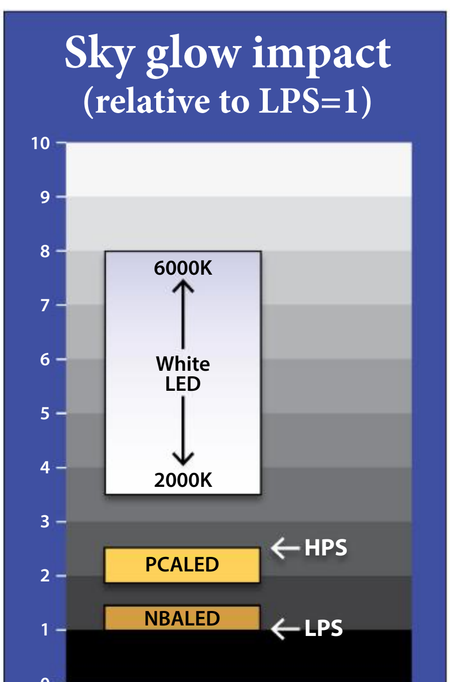
Preserving dark skies for astronomy — and more

Dark-sky protection in Flagstaff goes back to 1958, when at the impetus of Lowell and USNO astronomers, the city enacted the world's first law to protect night skies, banning advertising searchlights. Lowell (established in 1894) and USNO (1955) steadily grew, and they now have over $125 million in telescope assets in the area. Preservation of the sky quality necessary for astronomical research is contained in Flagstaff's lighting code and in its engineering standards.

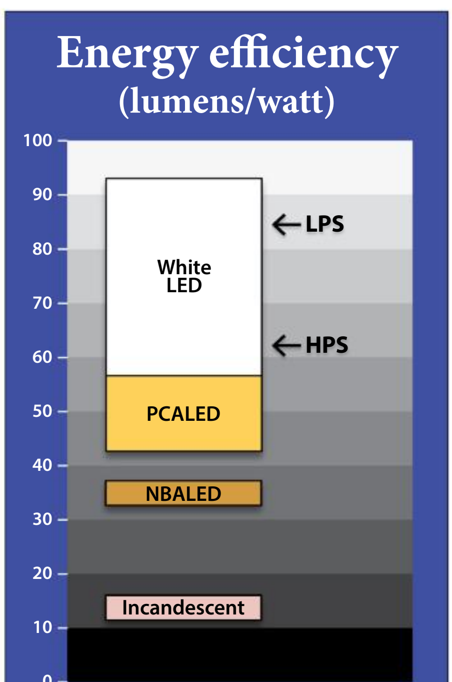
At the heart of these standards is a proverbial three-legged stool for dark-sky preservation: full shielding for outdoor fixtures, limits to the total amount of installed lighting per acre, and spectrum management calling for low-pressure sodium street and area lighting.

Astronomy, however, is only part of the equation. Flagstaff has built the idea of looking up and seeing a star-filled sky into the city's culture. You can find locals sipping a "dark-sky mocha" at Late for the Train Coffee, or unwinding at the end of the day at Dark Sky Brewing Company on Beaver Street. A bit west of downtown, you can turn off Flagstaff Ranch Road and onto Dark Sky Lane. The IDA proclamation of dark-sky city status is found on signs

FLAGSTAFF DARK SKIES COALITION



The impact on sky glow from outdoor lights can be huge, as with white LEDs, or minimal, as with low-pressure sodium (LPS) lamps or narrow-band amber (NBA) LEDs. Phosphor-convervted amber (PCA) LED is in between. FLAGSTAFF DARK SKIES COALITION



The energy efficiency of lighting varies widely, from the highly efficient (white LED and low-pressure sodium) to the less efficient (phosphor-converted amber and narrow-band amber LED), to the woefully inefficient (incandescent).

Venus sets among myriad stars above Flagstaff, Arizona, in this view of the sky from Buffalo Park, the site of the annual star party. FLAGSTAFF DARK SKIES COALITION

SENSIBLE DARK-SKY LIGHTING STANDARDS WOULD REDUCE SKY BRIGHTNESS OVER OUR CITIES BY 90 PERCENT OR MORE.

leading into town. The natural night sky — as an environmental quality, as a resource to be enjoyed, as a tourism driver, and as an ecological and health benefit — is part of the ongoing conversations of residents, city planners, and advocacy groups like the Flagstaff Dark Skies Coalition.

Decades ago, we all had to think consciously about whether refuse went in the trash or the recycle bin; today it's second nature. For a longtime resident of Flagstaff, it's startling to go to another city and not see the Milky Way from downtown. Seeing the galaxy and faint stars from the middle of a sizable town is second nature.

Unfortunately, it is also easy not to see them unless preserving the dark sky also becomes second nature.

Losing the night

The night sky has been a canvas of human hopes and inspirations since we have been aware enough to raise our eyes from the ground. Yet today, we find night's window closing almost everywhere, veiled by the spread of artificial light.

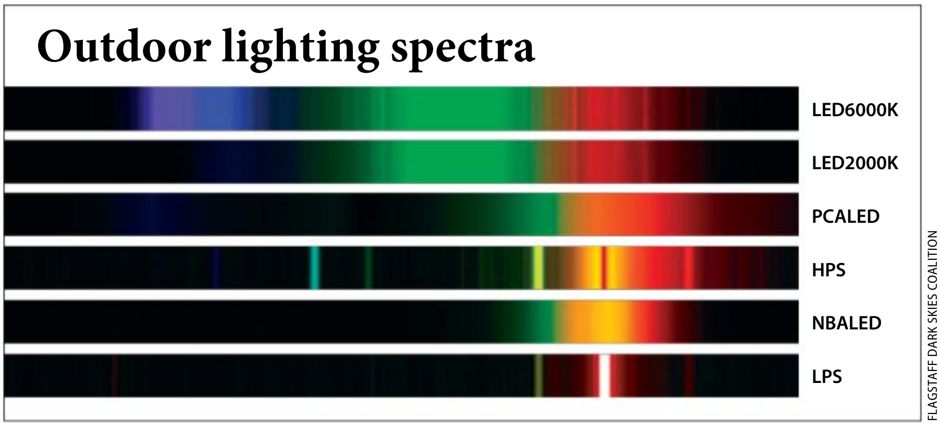
Sensitive individuals noticed this invasion long ago: In 1928, naturalist Henry Beston lamented, "With lights and ever more lights, we drive the holiness and beauty of night back to the forests and the sea" (*The Outermost House*). But in our modern age, the problem has vastly accelerated, with an ever-increasing demand to use more light in more circumstances and at more times. "The New World Atlas of Artificial Night Sky Brightness" (available online at http://advances.sciencemag.org/content/2/6/e1600377), published in the June 2016 issue of *Science Advances*, revealed in beautifully-colored maps the un-beautiful consequences of increased artificial light: None of the land area in Europe or nearly anywhere east of the Great Plains in the United States has naturally dark night skies; 60 percent of Europeans and nearly 80 percent of U.S. residents live where they can no longer see the Milky Way. Increases in the efficiency of lighting technologies (most recently LEDs), always touted as an opportunity to save energy, have instead only contributed to the relentless increases in the amount of light.

How many of us know that this is not necessary?

Recovering the night

It doesn't have to be this way. To examine the options, we return to our three-legged stool.

Shielding. Use of fully shielded fixtures, ensuring no light radiates above horizontal, is simple and effective. Flagstaff does it; other dark-sky communities do it; anyone can do it. Even absent any other



Spectra of common outdoor lighting types show narrow emission from low-pressure sodium, at bottom, which does little to interfere with night-sky viewing. On the other hand, broad spectrum LEDs, at top, emit light over a wide range of wavelengths, making them destructive to skywatching.

regulations, research shows that simply directing light to the ground where it is needed can reduce artificial sky glow by 50 percent or more.

