How we will find countless super-Earths p. 44

The world's best-selling astronomy magazine

Astronomy®

JULY 2017

NEW RESEARCH

WATER ON MARS

How a liquid planet became a frigid desert p. 22

19 big eclipse surprises p. 60

PLUS!

How to observe Pluto p. 56

Galaxies that rule our cosmic neighborhood p. 28

Is the Moon House an American Stonehenge? p. 50

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 45 • Issue 7

You and Your Shadow...
Tele Vue-60

Tele Vue-60 Specifications:

Objective:	APO Air-spaced Doublet
Ap/F.L./f-ratio:	60mm/ 360mm/ f/6
Length OTA:	10″
Weight OTA:	3lbs.
Focuser:	1¼″, push-pull/helical fine focus
Max. Visual Field:	4.3° (with 32mm Plössl/24 Panoptic)

Tele Vue-60 OTA shown with optional equipment.

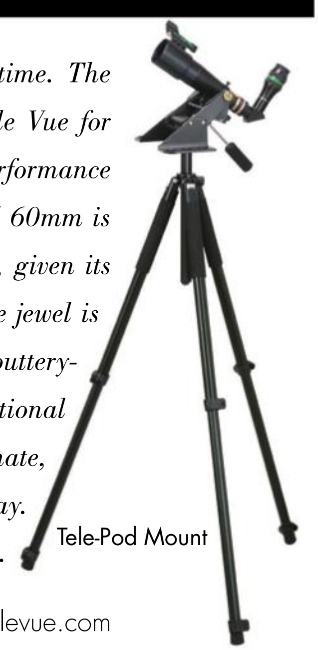
Case Dim. 14″x9″x4″ Total package weight as shown 5¾lbs.
*Solar viewing with any telescope requires proper solar filtering.

Wherever and Whenever You Stroll, Never Be Without Your Wanderlust Companion.

Fonemate:smartphone to eyepiece adapter

Sol-Searcher

The August 2017 solar eclipse will be a special few moments in time. The heirloom quality Tele Vue-60 is designed, built, and tested at Tele Vue for those moments plus all of your future observing adventures. With performance truly beyond expectation, this 4.3° max. true field, diffraction-limited 60mm is no mere toy. The Tele Vue-60 is an observing companion like no other, given its combination of ultra portability and stunning optical fidelity. This petite jewel is made of black anodized aluminum for lasting beauty and features a buttery-smooth dual stage focuser for that "snap-to-focus" image. Pack its optional custom carrying bag with an Everbrite diagonal, Sol-Searcher, Fonemate, and some Tele Vue eyepieces, grab a Tele-Pod Mount and chase away. For the 2017 eclipse and beyond, your observing time deserves the best.

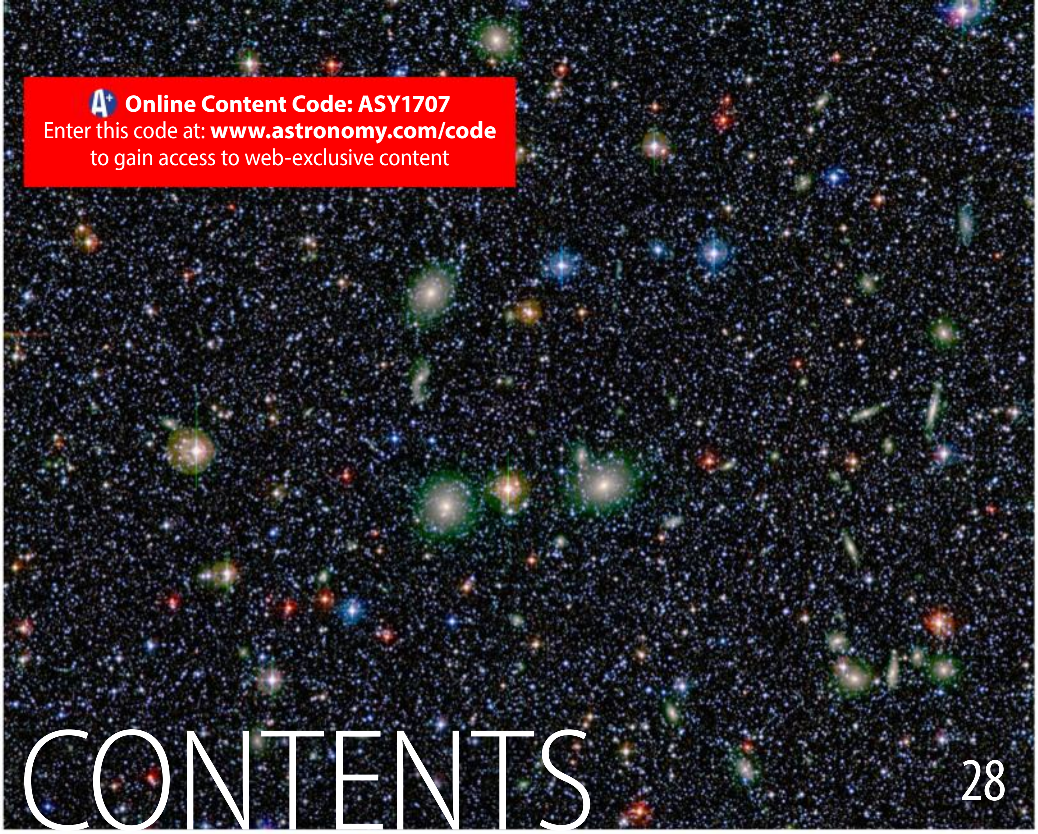


Tele-Pod Mount

TeleVue® Visionary 32 Elkay Dr., Chester, NY 10918 (845) 469-4551. televue.com

TV-85 Eclipse Image by Dennis diCicco, processing by Sean Walker.


Many areas in Kentucky will provide great viewing opportunities for this rare astronomical event. So make the most of your trip by also exploring our many outdoor adventures, restaurants and more. **For all the details and sample itineraries, visit KentuckyTourism.com/eclipse.**
COME FOR THE TOTAL SOLAR ECLIPSE. STAY FOR EVERYTHING ELSE.
#travelky
Kentucky
UNBRIDLED SPIRIT



Online Content Code: ASY1707
Enter this code at: **www.astronomy.com/code**
to gain access to web-exclusive content

CONTENTS

28

JULY 2017

VOL. 45, NO. 7

ESO/M. KORNMESSER/N. RISINGER (SKYSURVEY.ORG)

ON THE COVER

Nearly 4 billion years ago, during the so-called Noachian Era, Mars had water in seas and lakes filling its low-elevation areas.

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*.

Ask Astro Archive
Answers to all your cosmic questions.

Pluto Globe
Astronomy presents the first-ever Pluto globe!

Picture of the Day
Gorgeous photos from our readers.

Have questions?
We are here to help!
Use "Live Chat" today
on our website.

ORION®

SINCE 41st year 1975

EVERYTHING FOR THE AMATEUR ASTRONOMER

FREE SHIPPING on orders of $250 or more

INSTALLMENT BILLING on orders of $350 or more

NO SALES TAX* on most orders

NEW PRODUCT 2017

2.54" ID Set of Orion® E-Series Solar Filters for Binoculars
#7786 $49.99

Orion® ShoreView Pro II 8x42 ED Waterproof Binoculars
#51692 $179.99

Orion® DualBeam 2600mAH LED Waterproof Astro Lantern
#05017 $24.99

Orion® GrandView™ 12-36x50mm WP Zoom Spotting Scope Kit
#51690 $99.99

Orion® GrandView™ 20-60x80mm Zoom Spotting Scope Kit
#51691 $149.99

Orion® SkyQuest™ XT10 PLUS Dobsonian Reflector Telescope
#8987 $699.99

Orion® LHD 80-Degree Lanthanum Ultra-Wide 1.25"/2" Eyepieces
$269.99 ea

Orion® PinPoint Telescope Focusing Mask
$10.99-31.99

COUNTDOWN TO THE 2017 TOTAL SOLAR ECLIPSE

Orion is your one stop shop

NEW PRODUCT 2017

Orion® 2017 Total Solar Eclipse Viewing Guide
#51935 $12.99

Orion® 10x50 E-Series WP Binocular Solar Eclipse Kit
#24784 $119.99

Orion® Safety Film Solar Filter for 6" Reflector Telescopes
#7748 $39.99

5.81" ID Orion® Full Aperture Solar Filter
#7710 $89.99

NEW PRODUCT 2017

Orion® Solar Eclipse Safe Viewing Glasses, 5-Pack
#51907 $12.99

PACK of 5!

Orion® SkyQuest™ XT8 PLUS Dobsonian Reflector Sun & Moon Kit
#24796 $529.99

Orion® SpaceProbe™ 130ST EQ Reflector Telescope Sun & Moon Kit
#24791 $429.99

5.81" ID Orion® Deluxe Safety Film Solar Filter
#7756 $79.99

NEW PRODUCT 2017

PACK of 5!

Orion® Solar Eclipse Safe Viewer, 5-Pack
#51908 $14.99

4.30" ID Set of Orion® Binocular Solar Filters
#20032 $149.99

Retail prices shown are current as of 04/24/17 from Orion, excluding sale items. Prices are subject to change without notice. Please check OrionTelescopes.com for the most current pricing. Dealer pricing and/or promotions may vary.

OrionTelescopes.com

Orion Telescopes & Binoculars now accepts the following payment options:

Orders: (800) 447-1001
Customer Service: (800) 676-1343
*We only collect sales tax in CA & PA. See website for details.

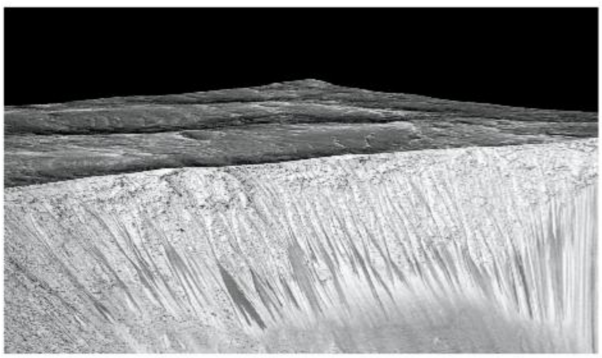
FROM THE **EDITOR**

BY DAVID J. EICHER

Where has all the water gone?

Long ago, on a planet not so far away, water flowed abundantly. That's the Red Planet, Mars, long a source of speculation about life outside Earth. As spacecraft have explored Mars in ever-greater detail, they've accumulated growing evidence that water was once abundant on our celestial neighbor.

But signs of water flowing on the martian surface today are scarce. They are shown in the accompanying image. It depicts dark streaks caused by seeping flows of briny water down the walls of a crater called Garni.



Dark streaks, called recurring slope lineae, mark the walls of the Red Planet's Garni Crater. Planetary scientists believe these are caused by flowing, briny water. These rare features stretch several hundred yards. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA

In her feature story this month, planetary scientist Tanya Harrison reveals the history of water on Mars. In what astronomers call the Noachian Era, between 4.1 billion and 3.7 billion years ago, water flowed abundantly on the planet. Most scientists believe that during the first billion years of the planet's history, liquid water existed on the surface. It likely filled low elevations like great lakes or small seas. Lakes in crater floors probably also existed, at least intermittently. Recent evidence collected by a variety of spacecraft suggests that these lakes were also present more recently than during the first billion years.

Past water-eroded valleys and gullies, along with lakebed streams and channels that must have been cut by free-flowing water, abound on the Red Planet. More recent evidence of flowing water suggests that salt-rich fluid seeps down and leaves erosion marks in a variety of places such as steep crater walls, as in Garni. But clearly the bulk of water on present-day Mars is locked up within the polar caps and in ice below the surface, and probably subsurface aquifers, too.

So what changed Mars from a liquid world to a dry one? The answer isn't entirely clear, but clues from a variety of sources are coming together. A climatic change has clearly transformed Mars. The planet's weak gravity allowed lots of water to escape. Mars also lost much of its magnetic field, permitting the solar wind to strip away the planet's atmosphere. And as Mars grew colder, what water remained was slowly absorbed into the surface and froze, creating substantial deposits of ice.

For the full story, see Tanya's article. It will change the way you think about Mars.

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 Coordinator 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
Corporate Art Director Maureen M. Schimmel
Art and Production Manager Michael Soliday
Corporate Advertising Director Ann E. Smith
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

ADVERTORIAL

Choosing Equipment for Eclipse Photography

Written by Ken Sklute and Dave Henry

Just about any camera will work to capture a solar eclipse, but some will produce a better experience depending on your expectations.

© DAVE HENRY, 2012
Canon EOS 50D DSLR camera
EF 800mm 5/5.6L IS USM lens

Safety

The foremost concern in photographing a solar eclipse is the protection of your eyes and camera's lens and sensor.

- Never look at the sun without accredited and approved solar filtration over your eyes.
- Never point your camera into the sun without a solar filter.
- Never improvise, modify, or use general photography neutral density filters.

Point-and-Shoot Cameras

Personal digital cameras like Canon's PowerShot point-and-shoot type cameras all have great image quality and are very cost efficient, but many aren't able to safely photograph a solar eclipse or don't have a zoom range long enough to produce a large enough sun disk. Many of the PowerShot cameras have lenses that fully retract into the body of the camera when the camera falls asleep or is powered down, so there is no way to mount a solar filter.

The **Canon PowerShot G3 X** and **PowerShot SX60 HS** are top-of-the-line versions of the all-in-one point-and-shoot cameras. They each have a long focal length telephoto lens capable of producing impressive sun disk sizes. This retractable lens has a bayonet mount that accommodates a filter mounting ring. When powering down the camera the lens only retracts up to that point. This means you can mount a solar filter onto the front of the lens without risking it being forced off the lens barrel.

Digital Single Lens Reflex Cameras

A DSLR camera will probably be the camera of choice for photographers looking for the highest image quality and most equipment flexibility. DSLRs fall into two sensor categories: the smaller APS-C sized sensor and the full-frame sensor.

APS-C Sensors

Just like wildlife, sports, and macro photography, solar and lunar photography will benefit from the smaller APS-C sized sensor due to the 1.6x crop factor. The smaller sensor produces a cropped image compared to the uncropped full-frame sensor. Your sun disk will be significantly larger with the APS-C sensor than with the full frame sensor.

Cameras such as the **Canon EOS Rebel T7i, EOS 80D** and **EOS 7D Mark II** all have an APS-C sensor and will be great performers for the upcoming total solar eclipse. If you already own a Rebel or any of the pro-consumer based DSLRs such as 30D through 80D, you're all set and ready to shoot the eclipse — once you secure that solar filter, of course.

Full-Frame Sensors

The full-frame sensor in the **Canon EOS 6D, EOS 5D series** and the **EOS-1D X Mark II** can produce high resolution images with low noise and, in the case of the EOS 5DS and EOS 5DS R, produce huge enlargement capability due to their 50.6 megapixel sensors. If you own a full-frame DSLR, you are ready to cover the eclipse. Your next task is to select the right lens to get the shot you want.

Choosing Your Lens

Choosing a lens to photograph the sun or moon depends on how large of a sun or moon disk you want. The size of the disk is controlled by two things: your DSLR's sensor size and the focal length of your lens.

The **Canon EF 400mm f/5.6L USM** or the **EF 100-400mm f/4.5-5.6L IS II USM** are affordable, high quality, long focal length lenses that will be ideal on an APS-C sensor camera body. You should be looking for a sun disk 1/3 to 1/4 the height of your sensor. An EF 400mm lens on an APS-C sensor produces a 1/4 size sun disk. An EF 400mm lens with a 1.4x extender will produce a 1/3 sensor size sun disk and has an equivalent focal length of 560mm.

If you're using a full-frame DSLR, you should be looking for a sun disk ratio-to-sensor size the same as with APS-C sensors. A good sun disk size will be created with 800mm focal length. This can be achieved by using an EF 800mm lens or an EF 400mm lens paired up with a 2x extender to produce the 800mm size. Using a 1.4x extender on an EF 800mm lens (1,120mm equivalent) on a full-frame sensor will produce a large sun disk but, during totality, you will cut off most of the corona.

Summary

When shooting a rare event such as an eclipse, you don't want to leave anything to chance. For most, the total eclipse of the sun in August will be a once-in-a-lifetime event so don't put off planning your camera equipment until the last minute.

Canon has the perfect equipment for capturing once-in-a-lifetime solar eclipse images.

Canon SEE IMPOSSIBLE

For more shooting tips and to purchase Canon's exclusive Solar Eclipse Bundles, go to usa.canon.com/eclipse.

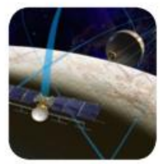
QUANTUM GRAVITY

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

HOT BYTES >>

TRENDING TO THE TOP

TARGET: VENUS
NASA and a group of Russian scientists met to discuss science objectives for the Venera-D mission, a return to Venus featuring an orbiter and lander.



CLIPPER SHIP
NASA's Europa mission has been officially designated the Europa Clipper, an informal name used during the mission's development.

MOON TRIP
SpaceX will take two tourists on a quick loop around the Moon in 2018, for an undisclosed price.

NASA/JPL-CALTECH/T. PYLE (IPAC). TOP FROM LEFT: ROSCOSMOS; NASA/JPL-CALTECH; SPACEX

The TRAPPIST-1 star system (shown here in artwork) holds the largest group of terrestrial planets in close proximity yet discovered, several of which could be habitable.

SNAPSHOT

A system of seven worlds

The TRAPPIST-1 star system, 40 light-years away, intrigues astronomers with potential habitats.

In February, NASA held a special news conference for an amazing announcement: A team of scientists described the discovery of the first known system of seven Earth-sized worlds orbiting one star.

The system, called TRAPPIST-1, was named for the small telescope in Chile used for the discovery. The planets orbit an ultra-cool dwarf star lying 40 light-years from Earth in the constellation Aquarius.

The discovery is the first to identify such a large number of small planets orbiting a star outside our solar system. "This discovery could be a significant piece of the puzzle of finding habitable environments, places that are conducive to life," says Thomas Zurbuchen, NASA's associate administrator for the Science Mission Directorate.

Using data from the Spitzer Space Telescope, the team measured the sizes of the seven planets and estimated masses for six of the seven, providing estimates of their densities. This led scientists to believe the planets to be rocky and terrestrial rather than gaseous.

Their calculations suggest the planets have diameters between 0.8 and 1.1 times that of Earth, and that their masses range from 0.4 to 1.4 that of our planet. Strangely, in this system in which rocky bodies are orbiting a cool sun, the orbital periods are very short, ranging from 1.5 to about 20 days. So these planets are whizzing around the star quickly, and they lie close in. They range from just 1 million miles (1.6 million kilometers) to about 6 million miles (9.5 million km) away from their host star. By contrast, Mercury, which we think of as really close to the Sun, is some 36.8 million miles away from it.

This discovery reminds us, once again, that the number of planets to be detected near us in the galaxy is enormous, and many more such surprises await. — **David J. Eicher**

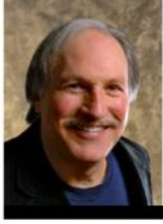
The Greatest Southern Sky Experience
with Bob Berman
The original Chile Astronomy and Nature Tour, and Still the Best!
Now with an Extension to San Pedro de Atacama
"The best stargazing of my life."
-2017 Tour Guest
March 16-21, 2018
www.specialinteresttours.com
727.330.7738 info@specialinteresttours.com

SkyShed POD MAX
Astronomy 2016 Star Products
12.5' Dome!
www.skyshedpodmax.com

Solar60
Auto Tracking, GOTO Solar/Night Telescope Packages Start From
$299.00
Check Out Our Website For More Exciting Eclipse Viewing And Imaging Products

ECLIPSES MADE REALLY, REALLY EASY
THE STAR ADVENTURER AND NEW STAR ADVENTURER MINI
You've been worrying about what filters you're going to use for the upcoming eclipse, but have you thought about which tracking mount you're going to use?
May we suggest the Star Adventurer or Star Adventurer Mini, designed specifically to make nightscapes and eclipses a snap?
For a complete list of specifications and features, please go to skywatcherusa.com
©2017 Sky-Watcher USA. Specifications subject to change without notice. 20-17009
So, that line over there about making it a snap? You see what we did there? Lol.
Sky-Watcher® USA
Be amazed.
Don't forget to follow us on Facebook, Twitter and Instagram!

all new
SkyGuider™Pro
Our new SkyGuider™Pro is packed with features,ones that enable you to capture images as you see them in your mind's eye. Visit our website or contact your iOptron dealer to learn more.
iOptron®
www.ioptron.com



STRANGE**UNIVERSE**

BY BOB BERMAN

Moon motion

Watching our satellite as it glides in front of the Sun is a moving experience.

The great eclipse is getting close now. I hope you will not stay put and be content with a mere partial event, but will travel to witness the unbelievable majesty of totality.

One often-neglected aspect of the spectacle involves motion. This is more singular and special than popularly realized. That's because a frozen visual scene is the norm in our profession or hobby. When we look through telescopes, it's a slide show. The images are static. Nothing moves. We're used to it.

The entire human race will come and go before the great globular cluster in Hercules looks any different. Even much closer to home at 410 light-years, the beautiful colored double star Albireo has not changed since the first telescopes were aimed its way in the 17th century. We know the blue-and-gold component stars whirl around each other at several miles a second. But that's not enough to let us detect the slightest change in the stars' positions, not even after four centuries.

By contrast, the tilt of Saturn's rings changes noticeably from one year to the next, and they're now wide open. We can remember just a few short years ago when the rings were nearly edge-on, making Saturn a very different animal. Jupiter is more animated, even if just barely. A few hours of observation reveal its spin and the whirling of its moon Io, which whizzes completely around that planet in less than two days.

But it's our "inconstant Moon" — the one Shakespeare's Juliet was wary of — that comes closest to providing bona fide movement.

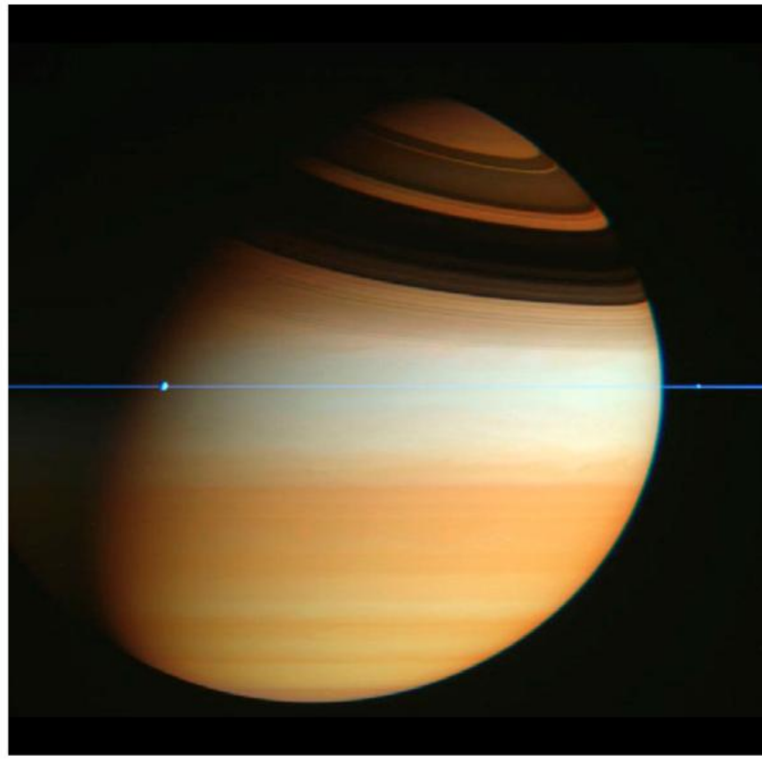
On the surface, shadows cast by lunar mountains shift position at 10 mph (16 km/h), the same speed as a jogger. A typical 62-mile (100 kilometers) crater like Copernicus changes its shadowing in just a few hours.

But it's the Moon's motion that holds our attention. As it lopes through space at just 1 kilometer per second, its nearness makes that movement more than obvious: Of the universe's substantial bodies, it's the very fastest in terms of angular shift.

In a single minute, the Moon glides against the background stars by the apparent diameter of Jupiter or Venus. In an hour, it moves its own width against the stars. The Moon is the only celestial body that fully shifts its position hourly. Its closeness alone makes its unimpressive orbital speed of 2,288 mph (3,682 km/h) visually obvious.

This motion reaches an exciting climax August 21, during the eclipse. No doubt, a major source of amazement will be seeing the Moon bustle as it glides in front of the Sun, and then later restores its light. You can actually see it moving.

True, the Moon's angular speed only equals that of a wall clock's minute hand. And yes, you can also observe the Moon's orbital motion during conjunctions and near conjunctions. But its motion during a total solar eclipse is like nothing else. And while other movements figure prominently in creating the magical eclipse stewpot — our planet's spin nearly doubles the eclipse's length — it is the Moon's responsibility for creating the precise three-dimensional lineup. This exact alignment of Sun, Moon, and your spot on Earth conjures a palpable effect on the human soul.



Saturn's rings are seen near-edge on in this photo from the Cassini spacecraft taken in 2005. Two unnamed moons appear alongside it, with dark shadows on the north pole of Saturn indicating the shadows of the rings. CASSINI IMAGING TEAM/ISS/JPL/ESA/NASA

We're not talking astrology. Astronomers do not believe in astrology for a very good reason: Countless statistical studies show that it has no validity. This is something else. It involves feelings.

Scientists do not generally discuss feelings, but observational astronomers aren't subtle about them. You cannot venture under the Milky Way in moonless, unpolluted conditions and not feel a sense of awe. You cannot telescopically observe the rings of Saturn and not feel joy and wonder. And you cannot view a total solar eclipse and fail to be swept up in rapture.

Rapture does not lend itself to analysis. It's not easy to identify what exactly makes a solar totality so otherworldly. Why do so many weep? While I do not have the answers, I'm guessing there's something particularly awesome about seeing the black Moon moving in space.

A paltry half-mile a second. The Moon moves the same speed as a rifle bullet, which might sound impressive. But by celestial standards, that's virtually a standstill. The moon is 80 times slower than next month's Perseid meteors. It boasts only one-tenth the speed of Saturn, the most lethargic of the bright naked-eye planets. Indeed, a lazy sedentary person used to be called saturnine. And here's the Moon, 10 times slower.

You wouldn't think that sort of speed could grab our attention. Or excite us. But watch it do exactly that.

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

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

ASTRO**LETTERS**

Trick of the light

Regarding Stephen James O'Meara's article "Twice-setting stars" in the March 2017 issue: When I lived along the Lake Michigan shoreline in my youth, it was fairly common to see inferior mirages of ships going over the horizon, but always later in the summer, which lends credence to the idea that a layer of moist, warm air over cooler waters creates this illusion. I have also seen lights over the lake in the early evening coming from Ludington, Michigan, which is directly across from Manitowoc, Wisconsin, where I lived. Ludington is completely over the horizon from Manitowoc, so the same effect must have occurred for these lights to be visible. People have also reported these sightings at night on the car ferry, which still runs between the two cities. — **Joseph A. Huycke,** Phillips, WI

From phone to telescope

I enjoyed the product rundown by Tom Trusock on phone-to-telescope adapters from the March 2017 issue. He seems to have found many models I did not. I purchased a Gosky Universal Cell Phone Adapter Mount for $25. I would rate it as difficult to set up and align, but once aligned, I get good images and videos.

Trusock seems to cover most of the considerations needed for the purchase of one of these adapters. There are two additional thoughts I would add to his list.

First, the weight of the adapter plus the smartphone can have a significant impact on a telescope's balance, particularly with longer tube lengths. In my case, it adds 10 ounces at the focuser and requires considerable counterbalance weight to stabilize the telescope.

Secondly, it may be necessary to remove the phone from any add-on protective case to obtain an accurate alignment and secure mounting in the adapter. How easy is it to remove your smartphone from its case? — **John Beaury,** Crestwood, MO

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.*

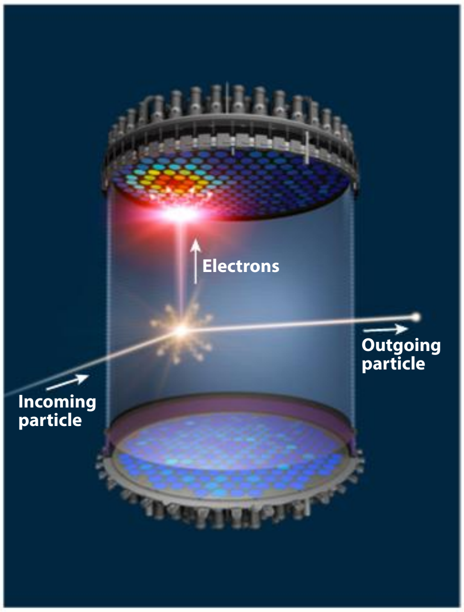

ESO/B. TAFRESHI/TWAN

A pleasant surprise

I was fortunate enough to have had an absolutely gorgeous view of the Moon and Venus setting over the ocean on New Year's Day. I looked forward to the Moon and Mars pairing on the next day, only to be even more thrilled to witness the Mars occultation. I was very surprised that this event was not mentioned in your Sky This Month section! Had I known that this was going to happen I would have set up the telescope and camera equipment ahead of time. As it was, there was only time to get the binoculars! — **Donna Yamada,** Honolulu, HI

VARIOUS VARIABLES. The star Delta Cephei was recently observed as an entirely new class of Cepheid variable star: a periodic pulsed X-ray source. When the star reaches a certain size as it pulses, it emits 400 percent more X-ray energy.

CAN TONS OF XENON FINALLY FIND DARK MATTER?



TINY BUT TOUGH. LUX-ZEPLIN will see dark matter if it interacts with xenon inside the experiment's giant chamber, creating electrons that will register on the detector. If the project fails to detect dark matter, prospects for dark matter as a form of matter different from protons, electrons, and neutrons may diminish. SLAC NATIONAL ACCELERATOR LAB

A dark matter experiment located deep underground will soon provide the means to find elusive axions, a type of hypothetical elementary particle.

The project, called LUX-ZEPLIN, will be built at the Sanford Underground Research Facility, an abandoned gold mine in rural South Dakota. At that location, 1 mile below the surface, cosmic rays can't interfere with potential detections of dark matter.