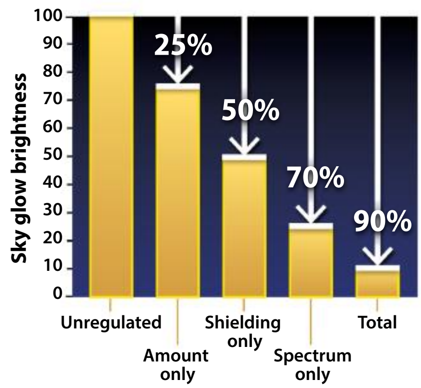
Appropriate lighting levels. One can find examples of excessive outdoor lighting everywhere, but it can be managed with practical limits on the amount of lighting. Flagstaff's code, for example, specifies anywhere from 25,000 to 100,000 lumens per acre. Implementing these limits will reduce sky glow by another 25 percent in typical communities.

Spectrum. When you take a nighttime flight, you can see the yellowish pinpoints of city lights going by below. Putting aside the point that if you're seeing them at 36,000 feet, they're not doing what they're supposed to be doing, the color, or spectral content, of the light is critical to light pollution impacts.

The yellow color arises from high-pressure sodium (HPS), the predominant technology for outdoor lighting. It's not a terrible dark-sky light, but it's not ideal, either, with broad emission redward of about 550 nanometers and some blue features mixed in. A much better solution is low-pressure sodium (LPS), considered the "gold standard" for dark-sky protection, with nearly monochromatic emission at 590nm, giving rise to its characteristic amber color. Flagstaff has long used LPS for roadway and general area lighting, such as parking lots.

Over the next five to 10 years, many or most of these lights are expected to be replaced with LEDs — and indeed already have been in many cities and towns.

Sky glow factors



The amount of sky glow reduction one sees results from three factors: reasonable limits to the amount of light, good shielding, and amber light sources. FLAGSTAFF DARK SKIES COALITION

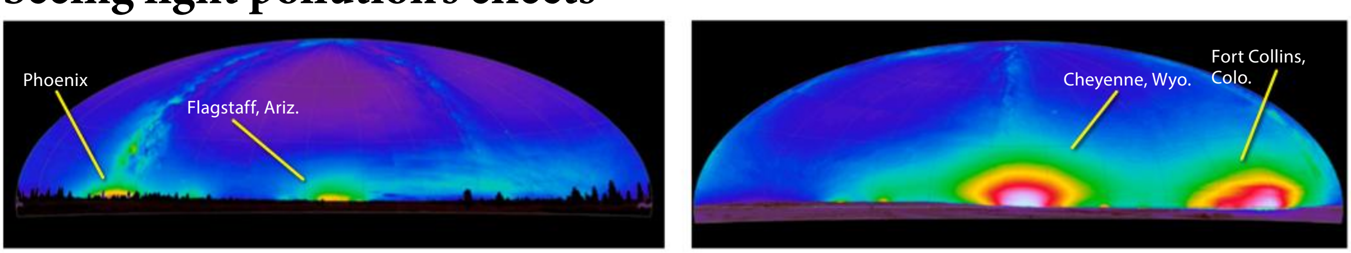
Improved energy efficiency is often touted as a principal reason for this change, but likely an even greater influence is the potential for dramatically reduced maintenance costs, as LED lights have expected lifetimes much greater than lamp-based technologies. But the spectral characteristics of most LED lighting create dramatic increases in sky glow, and any community considering an LED retrofit should consider the many alternative options available.

Sky glow impacts

The worst spectrum choice for sky glow impacts, unfortunately, is the one most often adopted: white LED. LEDs emit light across the entire visible spectrum — that's why they appear white — with dramatically greater emission in the blue and green portions of the spectrum compared with yellow light sources like HPS. Though white lights certainly provide more accurate color perception compared with HPS (and especially LPS), it is at a cost of two to four times more sky glow than HPS (and 3.5 to eight times more than LPS). Often suggested to arise from increased scattering in the atmosphere, the effect actually arises primarily because the night-adjusted eye, the eye that looks at night skies, is most sensitive to blue and green.

White lights, particularly the "cool white" varieties characterized by high "color temperatures" of 4,000 to 6,000 kelvins with their harsh, bluish-white glare, are ruinous to visual appreciation of the night sky. Some communities are taking notice of how unpleasant the worst of these

Seeing light pollution's effects



Sky brightness measurements show how startlingly dark Flagstaff is compared with a similar city at a similar distance. The all-sky map at left shows sky glow from Flagstaff (near center) measured from a distance of 17 miles (27 kilometers). Flagstaff's population is 70,320. Sky glow from Phoenix, far more distant, appears at left. The right-hand map shows sky glow from Cheyenne, Wyoming, from a distance of 19 miles (31km). This city has a similar population — 63,335. The sky glow at right in this map is from Fort Collins, Colorado. Lighting ordinances can really work! U.S. NATIONAL PARK SERVICE

The setting Big Dipper looms just over the horizon from the site of the Flagstaff Star Party, just 2 miles (3km) from the city center. Star-filled skies would shine over much more of the United States if effective lighting ordinances required better lighting. FLAGSTAFF DARK SKIES COALITION

THE INSPIRATION OF STAR-FILLED SKIES CAN RETURN TO MILLIONS OF OUR BACKYARDS IF WE MANAGE OUTDOOR LIGHTING SENSIBLY.

lights are, and implementing "warmer" (that is, lower color temperature) solutions. Tucson, Arizona, for example, has installed 3,000 K LEDs, and Phoenix, the sixth-largest city in the United States, is installing 2,700 K LEDs.

All white sources however, even at 2,700 K, have substantial blue and green emission not present in HPS or LPS. Filtered LEDs exist that remove all light blueward of 500nm, but they still emit substantial green and have notably greater sky glow impacts than yellow sources. Phosphor-converted amber (PCA) LEDs closely resemble HPS, and narrow-band amber (NBA) LEDs take one more step toward a truly dark sky-friendly LED solution, creating a reasonable approximation to LPS.

For its own LED streetlight solution, Flagstaff is considering options favoring NBA LEDs for most roadway lighting. A practical disadvantage to any of these yellow LED solutions is their lower energy efficiency relative to white LEDs, but technology steadily improves and, year by year, these options are becoming more viable.

Combined, these practices can dramatically reduce sky glow. With conservative estimates of the reductions likely from each of these three critical aspects, sky glow in many communities can be reduced by 90 percent! In a town of 70,000, a night sky populated with a paltry 500 stars can be amped to one with 2,000, 3,000, or more.

Your mileage may vary

Astronomy readers hail from all over the world, and your community may well not have two major observatories right at the city limits. The narrow-band emission of LPS or NBA LEDs is vital to maximum dark-sky preservation for 4-meter telescopes, but as described above, many other options exist, both in the type of lighting as well as where and how much of it is applied, to greatly reduce sky glow for both telescopes and human observers.

We encourage all readers to look at Flagstaff, and at other communities that have adopted dark-sky practices (especially those with IDA dark-sky community or dark-sky place status), and to think about — and work to implement — the optimal solution for your area. This discussion shows the range of options available, and how much could be gained. Flagstaff shows that all the solutions are within reach if the community sets its priorities to achieve the best for dark skies.

It can be done

Let's look at what happens when all three legs of the stool are applied.

During one September evening at the Flagstaff Star Party, we overheard a pair of visitors from Phoenix who had journeyed to Flagstaff for an evening of telescope viewing. It was the first night of the star party, and the locals were disappointed with some scattered clouds, given that September is usually reliably clear. With the clouds reflecting such light as Flagstaff does emit, the sky was looking as bright and unappealing as it ever does to Flagstaff natives. "Wow," remarked one of the visitors. "It really is dark here!"

With relatively simple measures, we can all ensure statements like that become more common. Nights when the Milky Way is so bright it looks three-dimensional, when vast numbers of faint stars peek out of the darkness alongside the bright ones, and when the light from the Andromeda Galaxy reaches our eyes after its 2½ million-year journey are moments of inspiration and deep connection to the cosmos for all of us, not just astronomers. Let's make sure we hold on to those moments — for ourselves, and for those who will follow us — and that there is darkness in the light. For more information on the Flagstaff Star Party, visit Flagstaffstarparty.org.