While 23 percent of the universe is believed to consist of dark matter — a type of matter initially theorized to explain discrepancies in the observed rotation rates of galaxies when compared with the rotation astronomers expected — scientists aren't exactly sure what dark matter is made of. Although there are several competing ideas, the two most popular scenarios are massive compact halo objects (MACHOs) and weakly interacting massive particles (WIMPs).

The MACHO scenario involves objects made of the same kind of matter we see elsewhere in the universe, but which don't give off enough radiation to make themselves known to astronomers. This could include dormant black holes, exhausted brown dwarfs, stars too faint for our current generation of telescopes to detect, or other sorts of massive but mostly invisible objects.

WIMPs, on the other hand, are an entirely separate state of matter from anything we know. This type of matter exists alongside particles such as the protons, electrons, and neutrons we see around us, but unlike antimatter, it only interacts incredibly weakly with regular matter.

LUX-ZEPLIN hopes to capture evidence of WIMPs by using a 2-ton tank of xenon insulated on all sides from interference. WIMPs, if they exist, should be able to move through this shielding. If a WIMP has a chance encounter with the xenon inside, the sensitive detector should be able to pick up the telltale radiation that results.

The detector is expected to come online by 2020. LUX-ZEPLIN will join a cadre of other existing dark matter experiments, all aimed at uncovering dark matter's true nature via indirect methods.

— John Wenz

BRIEFCASE

HIDDEN STAR FORMATION

Astronomers at the University of Massachusetts Amherst uncovered a high rate of star formation in a distant galaxy using the Large Millimeter Telescope. As much as 75 percent of this galaxy's star formation is hidden from optical telescopes by dust. Star formation in young galaxies is the precursor of the materials that form stars and planets in the local universe. Because this galaxy appears typical, a high rate of hidden star formation and dust production could change the way astronomers view these processes.

•

RESURRECTING ASTROPHOTOS

Astronomy Rewind is a citizen science project launched on March 22 to give new life to old images from the pages of astronomical journals. The project will resurrect "zombie" photos, charts, and maps scanned from paper publications by incorporating them into digital sky catalogs, where they can contribute to new science. Astronomy Rewind is part of the Zooniverse platform, which includes Galaxy Zoo.

•

COMETARY FACE-LIFT

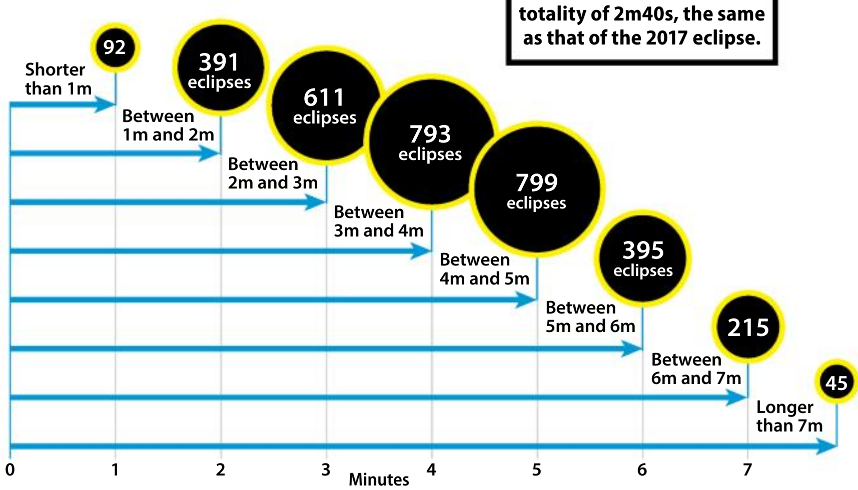
The European Space Agency's Rosetta mission recorded big changes as Comet 67P/Churyumov-Gerasimenko approached the Sun between August 2014 and September 2016. A crack on the "neck" of the dog bone-shaped comet widened by about 100 feet (30m) and developed a neighboring crack 500 to 1,000 feet (150–300m) long. These cracks could someday split the comet in two. Rosetta also saw a cliff collapse and a 282 million-pound (130 million kilograms) boulder shift 460 feet (140m). Both events are likely due to outbursts as ices turned to gas, forming a tail. **— Alison Klesman**

50 MILLION The number of years since the martian volcano Arsia Mons last erupted — around the time dinosaurs went extinct on Earth.

HOW DOES 2017'S TOTALITY COMPARE?

SHORT SHADOW. The total phase of a solar eclipse can last no longer than 7m29s, which happens once in 10,000 years. But how many fall between 2 and 3 minutes, or 5 and 6? Here's the breakdown between the years 4000 B.C. and A.D. 6000. — **Michael E. Bakich**

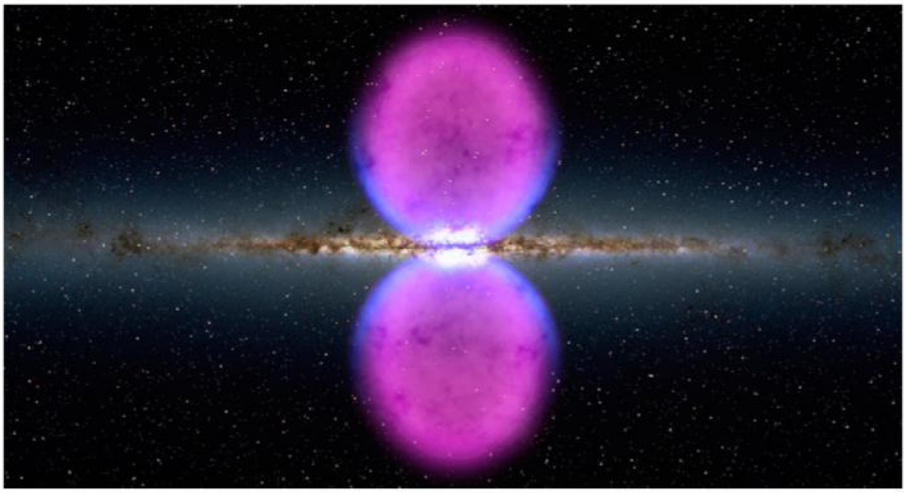
FAST FACT
Of the 3,341 total solar eclipses in this 10,000-year span, 10 of them have maximum durations of totality of 2m40s, the same as that of the 2017 eclipse.



ASTRONOMY: ROEN KELLY

ASTRO**NEWS**

TIGHT SPOT. A black hole-white dwarf pair in the globular cluster 47 Tucanae has the closest orbit of a star around a black hole ever seen. The star orbits the black hole roughly once every half-hour.



A GALACTIC BURP. If we could see the Milky Way from outside the galaxy, the Fermi Bubbles would appear above and below the plane in gamma-ray light. These bubbles were "burped" out by our supermassive black hole 6 million to 9 million years ago, when it consumed its last significant meal. NASA'S GODDARD SPACE FLIGHT CENTER

Our black hole's last known feast

The Milky Way's Fermi Bubbles are two huge structures billowing outward from its center like an enormous hourglass. Visible in gamma-ray light, they are the result of our galaxy's supermassive black hole gorging itself on interstellar gas and dust. Recently, a team led by MIT's Rongmon Bordoloi mapped the motions of cool gas within the northern bubble to pin down its age: 6 million to 9 million years.

The team used 47 distant quasars observed with the Hubble Space Telescope to study the northern Fermi Bubble, which extends 23,000 light-years above the galaxy's plane and contains enough gas to create 2 million Suns. Their results appeared in *The Astrophysical Journal* on January 10.

Quasars are active supermassive black holes in the early universe, sucking down huge amounts of material that shines brightly as it is funneled into a disk around the black hole. Sometimes material escapes from the disk as outflows that can span tens or hundreds of thousands of light-years. Discovered in 2015, the Milky Way's Fermi Bubbles are the remnants of such an outflow, when the Milky Way's supermassive black hole (called Sagittarius A*) was more active as the galaxy formed around it. Today, the black hole is relatively quiet.

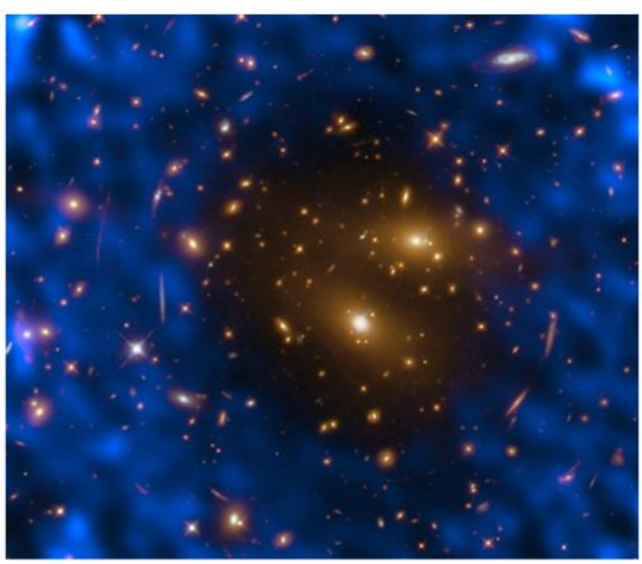
"We have traced the outflows of other galaxies, but we have never been able to actually map the motion of the gas," Bordoloi said in a press release. "The only reason we could do it here is because we are inside the Milky Way. This vantage point gives us a front-row seat to map out the kinematic structure of the Milky Way outflow."

As the quasars' light travels through the bubble, it highlights the gas, allowing measurement of its composition, temperature, and movement. The outflow itself contains gas at 18 million degrees Fahrenheit (nearly 10 million degrees Celsius), but it's also swept up cooler gas from the galaxy's disk. Bordoloi's team determined that the cool gas contains elements such as silicon and carbon moving at 2 million mph (3 million kph), at temperatures reaching 17,700° F (9,800° C).

They used the gas' velocity to turn back the clock and pinpoint its origin: Sagittarius A*'s last known big meal. "What we find is that a very strong, energetic event happened 6 million to 9 million years ago," Bordoloi explained. "It may have been a cloud of gas flowing into the black hole, which fired off jets of matter, forming the twin lobes of hot gas seen in X-ray and gamma-ray observations. Ever since then, the black hole has just been eating snacks." — **A. K.**

Boosting the background

COSMIC HOLE. The Atacama Large Millimeter/submillimeter Array (ALMA) in Chile is one of the most powerful radio telescopes in the world. One of its goals is to look into "cosmic holes," regions of space where hot gas in clusters creates voids in the cosmic microwave background (CMB) via a process called the Sunyaev-Zel'dovich effect. This effect occurs when radio waves from the CMB hit the hot gas in clusters, boosting the energy of these photons and leaving what is discernible as a "hole" when the region is studied with radio telescopes (blue). Until recently, imaging this effect in detail has been difficult with high resolution because the gas in clusters responsible for the effect is widely and evenly spread. ALMA's ability to map these cosmic holes with twice the resolution and 10 times the sensitivity of other instruments will further understanding of galaxy clusters in the future. — **J. W.**



ALMA (ESO/NAOJ/NRAO), KITAYAMA ET AL., NASA/ESA HUBBLE SPACE TELESCOPE

QUICK TAKES

CHAOTIC BALLOON
NASA selected the Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory as its next Explorer-class mission, with a proposed launch date of 2021. The high-altitude balloon mission will study the interstellar medium, the Milky Way's chaotic structure, and the Large Magellanic Cloud.

●

GIANT MAGNETS
German astronomers discovered evidence that magnetic field energy can span several galaxies within a cluster and act as one large magnetic field.

●

BREAK AWAY
Four stars in the Orion Nebula currently moving in different directions seem to have been part of the same star cluster before their mutual gravity broke the group apart.

●

NOT SO SUPER
The supernova SN2015bh may be a phony. Rather than exploding in one giant supernova, the massive blue star may just be experiencing periodic outburst events.

●

BIG SIGNAL
According to Harvard University researcher Avi Loeb, astronomers should contemplate whether fast radio bursts could be artificial in origin.

●

WE ARE STARDUST
An ALMA observation of the distant universe found one of the youngest dust clouds ever detected, illuminating the behavior of the earliest stars.

●

DANGEROUS WANDERING
Observations of the object ASASSN-14li show the trail of hot gas as a supermassive black hole rips apart an unfortunate star.

●

MAIN BELT COMETS
Astronomers identified P/2016 J1, the youngest asteroid pair ever discovered. The pair's progenitor split in two and eventually developed comet-like tails.

●

UNUSUAL PLANETS
A white dwarf-brown dwarf pair called SDSS 1557 appears to host a field of asteroid debris, opening up the possibility that rocky planets hide in the strange system. — **J. W.**

FOR YOUR CONSIDERATION

BY JEFF HESTER

The hermeneutics of bunk

How a physicist gave postmodernism a black eye.

For anyone who pays attention to popular accounts of physics and cosmology, quantum gravity is a thing. How could it not be? Quantum gravity is the place where the two pillars of modern physics — quantum mechanics and relativity — collide head-on at the very instant of the Big Bang. The two theories, each triumphant in its own realm, just don't play well together. If you are looking for fundamental challenges to our ideas about the universe, quantum gravity isn't a bad place to start.

A bit over two decades ago, quantum gravity also proved to be the perfect honey trap for a bunch of academics with a taste for nonsense and an envious bone to pick with science.

In 1994, NYU physicist Alan Sokal ran across a book by biologist Paul Gross and mathematician Norman Levitt. In *Higher Superstition: The Academic Left and Its Quarrels with Science*, Gross and Levitt raised an alarm about those in the new field of "cultural studies" who were declaring that scientific knowledge, and at some level reality itself, is nothing but a social construct. Unsure whether he should take Gross and Levitt at face value, Sokal went to the library and dove into the literature that they were criticizing. When he came up for air, he was much more familiar with the postmodernist critique of science. He was also appalled at the depth of its ignorance about the subject.

Most scientists respond to such nonsense with a muttered, "good grief," but Sokal felt compelled to do more. He decided to give postmodernists a first-hand demonstration of the destructive testing of ideas that tie science to a reality that cuts across all cultural divides.

Sokal had a hypothesis: Those applying postmodernism to science couldn't tell the difference between sense and nonsense if you rubbed their noses in it. He predicted that the cultural science studies crowd would publish just about anything, so long as it sounded good and supported their ideological agenda. To test that prediction, Sokal wrote a heavily footnoted and deliciously absurd 39-page parody entitled, "Transgressing The Boundaries: Toward A Transformative Hermeneutics Of Quantum Gravity."

The paper is worth reading just for a belly laugh. It promises "emancipatory mathematics" at the foundation of "a future postmodern and liberatory science." "Physical 'reality'," it declares, "is at bottom a social and linguistic concept." He embraces the notion, seriously proposed by some, that logic itself is invalidated by "contamination of the social." When he showed it to friends, Sokal says, "the scientists would figure out quickly that either it was a parody or I had gone off my rocker."

Sokal submitted his paper to a trendy journal called *Social Text*. Understanding the importance of ego, he freely and glowingly cited work by several of the journal's editors. For their part, the folks at *Social Text* were thrilled to receive Sokal's manuscript. Here at last was a physicist who was "on their side!" After minor revisions, the paper was accepted and scheduled to appear in an upcoming special "Science Wars" edition.

Did quantum mechanics and relativity intertwine in the Big Bang, creating quantum gravity? In 1996, physicist Alan Sokal used the theories of quantum gravity as the subject of a hoax paper intended to challenge postmodernist thinking and demonstrate the gullibility of certain academics. TONY HALLAS

The bait had been taken, but the trap had yet to be sprung. That came with a piece by Sokal in *Lingua Franca* that appeared just after *Social Text* hit the stands, exposing "Transgressing the Boundaries" as the hoax it was.

Parody sometimes succeeds where reasoned discourse fails. Sokal's little joke burst free of the ivory tower on May 18, 1996, when *The New York Times* ran a front-page article entitled, "Postmodern Gravity Deconstructed, Slyly." The Sokal Hoax became a hot topic of conversation around the world!

Reactions to Sokal's article were, shall we say, mixed. The editors of *Social Text* were not amused, to put it mildly, and they decried Sokal's unethical behavior. One insisted that the original paper was not a hoax at all, but that fearing reprisal from the scientific hegemony, Sokal had "folded his intellectual resolve." It was lost on them that had they showed the paper to anyone who knew anything about science or mathematics, the hoax would have been spotted instantly.

As most scientists did: When I heard about it, I busted a gut!

I still laugh, but the Sokal Hoax carries a serious message. In addition to diluting intellectual rigor, the postmodern assault on science undermines the very notion of truth and robs scientists and scholars of their ability to speak truth to power. As conservative columnist George Will correctly observed, "the epistemology that Sokal attacked precludes serious discussion of knowable realities." Today, from climate change denial, to the anti-vaccine movement, to the nonsensical notion of "alternative facts," that blade is wielded on both sides of the political aisle.

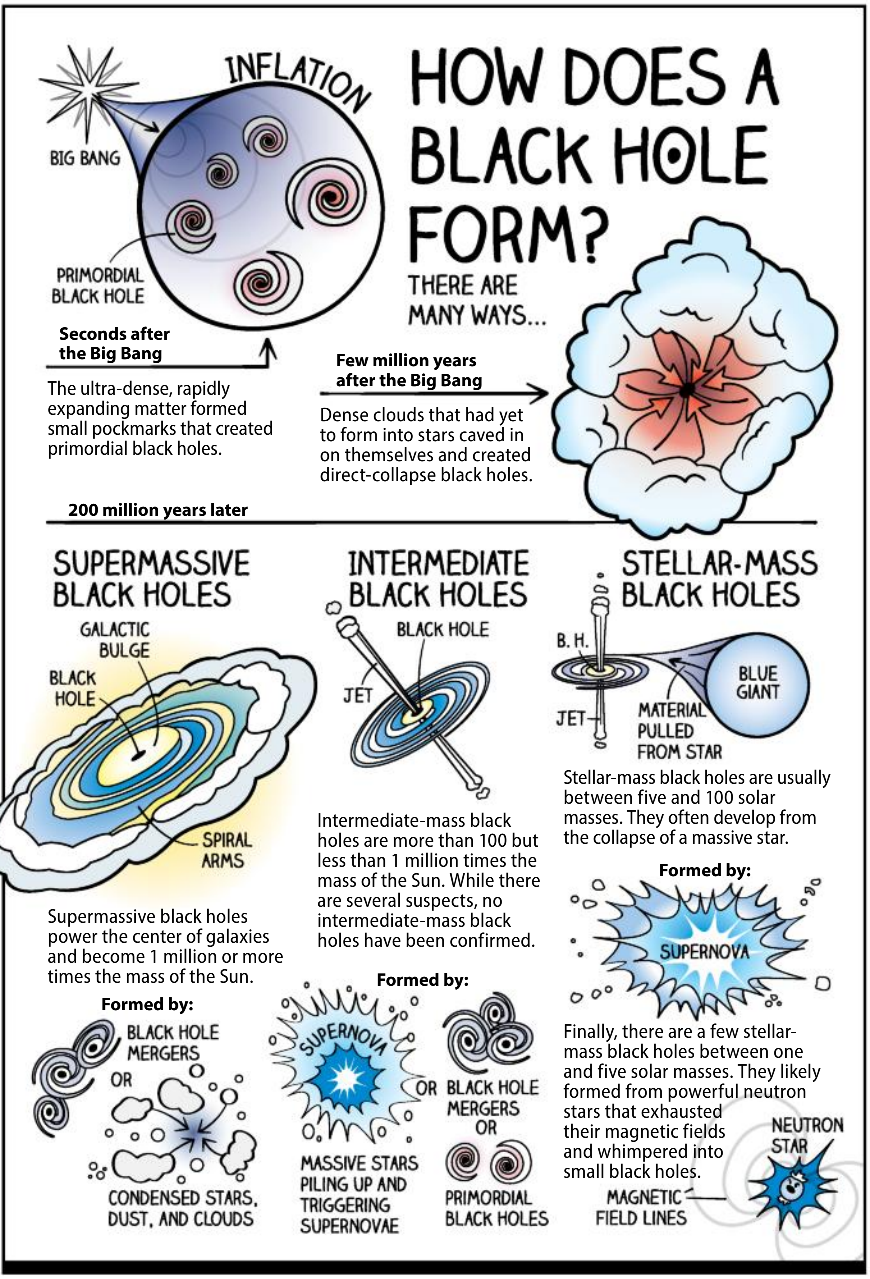
Sokal gets the last word. Quoting from his 1996 *Lingua Franca* article, "Anyone who believes that the laws of physics are mere social conventions is invited to try transgressing those conventions from the windows of my apartment. (I live on the 21st floor.)"

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

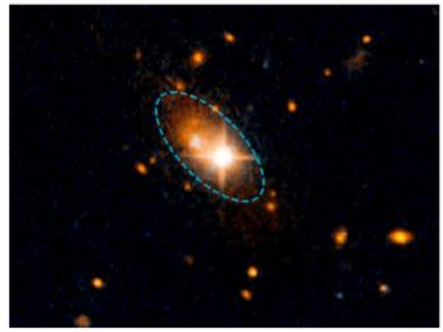
BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

ASTRONEWS

LIGHT MATTER. Galaxies 10 billion light-years away contain less dark matter compared with closer galaxies, meaning that dark matter clumps probably infiltrated galaxies later in the universe's history.



ASTRONOMY: JOHN WENZ AND ROEN KELLY



NASA, ESA, AND M. CHIABERGE (STScI AND JHU)

FLEEING FAST. The quasar 3C 186 appears as a bright starlike object clearly offset from the center of its hazy host galaxy, encircled by the dashed line. Because quasars should sit in the centers of galaxies, 3C 186's position and velocity are unexpected.

Quasar on the loose

The Hubble Space Telescope recently detected a quasar in the process of fleeing its galaxy at 4.7 million mph (7.6 million kph).

Marco Chiaberge, of the Space Telescope Science Institute and Johns Hopkins University, and his associates assembled data from Hubble, the Chandra X-ray Observatory, and the Sloan Digital Sky Survey to study the runaway quasar. Their results were published in *Astronomy & Astrophysics* on March 30.

A quasar is the disk of matter surrounding a supermassive black hole. This material heats up and shines brightly, enabling astronomers to spot it. The rogue quasar, 3C 186, has a mass of over 1 billion Suns and is associated with a galaxy 8 billion light-years away. It's offset from the galaxy's center by 35,000 light-years, almost one and a half times the distance between the Sun and the Milky Way's center.

"Black holes reside in the center of galaxies," Chiaberge explained, "so it's unusual to see a quasar not in the center."

But 3C 186's galaxy shows evidence of a past merger with another galaxy. If each galaxy hosted a supermassive black hole, the black holes could have merged as the galaxies combined. But if the black holes weren't precisely matched in mass or rotation, the gravitational waves emitted as they swirled ever closer would be asymmetrical. The imbalance when they finally merged could kick the resulting object off in one direction. 3C 186 may be the result of such an event, which would have generated energy equivalent to 100 million simultaneous supernova explosions.

If this scenario is accurate, it adds to the existing body of evidence that black holes really do merge. — **A. K.**

NASA, ESA, R. KIRSHNER (HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS AND GORDON AND BETTY MOORE FOUNDATION), AND M. MUTCHLER AND R. AVILA (STScI)

Revisiting an old friend

HAPPY ANNIVERSARY. In February 1987, light from the explosive death of a star in the Large Magellanic Cloud first reached Earth from 166,000 light-years away. Now known as SN 1987A, this nearby event helped astronomers better understand the life cycle of massive stars. In commemoration of the supernova's 30th anniversary, NASA released images of the remnant taken with the Hubble Space Telescope in January. SN 1987A now appears as an hourglass-shaped object, as light from the initial explosion reaches and illuminates material thrown out by the progenitor star 20,000 years before its death. — **A. K.**

100

million times

The magnitude of coldness reached by NASA's Cold Atom Laboratory, compared to the vacuum of space.

ASTRO**NEWS** **BIG ERUPTIONS.** Cornell University astronomers suggest that by looking for the signature of hot hydrogen associated with volcanoes, future observers may be able to identify habitable planets.

MAVEN spacecraft avoids collision with Phobos

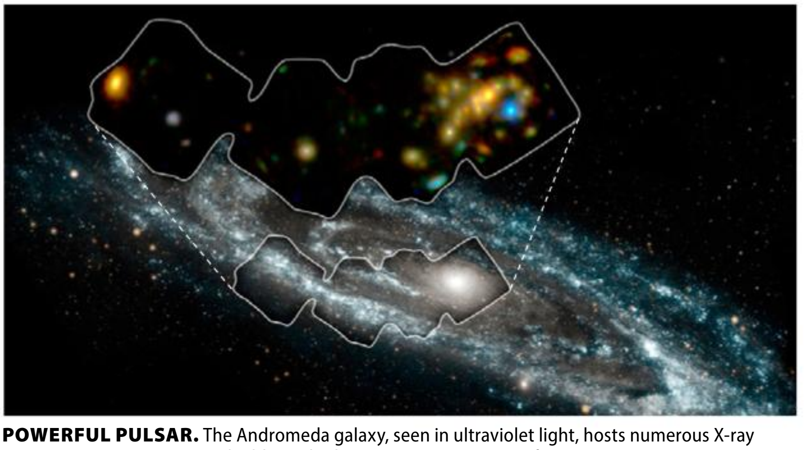
NASA's Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft underwent an unplanned rocket motor burn in late February to push it out of the path of a pending collision with Mars' moon Phobos. The collision would have occurred March 6.

MAVEN has been in an elliptical orbit around Mars for a little over two years. On February 28, the craft increased velocity by nearly 1 mph (0.4 meter per second) to avoid what was deemed too close a call with Phobos. The elliptical shape of MAVEN's orbit, which allows it to skim the martian atmosphere for sampling, crosses the orbit of Phobos regularly. The calculated position of any Mars orbiter carries uncertainties of several miles, particularly when projected weeks into the future, making short-term collision monitoring and avoidance critical to spacecraft operations.

NASA's Jet Propulsion Laboratory (JPL) monitors the potential for such collisions, allowing the navigation teams to schedule the maneuver with several days' notice. Rather than crossing Phobos' path within 7 seconds of the moon, which made a collision likely given Phobos' size, MAVEN instead missed Phobos by a much more forgiving 2.5 minutes after the course correction.

MAVEN principal investigator Bruce Jakosky of the University of Colorado Boulder said in a press release, "Kudos to the JPL navigation and tracking teams for watching out for possible collisions every day of the year, and to the MAVEN spacecraft team for carrying out the maneuver flawlessly." **— Nicole Kiefert**

COURSE CORRECTION. The MAVEN spacecraft, shown in this artist's rendition, has been orbiting Mars since 2014, beaming back valuable information about the Red Planet's atmosphere. Without the collision-avoidance maneuver executed February 28, it would likely have collided with the martian moon Phobos in early March. NASA



POWERFUL PULSAR. The Andromeda galaxy, seen in ultraviolet light, hosts numerous X-ray sources in its center (inset). The bluest, highest-energy source is Swift J0042.6+4112 — now a suspected pulsar. NASA/JPL-CALTECH/GSFC

Solving Andromeda's X-ray mystery

NASA's Nuclear Spectroscopic Telescope Array (NuSTAR) uncovered the source of mysterious X-ray emission near the center of the Andromeda Galaxy (M31) as a probable pulsar — a swiftly spinning stellar remnant beaming out energy along its magnetic poles.

The object, Swift J0042.6+4112, has been seen in lower-energy X-rays for decades, but its nature has been difficult to tease out among the many other low-energy X-ray sources nearby.

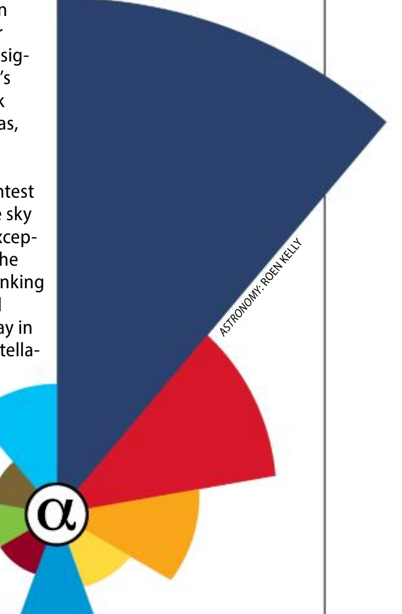
Now, NuSTAR has provided the final piece of the puzzle. In a paper published in *The Astrophysical Journal* on March 22, Mihoko Yukita of Johns Hopkins University and her co-authors concluded that the object is a pulsar in a binary system. As it pulls material off its companion, the pulsar spits out X-rays. The nature of these X-rays closely matches X-rays from known accreting pulsars in binary systems, indicating that Swift J0042.6+4112 is the same type of object.

The identification of Swift J0042.6+4112 as a pulsar is strange, however, because the X-ray emission from such a small object (1 to 3 solar masses) should be eclipsed by X-rays from Andromeda's supermassive black hole (100 million solar masses). Yet Swift J0042.6+4112 is much brighter.

Ann Hornschemeier of NASA's Goddard Space Flight Center, a co-author on the paper, said in a press release, "NuSTAR has made us realize the general importance of pulsar systems as X-ray-emitting components of galaxies, and the possibility that the high-energy X-ray light of Andromeda is dominated by a single pulsar system only adds to this emerging picture." **— A. K.**

HEAD OF THEIR CLASS

ALPHA STARS. German astronomer Johann Bayer introduced the idea of designating each constellation's brightest stars with Greek letters in his 1603 star atlas, *Uranometria*. He typically labeled the brightest star "Alpha," the second-brightest "Beta," and so on. But the sky is littered with notable exceptions. This chart depicts the Alpha star's brightness ranking in each constellation, and shows that it leads the way in 67 percent of the 88 constellations. It places lowest in Draco, where Alpha Draconis (Thuban) is the eighth-brightest star, and Sagittarius, where Alpha Sagittarii (Rukbat) is 15th. **— Richard Talcott**



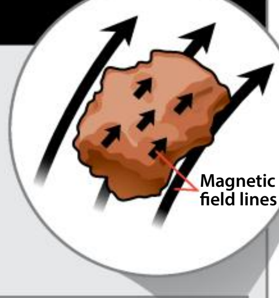
Ranking	Number of constellations
1st	59
2nd	12
3rd	5
4th	2
5th	3
6th	1
8th	1
15th	1
No Alpha star	4

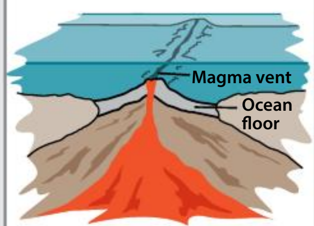
FAST FACT

Four constellations — Leo Minor, Norma, Puppis, and Vela — do not have an Alpha star.

MEASURING THE MAGNETIC FIELD

EARTHLY MYSTERY. Earth's magnetic field has been around nearly as long as the planet, but its precise origin and patterns of behavior remain unknown. It's constantly changing: jerking, spiking, dipping, and even flipping polarity completely. Geologists currently believe that the field arises in Earth's outer core, where the motion of liquid iron generates and maintains it. But why and how it changes, and its past behavior, are difficult to discern. Two measurements are needed to characterize the magnetic field: its strength and its orientation. — **A. K.**





Volcanic sediment

The iron within ocean floor sediment contains a record of the magnetic field at the time it cooled from magma into rock. However, sediment can only be dated with an accuracy of about 1,000 years, providing only a broad picture of the field's changes.

Magnetometer

Magnetometers measure the field directly. Although these instruments allow for precise measurements at a known time, magnetometer measurements only have been available since the device's invention in the 1830s.

Ceramics

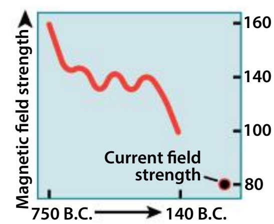
Magnetite in clay records magnetic field information when it is fired in a kiln. Ceramics and other archaeological artifacts can provide snapshots of Earth's magnetic field if they can be accurately dated.

Jar handles

Recently, a group led by Erez Ben-Yosef at Tel Aviv University used Judean jar handles created between 750 and 140 B.C. to pin down Earth's magnetic field during these centuries. The handles bore stamps unique to the ruler at the time, allowing for precise dating to within tens of years.

The results confirm a "geomagnetic spike" that caused Earth's magnetic field to rise to more than twice the current value, followed by a rapid drop in field strength of about 27 percent in just three decades, from 732 to 710 B.C.

Such sharp dips and spikes could shed light on the field's current behavior — Earth's magnetic field is losing at least 5 percent of its strength per century. The rapid loss has puzzled scientists, but the handles suggest it isn't strange at all.



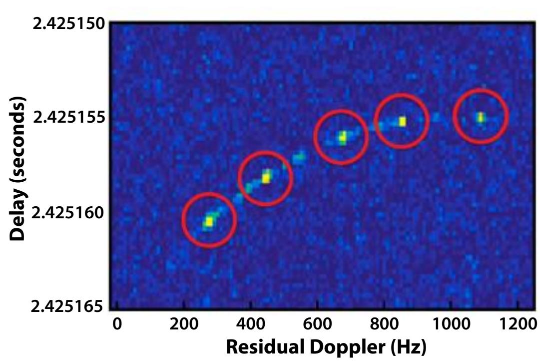
ASTRONOMY: ROEN KELLY

FAST FACT Earth's magnetic poles wander over time; recent surveys show the North Magnetic Pole moving north-northwest at about 34 miles (55 kilometers) per year.

Radar spots idle lunar probe

Scientists at NASA's Jet Propulsion Laboratory used a new ground-based interplanetary radar technique to locate two spacecraft orbiting the Moon: NASA's Lunar Reconnaissance Orbiter, which is still active, and the Indian Space Research Organization's dormant Chandrayaan-1 spacecraft.

Contact with Chandrayaan-1 was lost in August 2009. The lack of ongoing communication made it difficult to predict its location because it's been traveling above the Moon's mascons, areas with above-average gravitational pull, which can affect orbits and cause crashes.

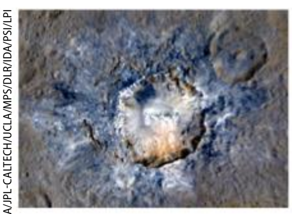


I SEE YOU. The path of Chandrayaan-1 over the Moon's south pole appears in this radar image, taken at the Goldstone Deep Space Communications Complex. Aside from the effect of the Moon's mascons, the dormant spacecraft's orbit has remained unchanged. J. MCMICHAEL/JPL/CALTECH/NASA

Chandrayaan-1 is a cube-shaped spacecraft about 5 feet (1.5 meters) on each side. The team was not sure such a small object orbiting the Moon could be detected, so finding Chandrayaan-1 proved the power of this new radar technique.

After determining that Chandrayaan-1 was in a polar orbit with a period of 2 hours 8 minutes, the team pointed NASA's 230-foot (70m) antenna at Goldstone Deep Space Communications Complex and the 330-foot (100m) Green Bank Telescope in West Virginia at the Moon's north pole. The radar signature showed a tiny spacecraft crossing the beam about every two hours. They continued to study the radar echoes for another three months to confirm the new orbital predictions.

The detection of such a small craft from so far away means this technique could be applied successfully to other projects, such as mapping space debris and locating other spacecraft when navigation or communication capabilities are lost. It also improves the ability to identify and avoid potential collisions in orbit. — **N. K.**



NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA/PSI/LPI

BENEATH THE SURFACE. This enhanced color image of Haulani Crater shows streaks of material believed to originate in Ceres' interior.

Ceres only recently lost its mountains

The dwarf planet Ceres has one lone mountain: Ahuna Mons is believed to be an inactive cryovolcano that formed 200 million years ago or less.

Yet fairly recently — geologically speaking — Ceres had more ice volcanoes on its surface. The Occator Crater shows bright salt features first detected by the Dawn spacecraft in 2015. Astronomers believe Occator's center is a mountain that collapsed after the collision that formed the crater itself, about 34 million years ago.

But materials on the crater's surface are only 4 million years old, pointing to likely cryovolcanism in the interim. Similarly, astronomers have seen hazes inside the brightest spot at the center of Occator, likely from sublimating ices. This indicates something is continuously feeding solid or liquid water from the interior to the surface.

So, what happened to the other mountains?

Researchers believe that Ceres' slowly shifting surface can pull on the dwarf planet's icy mountains until they are nearly flat, essentially hiding them.

Since it arrived at Ceres, Dawn has revealed an unusual world with not only a rich geologic past, but possibly a rich geologic present occurring just a few hundred miles below the craft. — **J. W.**

SECRETSKY

BY STEPHEN JAMES O'MEARA

Cloudshine

The Sun's not the only shadow creator in the daytime sky.

Most skywatchers are aware that when a young crescent Moon graces our skies, its "dark" side glows like a dying ember, allowing us to see its dark patches and bright surface features, albeit dimly. This visual paradox (when darkness appears light) materializes whenever the dark part of the Moon catches sunlight reflecting off Earth and returns that light to our eyes.

Observers call this faint glow "earthshine," and it is one of the most beautiful sights that emerges from the twilight sky. But there's another visual paradox related to Earth and sky that can emerge during twilight and briefly turn shadow into light by a similar feat of natural magic.

Twilit twist

One night during Botswana's rainy season, we had a thunderstorm that ended shortly before sunset, which then occurred in a clearing sky. In its dying gasps, the Sun tossed long golden spears into my garden and bathed the trees to the east in its delicious nectar against a slate gray sky. The world seemed in balance — until the Sun set and twilight deepened. Then it happened.

I was sitting under the roofed part of the veranda, staring out at the clearing sky above the garden wall to the west. The wall should have been in shadow because it stood between the Sun and me, but it wasn't; it was bathed in a weak ashen glow. What's more, the trees standing in front of the wall were casting shadows on its face toward the direction of sunset! What was going on?

If the Sun hasn't dipped too near the horizon (where its light is reddened), the cloud tops in the east will often appear bright white. RICK KOSTELNIK

I remained perplexed until I stepped out from under the eave, turned around, and saw a single towering thunderhead poking its head high above the slate gray clouds. The cloud tops were high enough to still catch rays from the Sun, which had already set from my terrestrial perch.

The contrast between the darkening sky and the thunderhead created a perfect situation: Light reflecting off the thunderhead (I called it "cloudshine") illuminated the garden with enough intensity that trees could cast shadows on the garden wall in the sunward direction.

STEPHEN JAMES O'MEARA

Tall thunderheads that tower in the east near sunset can catch the setting Sun's light and cast shadows.

Late afternoon, too!

Some time after this sighting, Rick Kostelnik of North Yarmouth, Maine, wrote to me saying he had seen a "very interesting phenomenon" July 22, 2016, that he had never seen before. He and his young son, Xander, were outside golfing. The Sun was near setting in the west, and some thunderstorms were rolling through the east; one of the clouds, Rick noticed, appeared extremely bright.

Returning to his game, Rick faced west and was about to hit his golf ball when he noticed that his body cast a shadow on the ground where his ball was sitting. The shadow, he realized, was coming from a light source in the east, which, he surmised, could only have been the cloud. "I had never seen a shadow from a cloud that was so bright before," Rick continued. "I have obviously seen shadows from a Full Moon and probably from Jupiter or Venus at night, but a shadow from a cloud during the daytime really surprised me."

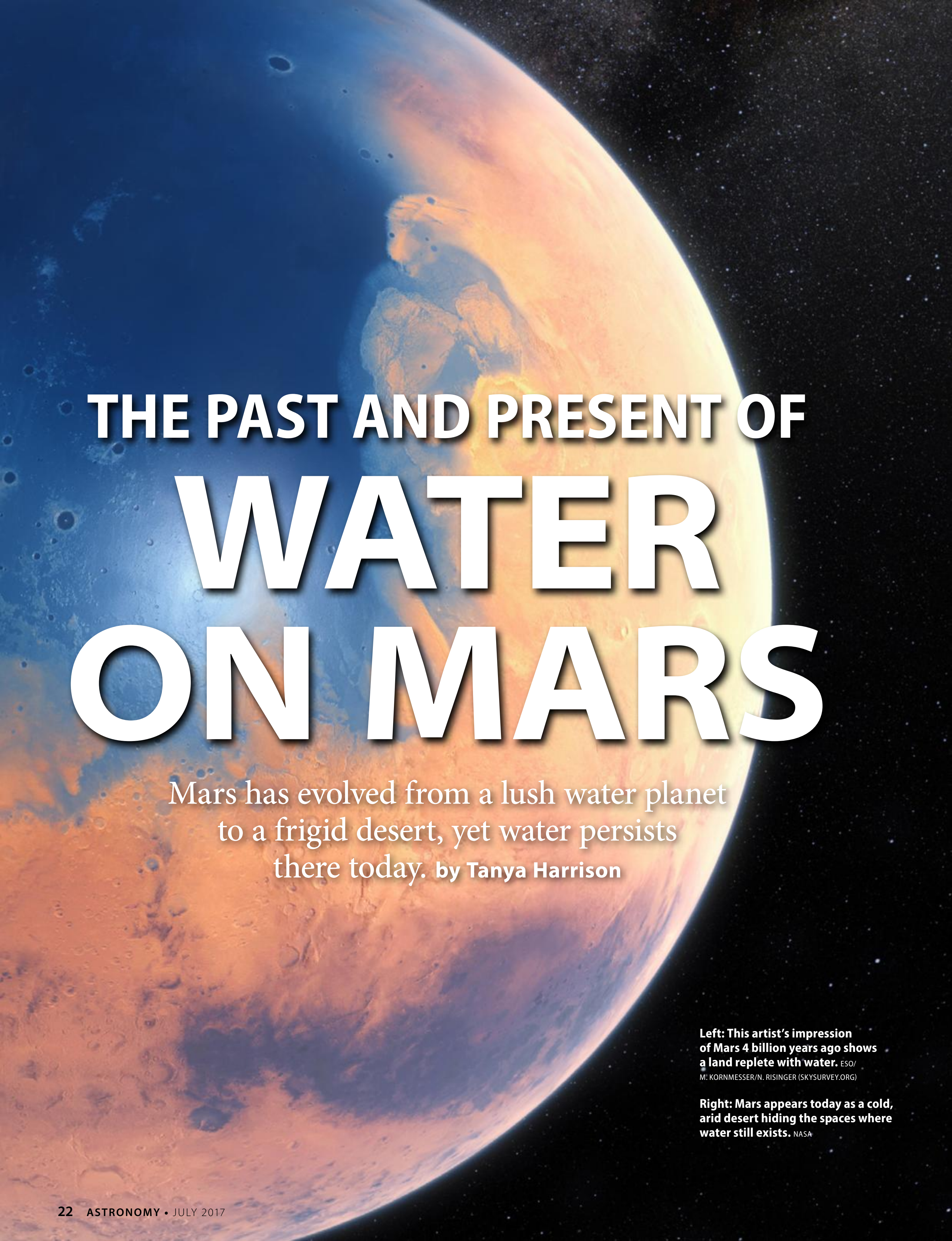
Now that it is summer in the Northern Hemisphere, when thunderstorms become prevalent, keep an eye open for this intriguing phenomenon. I'd love to hear of others' experiences. Send any thoughts or observations to sjomeara31@gmail.com.

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

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


Your Equipment Source for the
TOTAL SOLAR ECLIPSE
AUGUST 21, 2017
DAYSTAR
Solar Scout
From $1695.00
Dedicated
Carbon Fiber
Hydrogen Alpha Telescope
CAMERA QUARK!
From $1295.00
From $1195.00
QUARK
From $12.95
UNIVERSAL
LENS
FILTER
Making Safe Solar Filters for over 45 years
www.DaystarFilters.com
866-680-6563
DAYSTAR
SOLAR FILTERS


Aurora, Culture, & Scenic Wonders Tour • October 10-22, 2017
NORWAY
Join us for a one-of-a-kind journey to Norway, including:
• 8 nights of dramatic, dark-sky aurora viewing.
• 6 nights of cruising among scenic fjord ringed by snowcapped mountains.
• A rail journey through some of Norway's most magnificent landscapes.
• 3 days among the fascinating Sami people.
Our Norway adventure is limited, so reserve your
spot under the magnificent aurora borealis today!
TRAVELQUEST international
Astronomy magazine
Astronomy.com/2017-norway
P29576

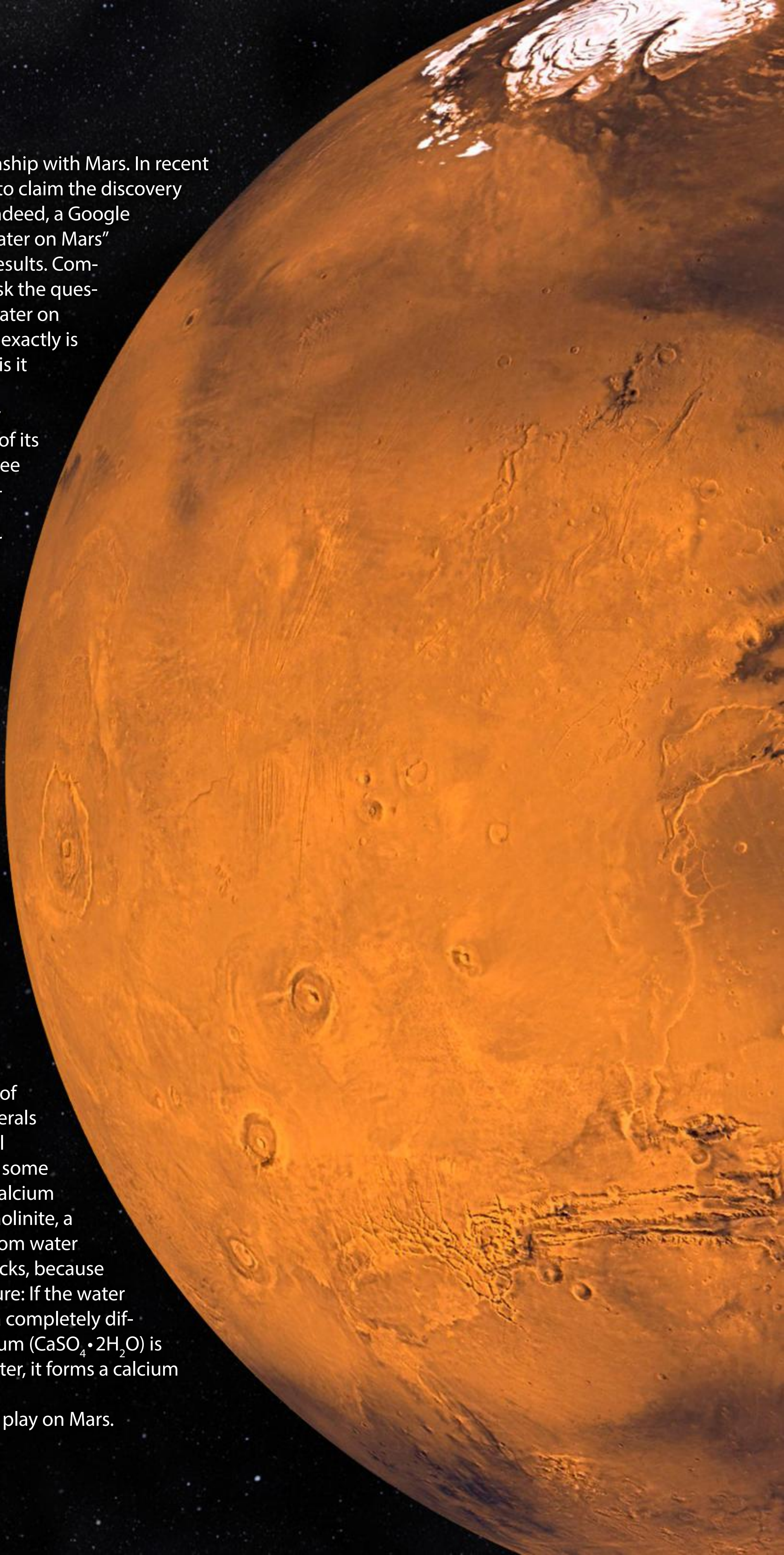


THE PAST AND PRESENT OF WATER ON MARS

Mars has evolved from a lush water planet to a frigid desert, yet water persists there today. **by Tanya Harrison**

Left: This artist's impression of Mars 4 billion years ago shows a land replete with water. ESO/M. KORNMESSER/N. RISINGER (SKYSURVEY.ORG)

Right: Mars appears today as a cold, arid desert hiding the spaces where water still exists. NASA



The public has a funny relationship with Mars. In recent years, repeated stories seem to claim the discovery of water on the Red Planet. Indeed, a Google search for "NASA discovers water on Mars" returns nearly half a million results. Comments on some of these articles often ask the question, "Hasn't NASA already discovered water on Mars?" Other questions may arise: What exactly is it that scientists keep discovering? Why is it repeatedly newsworthy?

To a geologist, water can mean many things. We tend to think of water in any of its three forms: solid, liquid, and gas. All three forms — and evidence of their action — are easily observable on Earth. Look up, and you'll see clouds formed from water vapor. Hillsides often bear scars of rain-carved channels, even after the storms subside. Mountainous regions are capped with snow and host massive valleys carved by glaciers, littered by debris deposited in their wakes.

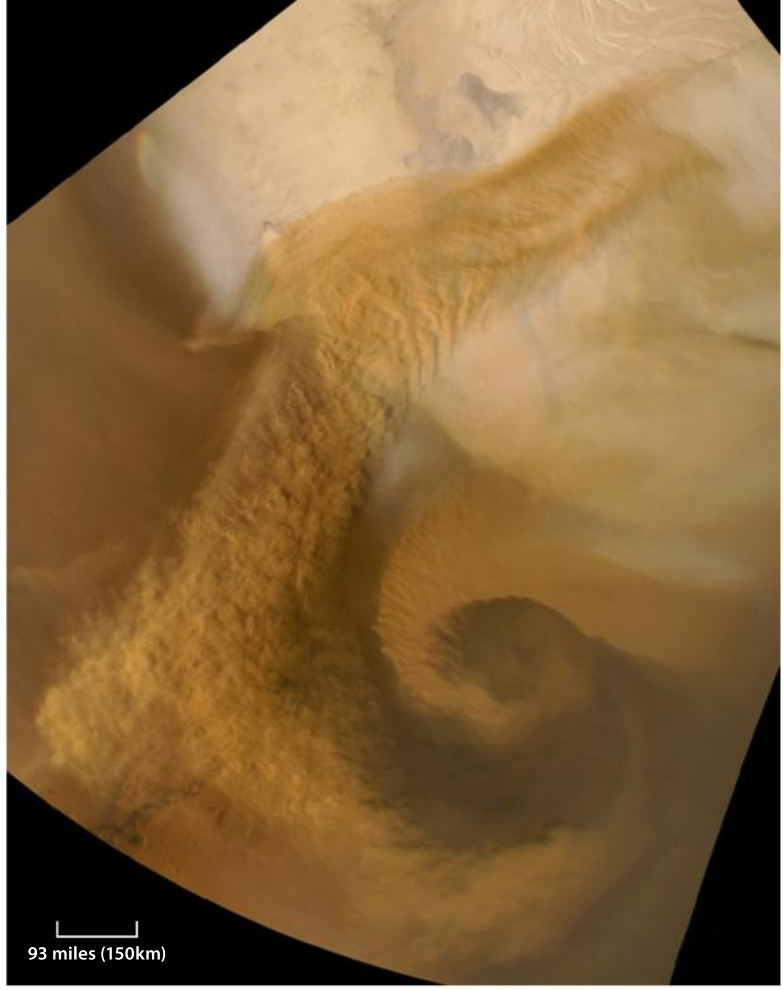
While water is easy to spot in plain sight, it is also often found sequestered within rocks and soil. Pore spaces — the fancy geologic term for "holes" — within rocks and soil can be filled with water in any of its three forms. Liquid water can flow through pore spaces and fractures in rock and soil; pretty much any pore space exposed to the atmosphere will contain some amount of water vapor; and in cold regions like the Arctic, ice can form giant subsurface blocks within the soil.

Water can be incorporated into the crystal structure of minerals in the form of either H_2O or a hydroxyl group, OH. Minerals containing either of these in their crystal structures are called hydrates. On Earth, some common examples include gypsum, a calcium sulfate hydrate containing water, and kaolinite, a clay hydrate. This type of water differs from water merely trapped in pore spaces within rocks, because it is fundamental to the mineral's structure: If the water is removed, the structure changes into a completely different mineral. For example, when gypsum ($CaSO_4 \cdot 2H_2O$) is dehydrated to remove the structural water, it forms a calcium sulfate called anhydrite ($CaSO_4$).

All of these forms of water come into play on Mars.

Left: A close-up image of the martian surface acquired by Mariner 4 reveals heavily cratered terrain in the southern hemisphere. NASA

Right: A dust storm spirals off the northern polar cap. Middle center: Water-ice clouds over Syrtis Major. Far right: A dust storm approaches the area of the Opportunity rover in Meridiani Planum. NASA



Channels, channels everywhere

When Mariner 4 returned the first close-up photos of the martian surface as it flew by in 1964, it passed over several of Percival Lowell's infamous "canals" but (unsurprisingly) saw nothing. In fact, the spacecraft found no evidence of water at all. Instead, it revealed a surface heavily littered with impact craters. The initial report of the geology of Mars from Mariner 4 even stated that it appeared that the planet never had Earth-like oceans. Our scientific view had completely shifted from thoughts that Mars was much like Earth to the sobering realization that the Red Planet — by all appearances at the time — was actually a cratered, dry wasteland much more like our Moon.

While Mariner 6 and 7 revealed unique landforms in their photographs, they also failed to capture any evidence of channels. It wasn't until Mariner 9 entered orbit in 1971 that our view of the Red Planet was revolutionized.

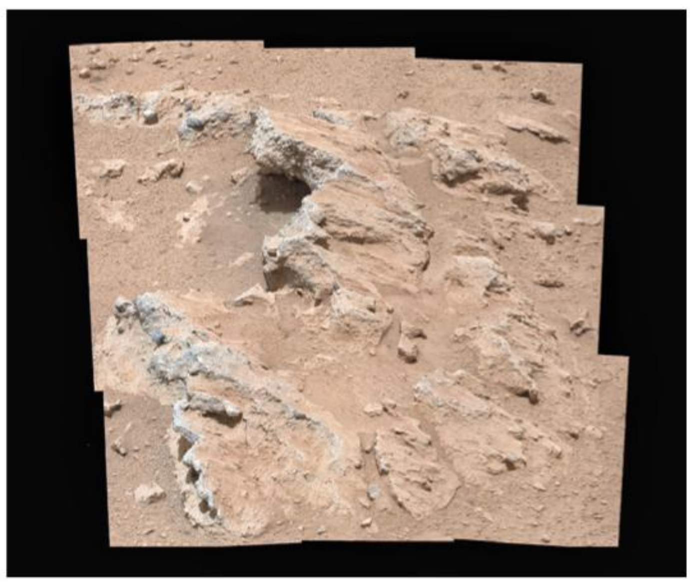
Mariner 9 captured the first images of the Valles Marineris canyon system and the massive outflow channels found nearby, carved by catastrophic floods that were orders of magnitude larger than anything ever observed on Earth. Other images showed smaller ancient valleys with shapes hinting they were carved by rain or snow.

The subsequent Viking orbiters (1976–1980) revealed even more channels and valley networks across the martian surface, along with evidence for possible ancient shorelines of a long-gone ocean in the northern plains. The Pathfinder mission in 1997 landed near the mouth of one of the giant outflow channels, Ares Vallis, where it found rounded rocks and boulders — evidence of transport by catastrophic floods.

The Mars Global Surveyor (MGS) changed our view of Mars yet again from 1997–2006, with its higher-resolution cameras. The onboard Mars Orbiter Camera (MOC), looking at slopes in the middle latitudes, captured images of small channels that appear to have been carved by water within the last tens to hundreds of thousands of years — practically yesterday in geologic terms. MOC also found the first "smoking gun" evidence of sustained flowing water on the martian surface: a preserved river delta in Eberswalde Crater. Deltas form where rivers enter another body of water, such as a lake or ocean. In this case, the river appears to have entered a crater lake.

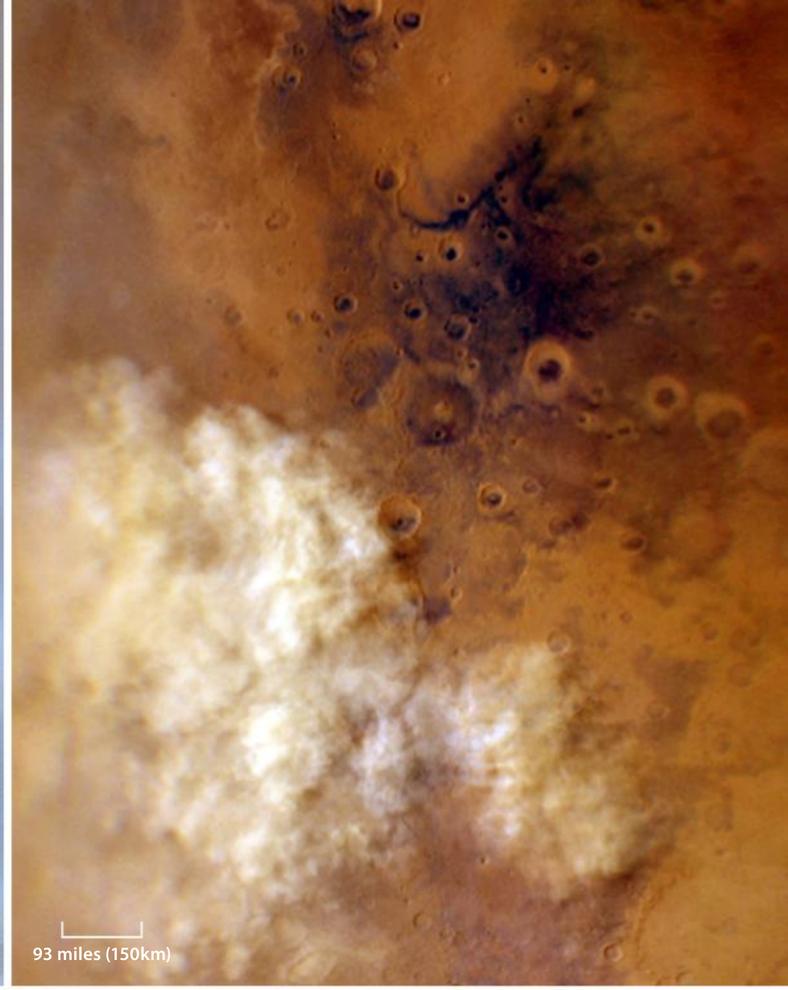
In the rocks

The composition of martian rock provided morphological evidence for past water on the planet's surface, as well as signs of a wetter world than once thought. Hydrated minerals have been detected within martian meteorites here on Earth. These types of minerals have also been observed spectroscopically on Mars, both from orbit and on the ground.



These rocks, called conglomerates, contain clumps of gravel and cobbles, suggesting the presence of a knee-deep stream that traveled at about 3 feet per second. NASA

The Surveyor's Thermal Emission Spectrometer detected crystalline hematite, or iron oxide, from orbit in Meridiani Planum. Since hematite can form in watery environments, Meridiani was chosen as the landing site for the Opportunity rover to investigate the hematite further. When Opportunity arrived in 2004, it found not only hematite, but also a slew of other mineralogical evidence



for ancient surface and subsurface water in the region.

In Eagle Crater, Opportunity found sulfate-rich sandstones with cross-bedded patterns, indicating the sand had been transported by flowing water. The rover also observed "blueberries" — hematite concretions likely formed when groundwater interacted with the sandstones. In Endurance Crater, Opportunity spied more sandstones arising from a shallow lake environment. The sulfate-rich sandstones began as mud at the bottom of the lake, and eventually became cemented into sandstone as the lake evaporated away. Later in its journey, along the rim of Endeavour Crater, Opportunity found mineral assemblages that signaled ancient, long-lived hydrothermal environments. This was an exciting discovery, as hydrothermal environments on Earth are fantastic abodes for microbial life.

Gusev Crater, the landing site for Opportunity's companion rover, Spirit, was chosen based on morphology: The crater's southern and northern rims are sliced through by a large valley called Ma'adim Vallis. This led scientists to hypothesize that Gusev once hosted an ancient lake.