The myriad stars still come to Flagstaff, Arizona. Let's see them everywhere.

Christian Luginbuhl, *a retired astronomer who spent many years at the U.S. Naval Observatory in Flagstaff, is a dark night sky activist.* **Jeffrey Hall** *is director of Lowell Observatory in Flagstaff.*

As twilight nears its end with a young Moon hanging overhead, an observatory readies at America's Darkest Sky Star Party near Animas, New Mexico, April 29.

FUN AT AMERICA'S

Several dozen people gathered in a small town under a clear, steady sky — all for the love of astronomy. **by Michael E. Bakich; images by David J. Eicher**

O

ON SATURDAY, APRIL 29, 2017, the inaugural "America's Darkest Sky Star Party" was held in Lordsburg and Animas, New Mexico. The event's host was Dark Sky New Mexico (DSNM), an astronomy community in Hidalgo County, 35 miles (56 kilometers) from Lordsburg, the county seat.

While planning the star party, the owners of DSNM — Larry Rosenberg, Steven Blum, and Michael Hensley — asked *Astronomy*'s editor, David J. Eicher, and me to speak at the event.

A wonderful spot

DSNM's location is ideal for observing and astroimaging. It sits 4,600 feet (1,400 meters) above sea level and boasts more than 300 clear days (and nights, of course!) each year. Meteorologists classify the region as semiarid, and the site receives an average of only 14 inches (36 centimeters) of rain per year, mostly during the southwestern monsoon season. (In recent years, however, precipitation has been far below normal.)

Both the sky clarity and the steadiness of the air are superb. Several well-known amateur astronomers, including a few longtime image contributors to *Astronomy*, have set up observatories there.

In addition, individuals and groups from as far away as South Korea have facilities on site. Owners operate most observatories remotely, collecting data or capturing images each clear night. DSNM

1. ***Astronomy*** **Editor David J. Eicher lies down to shoot straight skyward from the observatory as several amateur astronomers capture an image, creating this dramatic perspective with stars in the background.**

2. Amateur astronomer Al Acker controls his telescopes from a computer screen as they image distant galaxies during the star party.

3. Orion sets in twilight with a bright Moon lingering above it (out of view) in the star party's first couple of hours.

DARKEST SKY STAR PARTY

provides round-the-clock support and security. Staff can handle mechanical problems (such as repairs to telescope mounts), computer maintenance, and IT support of the fiber-optic internet. And if you see a dark sky in your future, DSNM has additional observatories available for immediate occupancy.

On our way

On Friday, April 28, Dave and I flew from Milwaukee to Denver and then on to Tucson, Arizona. After securing our rental car, we headed eastward from Tucson to Lordsburg along Interstate 10.

During the two-hour drive, conditions for observing could not have been worse: Thick clouds covered the sky from horizon to horizon, wind advisory signs appeared all along our route, sporadic rain pelted our vehicle, and a colossal wall of dust seemed to threaten all of existence south of the highway. More than once, we commented on how awful it would be if the weather didn't change.

Star party day

As Saturday dawned, I looked out my hotel room to see abundant sunshine and a partly cloudy sky. The clouds, however, were fair-weather cumulus, a type that generally appears during the daytime but dissipates as evening (with its cooler temperatures) begins. "It's gonna be clear!" I thought. But a quick look at the few trees planted around the parking lot brought another fear: The wind was still strong.

4. Eicher contemplates the cosmos as he delivers a talk based on his book *The New Cosmos* during the party's daytime hours.

5. *Astronomy* Senior Editor Michael E. Bakich tells star party attendees the details of the coming total solar eclipse that will wash across the United States in August.

6. Owners prepare large telescopes for observing prior to the end of astronomical twilight.

7. The new owners of Dark Sky New Mexico (from left), Michael Hensley, Larry Rosenberg, and Steven Blum, welcomed several dozen enthusiastic backyard astronomers to their first gathering.

8. As the Moon sets, Bakich casts a flashlight skyward, pointing out the constellation Leo.

As amateur astronomers know, high winds tend to ruin the seeing, the measure of atmospheric steadiness necessary for observers to discern small details in celestial objects. And wind is doubly troubling in the desert Southwest because it kicks up profuse amounts of dust. Too much dust over prolonged periods will coat optics, but the more immediate concern is its insidious penetration of the mechanical parts of telescopes — focusers, mounts, and drives. Oh well, nothing to do but wait and see what the next 12 hours would bring.

Chatting up astronomy

Of course, a lot happened in that half-day between breakfast and evening twilight. After a lunch whose quality far surpassed other star parties I'd attended, Dave and I each gave two talks. His first one was "The New Cosmos: Great Discoveries of the Past Decade," an up-to-date look at the state of astronomy. People asked lots of thoughtful questions, and I think Dave could have gone another hour if time had allowed.

After a short break, I was up next, and presented "The Great American Eclipse of 2017," my main focus during the past three years. My goal during that talk was to light a fire under anyone with an interest in astronomy who was thinking of skipping the eclipse.

A longer break followed, then Dave wowed everyone with "25 Exotic Targets for Deep-Sky Observers." Examples included the weird galaxies NGC 520, Centaurus A, and Maffei 1, and odd nebulae like the Witch Head Nebula and Hubble's Variable Nebula. His knowledge of objects outside the boundaries of our solar system is impressive indeed. Finally, I gave an overview of the objects that would be up when night fell with "What We'll See Tonight."

Nightfall

After my second talk, we adjourned for a two-hour break. Our caravan then gathered in the hotel lobby and drove from Lordsburg to the DSNM site in Animas. The half-hour drive was quite scenic. Plus, the percentage of cloud cover continued to diminish with each passing mile.

Upon arrival, we were all welcomed into the DSNM Ranch House for a chuck wagon-style dinner. There was plenty of food for everyone, including a chips-and-salsa appetizer, a wide variety of side dishes, and even sweets for dessert.

Roughly every two minutes, the door would open, and someone would venture out to take a quick look at the sky and assess the wind. "Sky's clear; wind's still up," was the report heard the most. As the Sun set, however, and the energy to drive the gusts continued to sink below the horizon, the wind began to decrease.

Several people came out and watched Earth's shadow climb above the eastern horizon, with the pink Belt of Venus above it. I shared that, especially during the past three years as we wait for the August 21 eclipse, I've been referring to this darkening as "the eclipsed sky."

Both the three-day-old crescent Moon and Jupiter were brilliant in the sky. Fortunately, the Moon was low enough in the west (and continuing to sink) that its light didn't detract all that much from the stars that were starting to appear. Also, the appearance of earthshine, the so-called "Old Moon in the New Moon's arms," was a nice point of conversation.

Three astroimagers who had observatories at DSNM kindly provided guided tours of their facilities. Wow! These were impressive structures indeed. All had remote control ability and contained multiple telescopes. When one of the owners talked about his recently purchased 20-inch telescope that should be arriving soon, my knees went weak. If I had that large a scope in such a pristine location, I literally would disappear for weeks at a time.

Back under the stars, several of us observed some meteors, including a nice yellow-white one of magnitude –2 that appeared a third of the way up in the northwest, creating a 30°-long trail and a breakup at its termination point. The date of the star party placed us between two meteor showers: the past Lyrids (which peaked April 22) and the upcoming Eta Aquariids (which would peak May 5).

Everyone commented on how spectacular the sky appeared. Indeed, I noticed that easily visible stars were nearly touching the mountain range toward the south. Those peaks lay in Mexico, some 40 miles (64km) away. And as the night progressed, the seeing improved steadily. That's because, by about an hour after sunset, there was no longer any wind blowing at all.

See you in October?

The first incarnation of any star party is always a test case. And even as successful as this one was, the organizers have planned an expanded agenda for the next star party to make it even better.

It includes adding a second night. This would make flying in or driving for several hours or longer more worthwhile. The talks will be shorter, but there will be more of them. At star parties, people want to be exposed to as many aspects of their chosen hobby as possible. And because not all attendees are avid amateurs, several of the talks next time will cover topics of particular interest to beginners.

The second DSNM Star Party also has a firm date. It will begin Friday, October 13, and continue through Saturday the 14th.

The organizers are excited that the Albuquerque Astronomical Society will co-host the event. The club is quite active in the region and boasts a membership of more than 300. Their participation will ensure lots of expertise for the talks and our time under the sky, and plenty of different types and sizes of telescopes to view through and talk about.

The stars of Orion and a bright Moon glow through the metallic superstructure of Pluto discoverer Clyde Tombaugh's 16-inch scope at the star party.

IT'S EASY TO GET TO THE DARKEST SKY STAR PARTY

Dark Sky New Mexico will hold a second star party in Animas October 13–14, 2017. Although it's true that getting to a very dark sky is a little out of the way for many, Animas is conveniently located near a number of cities.

Animas lies near the southwestern edge of New Mexico, not far from several major cities including Tucson, Arizona; Phoenix; El Paso, Texas; and Albuquerque, New Mexico. The site lies 162 miles from Tucson, 277 miles from Phoenix, 155 miles from El Paso, and 317 miles from Albuquerque. A drive of two and a half to four and a half hours is a relatively small price to pay for spectacularly dark skies.

ASTRONOMY: ROEN KELLY

In the age when light pollution is increasingly wiping out the night sky for millions, the astronomy enthusiast community really needs a dark sky sanctuary where we can occasionally go to soak in a breathtakingly dark view of the heavens. This is it. — *David J. Eicher*

Michael E. Bakich *is a senior editor of* Astronomy *and an experienced observer of the night sky.*

For more information, head to the DSNM website at DarkSkyNewMexico.com.

OBSERVING**BASICS**

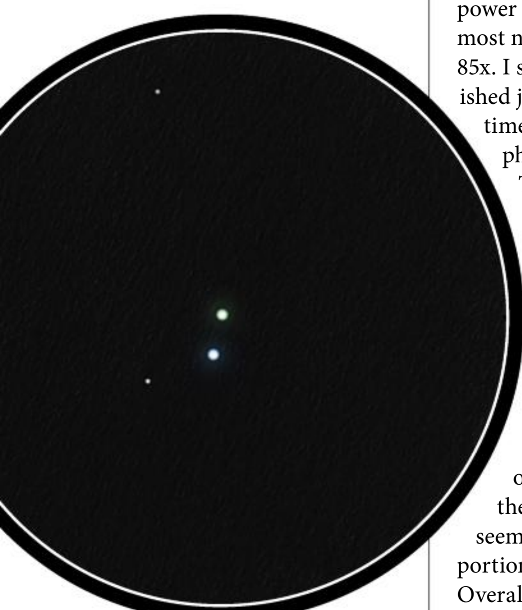
BY GLENN CHAPLE

The final four

This quartet of autumn binaries puts the finishing touches on the double star marathon.

I wish I could say that the double star marathon, introduced in this column in March 2016, has taken the astronomical community by storm. But the truth is, only a handful of backyard astronomers have tackled and completed this alternative to the Messier marathon. On the positive side, their successes prove that the marathon is doable.

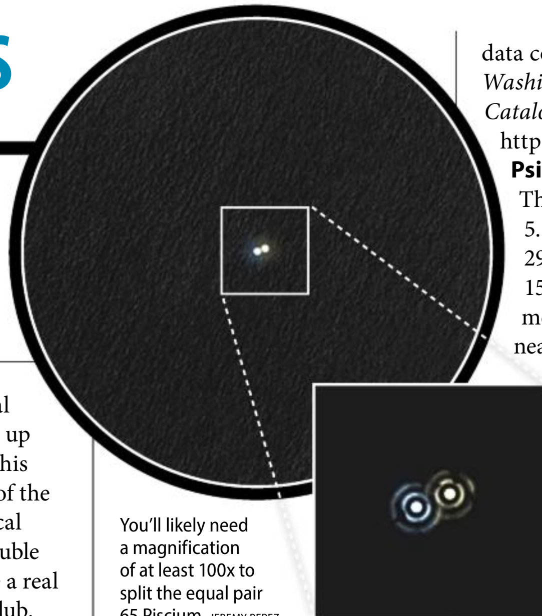
As I mentioned in a follow-up column this past March, Ben Rubel of Framingham, Massachusetts, was the first person to complete the entire double star marathon in a single night — quite an accomplishment for a 16-year-old! And Jerry Oltion of Eugene, Oregon, captured 96 of the 110 doubles over two consecutive nights. Inclement weather prevented Rubel and Oltion from repeating their performances in 2017.



The near-twin stars of Psi^1 (ψ^1) Piscium reside in the northern fish of Pisces. JEREMY PEREZ

But members of several astronomy clubs did take up the marathon challenge this past spring. Dee Friesen of the Albuquerque Astronomical Society emailed, "The double star idea turned out to be a real hit with our astronomy club. We had three days set aside for the marathon. On the night that I was the observatory opener, I did manage to get 69 doubles. On the other two nights several other observers got all of the stars. The concept was well received, and I am sure we will do it again next year."

Fellow club member Jim K (the tag he uses in his astronomical communications) responded: "I was able to complete the marathon at my local club's observing area near Belen, New Mexico. Some pairs were found/split at low power (about 17x) and some at high power (about 140x to 185x), but most needed only about 40x to 85x. I started at 8 P.M. and finished just after 5 A.M. local time [MDT]. This was a physically hard marathon. The wide range of separations and comparative brightnesses required me to swap eyepieces for every object, often several times, in order to view the separation. The early portion of the marathon felt rushed in trying to view objects before they set; the mid-part (after Orion) seemed relaxed, and the last portion was again frantic. Overall, it was fun, especially when I completed my last object of the 110 — Epsilon (ε) Pegasi (Enif)."



You'll likely need a magnification of at least 100x to split the equal pair 65 Piscium. JEREMY PEREZ

If you haven't tried the double star marathon yet and don't have the list, email me for a copy. Better yet, contact California double star enthusiast Phil Kane (icycomet1944@gmail.com), who made two Excel files of the list: One includes SAO numbers for users of go-to scopes and the other updates the data on my list. (Double stars have a nasty habit of changing separation and position angle in a short amount of time.)

Poring through a star atlas to find the page that pinpoints each double star can use up a lot of precious time. Jim K (jim-k@usa.com) took care of that ahead of time by noting the page number for each double in several popular star atlases, including the *Pocket Star Atlas*, *The Cambridge Double Star Atlas*, and the *Interstellarum Deep Sky Atlas*. He offers five files: a PDF for the list in number order, a PDF in constellation order, PDFs of these two files in landscape orientation with larger text, and an Excel spreadsheet.

Hidden pairs

I omitted some pairs from the marathon because they are essentially lost in sunlight during early spring. Here's a rundown on four of the best that I likely would have included if they were more visible. The data come from the *Washington Double Star Catalog*, which is accessible at http://ad.usno.navy.mil/wds.

Psi^1 (ψ^1) Piscium

These magnitude 5.3 and 5.5 stars are separated by 29.8" at a position angle of 159°. Phil Kane recommends adding this striking near-twin pair to my original list. Jim K suggests keeping my list as is, however, noting that omitting Psi^1 allows a wider observing window for the marathon. I'll be looking for this pair next spring and, depending on its observability, may ultimately decide to place it on the list, though I would hate to scratch one of my original 110.

Zeta (ζ) Piscium

These magnitude 5.2 and 6.3 stars are separated by 22.9" at a position angle of 63°. Visual observers disagree on the colors of these stars, which have spectral classes of A7 and F7. What colors do you see?

65 Piscium

These stars, both at magnitude 6.3, are separated by 4.3" at a position angle of 116°. This system of twin F-type stars shows up best at magnifications of 100x or more.