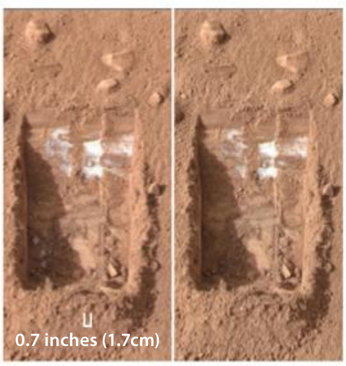
But when Spirit landed in 2003, it found no evidence of a lake. Instead, it found widespread volcanic material; any evidence of a lake had been long buried by lava flows. However, as the rover headed from the crater floor into Columbia Hill and Husband Hill, it spied hydrated sulfates and opaline silica — minerals pointing to past hydrothermal activity. Warm waters likely flowed through the rocks in these hills in a volcanic vent-type setting, leaving these minerals behind as a residue. Not only was this more evidence for habitable environments in the martian past, but silica is great at preserving evidence of microbial life. Because of this, Columbia Hill is currently on the short list of potential landing sites for the Mars 2020 rover, which will cache rock samples to be returned to Earth for analysis by a subsequent mission.

The composition of martian rock provided morphological evidence for past water on the planet's surface, as well as signs of a wetter world than once thought.

The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) aboard NASA's Mars Reconnaissance Orbiter (MRO) scans the martian surface in the visible and infrared spectrums. These wavelengths are well suited to hunting for hydrated minerals because water molecules within the crystal structures of many minerals create strong absorption lines in this range. CRISM has revealed widespread hydrated clays, sulfates, and carbonates across the martian surface.

The geologic setting of each of these finds tells us a lot about how water formed in each specific location. One such location is Gale Crater, the stomping grounds of the Curiosity rover. Within Gale lies a 3.4-mile (5.5 kilometers) tall mountain of layered sedimentary rock informally known as Mount Sharp. CRISM spectral data showed that the mountain's lowest layers contain hydrated clays beneath hydrated sulfates, implying these layers interacted with water at some point in their history.

The composition of those waters must have varied over time as well, as clays and sulfates are deposited under very different conditions (neutral vs. acidic). One hypothesis is that the lower layers of Mount Sharp were deposited in an ancient lake within the crater. In



Above: A thin layer of water frost covers Mars' surface at sunrise (about 6 A.M. local time) in the northern plains. This image, captured by the Phoenix lander, has been enhanced to show color variations. NASA

Left: Buried water ice is exposed just centimeters below the surface in these trenches dug by NASA's Phoenix lander in the northern plains in 2008. Over the course of a few sols, this ice began to sublimate. The pictures displayed here were taken four sols apart. NASA/JPL-CALTECH

Gullies on the pole-facing wall of Niquero Crater in the southern midlatitudes of Mars point to past movements of water. NASA/JPL-CALTECH/MSSS

addition, the walls of Gale Crater are covered with many small valleys that appear to have been carved by flowing water.

Curiosity landed on top of a fan of sediment associated with the largest valley in the northwestern part of the crater, called Peace Vallis. The rover quickly found ample evidence that it was indeed an alluvial fan, composed of material transported by water flowing through the valley. As Curiosity drove from Peace Vallis toward Mount Sharp, it discovered morphological and mineralogical evidence (such as hydrated salts) that Gale Crater hosted a series of lakes and streams about 3.8 billion to 3.3 billion years ago — another potential harbor for life.

Frozen in time

The northern polar cap is the largest reservoir of water on the surface of Mars today. Humans have known about both polar caps since the 17th century, when Giovanni Cassini and Christiaan Huygens first observed them through telescopes. (If you've ever looked at the Red Planet through even a poor-quality telescope, you can make out the bright white polar caps.) For nearly as long, we've observed the polar caps growing and shrinking with the seasons. This change is due to deposits of frost on the surface in late fall through winter.

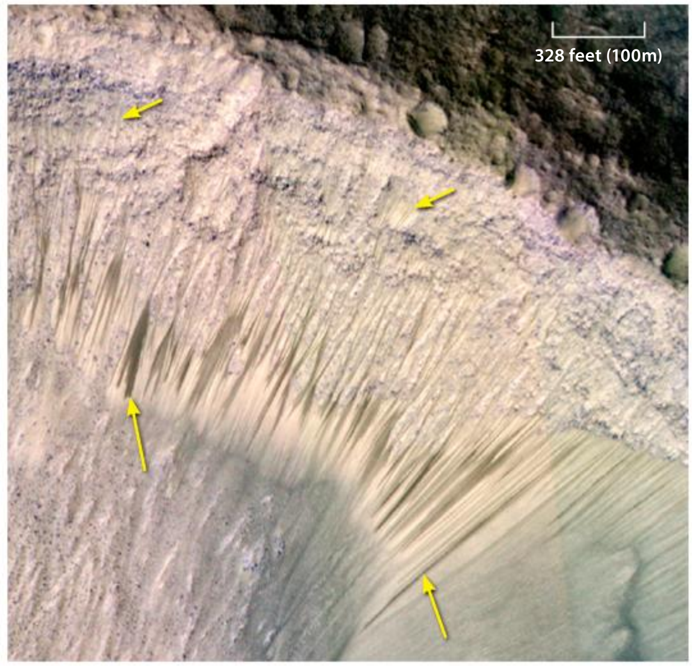
Mars has evolved from a world of rain and rivers to a dusty land of ice and frost. The more we look, the more water we seem to find on Mars.

The part of the cap that sticks around throughout the year is known as the residual cap, while the frost is dubbed the seasonal cap. Scientists speculated that the frost could be water ice, based on observations of the south polar seasonal cap from Mariner 6 and 7, but they thought it was more likely to be carbon dioxide. It turns out both cases are true: Water and carbon dioxide frost are deposited onto the surface, although the latter dominates. In springtime, when temperatures start to rise, this frost sublimates: It goes directly from solid to vapor without passing through the liquid phase (with the possible rare exception under perfect temperature and pressure conditions). When this happens, it can trigger avalanches of loose debris, as well as the formation of uniquely martian landforms informally known as "spiders."

Other landforms hinted at the presence of ice below the surface. The Viking orbiters imaged giant polygonal features in the northern plains. On Earth, polygonal terrain forms in areas with subsurface ice due to freeze-thaw action. Many of the areas of Mars hosting these polygons were found to have elevated concentrations of hydrogen with the MGS' Gamma Ray Spectrometer. Hydrogen doesn't tend to hang around on its own in rocks, so detecting it in a planetary surface is generally a proxy for water ice. In 1997, the Phoenix lander set down in an area of the northern plains covered with these polygons. With its robotic arm, Phoenix proceeded to dig a dozen trenches around its permanent home. In every single trench, it found icy soil. Some of the trenches even exposed slabs of nearly pure water ice buried under only a few centimeters of soil.

Almost serendipitously, scientists found another way to examine this buried ice: new impact craters. Between MGS and MRO, hundreds of newly formed impact craters have been spotted on the martian surface. In 2008, a few of these new impact craters in high latitudes were observed with MRO and found to have exposed light-toned, bluish material. Further investigation determined that this material was nearly pure water ice — like at the Phoenix site, it was buried by a very thin layer of soil.

Ground-penetrating radar also revealed buried water ice on Mars. The Viking orbiters captured images of landforms in Mars' middle latitudes that look similar to features created from flowing glaciers on Earth. Data from the Shallow Radar (SHARAD) instrument aboard MRO confirmed that these features are composed of nearly pure water ice buried by a thin (on the order of meters thick) layer of debris. SHARAD has also revealed two massive deposits of nearly pure water ice buried by only meters to tens of meters of soil beneath parts of Mars' northern plains — each roughly the volume of Lake Superior.



Arrows point to recurring slope lineae on the south-facing slope of a crater in Valles Marineris. These features are possibly formed by salty water flowing on the surface during warm periods. NASA/JPL-CALTECH/UA

Summer flows and winter snow?

While flowing liquid water has not been directly observed on Mars today, there are signs that it has potentially made some brief appearances on the surface. Repeat imaging of gullies by MOC revealed new flows of material within some gully channels. These were initially attributed to landslides abetted by a small amount of liquid water from melting or groundwater release.

However, continued monitoring with MRO hints that this activity may be due to frost-related processes. More recently, MRO discovered features dubbed recurring slope lineae — dark streaks that form on steep slopes during warm periods, grow incrementally over short periods of time, and then gradually fade. Their shape and growth suggests liquid water may be involved. Spectral data from MRO found the slopes on which lineae occur bear hydrated perchlorate salts, which can act as an extreme freezing-point depressant for water. This could allow liquid water to remain stable at martian surface temperatures and pressures for brief periods. Phoenix observed droplets of brine on its landing struts, likely thanks to perchlorate salts excavated from the martian soil by its descent rockets. Via a process called deliquescence, salts can absorb water vapor from the atmosphere until they dissolve, forming liquid brine. Deliquescence could be the agent behind these lineae as well, although melting or groundwater release, similar to the processes that form gullies, have also been proposed.

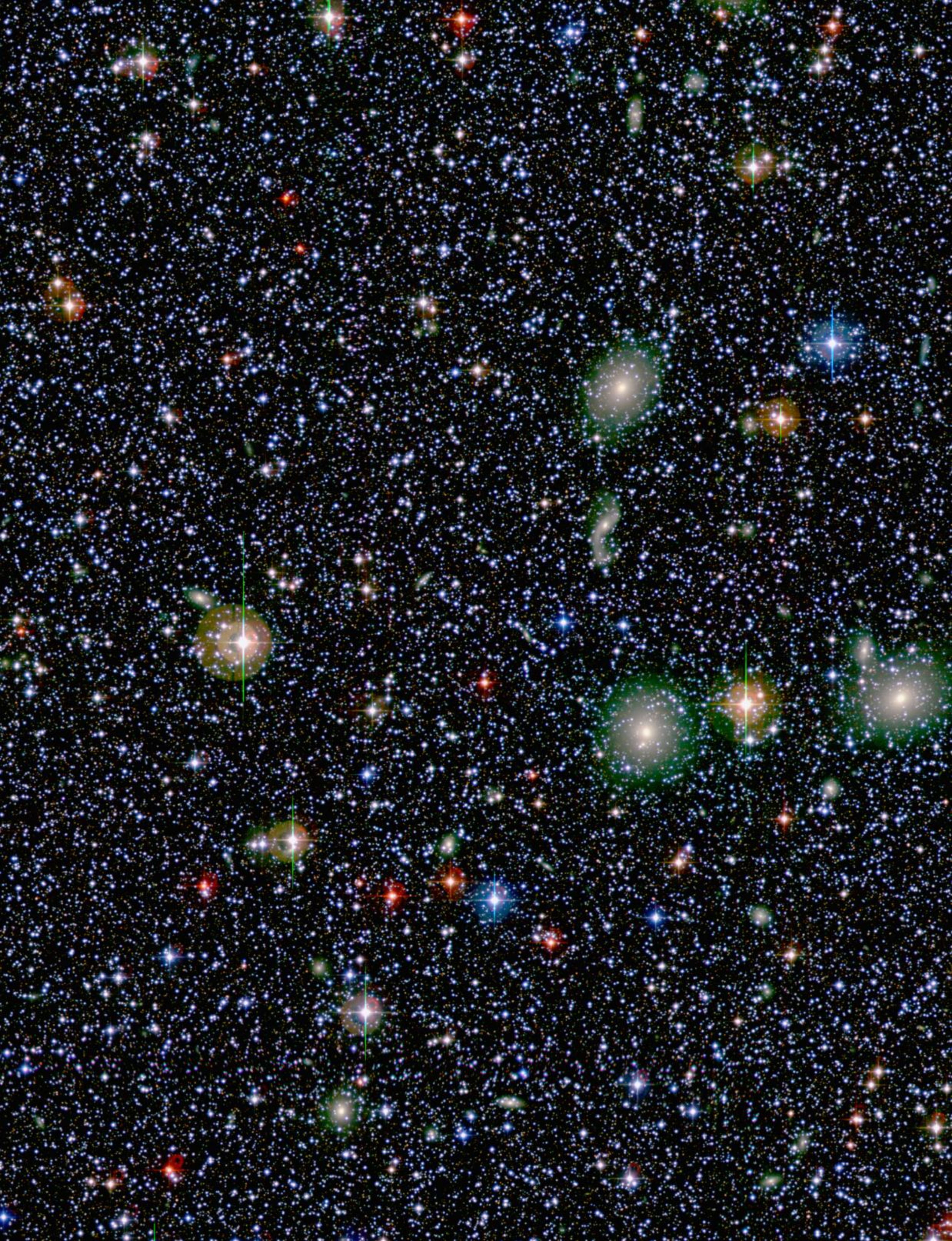
The dendritic shape of the ancient Warrego Valles suggests this network of channels was carved by rainfall. ESA/DLR/FU BERLIN (G.NEUKUM)

The presence of water vapor in the martian atmosphere was discovered spectroscopically in 1867 by English astronomer William Huggins. Over the next few decades, a series of papers came out in the journal *Science* by other astronomers validating the detection. Viking found that clouds in the atmosphere were composed of water ice, similar to cirrus clouds on Earth. These clouds show up prominently in color images of Mars, where they look a wispy whitish-blue compared with the pink of dust clouds.

Long-term monitoring of martian weather with MOC and the MRO Mars Color Imager (MARCI) helped to reveal patterns in these clouds. They tend to form over topographic obstacles, such as the summits of the large Tharsis volcanoes. In northern summer, they form a distinct band across the equatorial regions, when the atmosphere is laden with water vapor from the sublimation of the northern residual polar cap. Phoenix conducted the first in-depth studies of clouds from the surface with its Canadian-built meteorological station. Using LIDAR, it observed ice crystals precipitating from the clouds — the first evidence for snow on Mars. However, this snow never reached the surface, but rather sublimated away in the drier atmosphere beneath the clouds.

Mars has evolved from a world of rain and rivers to a dusty land of ice and frost. The more we look, the more water we seem to find on the planet. This is incredibly significant because on Earth, anywhere there's water, there's life — from the driest deserts to frozen glaciers, even inside clouds. So perhaps, locked away beneath Mars' shroud of red dust, microbial life is waiting to be found.

Tanya Harrison *(@tanyaofmars on Twitter) is a research scientist at Arizona State University specializing in martian surface processes.*



The cosmic bullies next door

How vast superclusters rule the tiny collection of galaxies we call the Local Group.

by Liz Kruesi

IN 1994 astronomer Renée Kraan-Korteweg spotted some 600 galaxies lying the same distance away from us, all clustered around the constellations Hydra and Vela. These findings hinted that the region might harbor an enormous structure, perhaps a supercluster, though learning more about it would not be easy. These galaxies sit behind the Milky Way's dense disk, which holds billions of stars and enormous clouds of dust, materials that obscure background light signals.

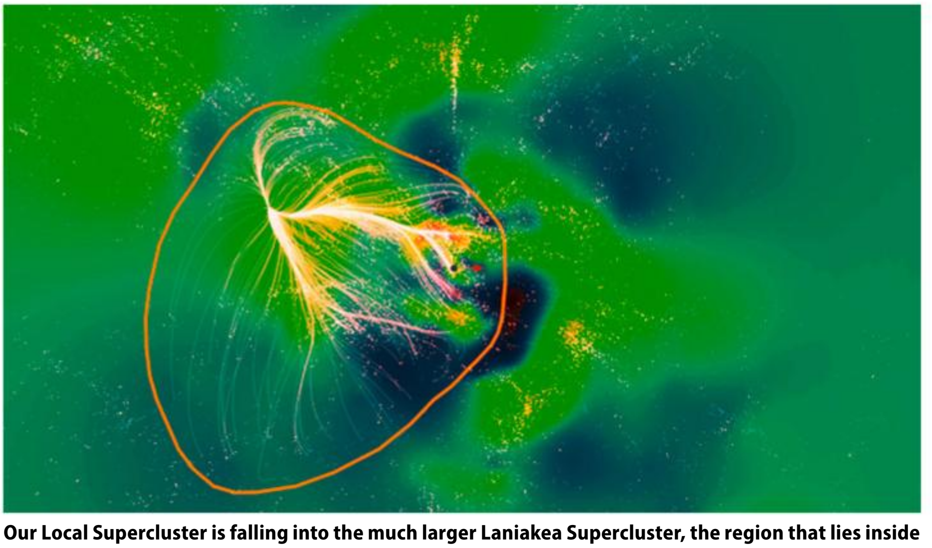
To study what lies behind this region, aptly named the "Zone of Avoidance" (ZOA), you need to find a way to subtract the dust from observations and use instruments advanced enough to separate foreground stars from background light. It's a lot of work, it takes a lot of time, and scientists in charge of those high-end instruments aren't always keen to allot time to difficult projects with no guarantee of discovery.

But over the next couple of decades, Kraan-Korteweg chipped away at the problem. In 2000, she persuaded the 6-degree Field Galaxy Survey team to use commissioning time to study the region. After analyzing the data, she learned that practically all the thousands of galaxies over the 12° of sky she studied lie at that same distance. She used radio surveys to study the hydrogen in galaxies behind the ZOA. She used infrared telescopes to peer through the Milky Way's dust.

And with each project, time after time, she kept returning to the unexplained conglomeration of galaxies. "It all seemed endless [for it] to come together," she says. But last year, Kraan-Korteweg and her team confirmed that

Galaxy cluster Abell 3627 lies at the heart of the Great Attractor — a massive collection of several large clusters that tugs the Milky Way and all nearby galaxies toward a spot in the constellations Norma and Triangulum Australe. The Great Attractor escaped notice until the 1980s because it lies behind the Milky Way's obscuring disk. ESO

The 2,000 galaxies of the Virgo Cluster reside 55 million light-years from Earth. This cluster marks the center of the Local Supercluster, a region that spans some 150 million light-years. Our Local Group of several dozen galaxies lies on this supercluster's outskirts. ESO/DSS2



Our Local Supercluster is falling into the much larger Laniakea Supercluster, the region that lies inside this map's orange contour. The twisting white lines show the velocity flows of individual galaxies within this 500 million-light-year-wide supercluster. R. BRENT TULLY, HÉLÈNE COURTOIS, YEHUDA HOFFMAN, AND DANIEL POMARÈDE

those thousands of galaxies belong to an enormous supercluster behind the ZOA and some 800 million light-years from Earth. "This supercluster just didn't want to be detected," she says.

Although the so-called Vela Supercluster is perhaps the most surprising large structure found in our local universe, it isn't the only one discovered recently. In 2014, another group of astronomers revealed that our neighborhood of galaxies, called the Local Group, and its home supercluster belong to a massive gravitational structure called Laniakea Supercluster.

With more than 400 years of telescope technology and decades of mapping the cosmic web, how can astronomers still be uncovering such enormous collections of galaxies in our corner of the cosmos? And is there any other place for large structures to hide?

To find such structures, astronomers spread out the light from galaxies into spectra. In each one, "you look at signatures in that spectrum that correspond to certain chemical processes, such as hydrogen gas being warmed by stars or cold gas absorbing light from a background star," says Mehmet Alpaslan, who studies the web of cosmic structure at NASA's Ames Research Center. Astronomers then compare that light signature with the color of light produced by the same chemical process in laboratories on Earth. They'll find a slight difference in color because the expansion of the universe stretches the galaxy's light and thus shifts its color to a redder hue, creating a "redshift." From that difference, astronomers can measure the distance to the galaxy.

"Once we have distance estimates and we know the positions on the sky," says Alpaslan, "we apply different algorithms to the data to identify these structures. I kind of joke about the fact that it's almost like a game of connect the dots." Ultimately, gravity binds these structures together.

Our neighborhood

The Milky Way, the Andromeda Galaxy (M31), the Pinwheel Galaxy (M33), the Large and Small Magellanic Clouds, and dozens of smaller and fainter galaxies are gravitationally bound together in what's known as the Local Group. Within our home group, which has a diameter of only about 10 million light-years, interactions have been common. For example, our galaxy's outer region hosts remnants of dwarf galaxies the Milky Way has torn apart and spit out. Our home galaxy and Andromeda are also on a collision course, with a target date billions of years in the future.

If we could hop in a spacecraft and tour the local universe, we'd quickly pass many groupings of dozens of galaxies, each like our Local Group. These galaxy collections adhere to a gravitational pull centered in the constellation Virgo, home to the nearest large galaxy cluster, the Virgo Cluster.

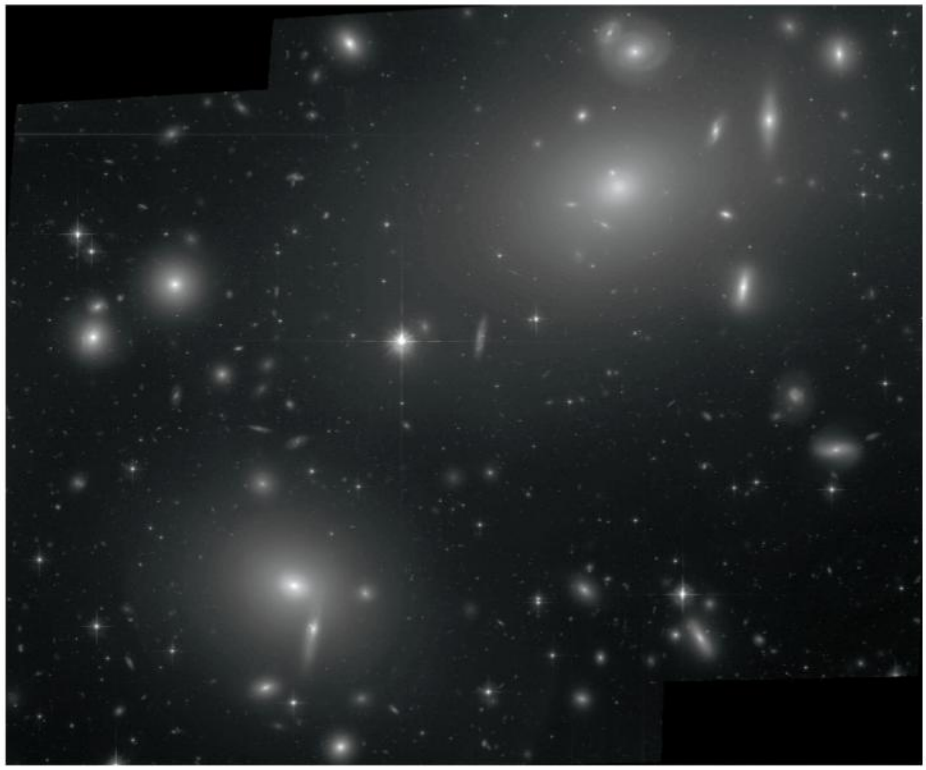
As our spacecraft travels farther out, we'd find dozens of other galaxy clusters in our neighborhood, all bound together by gravity. The galaxy clusters clump together, sometimes as cylindrical filaments and other times into more extended structures called walls. The roughly 100 groups and clusters within about 150 million light-years make up the Local Supercluster, also known as the Virgo Supercluster. The Local Group is an outlying member, clinging to the supercluster's gravitational edge. But it's a minor supercluster, younger and smaller than most seen in the universe. In fact, some astronomers wouldn't even define the structure as a supercluster at all.

Toward a great attractor

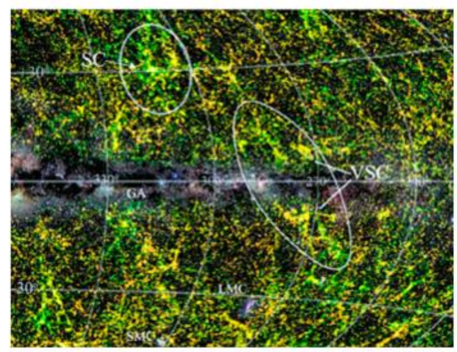
Whatever you call it, the Local Supercluster is still moving toward, or "falling into," another region. In the 1980s, when astronomers looked at the spectra of galaxies within 100 million light-years of Earth and compared them with the movement expected from cosmic expansion, they realized that our neighborhood is moving toward a region in the southern sky at 370 miles per second (600 km/s). Some conglomeration of mass — for which scientists had long been searching — is pulling us and all nearby galaxies toward it. They dubbed this mass concentration the "Great Attractor," but more recent work suggests it's likely not one attractor, but many.

Hélène Courtois of the University of Lyon and her colleagues announced in 2014 that the Local Supercluster is actually connected to and falling into the center of a larger structure, called Laniakea. To reach this conclusion, they used a method different from traditional cosmic-structure mapping surveys. Instead of relying solely on the redshift of galactic light, the team mapped the movements of objects: Where are galaxies flowing toward, and how fast are they getting there? Gravity controls motions in the universe, so by measuring the movements, you can measure gravity's pull, which reveals mass and distance.

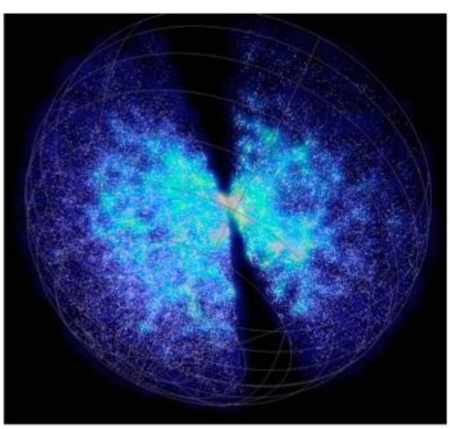
To map the motions, Courtois and her colleagues follow multiple steps. First, you need to understand that a galaxy's measured velocity is composed of two parts, says Courtois. One part is due to the universe's expansion; the second part is the attraction the galaxy feels from all the matter surrounding it. "This means we subtract the general expansion of the universe," says Courtois, and the "expansion is very, very fast, while the gravitational motions are very slow." In the galaxies her team focused on to reveal Laniakea, motion due to expansion was 10 times as fast as movement caused by gravitational pulls.



Above: With a mass of 10 million billion Suns, the Shapley Supercluster is the most massive structure in the local universe. It holds more than 40 galaxy clusters centered on Abell 3558, a small portion of which appears in this image. NASA/ESA/STScI/J. BLAKESLEE (WASHINGTON STATE UNIVERSITY)



Right: The newly discovered Vela Supercluster (VSC) consists of two large groups of galaxy clusters — one north of the Milky Way's plane and the other south — that lie about 800 million light-years from Earth. Astronomers suspect the structure continues behind our galaxy's disk. THOMAS JARRETT (UCT)



More than 125,000 galaxies pepper this map of the southern sky. At a glance, it reveals how galaxies in the local universe clump together, and how these structures cluster into vast filaments and walls. The two dark wedges mark the regions of extragalactic space blocked by stars and dust clouds in the Milky Way. C. FLUKE/6dFGS

The astronomers measure a galaxy's entire velocity from its redshift, the same way that other researchers find a galaxy's rough location, but the next step is different. They need to calculate the galaxy's precise position so that they can determine its expansion speed exactly. To do this, they use the largest radio telescopes across the globe to detect hydrogen in individual galaxies. It takes only a handful of minutes to measure the speed of rotation of that gas and thus of the galaxy itself, says Courtois. It turns out that the galaxy's rotation is directly related to how much light the galaxy emits, called its intrinsic luminosity. "So if I can measure the rotation of the gas, actually I have the measure of how bright it is in watts," says Courtois.

Next, they use optical and infrared telescopes to snap photographs of the galaxy, which tells them how bright it appears. They compare the observed brightness

EMPTINESS MATTERS

It's not only the superclusters, filaments, and walls that matter in our local universe — so does the emptiness between them. "It's like a tug of war game," says Hélène Courtois. The rope is pulled toward more mass, while being pulled away from less mass. In the same manner, the empty regions of cosmic structure — voids — are important because they enable mass to flow.

The nearest large void to us is the Local Void, which is centered some 75 million light-years away. Although it spans about 100 million light-years, astronomers discovered a larger void just last year that has a much greater effect on our movement.

Courtois and her Cosmic Flows colleagues announced their discovery, called the Dipole Repeller, in January. To find it, they used the same method of mapping the motions of galaxies, but with a twist. "Instead of trying to look where the velocities are going, we wanted to visualize where they come from," says Courtois. And those motions stemmed from an empty region centered about 650 million light-years from Earth that is perfectly anti-aligned to our motion toward the Great Attractor. — *L. K.*

Spiral galaxy NGC 6503 in Draco appears isolated, and for good reason. Despite lying only 18 million light-years from Earth, this solitary object resides on the edge of the Local Void, a vast region that spans some 100 million light-years and is centered 75 million light-years away. The lack of galaxies in the void's direction helps pull the Milky Way in the opposite direction. NASA/ESA/DSS2

with the intrinsic luminosity to measure the galaxy's precise distance, and from that, they can calculate its movement due to cosmic expansion. Then they subtract that value from the velocity determined by redshift. "We spend all of our time measuring the distance of galaxies in order to remove the expansion and to see finally the gravitational motion," says Courtois.

When they mapped the movements caused by gravity alone of more than 8,000 galaxies, they found all of them moved toward one place — what became known as the heart of Laniakea. Courtois likens Laniakea's central region to a valley, toward which the rivers of material flow. Perhaps the long-hunted Great Attractor lies at the heart of this 500 million-light-year-wide supercluster.

Except the solution isn't that simple. Other heavyweight structures nearby are also exerting their pulls.

An old friend

Just outside Laniakea lies a much more massive structure that astronomers have known about for decades. First studied in the 1930s, the Shapley Supercluster — named for Harlow Shapley, who first uncovered it — is the most massive assembly of objects in our local universe. It's a collection of more than 40 galaxy clusters and dozens more smaller systems (that telescopes have so far resolved), and it holds the mass of 10 million billion Suns. This supercluster lies toward the constellation Centaurus at a distance of some 600 million light-years, though different sources give estimates that range anywhere from 500 million to a billion light-years.