94 Aquarii

These magnitude 5.3 and 7.0 stars are separated by 12.3" at a position angle of 353°. The primary is a golden yellow star of spectral class G8.5. The K2 secondary should share this hue, but the color isn't as rich because it is just 20 percent as bright.

Be sure to include these stellar binaries in your observing plans this autumn.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: an asteroid double-header. Clear skies!

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

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

ASTRO**SKETCHING**

BY ERIKA RIX

Sketching totality

Don't let the brief span of totality deter you.

The wait for the Great American Eclipse is nearly over. Depending on your observing location within its path, totality on August 21 will last up to 2 minutes, 40 seconds — so make each second count! Have a solid plan for the type of instrument you'll use during the observation, as well as the sketch media and technique to render it with.

Your drawing kit should be minimal and consist of familiar materials. I recommend watching videos of past solar eclipses so that you can practice your technique. It will help give you a sense of the timing required to sketch live on eclipse day.

I prefer a white pencil with black paper for sketching the filamentary structure of the corona against the dark background of the sky. But if you're more comfortable with graphite, you can draw a negative sketch onto white paper and then later scan and invert it with image-editing software. Green is the opposite of red, so if you use white paper, a green pencil will do the trick for prominences.

Prepare the paper ahead of time by creating 2- to 4-inch circle templates. You can fit several on a single page if you wish to sketch the partial phases. But during totality, remember that you'll need extra room to draw the outermost layer of the Sun's atmosphere.

During the partial phases, you must fit the front end of your telescope with a proper solar filter to prevent eye damage (or even blindness). With each sketch as the Moon advances in front of the Sun, draw the curvature of its limb within the circle template first, and then note the time and orientation before adding any solar features you observe. These might include sunspots if you're using a white-light filter or prominences if you're viewing through a Hydrogen-alpha filter.

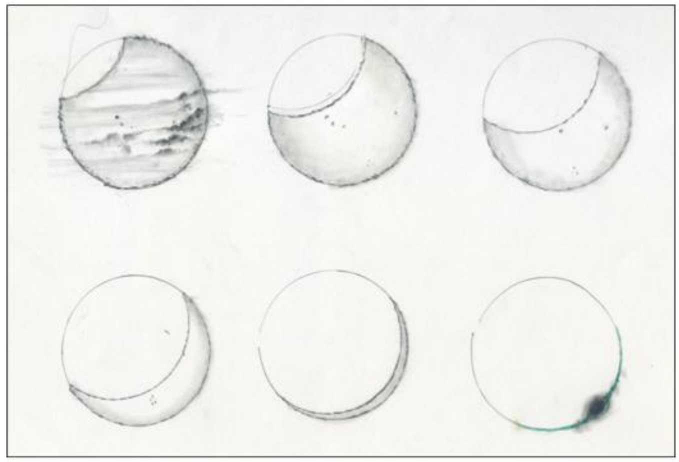
Moments before totality, focus your attention on the bright points of light known as Baily's beads, the last of which will produce the well-known diamond ring. Draw the beads quickly, but wait to soften their glow with a blending stump until after the eclipse has ended.

Once the Sun is entirely hidden from view, you can safely remove the solar filter. Try to memorize every aspect of the corona's feathery extensions during those few precious moments so that you can later visualize them on paper. Reattach the filter before totality ends, and then begin your sketch.

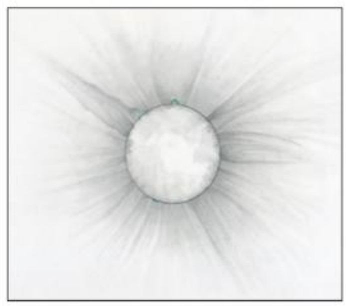
You'll need to use light pencil pressure to render the ethereal appearance of the Sun's corona. I suggest drawing the most distinguishable streamers first by recalling their shapes, lengths, and positions around the disk. Start near the edge of the circle and ease the pencil pressure as you work your way near the diffuse tips of each extension. To render the faint glow surrounding them, hold your pencil near the end with the side of its tip lightly resting on the paper. Soften the markings with a clean blending stump to complete your sketch.

Above all, try to relax and enjoy every moment. I'll be wishing you success! 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).*



The total solar eclipse of November 13, 2012, provided the chance to sketch this sequence of the partial phases leading to totality. The artist used a white-light filter and 2-inch circle templates. He observed the eclipse with his astronomy club, Magnitude 78, on the path's central line north of Cairns, Australia. The club chose that site based on meteorological statistics to maximize their chances of success. ALL IMAGES: SERGE VIEILLARD



Seconds after totality, while the filamentary details were still fresh in his memory, the artist completed this sketch. He used a 3.2-inch refractor without a solar filter during the first 90 seconds of totality, followed by 15 seconds of observing through a non-filtered 16-inch reflector and a 22mm eyepiece. The larger scope helped him capture the structure within the inner corona. He used HG graphite pencils, a green colored pencil, and white paper with a 4-inch circle template.

Image-editing software allowed the artist to invert, colorize, and combine his scanned drawings into a captivating montage of the event.

BINOCULARUNIVERSE

BY PHIL HARRINGTON

Rogue globular clusters

Check out these two overlooked star groups.

M55 is a large, loose globular cluster in Sagittarius that can be spied in binoculars on a dark night. DANIEL VERSCHATSE

Before summer slips away entirely, let's hunt down a pair of Sagittarian globular clusters that lie off the beaten path. While western Sagittarius commands our attention thanks to the gentle glow of our Milky Way billowing out of the Teapot's spout like steam, the constellation's eastern half often passes unnoticed.

Eastern Sagittarius is highlighted by a distinctive asterism that's easy to spot through binoculars. Begin at the top of the Teapot, and then shift about 10° northeast. There, you'll find a slender triangle created by the stars Pi (π), Omicron (ο), and Xi (ξ) Sagittarii. All shine between 3rd and 4th magnitude.

Examine the triangle with your binoculars, and you'll see that its western corner star is actually two. Both carry the "Xi" designation. Xi^1 and Xi^2 are separated by half a degree, making them easy to resolve through even the smallest pocket binoculars. Can you also see any subtle color difference in them? Xi^1 is a 5th-magnitude blue-white supergiant, while 4th-magnitude Xi^2 is an orange giant. Although they form a pretty pair, in reality they are nowhere near each other in space. Xi^1 is at least 2,300 light-years from Earth, while Xi^2 is much closer at 372 light-years away.

By adding two more stars, Rho^1 (ρ^1) and 43 Sagittarii, found northeast of the triangle, we can draw an asterism that many call the Teaspoon. The Teaspoon measures 6.5° tip to tip, and so should just fit into a typical 10x50 field of view.

We can use the Teaspoon to help find a pair of globular clusters that are often missed due to their sparse surroundings. To begin, extend the bottom of the Teaspoon from Xi^2 through Omicron Sagittarii and on toward the southeast. About a field of view away, you'll pass Chi^1 (χ^1) and Chi^2 (χ^2) Sagittarii, a wide pair of stars. Keep going. Half a field later, you'll pass 51 and 52 Sagittarii, another easy stellar duet. A field farther still, you'll arrive at a four-star asterism that looks like a kite. The stars in the kite — Omega (ω), 59, 60, and 62 Sagittarii — all shine around 5th magnitude.

KEN SIARKIEWICZ/ADAM BLOCK/NOAO/AURA/NSF

The relatively dim globular cluster M75 can be challenging to spot in binoculars.

The kite is exactly halfway between our two globulars. Extend the kite's crossbeam to the southwest for 5°, and you'll come to **M55**. This is one of those deceiving objects that, on paper, sounds like it should be an easy catch, but in reality often proves to be anything but. M55 is rated at 7th magnitude and measures 19' across. Those numbers, however, do not take into account that, unlike most other globular clusters with bright central cores, M55 is spread out more evenly. As a result, its surface brightness (its brightness per unit area) is deceptively low. With most binoculars, it looks like a dim ball of light just above the background sky glow. If you have trouble seeing it, support your binoculars steadily using a tripod or some other method.