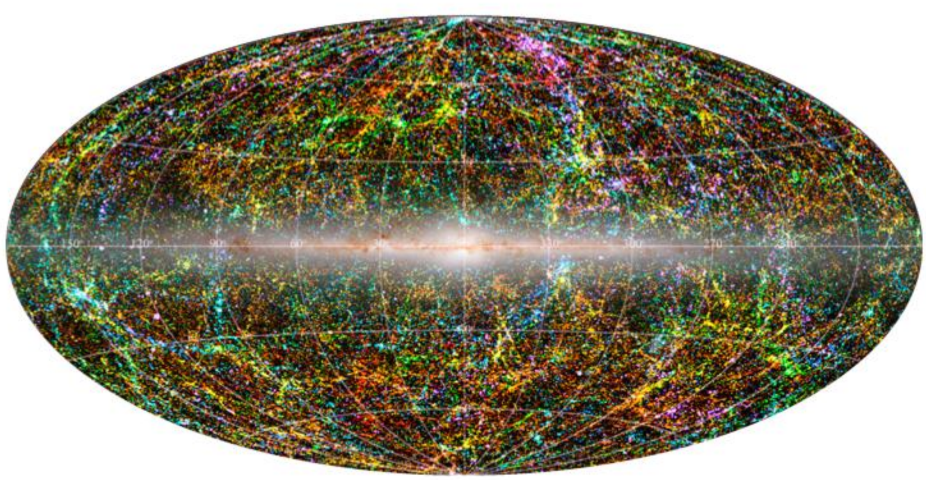
Recent research shows that Shapley spans more than 120 million light-years and has a densely packed core. Over time, gravitational interactions seem to have slowed, and the constituent galaxy clusters have settled. This stability implies that the supercluster has reached "equilibrium," a characteristic that means it is an evolved and older supercluster.

Both Shapley and the heart of Laniakea lie in the same direction on the sky — the spot toward which the Milky Way is being pulled. But even these two structures don't fully explain our motions.

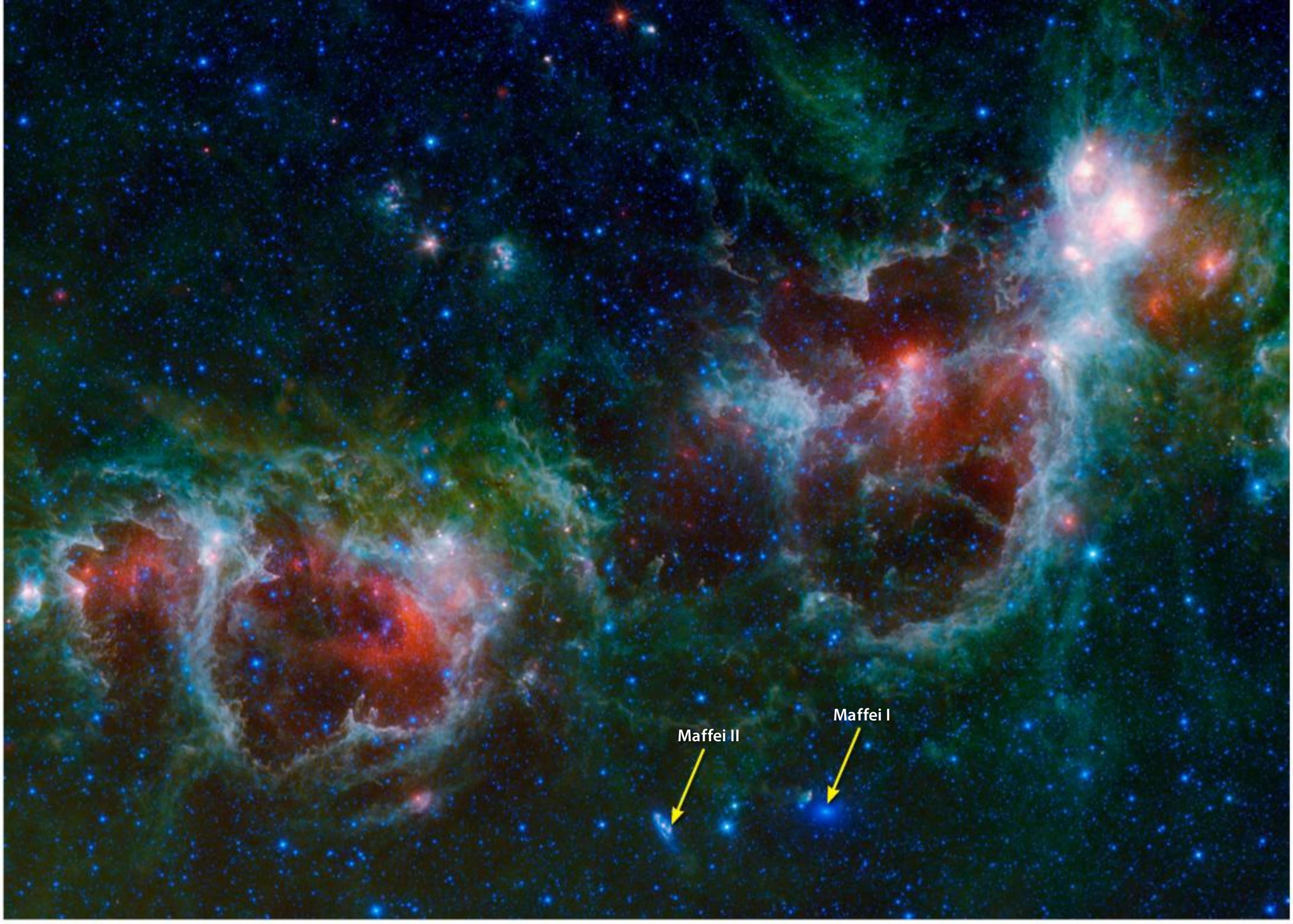
The newest pull

Kraan-Korteweg knew that another massive structure was hiding behind the ZOA, and uncovering it would be tricky. Part of that trickiness arose in convincing telescope operators that the observing time would lead to results. "People say, 'Well the Zone of Avoidance — it's too dusty, it's too difficult, you can't see anything in the optical,'" says Michelle Cluver of the University of Cape Town, who was part of Kraan-Korteweg's team that discovered the Vela Supercluster. "And it's really not true."

In 2014, these two and their colleagues proved that fact. During six nights of observing, the researchers operated like a well-oiled machine. Kraan-Korteweg picked the fields of view that were most likely to hold part of this shy structure, while Cluver ran each spectrum through a simple computer algorithm to measure how far from Earth each galaxy lay. "It was



Roughly 1.5 million galaxies scatter across the local universe in this all-sky view taken at near-infrared wavelengths. Each galaxy is color-coded by its distance from Earth, with blue objects closest to us, green objects at intermediate distances, and red objects farthest away. The plot shows normal galaxies out to a distance of 1 billion light-years. THOMAS JARRETT (IPAC/CALTECH)



NASA/JPL-CALTECH/UCLA

Although the Milky Way's stars, dust, and gas create a Zone of Avoidance that blocks optical light, infrared radiation penetrates most of this material. Galaxies Maffei I and Maffei II shine through the galaxy's plane in this infrared view showing the Heart (IC 1805, right) and Soul (IC 1848) nebulae.

unbelievable how practically all the galaxies were at a similar distance and over an extended region," says Kraan-Korteweg.

The astronomers measured thousands of galaxies at the same distance from Earth, about 800 million light-years. They uncovered one conglomeration below the Milky Way's plane, and another above. Clearly, gravity holds these structures together, but how tightly? The team thinks the fact that galaxies are seen on both sides of the plane means there's some sort of connection. But how much mass sits behind the plane and how the two groupings connect are extremely important pieces to the puzzle of the Vela Supercluster.

If Vela has a massive central core, the supercluster could hold as much mass as Shapley. But if the two conglomerations are actually separate superclusters in the process of merging, Vela would be less massive than Shapley.

Although there's no hope of seeing behind the Milky Way's dense disk and its billions of swarming stars using optical light, these astronomers do hope to uncover more of Vela with a radio telescope array called MeerKAT, now coming online in the Northern Cape of South Africa. They'll look for a specific wavelength of radio radiation characteristic of hydrogen that passes through the ZOA mostly unhindered. The amount of hydrogen they observe in each Vela member will provide an estimate of the galaxy's mass. (Kraan-Korteweg recently used another, less sensitive radio telescope to discover hundreds of galaxies hiding behind the Milky Way's plane.)

Another way to measure Vela's mass is to study the motions of its member galaxies and map how they're falling into the supercluster. That's what Courtois does with the Cosmic Flows group, and Kraan-Korteweg is working with Courtois and her colleagues to look at the flows. Although the work is still preliminary and no paper has been published, "We see the pull of Vela," says Courtois. "We identify highways in the network of motions of matter. There is a highway that is linking us to Shapley, and Vela is en route. It's one big city on the highway."

Other neighbors?

Our local universe seems to be infested with enormous structures: Shapley, Laniakea, and Vela. Surely by now, astronomers have found all the major mass concentrations in our neighborhood, right? Yet not one of the dozen cosmic cartographers I spoke to thinks our entire local universe has been revealed.

After all, the Cosmic Flows project — which last year released its newest catalog and more than doubled its observed galaxy motions, from about 8,000 to nearly 18,000 — has only just started analyzing all those motions. In January, the project announced yet another structure. (See "Emptiness matters," p. 32.) Plus, all the Cosmic Flows data are publicly available for other astronomers to search through, offering them the chance to find even more structures.

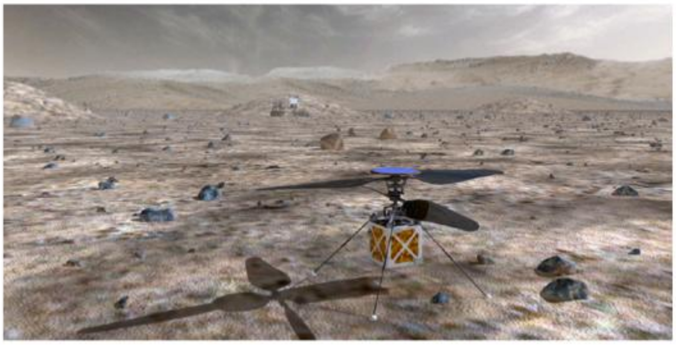
And then there's Kraan-Korteweg's work, which has proven it's possible to peer through much of the material in the Milky Way's plane and reveal structures in this long-avoided area. What else might the ZOA hide? "We feel like sailors of old, going into entirely foreign waters," says Cluver. They're following the cosmic flow — wherever it comes from and points to.

Contributing Editor **Liz Kruesi** *writes about the universe from Austin, Texas.*

DRONES ON MARS

Q: IN THE TV SERIES *MARS* ON NATIONAL GEOGRAPHIC, WE SEE DRONES FLYING ON THE RED PLANET. CAN DRONES LIFT OFF AND FLY IN MARS' ATMOSPHERE?

Guillermo Pena, *Ciudad del Carmen, Campeche, Mexico*



A Mars helicopter could vastly increase the distance a rover could cover each sol, as well as help identify science targets. This artist's rendition shows one possible design. NASA/JPL-CALTECH

A: Drones can fly on Mars. Although the martian atmospheric density is around 1 percent of Earth's, the gravity is only about one-third of Earth's. As a result, small, lightweight helicopters can fly on Mars. Tests in vacuum chambers pumped down to Mars' atmospheric pressures at NASA's Jet Propulsion Laboratory have demonstrated that fully autonomous lightweight helicopters can achieve controlled flight. Mars' thin atmosphere would limit the size (and mass) of large helicopters, but small drones are possible.

Scientists are particularly interested in the unique capabilities that small helicopters could bring to the exploration of the Red Planet. Presently, NASA has two rovers operating on Mars. Because of the great distance between Earth and Mars, it can take light up to 24 minutes to travel between the two planets in one direction. This one-way light time delay does not allow real-time operations. Instead, all rover operations are compartmentalized into instructions for a full sol (the term for a martian day). The instructions are transmitted ahead of time and carried out autonomously by the rover each day. Although high-resolution orbital images help plan where the rover will traverse, the daily drives require surface images from the rover itself to identify rocks below the resolution limit of orbital images and find a safe path. This requires that end-of-drive images of the terrain ahead be returned to Earth in time for the next rover planning cycle, limiting the distance the rover can drive in a sol to about as far as can be seen from the rover (about 330 feet [100 meters]).

Images from a flying helicopter could dramatically improve surface operations. Tests show that even a simple, lightweight drone with a single cellphone camera communicating to a surface rover could fly sorties over hundreds of meters at heights that could provide overlapping stereo images at a resolution 10 times higher than those obtained from orbit. The images could identify key regions for study by the rover and provide regional context. The helicopter could also fly the rover's path in advance and provide stereo images to operators on Earth that could triple the distance the rover could drive in a sol. These tasks are just one example of the dramatic improvement that even simple, lightweight drones could offer humankind's exploration of Mars.

Matthew Golombek
Senior Research Scientist,
Jet Propulsion Laboratory,
California Institute of Technology,
Pasadena, California

The zodiacal light glows shortly after sunset at the European Southern Observatory's La Silla Observatory in Chile. The "horizon" at the bottom is actually the clouds and mountain peaks that sit below La Silla's 7,874-foot (2,400 meters) altitude. ESO/Y. BELETSKY

Q: IS THERE A BEST TIME OF THE YEAR TO OBSERVE THE ZODIACAL LIGHT? IS IT BETTER TO SPY IT AT SUNSET OR SUNRISE?

Doug Kaupa
Council Bluffs, Iowa

A: The zodiacal light can be observed as a diffuse triangle of light extending up from the horizon before dawn or after sunset. It is caused by sunlight scattering off dust particles in the zodiacal cloud — the debris disk of our solar system. This disk of dust, which blankets the inner solar system and extends outward from the Sun to about the orbit of Jupiter, primarily originates from dust released by cometary sublimation and as a result of asteroid collisions. These interplanetary dust particles typically range in size from a few micrometers up to a few centimeters.

The zodiacal light has long been observed and, according to biblical sources, ancient astronomers referred to it as the "wings of the morning" because it sometimes appears before sunrise, signaling the dawn.

Zodiacal dust particles predominantly orbit in the ecliptic plane — the same plane as the orbital motion of Earth and the planets. Therefore, the best time to observe the zodiacal light is when the tilt of Earth's rotational axis projects the ecliptic plane almost perpendicular to the horizon at sunrise or sunset. This happens at the equinoxes. During these times, the zodiacal light will appear as an upright cone of light on the horizon. In the Northern Hemisphere, the best time to observe the dust at sunset is on the western horizon about an hour after dusk around the time of the spring equinox (March-April). If you want to observe it at sunrise, look toward the eastern horizon before dawn around the time of the autumnal equinox (September-October).

One way to distinguish the zodiacal light from that of actual dusk is that the zodiacal light won't appear reddish (an atmospheric effect), since it is originating from well outside Earth's atmosphere.

Ashley Kehoe
Assistant Professor of Astronomy, Embry-Riddle Aeronautical University, Daytona Beach, Florida

---

Q: IS THERE ONE PART OF THE ELECTROMAGNETIC SPECTRUM THAT IS THE MOST FRUITFUL FOR OBSERVATIONS, OR ARE THEY ALL EQUALLY PROFITABLE?

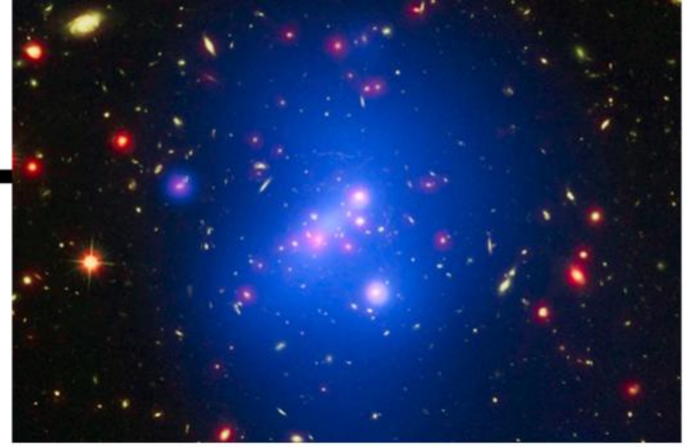
Peter Burbery
Huntington, West Virginia

A: It is certainly true that different spectral regions have specific advantages for observing various classes of astronomical objects. For example, infrared wavelengths are well suited for observing cool objects such as brown dwarfs and planets or penetrating obscuring interstellar or circumstellar dust. However, because different spectral regions probe different physics, coverage of as much of the electromagnetic spectrum as possible is always a desirable goal. Even an obviously visible target such as our Sun has been extensively studied from radio to gamma-ray frequencies, with each spectral region providing insight into the atomic, molecular, and magnetic phenomena occurring at different levels in the solar atmosphere.

An example of this multispectral synergy is the fast radio burst (FRB) source FRB 121102. FRBs are intense millisecond bursts of radio emission of unknown origin. This particular source was originally discovered by the Arecibo radio telescope, but was unusual in that the bursts repeated at irregular intervals. The Arecibo observations could provide only an approximate location in the sky, but the repeatability allowed follow-up observations with the Very Large Array and the European Very Large Baseline Interferometer to provide an extremely accurate radio position coinciding with a faint dwarf galaxy. Additional optical observations with the Gemini North 8.2-meter telescope yielded a spectral redshift distance of more than 3 billion light-years. Identification of this FRB with a specific target will enable additional observations at other wavelengths.

The developing field of time-domain astronomy studies phenomena that change over short periods of time, ranging from exoplanet transits to one-off events such as supernovae or neutron star mergers. Multiwavelength coverage is really important in getting to the physics of these objects, and the need for a fast response because of their transient nature is a challenge. For example, gamma-ray bursts can produce a short-lived "afterglow" observable from radio through X-ray wavelengths, but must be followed up on quickly.

Richard Joyce
Telescope Scientist and Instrument Scientist, National Optical Astronomy Observatory, Tucson, Arizona



Astronomers have imaged the galaxy cluster IDCS J1426.5+3508 in multiple wavelengths: optical (green), infrared (red), and X-ray (blue). This multiple-wavelength coverage reveals clues of past interactions and shows where stars, dust, gas, and even dark matter reside today.
X-RAY: NASA/CXC/UNIVERSITY OF MISSOURI/M. BRODWIN ET AL.; OPTICAL: NASA/STSCI; INFRARED: JPL/CALTECH

Q: IS THE NEW MOON EVER VISIBLE? CAN IT BE SEEN WITHOUT A TELESCOPE?

Esther Bock
Milwaukee, Wisconsin

A: When we look at the Moon, we are seeing reflected sunlight; the phases are due to changes in the Earth-Moon-Sun alignment. Only the part of the Moon that faces the Sun is illuminated. This means that at any point in time, only half of the Moon's surface is potentially visible.

Remember: We are not always facing the lit side of the Moon! If the Moon is between Earth and the Sun, we are facing the unlit side of the Moon. Because there is no sunlight hitting this part of the Moon, it is not visible. This is what we call a New Moon.

Under certain conditions, we can see the Moon near this otherwise unobservable phase. Because the New Moon rises and sets with the Sun, within a day or two the Moon will appear as a thin waxing crescent that is observable with the naked eye immediately following sunset. Serious lunaphiles have photographed the New Moon at the instant it occurs, but this requires a telescope, a special filter, and a camera.

The most credible observation of the "youngest" Moon seen by eye alone was made by *Astronomy* Contributing Editor and columnist Stephen James O'Meara. He viewed the thin crescent Moon just 15 hours and 32 minutes past its New phase in May 1990, thanks to a steady, transparent sky. With a bit of calendar watching, you can expect to view New Moons less than 24 hours old.

When Earth, the Moon, and the Sun align in that order, we can see the disk of the New Moon unaided as it passes across the Sun, blocking it as a solar eclipse. However, the only time it's safe to observe the New Moon during this event without equipment (such as eclipse glasses or solar filters) is during totality itself, when the sun is completely blocked. In the moments before and after totality, you'll need protection to prevent damaging your eyes.

On August 21, for the first time in decades, a total solar eclipse will be visible across the United States. (Stay tuned to *Astronomy* magazine for more information about and coverage of the eclipse.)

April Russell
Visiting Professor, Siena College, Loudonville, New York

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.

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

July 2017: A warm-weather showcase

An outbreak of storms in Jupiter's South Equatorial Belt earlier this year highlights the dynamic nature of the giant planet's atmosphere. The photographer captured this view (with north up) March 1. CHRISTOPHER GO

The solar system's two largest planets, Jupiter and Saturn, put on superb shows every clear summer evening. Each has an orbiting spacecraft returning detailed images from close-up to complement your telescopic views from afar. Meanwhile, Uranus and Neptune stage nice but more-subtle displays after midnight. July nights wrap up with brilliant Venus making a dash across the splendid backdrop of Taurus the Bull.

But your first target these summer nights should be **Mercury**. From mid-northern latitudes, this planet hugs the horizon as darkness falls all month. On July 1, it stands 3° high in the west-northwest 30 minutes after sunset. Mercury shines brightly, at magnitude –1.0, which helps it show up against the twilight glow.

The planet's altitude doubles by the 9th, when it passes through the northern edge of the Beehive star cluster (M44). Unfortunately, twilight renders the cluster nearly invisible unless you have an exceptionally clear sky.

You'll have an easier time viewing Mercury's next conjunctions July 24 and 25. The planet then appears 1° from Regulus, Leo the Lion's brightest star, with the waxing crescent Moon standing watch nearby. On the 24th, the Moon lies 5° to the lower right of the close pair; the following evening, our satellite moves 8° to the duo's upper left. Mercury shines at magnitude 0.2, a full magnitude brighter than Regulus, and both climb nearly 10° high in the west a half-hour after sundown. A telescope reveals Mercury's yellow-orange disk, which spans 7" and appears about half-lit.

Jupiter is the first of the evening's giant planets to come into view. Shining at magnitude –2.0, it's a dazzling object in the southwest after sunset. The world lies among the background stars of Virgo northwest of the Maiden's brightest star, 1st-magnitude Spica. The gap between the two closes from 11° to 8° during July. A gibbous Moon stands nearly 10° to Jupiter's upper left July 1. On the 28th, our satellite — now a crescent — passes just 3° above Jupiter.

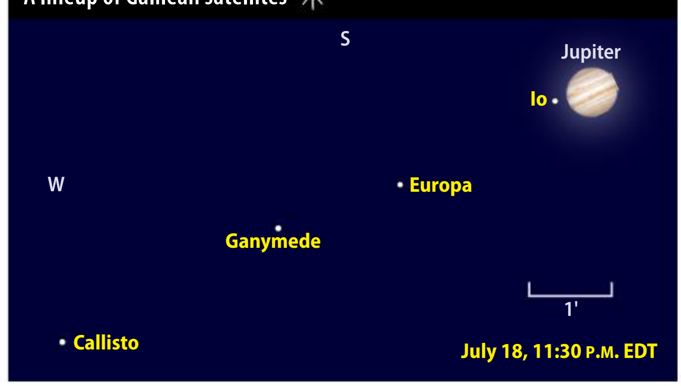
Slew your telescope toward Jupiter for dramatic views of its cloud features and four big moons. But do so in early evening — Jupiter sets by 1 A.M. local daylight time in early July and some two hours earlier by month's end. As you study the gas giant, bear in mind that the Juno spacecraft is doing the same from its polar orbit.

Late last year, amateur astronomers noticed an outbreak of storms in Jupiter's South Equatorial Belt, the first since 2010–11. This renewed activity continued through the first few months of 2017, and likely will endure this summer. The outbreak highlights the dynamic nature of Jupiter's atmosphere. New storms can erupt at any time, and even small scopes allow you to follow their progress. So don't pass up a chance to view the planet in July, when it displays an impressive 36"-diameter disk at midmonth.

Also keep an eye out for Jupiter's four Galilean satellites. Io, Europa, Ganymede, and Callisto (in order of distance from the planet) show up easily through any scope. The moons appear in different positions from night to night, so it often can be difficult to tell them apart. Use "Jupiter's moons" on p. 41 to differentiate them. Or simply wait until the evening of July 18, when they string out in distance order west of the planet.

The satellites typically appear in a nearly straight line, but that's not always the case. If you target Jupiter the evening of July 15, you'll find Callisto due north of the planet. Although all the moons orbit in the same plane, that plane now tilts 3° to our line of sight. This slope

A lineup of Galilean satellites



Jupiter's four bright moons appear in order of their orbital distance from the planet the evening of July 18. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

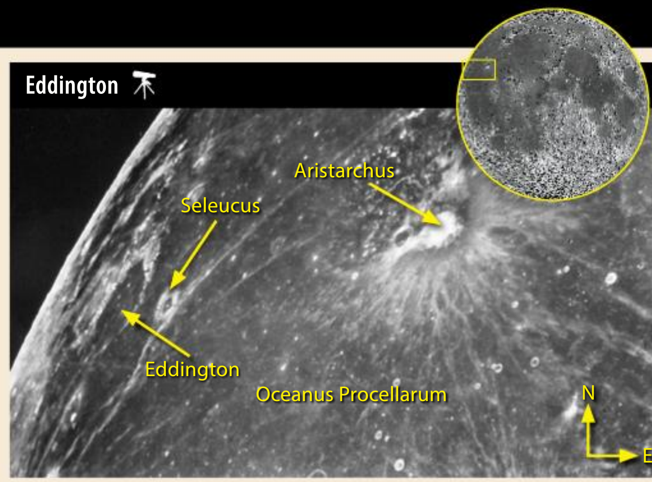
Swimming in the Ocean of Storms

Thanks to good timing, this month we can stroll along the western shoreline of Oceanus Procellarum (Ocean of Storms) during the evening hours. This giant "sea" — a lava-filled basin with a surface area somewhat bigger than Earth's Gulf of Mexico — occupies much of the Moon's northwestern quadrant. Its western shore often tilts out of view or appears after a midnight moonrise, but this month these highlands show up for a whole week starting at Full Moon the night of July 8/9.

You can get a preview on the evening of the 7th. Look for the prominent horseshoe-shaped crater Eddington near the terminator, the line that divides lunar day from night. First find blazing Aristarchus — the Moon's brightest feature — and then head west just past Seleucus. Most of the southern half of Eddington's rim lies buried under a sea of lava.

The evening of July 8 gives us our first view of Einstein west and a little south of Eddington. Einstein appears as a battered ring surrounding a smaller, sharp-rimmed crater. But Einstein won't look like a typical crater on the 8th because it lies edge-on to our line of sight. Instead, look for three bumps on the limb. This is the crater's rim and central peak seen in profile. The outer two high spots are a bit farther apart than Eddington's width.

With each passing night, the Moon's western limb appears to roll a bit toward us, transforming our view from edge-on to a slightly elevated angle. By July 12, Einstein's inner crater emerges nicely, surrounded by some of the darker lava that flooded Einstein's interior.



Lava from Oceanus Procellarum washed over and buried the southern rim of Eddington Crater. CONSOLIDATED LUNAR ATLAS/UA/LPL; INSET: NASA/GSFC/ASU

means the outermost satellite clears the planet's disk when the two are in conjunction with each other.

Astroimagers should try to photograph Jupiter on July 31, when it stands 9' west of the 11th-magnitude spiral galaxy NGC 4941. You'll need to take multiple exposures to capture the bright planet, its moons, and the faint galaxy. Once you have the exposures right, you'll be ready to shoot August 1 when Jupiter sits right in front of the galaxy.

As Jupiter dips low in the west, **Saturn** rides high in the south. The ringed planet shines at magnitude 0.2, far brighter than any of the background stars in Ophiuchus. A nearly Full Moon passes 3° north of Saturn on the evening of July 6. Under darker skies a week later, you'll be able to see the world nestled among the star-studded fields of the Milky Way.

Saturn always rewards a look through a telescope. The best views come when it lies high in the sky and its light

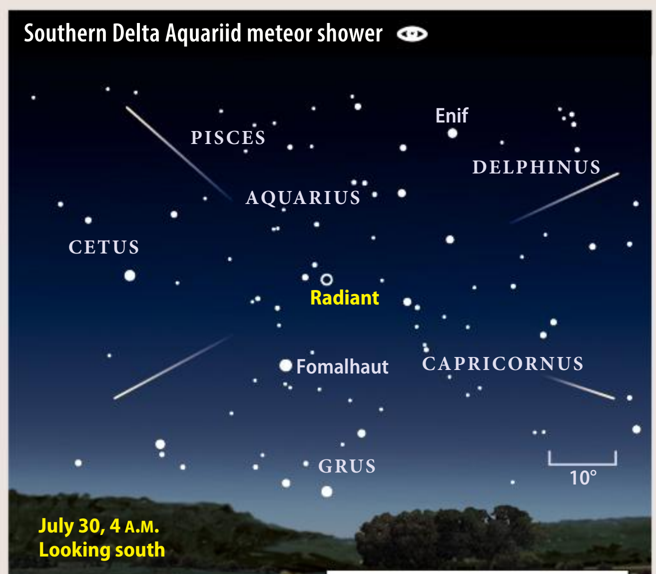
— Continued on page 42

METEORWATCH

Precursors to the Perseids

Meteor observers often view July as a warm-up act for August's grand Perseid display. But in 2017, the Perseids peak under a waning gibbous Moon, which will drown out most of the fainter meteors and render the brighter ones less impressive.

This year, meteor viewing should be better in late July. The Southern Delta Aquariid shower peaks the morning of July 30, when the First Quarter Moon sets just after midnight local daylight time and leaves the predawn hours free from its unwelcome light. Under a dark sky, observers can expect to see up to 25 meteors per hour, and rates stay above 20 per hour from July 27 to August 1. The best views come from equatorial and Southern Hemisphere sites, where the radiant, which lies in the constellation Aquarius, climbs higher in the sky.



This summer's finest meteor display should deliver one "shooting star" every three minutes, on average.

Southern Delta Aquariid meteors

Active dates: July 12–Aug. 23
Peak: July 30
Moon at peak: First Quarter
Maximum rate at peak: 25 meteors/hour

OBSERVING HIGHLIGHT Pluto reaches opposition and peak visibility July 9/10, when it glows at magnitude 14.2 among the background stars of northern Sagittarius.

STAR DOME

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

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

midnight July 1
11 P.M. July 15
10 P.M. July 31

Planets are shown at midmonth

STAR MAGNITUDES

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

STAR COLORS

A star's color depends on its surface temperature.

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

MAP SYMBOLS

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

JULY 2017

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

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

Calendar of events

1 The Moon passes 3° north of Jupiter, 3 A.M. EDT

2 Asteroid Juno is at opposition, 9 A.M. EDT

Mercury passes 5° south of Pollux, 8 P.M. EDT

3 Earth is at aphelion (94.5 million miles from the Sun), 4 P.M. EDT

6 The Moon is at apogee (252,236 miles from Earth), 12:28 A.M. EDT

The Moon passes 3° north of Saturn, 11 P.M. EDT

9 Full Moon occurs at 12:07 A.M. EDT

10 Pluto is at opposition, 1 A.M. EDT

13 The Moon passes 0.9° south of Neptune, 2 P.M. EDT

14 Venus passes 3° north of Aldebaran, 7 A.M. EDT

16 Last Quarter Moon occurs at 3:26 P.M. EDT

The Moon passes 4° south of Uranus, 8 P.M. EDT

19 The Moon passes 0.4° north of Aldebaran, 8 P.M. EDT

20 The Moon passes 3° south of Venus, 7 A.M. EDT

21 The Moon is at perigee (224,462 miles from Earth), 1:12 P.M. EDT

23 New Moon occurs at 5:46 A.M. EDT

25 The Moon passes 0.9° north of Mercury, 5 A.M. EDT

The Moon passes 0.07° north of Regulus, 7 A.M. EDT

26 Mercury passes 1.1° south of Regulus, 5 A.M. EDT

Mars is in conjunction with the Sun, 9 P.M. EDT

28 The Moon passes 3° north of Jupiter, 4 P.M. EDT

30 Mercury is at greatest eastern elongation (27°), 1 A.M. EDT

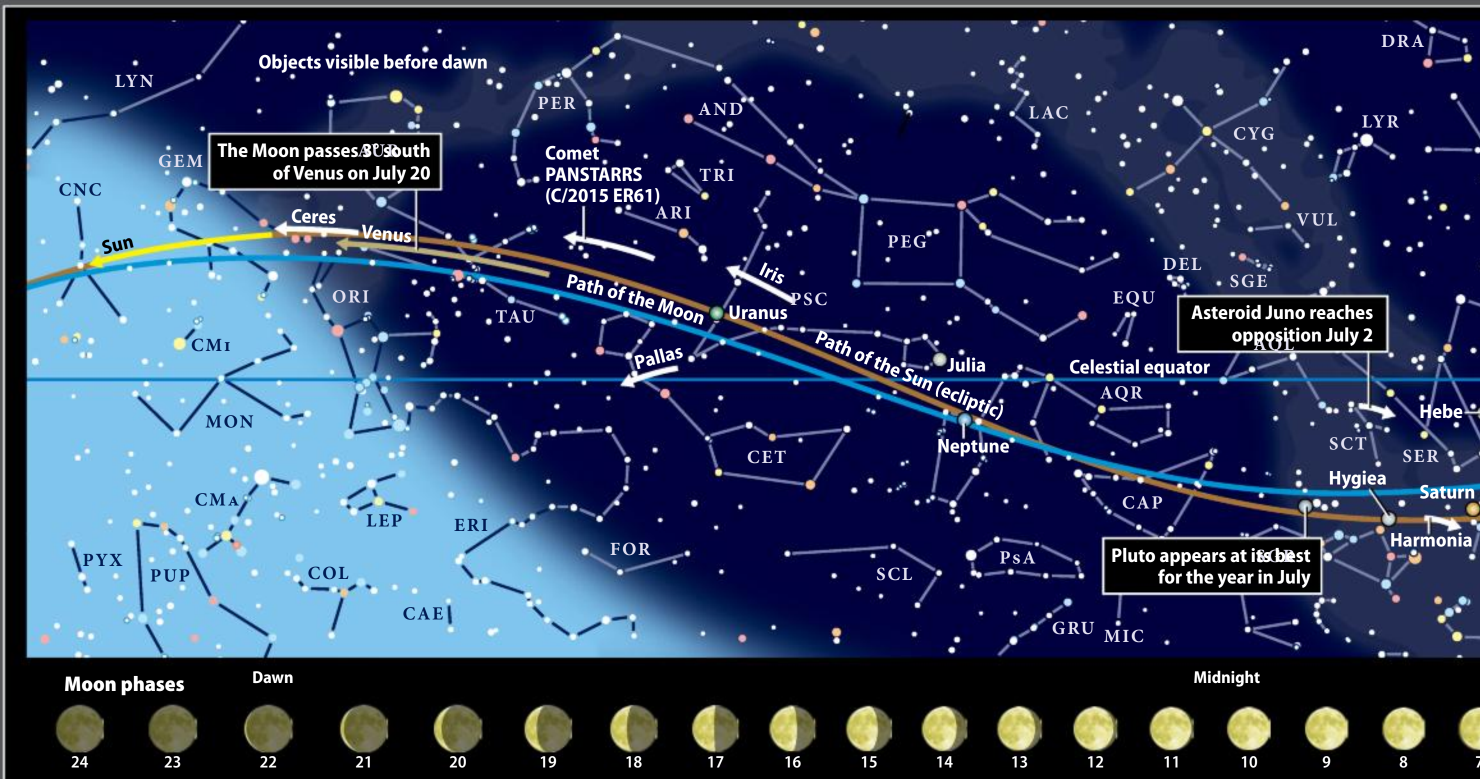
First Quarter Moon occurs at 11:23 A.M. EDT

SPECIAL OBSERVING DATE

30 The Southern Delta Aquariid meteor shower peaks under Moon-free conditions before dawn.

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

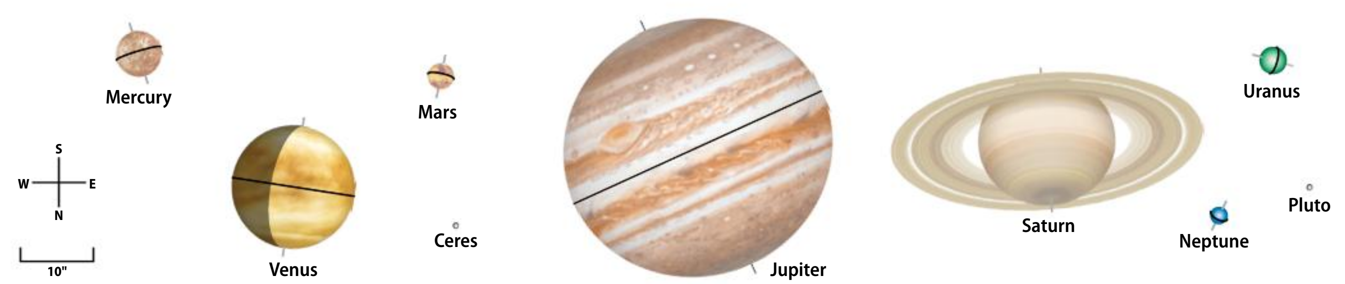
The planets in July 2017



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.

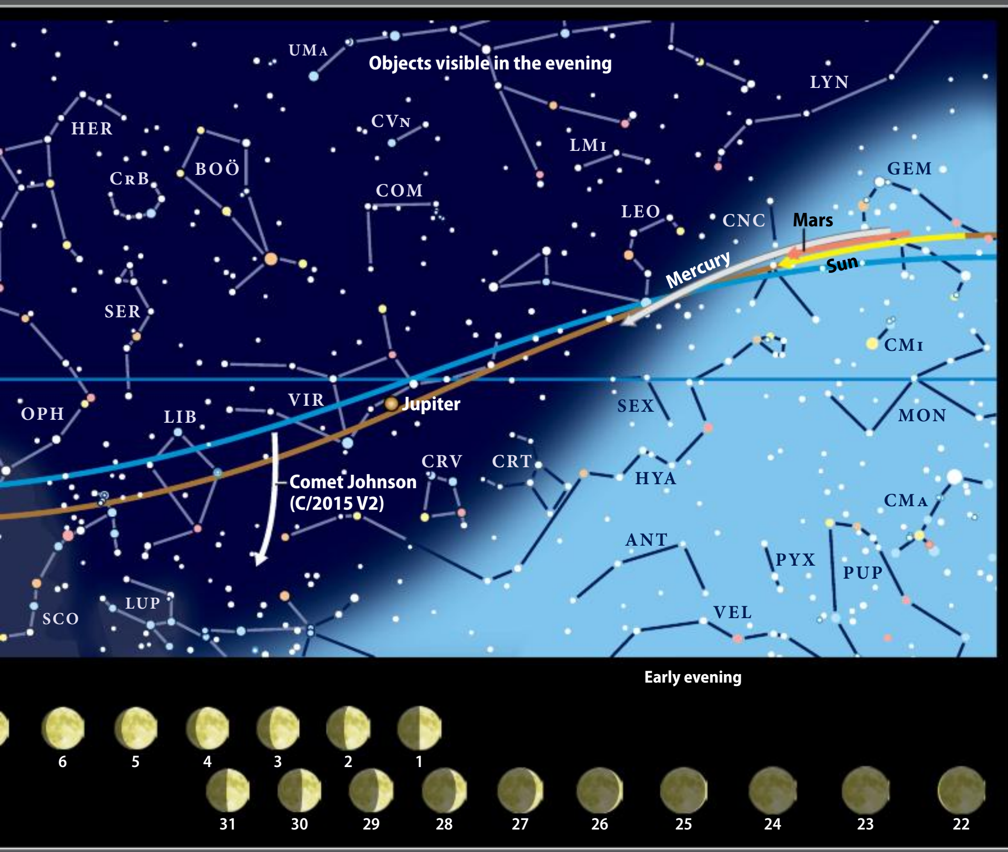
The planets in the sky

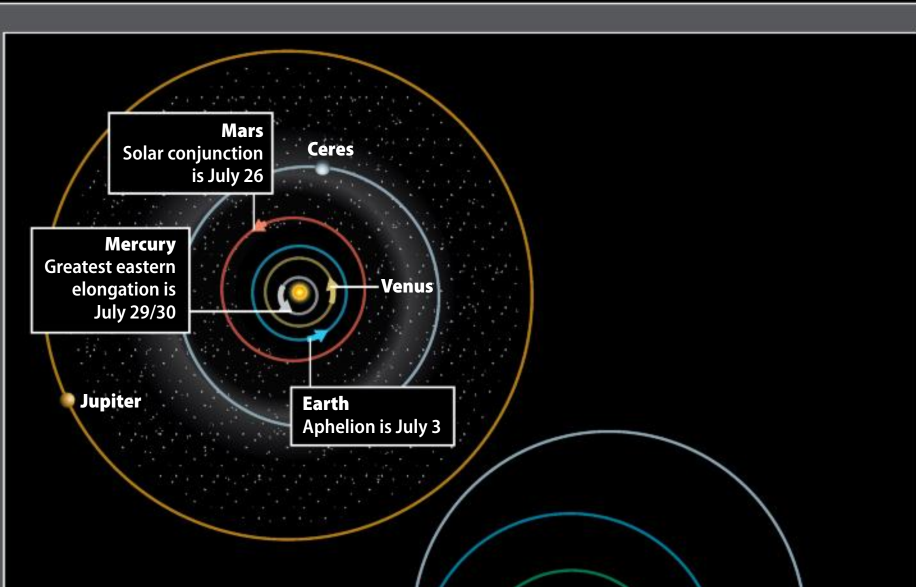
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	July 15	July 15	July 15	July 15	July 15	July 15	July 15	July 15	July 15
Magnitude	–0.2	–4.1	1.7	8.8	–2.0	0.2	5.8	7.8	14.2
Angular size	6.1"	16.3"	3.5"	0.4"	35.9"	18.1"	3.5"	2.3"	0.1"
Illumination	69%	68%	100%	100%	99%	100%	100%	100%	100%
Distance (AU) from Earth	1.098	1.025	2.644	3.606	5.494	9.169	19.995	29.302	32.354
Distance (AU) from Sun	0.421	0.726	1.631	2.680	5.451	10.060	19.921	29.948	33.367
Right ascension (2000.0)	9h11.2m	4h38.4m	7h53.7m	6h07.2m	12h56.3m	17h26.5m	1h45.4m	23h01.7m	19h16.6m
Declination (2000.0)	17°27'	19°47'	21°57'	23°56'	–4°40'	–21°55'	10°16'	–7°13'	–21°30'

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



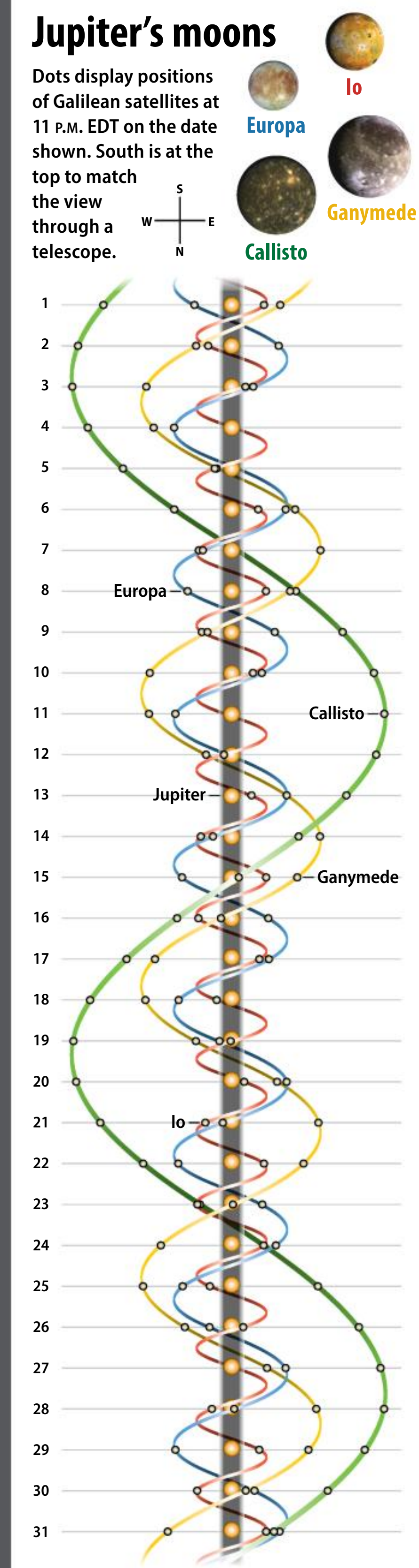


The planets in their orbits

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

Jupiter's moons

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



ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— Continued from page 37

WHEN TO VIEW THE PLANETS

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

passes through less of Earth's turbulent atmosphere. It peaks some 30° above the southern horizon around midnight local daylight time July 1; it reaches the same position a half-hour earlier with each passing week.

Small scopes reveal the gas giant's 18"-diameter disk surrounded by a spectacular ring system that spans 41" and tilts 27° to our line of sight. The wide-open rings offer dramatic vistas. You can't help but notice two distinct rings — the outer A ring and the brighter B ring — separated by a dark gap known as the Cassini Division. You'll need good viewing conditions to spot the gossamer-thin C ring closest to Saturn's cloud tops. The planet's disk shines through this ring with reduced intensity as the ring particles block some of the reflected sunlight.

The Cassini mission to Saturn is now in its dramatic final two months. Since April, the spacecraft has been executing a series of polar orbits that carries it between the giant planet and the C ring. The mission will end in mid-September when the probe makes a fiery plunge into Saturn's atmosphere.

Although Cassini has made its final close-up observations of Saturn's large moons, these worlds remain tempting targets through amateur telescopes. Any scope reveals 8th-magnitude Titan, which orbits the planet once every 16 days. It passes due south of Saturn on July 1 and 17 and due north of it on the 9th and 25th.

Tethys, Dione, and Rhea all shine at 10th magnitude and orbit well inside Titan's leisurely path. You can spot them through a 4-inch scope on most clear nights. Their tighter orbits mean they circle Saturn quite a bit faster than Titan, so they change positions significantly from night to night.

At the other end of the speed scale, distant Iapetus takes 79 days to complete an orbit around the planet and barely budges most nights. Your best chance to spot it comes in the week or so around its July 25 greatest western elongation. Iapetus then shines brightest, at 10th magnitude, because its more-reflective hemisphere faces Earth. You can find the moon

Venus passes between the Bull's brightest star clusters

Venus slips between the dipper-shaped Pleiades and the larger, V-shaped Hyades clusters this month, mimicking this scene from April 1999. ALAN DYER

COMETSEARCH

See it from the suburbs

Comet hunters typically seek out dark skies and avoid the Moon like the plague. But July provides an exception in Comet Johnson (C/2015 V2), which should glow at 6th or 7th magnitude in the evening sky and show up quite easily through binoculars or a telescope from the suburbs. And the only time you'll have to steer clear of the Moon is on the 2nd, when our satellite appears as a waxing gibbous less than 5° north of the comet.

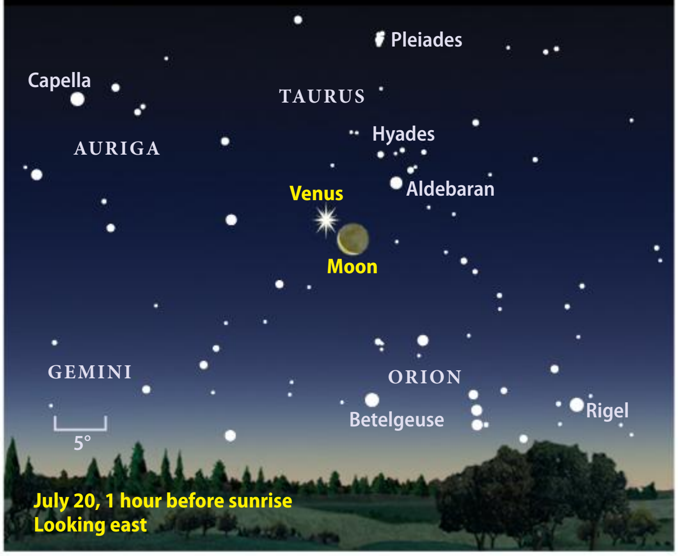
Comet Johnson passed closest to both the Sun and Earth in June, so it should deliver an excellent performance during July. Early in the month, binoculars will show it as a cotton ball some two fields of view to the upper left of 1st-magnitude Spica in Virgo. A 6-inch telescope should reveal a fuzzy ball with both a gas and dust tail flowing to the east. If we're lucky, the gas tail might glow bright enough to show a subtle green color through 10-inch instruments.

On the evening of July 1, the comet lies just 0.3° south of magnitude 4.2 Kappa (κ) Virginis. It then heads south, passing 2° west of magnitude 4.5 Lambda (λ) Vir on the 4th. It enters Hydra in mid-July and skirts 3° east of magnitude 3.3 Pi (π) Hydrae on the 22nd. It crosses into Centaurus during July's final week, when it will hang low in the southwest after darkness falls.

Comet Johnson (C/2015 V2)

One of this year's finest comets should glow at 6th or 7th magnitude as it dives south from Virgo through Hydra during July.

Venus poses with the Moon



A crescent Moon passes near brilliant Venus in front of the background stars of Taurus in the predawn hours of July 20.

9' (some 13 ring diameters) west of Saturn.

Our next target lies 25° east of Saturn in Sagittarius the Archer. **Pluto** reaches opposition and peak visibility the night of July 9/10, but it remains a worthy target through 8-inch and larger instruments all month. For tips and finder charts to help you find this distant world, see "In pursuit of Pluto" on p. 56.

Neptune rises in the east before midnight local daylight time and climbs highest in the south around the time twilight commences. The planet glows at magnitude 7.8, bright enough to show up through binoculars if you know where to look. To find it, first locate 4th-magnitude Lambda (λ) Aquarii. Neptune lies 2° east of this star and just south of 6th-magnitude 81 Aqr. The planet begins July 0.2° southeast of 81 Aqr and moves to a position 0.3° southwest of the star by month's end. A telescope reveals Neptune's 2.3"-diameter disk and subtle blue-gray color.

You'll want to search for **Uranus** in the hour before twilight starts to paint the sky. It then lies 40° high in the east-southeast among the background stars of Pisces the Fish, just 1° north of magnitude 4.3 Omicron (o) Piscium. Although you can see the magnitude 5.8 planet with the naked eye under a dark sky, binoculars make the task much easier. When viewed through a telescope, Uranus appears 3.5" across and distinctly blue-green.

You won't need any help finding **Venus** before dawn. The brilliant planet shines at magnitude –4.2 in early July and dims just 0.2 magnitude by month's end. It rises around 3 A.M. local daylight time and climbs some 20° high in the east an hour before sunup.

You'll want to follow Venus as it treks eastward against the backdrop of Taurus the Bull. The planet passes 7° south of the Pleiades star cluster (M45) in July's first few days and then traverses the northern edge of the Hyades cluster at the end of July's second week. You'll find it 3° due north of 1st-magnitude Aldebaran, the Bull's orange-colored luminary, on the 14th.

As Venus continues its march, it meets up with a waning crescent Moon on July 20. The two lie 3° apart and make a spectacular pair in morning twilight. The planet then passes less than 1° south of the Crab Nebula supernova remnant (M1) on the 26th and 0.4° north of 3rd-magnitude Zeta (ζ) Tauri the following morning. Venus spends the final two days of July in the narrow northern sector of Orion.

Unfortunately, Venus' appearance through a telescope pales in comparison to the view with the naked eye or binoculars. The planet shows a gibbous disk all month that shrinks from 18" to 15" in diameter.

Mars is in conjunction with the Sun on July 26 and remains hidden in our star's glare all month.

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**

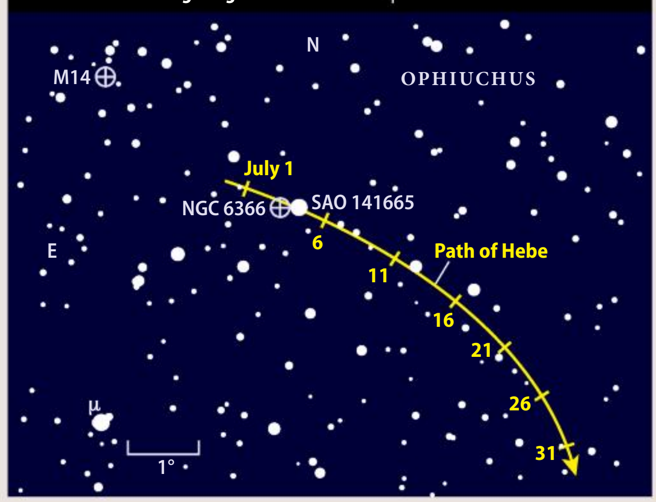
An opportunity in Ophiuchus

If you observe the globular cluster NGC 6366 in Ophiuchus on July 3, you can be forgiven for thinking that one of its stars has gone nova. That evening, asteroid 6 Hebe masquerades as the brightest star on the cluster's northern fringes. It's a pity this minor planet moves too slowly for us to see it change position in one night, but you'll definitely notice it has shifted if you return to the field on the 4th. Hebe then lies on the other side of the cluster and about halfway toward the magnitude 4.5 star SAO 141665.

Located on the Serpent-bearer's hipbone halfway between Beta (β) and Eta (η) Ophiuchi, SAO 141665 sits in an empty field. If you've ever star-hopped to the bright globular M14, you've probably stopped at this star along the way. It will be your anchor for finding 9th-magnitude Hebe this month.

The smattering of field stars brighter than this main belt asteroid will help you zero in on it. The evenings of July 12–17 are particularly convenient because Hebe then slides just south of a pair of 6th-magnitude stars. By the end of the month, the asteroid stands nearly alone in front of an uncataloged strip of dark nebulosity.

Hebe slides through a globular cluster



The westward motion of asteroid Hebe carries it directly in front of globular star cluster NGC 6366 in Ophiuchus during July's first week.

Get ready for the **next generation planet hunter**

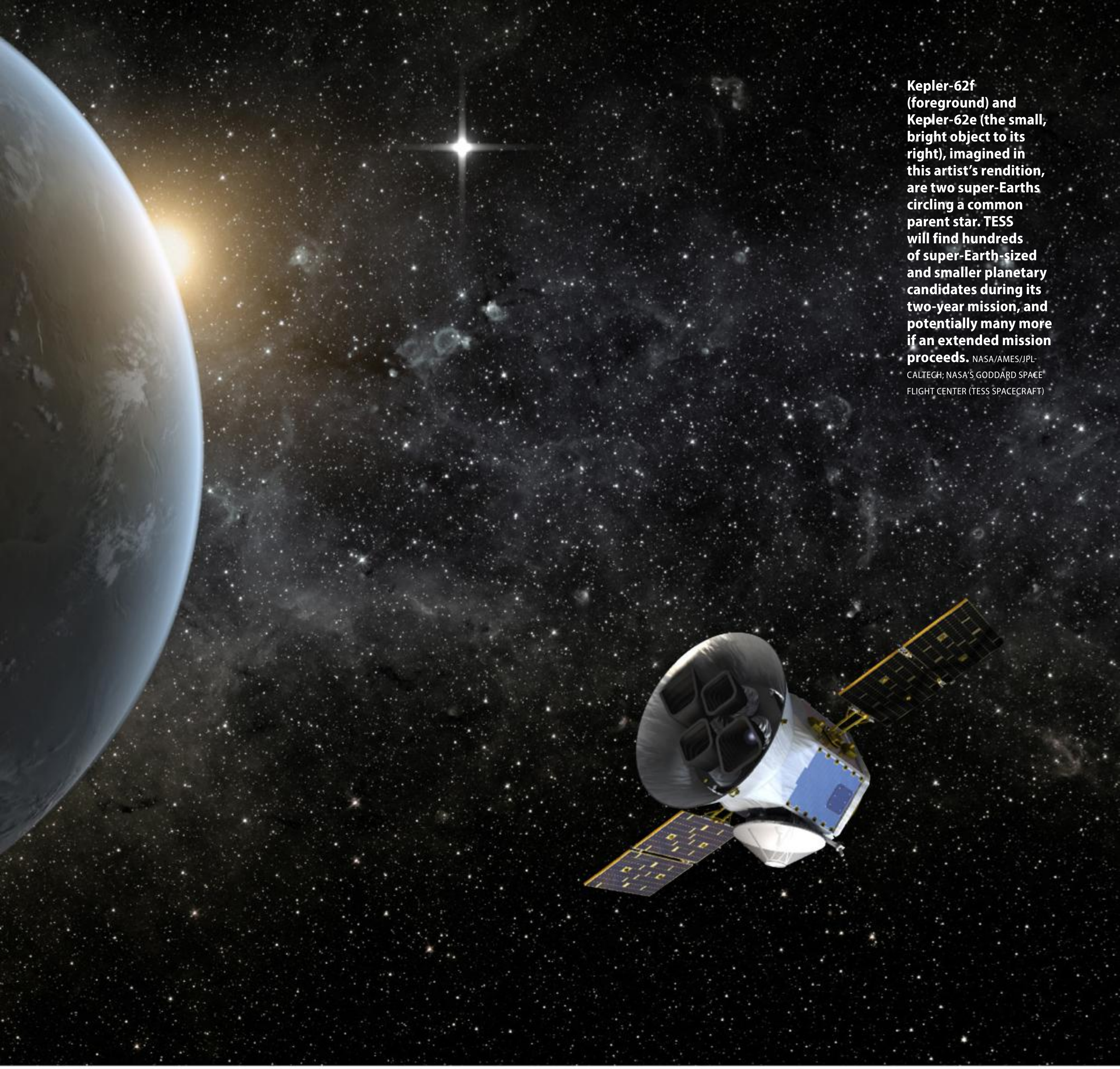
During its two-year mission, TESS should find thousands of new exoplanet candidates, including hundreds of Earth- and super-Earth-sized planets in our local neighborhood. **by John Wenz**

Late this year — or, more likely, early next — a SpaceX Falcon 9 rocket will launch a spacecraft to an orbit 62,000 miles (100,000 kilometers) high, three times the distance of geosynchronous orbit. Using leftover fuel from its second-stage insertion, the craft will gradually approach the Moon, then finally swing into an orbit 40° above the plane between Earth and its satellite. For every one orbit the Moon makes, this craft will make exactly two.

Its goal? To find the nearest, most promising Earth-like planets. The Transiting Exoplanet Survey Satellite (TESS) isn't just a follow-up mission to Kepler, the planet-hunting telescope responsible for thousands of exoplanet discoveries. It will provide a way to find out what's in our neighborhood — and maybe catch a few supernova events or black holes devouring stars in the process.

"I personally view, and I think my colleagues would agree, that TESS is a natural successor," says Jeff Coughlin, a SETI Institute-based support scientist for NASA's Kepler team. "In short, now that Kepler has found planets are extremely common, TESS will help discover some of the most interesting ones that are closest to us."

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



Kepler-62f (foreground) and Kepler-62e (the small, bright object to its right), imagined in this artist's rendition, are two super-Earths circling a common parent star. TESS will find hundreds of super-Earth-sized and smaller planetary candidates during its two-year mission, and potentially many more if an extended mission proceeds. NASA/AMES/JPL-CALTECH; NASA'S GODDARD SPACE FLIGHT CENTER (TESS SPACECRAFT)

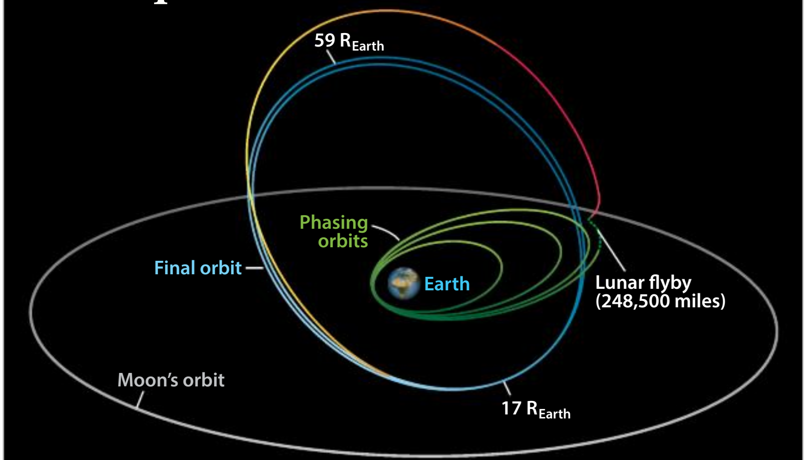
So what's different?

Kepler and TESS both look for transiting exoplanets. Transits occur when a planet crosses the face of its star and causes a perceptible dip in the star's light. But whereas Kepler focused deeply on a small patch of sky, TESS will map as much of the heavens as possible while looking for a few good planets.