Once you spot M55, and if you have sharp eyes, you just might make out a dim point of light slightly off-centered in M55. That lone star, shining at about 9th magnitude, is most likely a foreground object and not actually a member of the cluster.

To find our second globular, head back to the kite and extend the crossbeam in the opposite direction for about 5° to the northeast. That's where you'll find **M75**. M75 also poses a challenge through binoculars, but for a different reason. M75 is just plain dim at magnitude 8.6. Between that and its small apparent size, M75 will need a clear, dark sky to be seen. Visually, it looks perfectly round and is accented by a brighter nucleus.

Once you find both M55 and M75, skip back and forth to compare one against the other. There is quite a difference in appearance. Part of that is due to their distances. M55 is 17,600 light-years from Earth, while M75 is about 67,500 light-years away. But it's also partly due to their density. Globulars are rated on a I-to-XII concentration scale. According to this system, M75 is a Class I globular, notable as the most densely packed of the 29 globulars in the Messier catalog. By comparison, loosely packed M55 is rated Class XI. That makes it the weakest globular in Messier's catalog, save for M71. One reason for M55's loose structure is that it never gets farther than 20,000 light-years from the core of the Milky Way, and sometimes it gets as close as 5,000 light-years. These close passages likely cause it to shed stars over time, weakening its concentration in the process.

Do you have a favorite binocular target that you would like me to feature in a future column? Please send your suggestions to me via my website, philharrington.net.

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

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

NEW PRODUCTS

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

Binoculars

Nikon USA
Melville, New York

Nikon's 16033 7x50 IF WX Binoculars employ extra-low dispersion glass, Abbe-Koenig prisms, and a field flattener lens system. Each optical surface receives a multilayer coating. The company includes a tripod adapter and hard case.

$5,999.95
800.645.6687
www.nikonusa.com

HD video camera

MallinCam
Ottawa, Canada

MallinCam's HD-10 is a high-definition camera for astronomers. The HD-10, which has an HDMI output, can be used as a standalone unit: It has a computer, memory, and processor built in. Its 2.1-megapixel Sony CMOS sensor can take exposures from 1 millisecond to 10 seconds, and it has 63 levels of gain adjustment.

$899.99
613.749.7592
www.mallincam.net

Star diagonal

Orion Telescopes & Binoculars
Watsonville, California

Orion's 1.25" Twist-Tight Dielectric Mirror Star Diagonal features a twist-tight clamping mechanism that securely grasps inserted 1¼" eyepieces and accessories with a simple clockwise twist. The coated mirror provides 99 percent reflectivity. Orion threaded the nosepiece barrel to accept filters.

$119.99
800.447.1001
www.telescope.com

Monopod

Orion Telescopes & Binoculars
Watsonville, California

Orion's Tritech II-M Stabilized Monopod with Pan Head has a four-section staff that extends from 22.5 inches (57 centimeters) to 57.5 inches (146cm) and features quick-lock clamps and a foam grip. The monopod weighs 2.2 pounds (1 kilogram) and comes with a zippered case with adjustable shoulder strap.

$39.99
800.447.1001
www.telescope.com

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

2017 Astro Sweepstakes • OFFICIAL RULES

NO PURCHASE NECESSARY TO ENTER OR CLAIM PRIZE.
A PURCHASE WILL NOT INCREASE YOUR CHANCE OF WINNING.
VOID WHERE PROHIBITED.

1. **Eligibility.** The 2017 Astro Sweepstakes (the "Sweepstakes") is open to residents of the United States and Canada (except Rhode Island and Quebec) only, who are age 18 years or older and have reached the age of majority in their state/province of residency at the time of entry. Employees (and their dependents and immediate household members) of Kalmbach Publishing Co., ("Sponsor"), and of Celestron Telescopes, their advertising and promotional agencies and sponsoring companies are not eligible to participate. Void in Rhode Island, Quebec and where prohibited by law. Sweepstakes is subject to all applicable federal, state and local laws.

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

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

4. **Prizes/Approximate Retail Value ("ARV") in U.S. Dollars. One (1) Grand Prize** consisting of a Nexstar Evolution 6 Wi-Fi Telescope (ARV: $1,299.00). **One (1) First Prize** consisting of an Astro Fi 90mm Refractor Telescope (ARV: $399.95). **One (1) Second Prize** consisting of an Inspire 70AZ Refractor Telescope (ARV: $179.95). **One (1) Third Prize** consisting of Cometron 12x70 Binoculars (ARV: $89.95). **Five (5) Fourth Prizes** consisting of a one-year subscription to *Astronomy* magazine (ARV: $42.95 each). Total ARV of all prizes: $2,183.60.

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

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

7. **Validation and Acceptance.** Winner(s) in the Sweepstakes will be selected in a random drawing. The potential winner(s) may be required to sign and return an Affidavit of Eligibility, publicity release, and Release of Liability within fourteen (14) days of notification. If a potential winner cannot be contacted within a reasonable time period, if the potential winner in ineligible, if any notification is undeliverable, or if the potential winner otherwise fails to fully comply with these Official Rules, he/she will forfeit that Prize, and if time permits, an alternate winner will be randomly drawn from among all remaining Sweepstakes entries. Canadian prize winners subject to skill test requirement.

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

9. **Limitations of Liability.** Sponsor and Celestron Telescopes are not responsible for and shall not be liable for: (i) telephone, electronic, hardware or software program, network, Internet, or computer malfunctions, failures, or difficulties of any kind; (ii) failed, incomplete, garbled, or delayed computer transmissions; (iii) any condition caused by events beyond the control of Sponsor that may cause the Sweepstakes to be disrupted or corrupted; (iv) any injuries, losses, or damages of any kind arising in connection with or as a result of the prize, or acceptance, possession, or use/misuse of the prize, or from participation in the Sweepstakes; (v) any printing or typographical errors in any materials associated with the Sweepstakes; (vi) any change in participant's telephone number, mailing address or email address. Sponsor reserves the right, in its sole discretion, to suspend or cancel the Sweepstakes at any time if a computer virus, bug tampering, unauthorized intervention, or other technical problem of any sort corrupts the administration, security, or proper play of the Sweepstakes. Sponsor also reserves the right to disqualify, in its sole discretion, any person tampering with the entry process, the operation of the website, or who is otherwise in violation of the rules. By participating in the Sweepstakes, each participant agrees to release and hold Sponsor, Celestron Telescopes, their employees, officers, and directors, their advertising and promotional agencies, and sponsoring companies harmless from any and all losses, damages, rights, claims and actions of any kind in connection with the Sweepstakes or resulting from acceptance, possession, or use/misuse of any prize, including without limitation, personal injury, death, and property damage, and claims based on publicity rights, defamation, or invasion of privacy.

10. **Additional terms.** By entering the Sweepstakes, participants agree to be bound by these official rules and all decisions of Sponsor. Except where prohibited, each entrant agrees that: (1) any and all disputes, claims and causes of action arising out of or connected with this Sweepstakes shall be resolved individually, without resort to any form of class action, and exclusively by state or federal courts situated in Wisconsin, (2) any and all claims, judgments and awards shall be limited to actual out-of-pocket costs incurred, but in no event attorneys' fees, (3) no punitive, incidental, special, consequential or other damages, including, without limitation, lost profits, may be awarded (collectively, "special damages"), and (4) entrant hereby waives all rights to claim special damages and all rights to such damages multiplied or increased. Wisconsin law, without reference to choice of law rules, governs the Sweepstakes and all aspects related thereto.