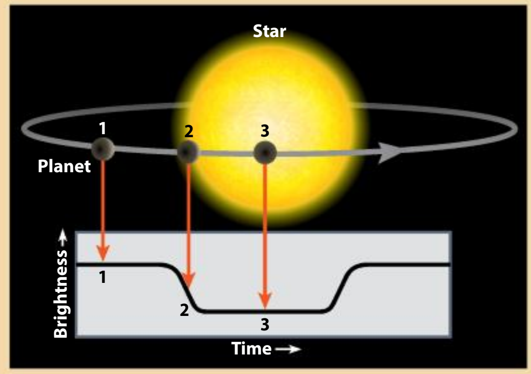
"Kepler is going for completeness — the goal is to produce an accurate estimate of exoplanet populations. TESS is almost like a cherry-picking mission," says Padi Boyd, who leads the TESS Guest Investigator Program. "We've got the entire sky. We want to measure masses of 50 small planets; we think we'll have many, many times that in candidates. We don't necessarily have to have completeness. We just have to make sure that the planets that TESS discovers, we have solid measurements for."

To do this, TESS will be equipped with four cameras. For one year, it will survey an entire hemisphere of stars in neighboring observation segments lasting 27 days each, waiting for nearby planets to pass between us and their parent stars. Rather than get an idea of how many planets are out there, TESS is on an info-gathering mission to find the best planet candidates that will help the next generation of telescopes find another Earth.

A unique orbit



The orbit TESS will follow has never been used before; with a period of 13.7 days, it will complete two orbits for every Moon orbit. At closest approach, it will sit 17 Earth radii (67,000 miles [107,800km]) from Earth, while its farthest point is 59 Earth radii (232,000 miles [373,400km]) away. This diagram shows the orbits of the Moon and TESS with respect to Earth, including the 40° equatorial inclination of TESS's final orbit. To reach this orbit, TESS will undergo three phasing orbits and a lunar gravity assist at 248,500 miles (400,000km). *ASTRONOMY*: ROEN KELLY, AFTER RICKER ET AL. (2014)



ASTRONOMY: ROEN KELLY

THE TRANSIT METHOD

TESS will employ the transit method of exoplanet detection to identify planet candidates. This method will find an exoplanet only if the plane of its orbit crosses the face of its parent star when viewed from Earth. As the planet passes in front of its star, it blocks some of the emission from the star and its observed light decreases. When the planet clears the star, the light returns to its previous intensity. Because this effect is not always large, particularly for small planets or planets far away from their star, a sensitive instrument is needed to spot these signals.

By watching a star over time, repeated dips in brightness can signal a planet. The period of the planet's orbit can be determined by measuring the time between subsequent dips, and the size of the planet can be estimated based on the amount of starlight it blocks (the depth of the dip). Because a transiting planet is illuminated by its star from behind, some of the starlight will pass through the planet's atmosphere if it exists. This allows astronomers to determine the composition of the atmosphere using a technique called spectroscopy, which breaks up light and reveals any elements present in the path as the light travels from the star to Earth.

As of April 2017, NASA reported 2,719 exoplanets discovered via the transit method. — *Alison Klesman*

TESS is on an info-gathering mission to find the best planet candidates that will help the next generation of telescopes find another Earth.

When planets are found, TESS will tell scientists roughly how big they are. Using instruments like the High Accuracy Radial Velocity Planet Searcher in Chile, researchers will then be able to determine the mass and density of the planet by measuring how much the star and the planet tug on each other via a process called radial velocity measurement.

From there, a fleet of next generation telescopes will make follow-up observations of the most promising candidates to find their composition. This includes orbiting telescopes, like the upcoming James Webb Space Telescope (JWST). Some people view TESS and JWST as companion missions. But the Hubble Space Telescope, the 26-year-old venerable gateway to the cosmos, will also get in on the action. So will the Wide Field Infrared Survey Telescope (WFIRST) mission, one of two telescopes donated to NASA by the National Reconnaissance Office. Once upon a time, WFIRST was a Hubble clone meant to spy on Earth. But when it launches next decade, it'll be a planet-spotting behemoth.

The fleet also contains ground-based telescopes. Some, like the Subaru Telescope, are fully armed and operational. Others, like the European Extremely Large Telescope and the Giant Magellan Telescope, are still a few years away. (Another extremely large telescope, the Thirty Meter Telescope, is currently in limbo due to protests from native Hawaiians over its construction on land they consider sacred.)

Origin story

Let's go back to the beginning. TESS wasn't always part of NASA's grand plan in its hunt for exoplanets. Its roots start with the High Energy Transient Explorer-2 (HETE-2), a mission that ran from 2000 to 2006 based out of the Massachusetts Institute of Technology (MIT). The mission was meant to track the motion of stars; to do that, MIT built an excellent photometer.

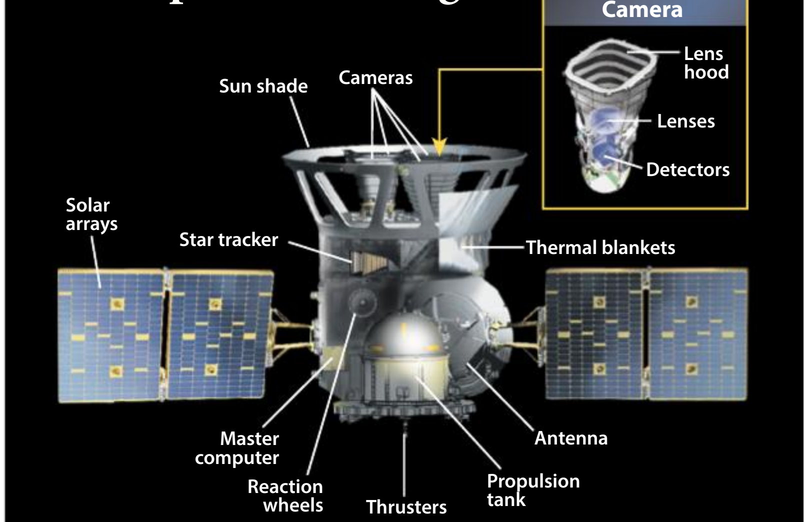
During this time, the idea of identifying a planet by its transits was coming to the forefront with the 2002 discovery of OGLE-TR-56b. To detect transits, you need a good photometer — and that's exactly what HETE-2 had.

"We ended up accidentally making a star tracker that had amazing photometric capability that went down to about 1,000 parts per million," says George Ricker, TESS principal investigator.

The photometric capabilities got Ricker and his team thinking of bigger possibilities. Their original photometer had a resolution of about 100 square degrees. They realized that by expanding the field of view, they could create a fairly sophisticated sky telescope to find planets around nearby stars.

By 2006, Ricker's team was working on an early version of what became TESS. Google kicked in $250,000, and private investors became interested in the project. Then the recession hit, and the private investors backed out. Thankfully, it was around this time that NASA began a call for proposals for Phase 8

TESS spacecraft design



The workhorses of the TESS spacecraft are its four wide-field (24° by 24°) CCD cameras, which will monitor star brightness. Each camera is surrounded by a lens hood designed to block out stray light for more precise measurements and increased sensitivity to transits. *ASTRONOMY*: ROEN KELLY, AFTER NASA GSFC

of the Explorers Program, which focuses specifically on orbiting physics experiments (including geo-, helio-, and astrophysics).

TESS became one of three finalists, but NASA ultimately chose the Swift Gamma-Ray Burst Explorer for Phase 8 of the medium class mission proposals. Undeterred, the team went back to the drawing board and came up with the idea of a novel Moon-resonant orbit, which added "very powerful capabilities" for TESS, according to Ricker.

Finally, in 2013, TESS was chosen by NASA as an Explorer mission.

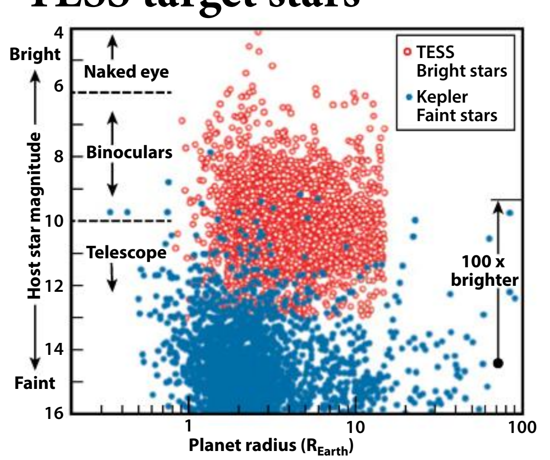
"At that time, the full impact of Kepler was known, so the idea was to go for bright, nearby stars that could be fully characterized," Ricker says. "In the time between 2009 and 2013, it had become clear how productive Kepler was being, but how frustrating it was to do follow-up characterization because the host stars were just too faint, and we needed to have something that studied stars 15 to 40 times brighter. That's what TESS really focused on."

The mission

Compared to Kepler, TESS is a more selective mission with less sensitive photometers and a bias toward brighter stars — but that's the intent. Its effective search radius is about 100 parsecs (or 326 light-years) out, but within 76.6 parsecs (250 light-years), there are 200,000 stars. Overall, there will be 40 million objects total in the field of view, including 10 million detectable galaxies.

"It's actually less sensitive than Kepler on purpose," Boyd says. "Kepler needed to monitor a lot of stars in a small region, which meant it needed to reliably measure many faint stars. With TESS, we actually want to go after bright stars, so TESS's bandpass, field of view, and detector characteristics were specifically chosen to get high-quality data on brighter, nearby stars."

TESS target stars



The stars targeted in the TESS data (open red circles) are on average 5 magnitudes brighter than those in Kepler's catalog (filled blue circles), allowing for much easier follow-up with ground- and space-based telescopes. This diagram compares the two missions' results in terms of both host star brightness and planet radius. *ASTRONOMY*: ROEN KELLY, AFTER GEORGE RICKER

In other words, TESS will still have a lot of objects at its disposal, even if only 50 or so of its detections go on to receive a dedicated study. Some candidates may end up brighter M dwarfs, so called "red dwarf" stars that are the smallest stars still capable of fusing hydrogen into helium. This includes stars like Proxima Centauri, the Sun's nearest neighbor. But at the same time, TESS will also be able to peer at brighter nearby stars, like Alpha Centauri A and B, one of which is slightly bigger and the other slightly smaller than the Sun. Such bright nearby stars also include Vega, a bright young star known to possess a protoplanetary disk, and Sirius A, the brightest star in the night sky.

These stars will be some of the easiest to study, and indeed, could net Earth some newly found neighbors — so long as the planets are at the right inclination.

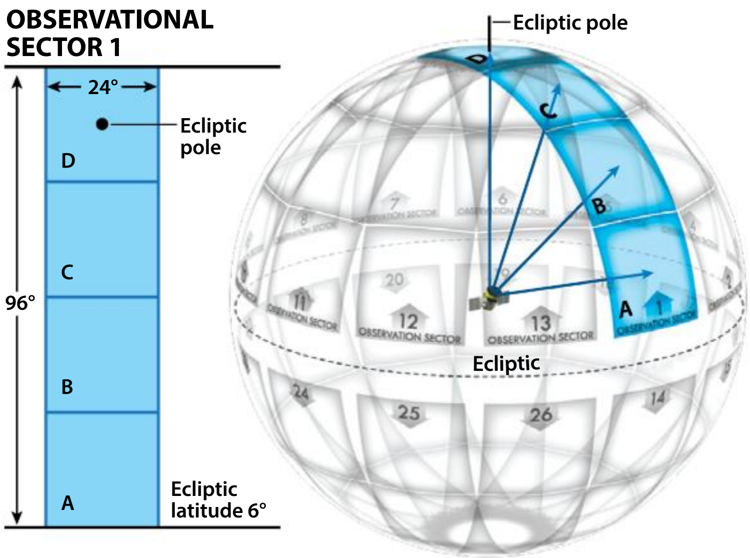
"It's looking for the planets in a sphere around Earth that are orbiting brighter stars. And what brighter stars are good for is that they're much easier to get the high-quality follow-up observations for with the bigger telescopes, because we get more signal from them," Boyd says.

For the first 351 days of its proposed two-year mission, TESS will study the Southern Hemisphere sky. For the second half, it will study the northern sky. Every 30 minutes, it will create a complete picture of its field of view to send down to Earth. By comparing these segments over time, researchers can detect planets through minute dips in starlight. The 13.7-day orbit will be spent looking entirely in the opposite direction of the Sun, so "the TESS objects are always going to be transiting near midnight for ground-based observers," Ricker says.

But because it's staring at the same patch of sky, there are other tantalizing possibilities. For instance,

"We're certainly excited about the mission, and we've done everything we can to make it useful to astronomers. It was designed to do exoplanet studies, but it's capable of so much more."
— George Ricker

Mapping the sky



The four cameras aboard TESS will map the sky one hemisphere at a time. Each will be divided into 13 observation sections (24° by 96°) for a total of 26 sections over the course of the two-year mission. *ASTRONOMY*: ROEN KELLY, AFTER RICKER ET AL. (2014)

Amateurs will be able to sift through the data on the hundreds of thousands of stars in the catalog and identify some planets the TESS and JWST teams may have overlooked.

TESS could catch other stellar events. If a supernova begins to appear, TESS can alert the Gamma-Ray Burst Coordinates Network/Transient Astronomy Network (GCN/TAN) of gamma-ray activity, and researchers can catch a star just beginning its dramatic death. It could also provide flare data about active stars and witness black hole activity.

That's why Boyd is leading the Guest Investigator (GI) Program. Researchers can request data on targets within TESS' field of view to study objects beyond the stars that interest the primary team. If an astronomer wants to, say, study the times of peak brightness of a variable star that is not a good candidate for exoplanet detection, the GI Program will make that possible.

"We're going to invite the community to submit proposals for targets they can sprinkle in those observing segments," Boyd says.

Uplink-downlink

Kepler and TESS may have some superficial similarities, but NASA is handling the datasets differently for each mission, rather than combining them as one long exoplanet catalog.

"There is going to be very little overlap between the stars that Kepler observed and the stars that TESS will observe, so their data will be analyzed separately," Coughlin says. "However, we have learned a lot of lessons from Kepler than we can apply to TESS to find planets faster and more reliably. Ultimately, all planets from all missions are collected by the NASA Exoplanet Science Institute and archived so scientists can use planets found from multiple missions to calculate better statistics and pick out the best ones for further study."

Every 30 minutes, TESS will send down a snapshot of its entire field of view. Every 13.7-day cycle, it will initiate a complete data downlink with the Deep Space Network, three NASA-operated telescopes used to communicate with distant spacecraft. These telescopes — one in the United States, one in Spain, and one in Australia — have high bandwidth able to handle the vast amount of TESS data. Each data drop will have about 384 gigabytes of data. That's more than 19 terabytes of data over the span of the mission.

The mission will have a quiet start. The TESS team, using advanced supercomputers, will take six months to sift through the vast amount of data coming down and identify transit events.

Ground-based observatories will then have to perform follow-up observations to confirm these targets, reducing this data to the nearest, most promising candidates. "They're going to be the ones we can characterize the best for future generations of scientists," Boyd says.

After the first six months, the data will take less and less time to reduce — four months at maximum as the database accumulates data and helps the computers orient where the data is in relation to the night sky. All of the data will be free and publicly available.

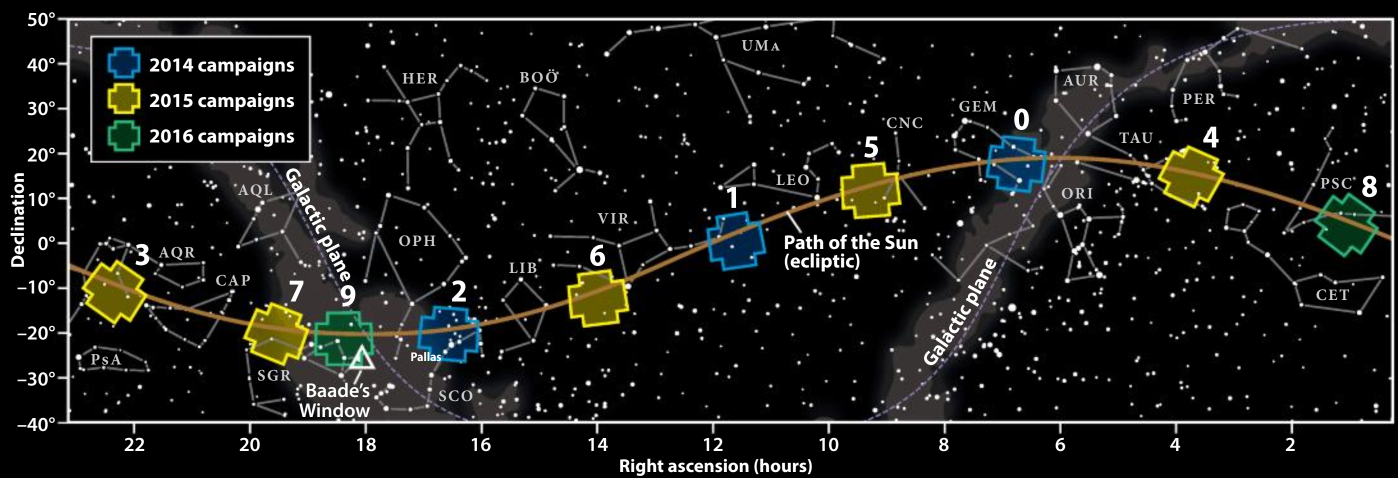
This allows for a sort of unofficial volunteer Guest Investigator program. Some of Kepler's planets have been found by amateurs sifting through the data. In the end, in fact, only 5 to 10 percent of TESS data is set for official follow-up investigation. Amateurs will be able to sift through the data on the hundreds of thousands of stars in the catalog and identify some planets the TESS and JWST teams may have overlooked. They may even find other cosmic events, like the 2015 discovery of a periodically dimming star with as-yet unknown causes.

BY THE NUMBERS

Since the first extrasolar planets were confirmed in 1992, we've discovered thousands more. Here are a few planetary statistics you need to know. — *J. W.*

Number of exoplanets known	3,475
Number discovered by Kepler, predecessor of TESS	2,331
Number of planets found by the reconfigured Kepler mission (K2)	147
Number of planets found by radial velocity (monitoring star spectral shifts)	631
Number found by transit	2,719
Number found by direct imaging	44
Number of Earth-sized or smaller planets	368
Number of planets in the habitable zone	12
Shortest orbit	2 hours (PSR J1719–1438 b)
Longest orbit	1 million years (2MASS J2126–8140)
Closest exoplanet	4.3 light-years (Proxima Centauri b)
Farthest exoplanet	27,710 light-years (SWEEPS-04 and -11)
Closest habitable planet	4.3 light-years (Proxima Centauri b)
Most distant habitable planet	Kepler-452b (1,400+ light-years)

K2 campaign fields



The Kepler spacecraft's field of view covers about 105 square degrees, but it cannot survey the entire sky. Instead, it is limited to a few fields near the plane of the Milky Way. *ASTRONOMY*: ROEN KELLY, AFTER NASA

"We're certainly excited about the mission, and we've done everything we can to make it useful to astronomers," Ricker says. "It was designed to do exoplanet studies, but it's capable of so much more."

Beyond its shelf life

All told, the TESS primary mission will last two years. But it's a solar-powered craft, so in the long term, power won't be an issue. After its orbital insertion, it will still have some fuel left. And its bizarre orbit is stable for up to a century.

NASA craft have a long history of outlasting their intended shelf life. NASA gave the Opportunity Rover a 92.5 Earth-day mission when it landed on Mars in 2004. Opportunity is still operating 13 years later, chugging along while its successor, Curiosity, roves a different area of the planet five years into its mission. And no one knew that Cassini would explore Saturn for 13 years — they'd initially hoped for four. That's not even scratching the surface of the mighty Voyagers, 40 years old and still going strong.

Kepler is still operational, too. NASA gave it a three-and-a-half-year mission, which was then extended. But a few months into this extension in 2013, a reaction wheel broke, hobbling the craft from performing its original mission. Kepler's first mission found 2,331 confirmed planets and more than 4,600 candidates awaiting confirmation.

But Kepler wasn't quite done yet. The team realized it could balance the craft with solar radiation pressure and still keep searching for planets, albeit with lesser capabilities. Four years later, that mission, called K2, has confirmed 147 planets.

Similarly, there are already extended mission plans for TESS. After the primary mission's two years wrap up, Ricker says, the craft will roll onto its side, where its four cameras will face a field similar to the one K2 has studied near the equator. TESS will have completed the equivalent of 70 to 80 K2 missions in the extended two-year mission. Beyond that? The sky's the limit.

The big score

One day, it may happen. Maybe the follow-up observations will come from JWST, or maybe from the Giant Magellan Telescope. A TESS-identified planet will pass in front of its star. The telescope will know exactly when to look. As it transits, the star's light will bend through the planet's atmosphere.

The data will return to Earth. A rainbow of element absorption will paint a clear picture. Nitrogen, oxygen, a bit of argon, a hint of carbon dioxide. Water vapor.

We already know it's as massive and dense as Earth. We already know that it's roughly our diameter. Researchers have already spent hours refining every detail they can suss out of the planet's existing data.

But this? It's a planet not just in the habitable zone, but a whole lot like our own, greenish-blue from a distance. This is the moment when we finally find it: another Earth, tantalizingly near to us.

It's the day humanity has waited for. And a little telescope in a bizarre orbit will have kicked off the whole event.

"Every additional planet we find, from any mission, is very valuable in order to perform detailed study of as many as possible," Coughlin says. "This lets us better compare how different planets form and evolve, establish which factors allow rocky planets to form and maintain substantial atmospheres, and ultimately one day be able to probe nearby planets to establish if any of them have an atmosphere like ours."

"Every additional planet we find, from any mission, is very valuable in order to perform detailed study of as many as possible." — Jeff Coughlin

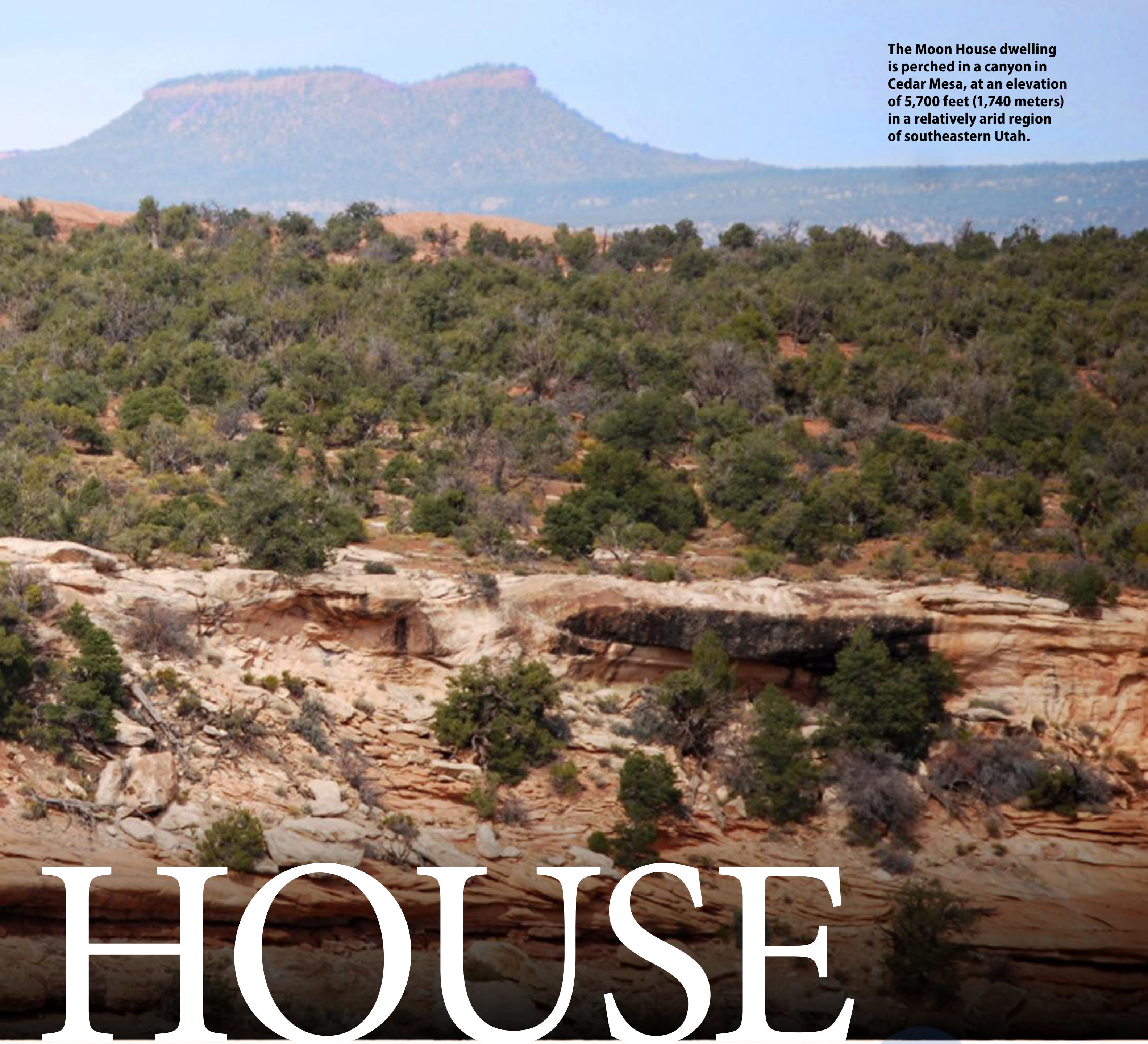
Is the MOON an AMERICAN

This ancient Puebloan structure, now a historical landmark, may have been inspired by a pair of eclipses.

text and images by Mark Boslough

Imagine that you live in isolation on a beautiful mesa with a small band of subsistence farmers. Your territory is rugged and difficult to traverse, with steep slopes, deep canyons, and sandstone cliffs, and is strewn with boulders, hoodoos, balanced rocks, and other obstacles. Even the flat places are uneven and covered with piñon, cedar, shrub oak, yucca, cactus, and scrubby desert plants.

The key to your survival is your ability to grow, store, and defend your food. You must cultivate it where you live, because



The Moon House dwelling is perched in a canyon in Cedar Mesa, at an elevation of 5,700 feet (1,740 meters) in a relatively arid region of southeastern Utah.

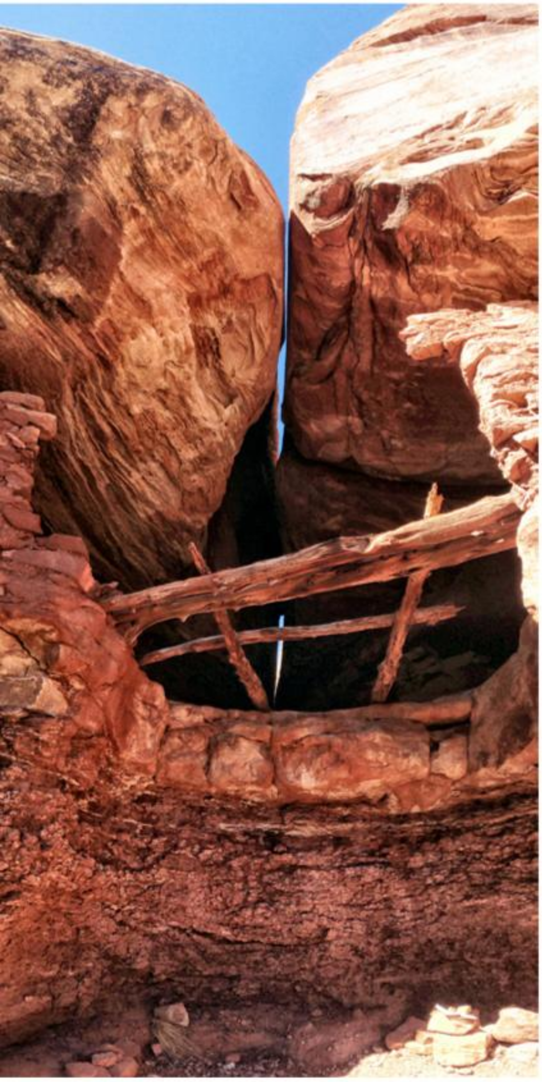
HOUSE STONEHENGE?

transporting it over long distances would be impossible. You have no government or societal safety net. Your survival is up to you, and you are acutely aware that plants require sunlight, warmth, and water.

You have no written language, books, television, computer, phone, internet, or recorded music. All you have is your intellect, your community, your family, and your civilization. You've identified items you can make without much technology, like rock art, baskets, stone tools, and clothing. When darkness falls, you have sky, fire, voices, faces, drums, flutes, food, sex, and dreams. That's pretty much it.

Such was life for the ancestral Puebloan people, often called the Anasazi, who inhabited southeastern Utah. Their cliff-dwelling stage lasted between 1150 and 1300. During this span, they built and decorated a complex some 6,500 feet (1,980 meters) above sea level on a plateau called Cedar Mesa. In the 1960s, archaeologist Bill Lipe of Washington State University dubbed it the "Moon House." The name stuck.

The Moon House divides into three sections: a living area with about half a dozen households, a



Above: The outer wall of the Moon House stands beneath an overhanging cliff that has helped to protect the interior from wind and rain. Left: Getting to the Moon House isn't easy. As you approach it, you'll see old wooden support beams spanning the gaps between rocks.

storage area, and a large room reserved for religious or social meetings. Throughout the structure, its walls carry decorations that may indicate that those who lived there carefully watched the sky.

Life as they knew it

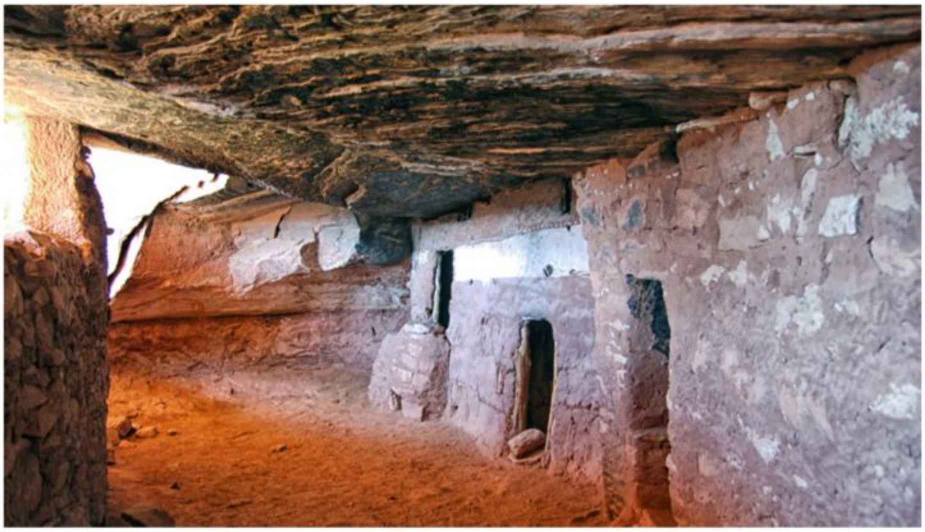
The people who built the Moon House had a lot of time for observing. They certainly kept an eye on the weather: how clouds form, how storms move, and how and when rain, virga, and snow falls. When the sky was cloud free, they observed how the Sun, Moon, stars, and planets track across it. Their understanding of natural cycles was handed down by their elders and reinforced by observations and personal experience. And because those cycles were the keys to their survival, they paid attention to the slightest detail and any variation in the pattern.