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

INDEX *of* ADVERTISERS

ADM Accessories 71
AP Theory 71
Ash Manufacturing 71
Astro Haven 71
Astro-Physics 15
Astrodon 71
Astronomy Constellation Flash Cards 17
Astronomy Eclipse Products 21
Astronomy magazine 17
Bob Berman Tours 15
Bob's Knobs 71
Celestron 76
Celestron Summer 2017 Sweepstakes Giveaway 9, 70
Daystar Filters 19
Geppetto Electronics 71
iOptron 11
Jewelry Designs for Men 7
Lumicon 7
Media Brokers 5
Morehead State University 3
Norway's Aurora, Culture and Scenic Wonders 2017 69
Oberwerk 71
Obsession Telescopes 71
Optic Wave Laboratories 70
Precise Parts 70
Rainbow Symphony 15
Scope Buggy 71
ScopeStuff 71
Sky Shed 71
SkyWatcher - USA 7
Stellarvue 75
Technical Innovations 71
Tele Vue Optics, Inc 2
Total Solar Eclipse Tours 2017 67
TravelQuest Tours - Coast Rica 65
Woodland Hills Cameras & Telescope 7

The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

ScopeStuff
Telescope Accessories & Hardware
World's largest inventory of telescope accessories, adapters and hardware. **Free shipping in the USA!**
www.scopestuff.com
512-259-9778

REWARD
$25,000.00
The solar system formation theories have all been disproven. The first person to PROVE the Accretion Theory or DISPROVE The AP Theory which logically states that gravity is not holding our atmosphere and describes the formation of water and our solar system wins. Must include an example in nature (on Earth) and a successful experiment.
READ: www.aptheory.info
www.21st-century-astronomyHOME.com
COMMENT: aptheory@aptheory.info
no purchase necessary

FOCUS ON
The Werner Schmidt Observatory
South Yarmouth, MA

The observatory located on the grounds of the Dennis-Yarmouth Regional High School is the only public observatory on Cape Cod. It has generated interest in astronomy. The project was funded by the Cape Cod Astronomical Foundation and built by the Cape Cod Regional Technical High School students. The building was designed to provide people with disabilities access via a CCD camera and monitor screen. It has been a welcome addition to the educational community.

ASH MANUFACTURING COMPANY
P.O. Box 312
Plainfield, IL USA 60544
815.436.9403 • FAX 815.436.1032
web site: www.ashdome.com
email: ashdome@ameritech.net

ASH-DOME is recognized internationally by major astronomical groups, amateurs, universities, colleges secondary & primary schools for their performance durability and dependability. Manual or electrically operated units in sizes from 8 to 30 feet in diameter; sensibly priced. Brochures and specifications available.

1

1. SOUTH OF THE BORDER
The stars of the constellation Crux the Southern Cross glow brightly at the upper left of this image. Its bottommost star, Acrux (Alpha [α] Crucis) lies next to an intensely dark nebula called the Coalsack. On the right, the spectacular Carina Nebula (NGC 3372) glows intensely red.
• Carlos Eduardo Fairbairn

2

2. CAMERA SHY
Most amateurs consider M89 to be just another boring elliptical galaxy, so they don't target it. As this image proves, however, it's anything but that. The photographer captured and combined an incredible 16 hours of exposures. Some of the outer shell seen here is newly discovered.
• Mark Hanson

3

4

5

6

7

3. LOOP DE LOOP
This mind-blowing image shows the retrograde loops of Mars (brighter) and Saturn. The Red Planet's symmetrical S spans 16° while the ringed world's path is only 7° across. The photographer took the first exposure December 15, 2015. He finished the sequence November 21, 2016, when Saturn was nearly lost against the Sun's glare. • ***Tunç Tezel***

4. MIRROR FOR THE SUN
This stack of four exposures (three of the Sun and one after sunset to highlight the landscape) shows our daytime star's light reflected in the Canale Zaniolo, near Voltana, Italy. The photographer waited four minutes between shots. • ***Fabrizio Melandri***

5. OPEN BAR
NGC 1672 in Dorado is a barred spiral galaxy that glows relatively brightly at magnitude 9.7. From the nucleus, which is a starburst region, four filamentary spiral arms extend out from the ends of the central bar.
• ***Warren Keller/Steve Mazlin/ Mark Hanson/Rex Parker/Tommy Tse***

6. 45P SAILS IN THE DARK
Comet 45P/Honda-Mrkos-Pajdusakova travels through the constellation Canes Venatici on February 19, 2017. The photographer captured it, the Whale Galaxy (NGC 4631, right of the comet's head), and the Hockey Stick (NGC 4656, above the comet). The comet's head is green, and its grayish-white dust tail points to the west, or downward in this shot. • ***José J. Chambó***

7. FIT FOR A KING
This wide shot consisting of seven exposures shows the region around IC 1396 in the constellation Cepheus. Dark nebulae made of dust and ultra-cold gas seem to writhe through the reddish emission nebulosity.
• ***Robert Fields***

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

Superstars of the SMC

Dust clouds pervade the Small Magellanic Cloud (SMC), the Milky Way's second-largest satellite galaxy. But this view strips away most of that dust to reveal its myriad stars in unprecedented detail. Astronomers captured the SMC at dust-penetrating infrared wavelengths with the 4.1-meter Visible and Infrared Survey Telescope for Astronomy at Chile's Paranal Observatory. The observations show that most of the SMC's stars formed fairly recently, with the biggest bursts coming 5 billion and 1.5 billion years ago. The SMC lies about 200,000 light-years from Earth, while the Milky Way star cluster 47 Tucanae (at bottom) is only 15,000 light-years away. ESO/VISTA VMC

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

November 2017: Saturn's last hurrah

On each evening in early November, the familiar shape of Scorpius the Scorpion appears to dive toward the western horizon. To its right lies the less-recognizable constellation Ophiuchus the Serpent-bearer. But this month, Ophiuchus bears a bright interloper: the ringed planet **Saturn**. The solar system world shines at magnitude 0.5 just to the right of a short line of stars anchored by 3rd-magnitude Theta (θ) Ophiuchi.

Although Saturn draws closer to the Sun and dips lower in the evening sky with each passing day, it remains a tempting target for observers in early November. A telescope reveals the planet's flattened disk, which measures 15" across the equator, and a glorious ring system that spans 35" and tilts 27° to our line of sight. Also keep an eye out for Saturn's family of moons. Any telescope shows 8th-magnitude Titan, and three 10th-magnitude satellites come into view through 10-centimeter and larger instruments.

Look closer to the horizon and you should be able to pick out **Mercury**. The innermost planet will be hard to spot in the twilight glow in early November, but it gets progressively easier as it pulls away from the Sun. By the time it reaches greatest elongation November 23/24, it lies 22° east of our star and stands 11° high in the west-southwest 45 minutes after sunset. Mercury then shines at magnitude –0.4 and shows up easily in the twilight. A few days later, on the 28th, Mercury slides 3° south (to the upper left) of fainter Saturn.

Mercury is an interesting telescopic object throughout November, particularly later in the month as its disk grows larger and its illuminated hemisphere turns away from Earth. At greatest elongation, the planet appears 6.6" across and 63 percent lit. On the month's final evening, Mercury's disk spans 7.8" and shows a distinct crescent phase, just 40 percent illuminated.

The other bright planets don't fare as well. Although **Mars** gradually pulls away from the Sun during November, it remains fairly low in the east before dawn. By the 30th, it climbs nearly 15° high an hour before sunrise and should appear conspicuous among the background stars of Virgo. Mars then lies 3° north (to the lower left) of the Maiden's brightest star, 1st-magnitude Spica. At magnitude 1.7, the Red Planet shines half as bright as the blue-white star, though the color contrast between the two should be obvious. A telescope won't show any detail on the planet's 4"-diameter disk.

Jupiter returns to the morning sky in the latter half of November. Look for the giant planet well to the lower right of the Mars-Spica pair. By the 30th, Jupiter climbs 10° high a half-hour before sunrise. You shouldn't have any problem identifying it because it shines so brightly, at magnitude –1.7. There's not much point in targeting the planet through your telescope, however — its low altitude means you have to look through thick layers of Earth's turbulent atmosphere and thus won't see much detail.

The brilliance of **Venus** will go unappreciated by observers at mid-southern latitudes. On November 1, the inner planet rises just 40 minutes before the Sun and is essentially lost in the bright glow of twilight. If you live closer to the equator, however, you might want to give the magnitude –3.9 object a shot. If you do, target Venus the morning of the 13th when it passes just 0.3° north of Jupiter.

The starry sky

Late on November evenings, a beautiful string of stars stretches across the sky from Aldebaran in the northeast to the Southern Cross and the pointer stars nearly due south.

In comparison, the sky to the north looks barren, especially about halfway from the horizon to the zenith. The region is not completely devoid of brighter stars, however. One of the most conspicuous is Beta (β) Ceti, also known as Diphda.

Diphda is the brightest star in the constellation Cetus the Whale, though some skywatchers refer to it as a sea monster. Whichever shape you prefer, Diphda marks the beast's tail.

The star's name comes from an ancient Arabic title meaning "second frog," while the "first frog" happens to be Fomalhaut in Piscis Austrinus. Diphda came second because it follows the first frog across the sky as Earth rotates beneath it.

Although the International Astronomical Union formally accepts the name Diphda, it has also long been known as Deneb Kaitos, which means "tail of the whale." However, its full Arabic name described it as the "tail of the whale to the south." To add to the confusion, another star, Iota (ι) Ceti, was also once described as the whale's tail, though its full name meant "tail of the whale to the north." Iota lies 11° north-northwest of Beta.

Diphda is a yellow-orange giant star of spectral type K0. It possesses about three times the mass of the Sun and is in the latter stages of its life. Surprisingly, unlike most such stars, it is a relatively strong X-ray source. Astronomers suspect that the X-rays come from Diphda's superheated corona, which gets warmed by the star's magnetic field.

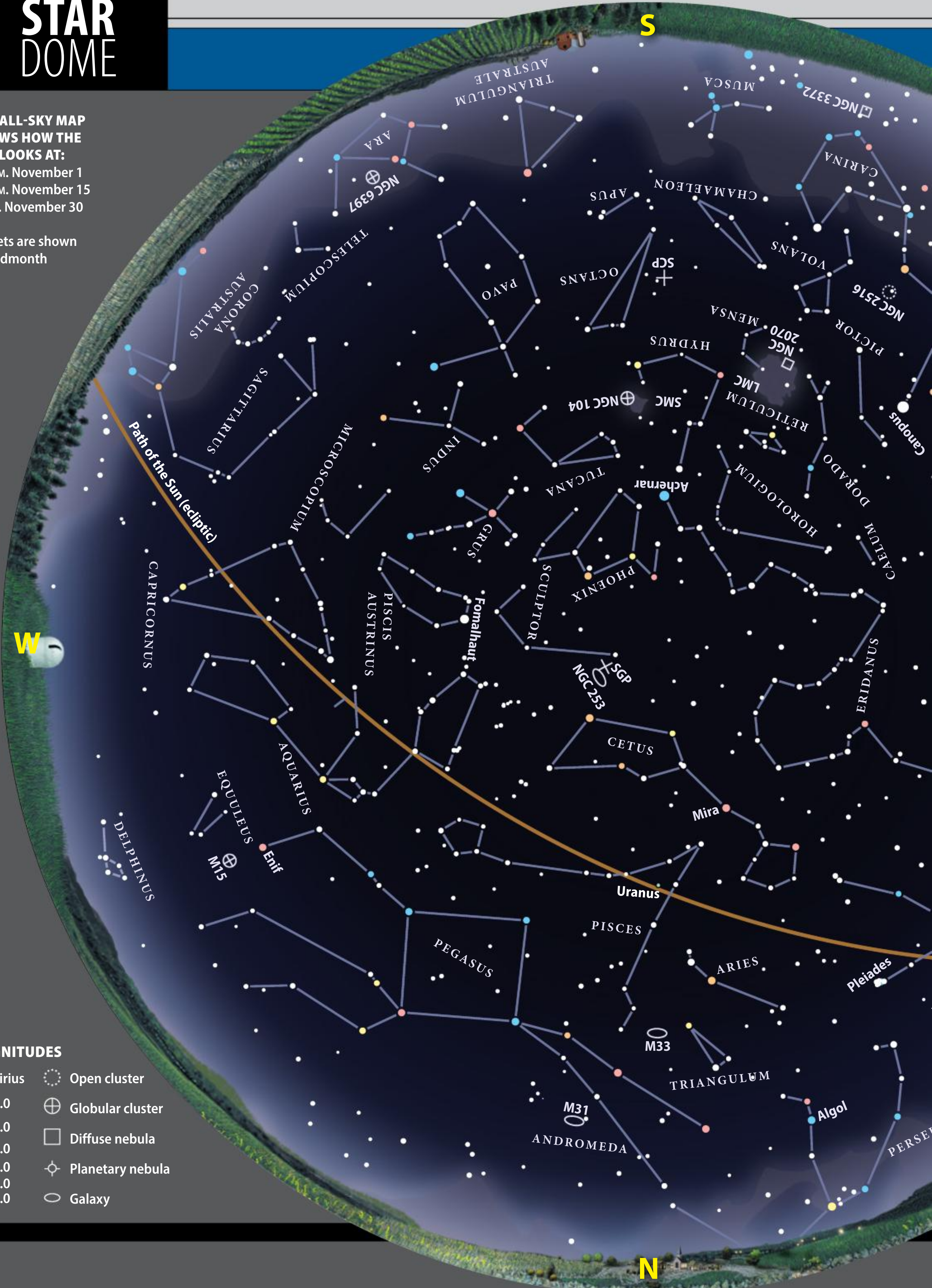
It may seem surprising that magnitude 2.04 Diphda has the Bayer designation of Beta when the constellation's Alpha (α) star, Menkar, comes in significantly fainter at magnitude 2.54. There is some evidence that Diphda brightened noticeably in the 17th century, however. Leading astronomical historian Agnes Clerke documented this brightening in the 1800s, and Jean-Baptiste Biot also noted it in his *Traité d'Astronomie Physique* (*Treatise on Physical Astronomy*).

There have been other reports of temporary brightening as well. Observers in Perth, Western Australia, carefully followed one such episode in 1923. Needless to say, Diphda seems far more intriguing than your typical giant star.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
11 P.M. November 1
10 P.M. November 15
9 P.M. November 30

Planets are shown at midmonth



MAGNITUDES

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

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

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

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

Illustrations by *Astronomy*: Roen Kelly

NOVEMBER 2017

Calendar of events

1 Venus passes 4° north of Spica, 15h UT

3 The Moon passes 4° south of Uranus, 1h UT

Asteroid Nysa is at opposition, 6h UT

4 Full Moon occurs at 5h23m UT

6 The Moon is at perigee (361,438 kilometers from Earth), 0h10m UT

The Moon passes 0.8° north of Aldebaran, 3h UT

10 Last Quarter Moon occurs at 20h36m UT

11 The Moon passes 0.4° north of Regulus, 17h UT

12 Mercury passes 2° north of Antares, 15h UT

13 Venus passes 0.3° north of Jupiter, 6h UT

15 The Moon passes 3° north of Mars, 1h UT

16 The Moon passes 0.4° south of asteroid Vesta, 9h UT

The Moon passes 4° north of Jupiter, 21h UT

17 The Moon passes 4° north of Venus, 6h UT

Leonid meteor shower peaks

18 New Moon occurs at 11h42m UT

20 The Moon passes 7° north of Mercury, 9h UT

21 The Moon passes 3° north of Saturn, 0h UT

The Moon is at apogee (406,132 kilometers from Earth), 18h53m UT

22 Neptune is stationary, 21h UT

24 Mercury is at greatest eastern elongation (22°), 0h UT

26 First Quarter Moon occurs at 17h03m UT

27 The Moon passes 1.2° south of Neptune, 5h UT

28 Mars passes 3° north of Spica, 0h UT

Mercury passes 3° south of Saturn, 9h UT

30 The Moon passes 4° south of Uranus, 10h UT

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