Every once in a while, something out of the ordinary would happen. A brilliant light streaks across the clear sky, lighting up the entire mesa and causing hoodoos to cast moving shadows in the night. A fuzzy patch appears, grows a tail, and moves through the constellations like a fast planet. A bright star that never existed before appears and then fades out. Many stars fall at once, like snowflakes. The Full Moon is swallowed up and glows a dim blood red. In their world, these were the dramatic, emotional, and terrifying external events that everyone would talk about, tell their grandchildren, and record.

Their lives and everything they knew and cared about depended on the seasonal cycle, which happened the same way every year. Where the Sun came up and where it set told them when to plant, because the sky was their calendar as well as their clock. After the harvest, the days got short and cold, and the nights got long. But even before they witnessed them, they knew from their elders that unexpected and unpredictable things could happen, so surely they wondered if it was also possible that dependable and regular things could stop happening.

Endless routine?

It took faith to believe that the Sun would come back and that it would ever be warm enough to grow food again. The Puebloans watched as the Sun set earlier and farther to the south on the horizon at the fall of night — each night longer and colder than the one before. Everyone expected and hoped the rate would slow, and eventually stop, because it always had.



Top: The Moon House is larger than it appears when you view it from the outside. The interior has areas for living, storage, and meetings. Above: Visitors can see many colorful vistas from inside the Moon House, and the closer you get to the entrance, the more the sky comes into view.

BEARS EARS: AMERICA'S NEWEST NATIONAL MONUMENT

One of President Barack Obama's final acts while in office was to issue a Presidential Proclamation on December 28, 2016, to establish Bears Ears National Monument. The proclamation reads:

"Rising from the center of the southeastern Utah landscape and visible from every direction are twin buttes so distinctive that in each of the native languages of the region their name is the same … 'Bears Ears.' For hundreds of generations, native peoples lived in the surrounding deep sandstone canyons, desert mesas, and meadow mountaintops, which constitute one of the densest and most significant cultural landscapes in the United States. Abundant rock art, ancient cliff dwellings, ceremonial sites, and countless other artifacts provide an extraordinary archaeological and cultural record that is important to us all, but most notably the land is profoundly sacred to many Native American tribes. … Resources such as the Doll House Ruin in Dark Canyon Wilderness Area and the Moon House Ruin on Cedar Mesa allow visitors to marvel at artistry and architecture that have withstood thousands of seasons in this harsh climate."

With the stroke of his pen, President Obama preserved this vast treasure of geological, ecological, archaeological, historical, cultural, and astronomical heritage. These lands are withdrawn from any new mineral exploration or development, and the same dark skies that 13th-century ancestral Puebloan inhabitants once enjoyed will forever remain available for stargazing and tranquil contemplation by future visitors. — M. B.

And then one evening, the glowing orb stopped moving south. Across the mesas, that last beam of sunlight shone through a natural V in the rock, lighting up a spot on a nearby wall. Somebody pecked a spiral into the desert varnish as a reminder of where the beam would be on this day of celebration of the return of the Sun — the winter solstice.

A half-year later, the opposite happened. Unlike winter, this was a joyful time of year with long, hot days and short nights. The crops would be growing fast, nourished by the Sun's heat and light. Now the Puebloans watched as the Sun rose further to the north on the horizon every day, and another marker that told them when the longest day — the summer solstice — would arrive. On that day of celebration, they watched as the Sun rose nearly to the zenith (the overhead point) at midday. Its brilliant light bathed the canyons, and they welcomed it.

Surprise!

And then, one day, something odd began to happen, something they had never witnessed before. In the middle of the day, the light started to fade and it got a little cooler. It was almost imperceptible at first, but then it became obvious. Something was wrong with the Sun. Imagine the emotions people felt as they saw the golden orb, bit by bit, disappear.

To scientists, total solar eclipses are fascinating, but they are also gut wrenching and emotional to experience. We now know what causes them, and we have the technology to precisely predict their timing and tracks, but they are still adrenaline- and tear-inducing events as best described by Annie Dillard in her essay, "Total Eclipse." One paragraph captures the terror, but I highly recommend that you read the whole thing:

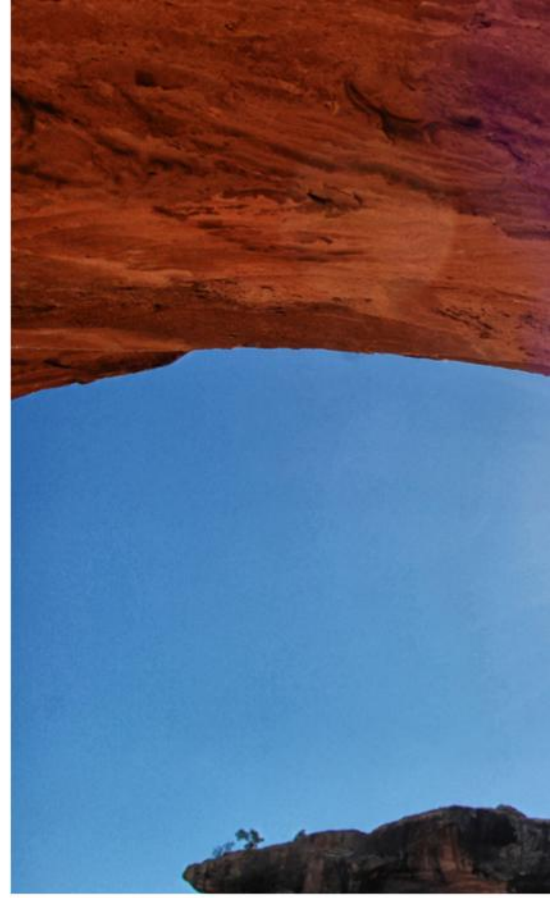
"From all the hills came screams. A piece of sky beside the crescent Sun was detaching. It was a loosened circle of evening sky, suddenly lighted from the back. It was an abrupt black body out of nowhere; it was a flat disk; it was almost over the Sun. That is when there were screams. At once this disk of sky slid over the Sun like a lid. The sky snapped over the Sun like a lens cover. The hatch in the brain slammed. Abruptly it was dark night, on the land and in the sky. In the night sky was a tiny ring of light. The hole where the Sun belongs is very small. A thin ring of light marked its place. There was no sound. The eyes dried, the arteries drained, the lungs hushed. There was no world. We were the world's dead people rotating and orbiting

The ancestral Puebloans decorated the walls of one of the inner rooms with evenly spaced dots. At each end is a shape (not pictured) that could depict a crescent Moon or partially eclipsed Sun.

HOW TO GET TO THE MOON HOUSE

For our trip, we made arrangements by calling the Bureau of Land Management's Kane Gulch Ranger Station at 435-587-1500. The permit fee cost $2 per person, and groups of up to 12 were allowed. Reservations are required during the spring and fall high seasons when Kane Gulch Ranger Station is open (March 1 to June 15 and September 1 to October 31). The number of visitors is limited each day to provide a quality experience.

The closest accommodations are in Blanding, Utah, about 45 minutes away. We stayed at the Stone Lizard Lodge, which serves breakfast and has knowledgeable staff. Its phone number is 435-678-3323. The closest major airports are in Albuquerque, New Mexico, and Salt Lake City. The drive from either city is about the same: a bit more than 300 miles (480 kilometers) that takes a bit over five hours. — M. B.



around and around, embedded in the planet's crust, while the Earth rolled down. Our minds were light-years distant, forgetful of almost everything. Only an extraordinary act of will could recall to us our former, living selves and our contexts in matter and time. We had, it seems, loved the planet and loved our lives, but could no longer remember the way of them. We got the light wrong. In the sky was something that should not be there. In the black sky was a ring of light. It was a thin ring, an old, thin silver wedding band, an old, worn ring. It was an old wedding band in the sky, or a morsel of bone. There were stars. It was all over."

House of the Moon

Because we now have tools for precise astronomical calculations, we know that there was a total eclipse of the Sun about 10 minutes after local noon on Cedar Mesa on the summer solstice in the year 1257. Given Dillard's description of the reaction to an expected eclipse, imagine what it must have felt like to a 13th-century ancestral Puebloan cliff dweller.

I learned about this eclipse and its significance from Don Simonis, a recently retired Bureau of Land Management archaeologist who is an expert on the Moon House. I was attending the 2015 Pecos Conference at a campground in Mancos, Colorado, near Mesa Verde National Park.

Simonis became aware of the event a couple of years earlier from Ron Barber, a Los Alamos National Laboratory engineer. Barber has become obsessed with the presence of ancient stone glyphs that align with unique shadows and sunbeams on special astronomical dates across the southwest and beyond. His Stone Calendar Project is an effort to combine advanced surveying techniques and 3-D modeling along with field observations to discover, document, and understand petroglyphs, pictographs, and other markers that indicate important dates and events such as solstices, equinoxes, and the four cross-quarter days each year, which lie midway between solstices and equinoxes.

Barber had given a lecture on archaeoastronomy that included maps of the paths of total solar eclipses across the area in 1257 and 1259. The intersection of the zones of totality formed a large parallelogram across southwestern Colorado and southeastern Utah, including Mesa Verde and Cedar Mesa. Amazingly, the indigenous people who occupied those places witnessed two total eclipses of the Sun in just 28 months.

Connections

Simonis knew something that Barber didn't, because he was aware of the Moon House. He had spent the previous several years working with the National Park Service to have it listed on the National Register of Historic Places.

The Moon House is unusual for many reasons. It is well preserved, partly because

On June 20, 1257 (by our modern calendar), the inhabitants of the Moon House would have witnessed a total solar eclipse with totality lasting an amazing 5 minutes 55 seconds. Two years later, on October 24, 1259, another total solar eclipse occurred within the region; totality lasted 1 minute 11 seconds.

Sunlight beams through small openings in the wall of the Moon House. Although they don't correspond to obvious lineups or markings, the sunbeams lend a touch of mystery to an already enigmatic site.

How would you interpret this piece of rock art? Is it a snake? A flowing stream? Lightning during a storm? Your interpretation may be wrong and lead nowhere, or it could be the key to unlocking the secrets of the site.

unlike most sizable cliff dwellings, it was not rediscovered until the 20th century. Its architecture is unique and fascinating, with an outer wall underneath a cliff overhang, and a set of protected rooms inside. The Sun passes over the outer wall and through peepholes into the alleyway between it and the rooms, where it is easy to imagine ceremonies taking place on special days.

In one of the inner rooms, the walls are decorated with evenly spaced white dots. At one end is a large circle, and the opposite end has a crescent. One must be careful when interpreting ancient rock art. For example, is a zigzag meant to be a snake? A waterway? Lightning? A circle can be just about anything round, including the Sun or the Moon. But not too many things form crescents. Other than the Moon, only melon slices and fingernails come to my mind.

Simonis also knew that the Moon House was one of the best dated archaeological sites in southwestern Utah. Because its construction contained a lot of wood, researchers could count tree rings. When he saw the maps of the 1257 and 1259 eclipses, he thought of the Moon House because it contained wood that was harvested from trees between 1250 and 1268. It was apparently built during the time of these eclipses, so the builders must have witnessed them.

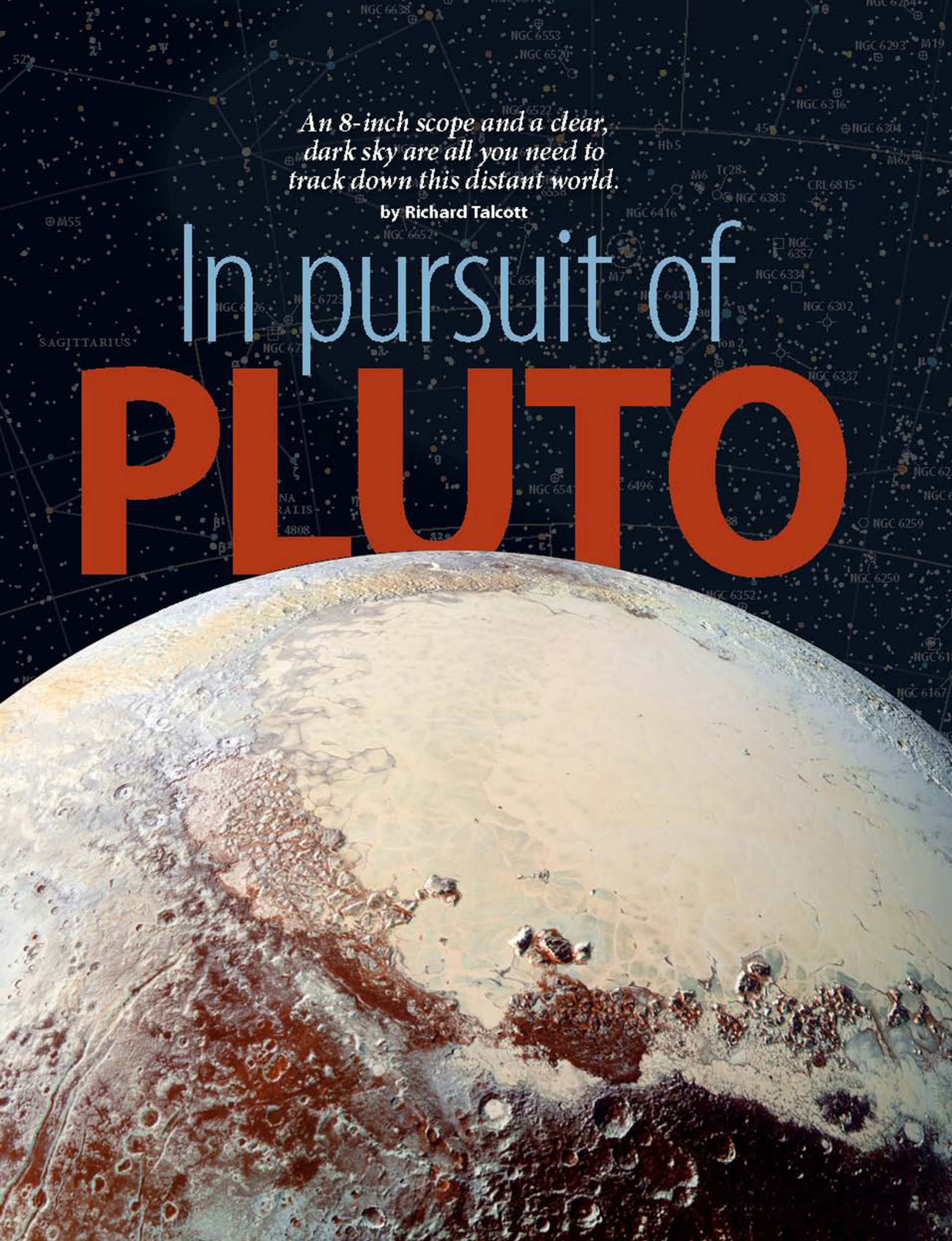
After I returned from the Pecos Conference, I immediately went onto the NASA eclipse website and learned that the Moon House was just west of the path of totality in 1259. It was a late October eclipse, at midafternoon, when the Sun stood in the southwestern sky. At maximum obscuration, the Moon covered 99.99 percent of the Sun's disk. Our star would have appeared as a thin crescent with horns pointing to the left, just like the pictograph of the west wall of the Moon Room.

Keep calm and science on

At this point, it's easy to get carried away with speculation. Was the Moon House really a Sun House? Was it a shrine to commemorate the great eclipses of the 13th century? Was it a solar observatory? Perhaps fancy 3-D models and observations will help answer these questions.

On the weekend of October 22 last year, I went with a group of friends on a reconnaissance trip to the site to commemorate the 757th anniversary of the second eclipse. I also wanted to watch the Sun track across the sky to see if there were any sunbeam or shadow markers. Despite the lack of any obvious scientific evidence, it was a moving experience and one that I will always remember. At about the time that the eclipse would have reached the diamond ring phase, I proposed to my sweetheart in the Moon House. She said yes.

Mark Boslough *is a physicist who is active in defending science and evidence-informed decision making.*



An 8-inch scope and a clear, dark sky are all you need to track down this distant world.

by Richard Talcott

In pursuit of PLUTO

Despite the International Astronomical Union's 2006 decision to demote Pluto to a dwarf planet, many planetary scientists and an overwhelming majority of the public still consider this distant world to be a full-fledged planet.

NASA's New Horizons spacecraft only fueled the debate when it encountered Pluto in July 2015. Most astronomers expected the probe to return images of barren, crater-pocked landscapes that had changed little since the solar system's early days. Instead, New Horizons revealed a geologically active world of broad canyons, flowing ice, lofty mountains of frozen water, and a Texas-sized glacier no more than 10 million years old.

This year's details

This summer provides amateur astronomers with a terrific chance to view Pluto with a fresh perspective. Although the distant world glows feebly at magnitude 14.2 and appears as a mere point of light through any telescope, observers with the right equipment at a dark site who know precisely where to look can glimpse Pluto's dim glow with their own eyes.

Pluto reaches opposition and peak visibility the night of July 9/10. The dwarf planet then lies among the background stars of Sagittarius, as it has for the past decade. This region rises near sunset, climbs highest in the south around 1 A.M. local daylight time, and sets as the Sun comes up. Pluto's visibility changes slowly, however, so it remains a tempting target throughout July.

To take advantage of this viewing opportunity, you'll want to use an 8-inch or larger telescope. Although expert observers under pristine conditions have seen the speck of light through 5-inch scopes, those sightings occurred several years ago when Pluto appeared brighter. And the larger the instrument, the more light it gathers, making the task much easier. If you don't have a scope big enough, connect with a member of a local astronomy club who does. Astroimagers can get by with smaller apertures, though they won't enjoy the thrill of seeing Pluto with their own eyes.

Once you've got your gear ready, line up a first-class observing site, one that offers a dark sky and good seeing conditions. (Seeing is a measure of the steadiness of the atmosphere.) It helps if you aim your scope over a grassy field or a wooded area. Don't try to view Pluto over a spot that absorbs the Sun's heat in daytime and reradiates it at night, such as an asphalt parking lot or a neighbor's house.

Just as city lights can drown out Pluto's glow, so too can dazzling moonlight. Try to avoid observing when our satellite lies near Pluto's position, as it does around the Full Moon on July 8/9.

Once the night you've targeted for your quest arrives, plan to reach your site by sunset. Set up your scope right away so it can start to cool (or warm) to the air temperature. In the hour or so this takes, your eyes will adapt to the darkness.

Pluto displayed a vast array of features to the New Horizons camera. The largest is Tombaugh Regio, the bright expanse that covers approximately half of this image. Scientists enhanced the subtle colors of the landscape by combining images taken through blue, red, and infrared filters. NASA/JHUAPL/SwRI

To show Pluto's movement over five nights, the photographer stacked three individual exposures taken July 8, 10, and 12, 2013. At the time, Pluto was in the constellation Sagittarius. The dwarf planet moved 6'. KFIR SIMON

ASTRONOMY MAGAZINE'S PLUTO GLOBE

As soon as the New Horizons spacecraft began to send data — especially photographs — back to Earth, *Astronomy* Senior Editor Michael E. Bakich started thinking about creating the very first globe of the distant world. He knew it would be popular with our readers.

Bakich initially contacted New Horizons Principal Investigator S. Alan Stern, who directed him to Ross A. Beyer, an affiliate of New Horizons' Geophysics Imaging Team.

Beyer collected and organized the data and circulated drafts of the maps among his team for comments and approval. He also worked with *Astronomy* Art Director LuAnn Williams Belter to make sure the features were displayed correctly, the hemispheres lined up, and the color was correct.

If you'd like to adorn your home with a 12-inch globe of this most distant world, head online to **www.myscienceshop.com**.

From Teapot to Teaspoon

Now you're ready to search for Pluto. Use a dim red light to illuminate the three charts on this page spread. Start with the naked-eye view at the top of this page and identify Sagittarius' prominent Teapot asterism. Next, scan north of the Teapot's handle to pick up the chain of four stars — Rho[1] (ρ^1), Pi (π), Omicron (o), and Xi[2] (ξ^2) Sagittarii — that forms the constellation's less conspicuous Teaspoon asterism.

This stellar quartet dominates the binocular field of view, displayed below the naked-eye chart. Then, use magnitude 2.9 Pi as a starting point to star-hop to the vicinity of Pluto shown in the telescopic view on the opposite page. The brightest star in this field is magnitude 8.18 SAO 187913, which lies 1.7° east-southeast of Pi.

We plotted Pluto's positions during the evening hours for North America. The chart shows background stars to magnitude 15.0, so you should be able to pick out Pluto. If you can't tell which point of light it is, sketch five or six stars near the indicated position. Then return to the same field a night or two later. The "star" that moved is Pluto.

If you try this technique at the beginning of July, a fairly bright star helps point the way. On the 1st, Pluto passes 4' due north of magnitude 8.2 SAO 187934. Only a handful of other background objects appear between this star and the dwarf planet.

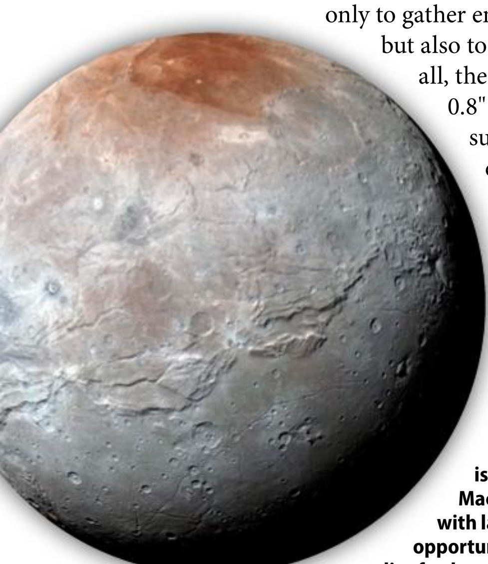
But there's one night this month when Pluto's motion should be obvious to all observers and imagers: On July 10/11 (two nights after Full Moon), it skims past SAO 187913 and its magnitude 9.8 neighbor. These two stars appear 37" apart, providing a convenient yardstick for locating Pluto.

At 9:30 P.M. EDT on July 10, Pluto lies 29" due north of the brighter star. It draws closer to the fainter companion during the course of the night. Pluto appears 23" northeast of this star at 12:30 A.M., and just two hours later, the gap shrinks to 16". It passes only 7" due north of the star at 6:00 A.M. Observers and imagers should be able to detect these shifts over an hour or two, with the motion confirming Pluto's identity.

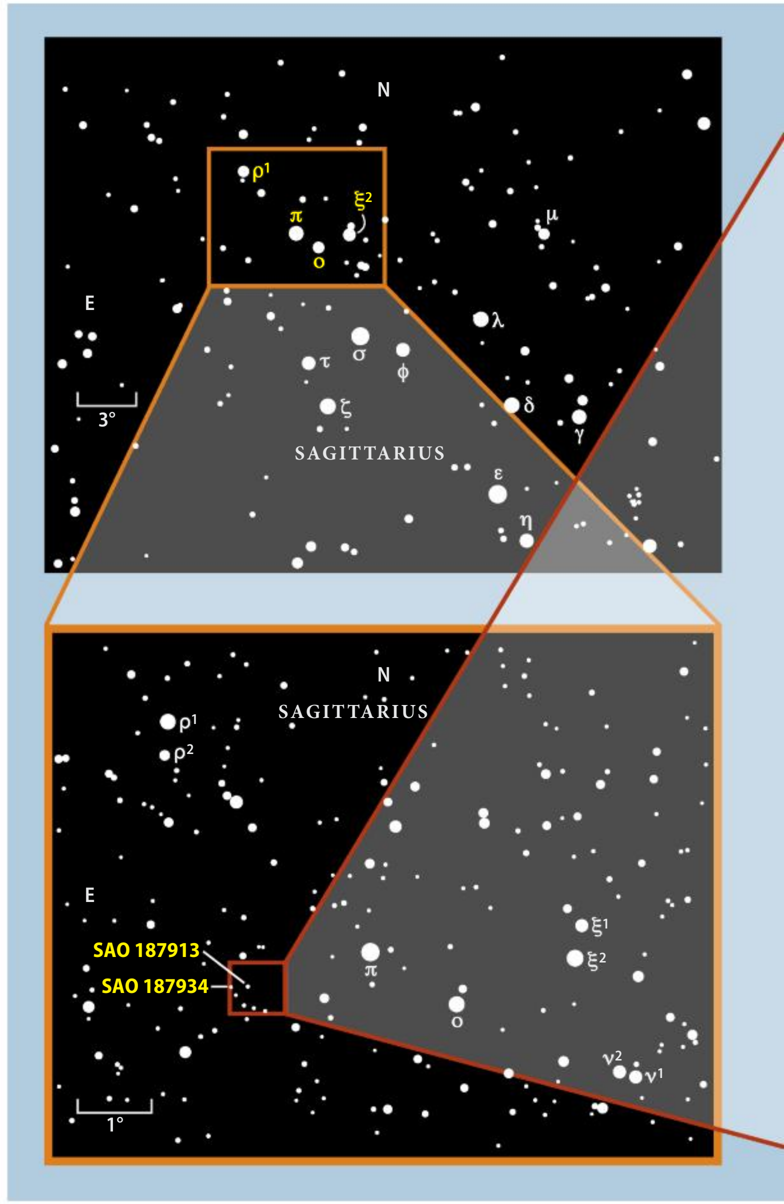
Going deep for Charon

Although no one claims that spotting Pluto is easy, it has a companion that will really test your observing skills. Its biggest moon, Charon, glows some two magnitudes fainter than Pluto and shows up, barely, through large amateur instruments.

You need lots of aperture — think 20 inches or more — not only to gather enough light to see Charon, but also to split it from Pluto. After all, the two never stray more than 0.8" from each other. Throw in superb viewing conditions, excellent optics, and high magnifications, and you have a shot at seeing the moon.



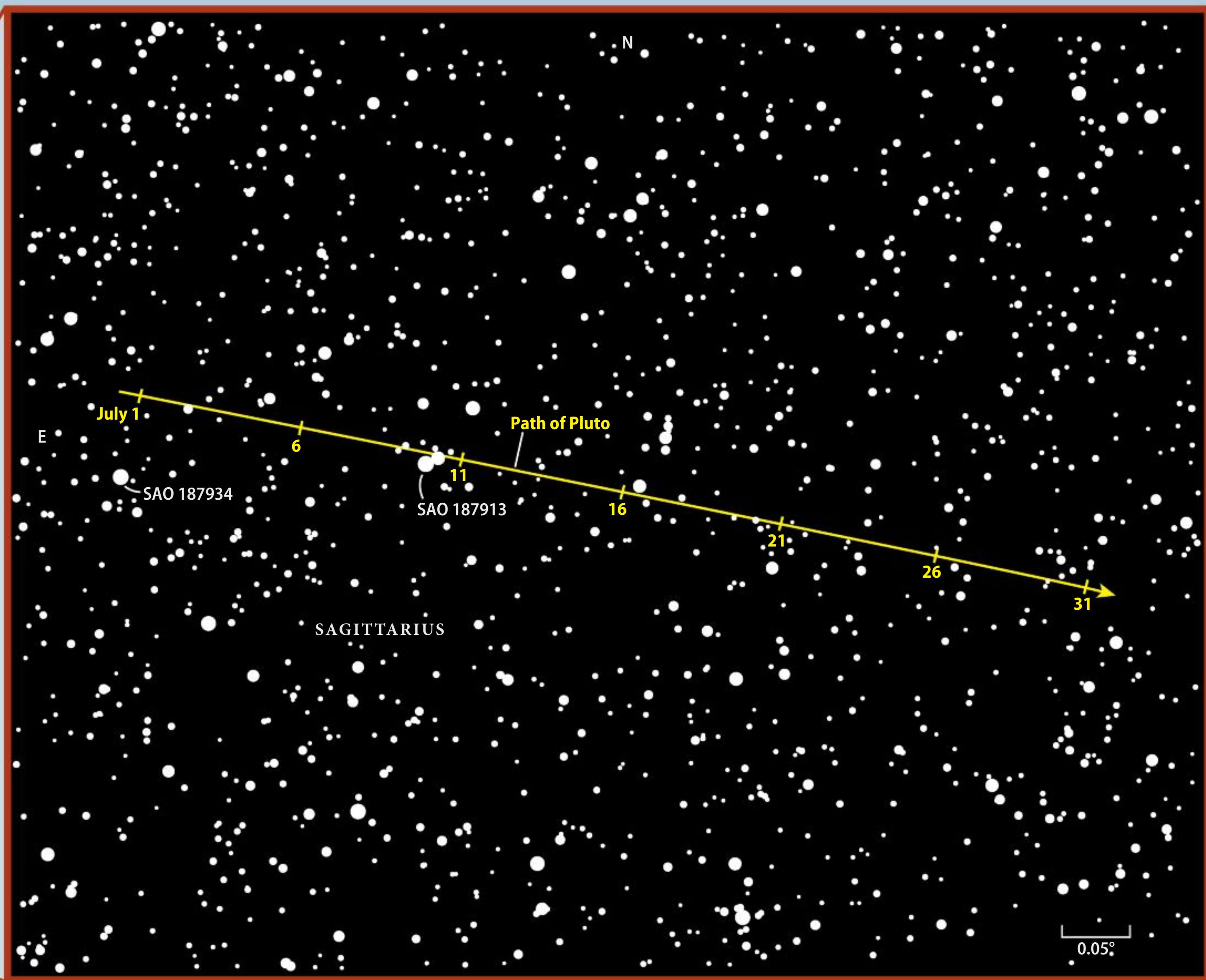
NASA's New Horizons spacecraft captured this high-resolution enhanced color view of Pluto's moon Charon just before closest approach on July 14, 2015. Charon's striking reddish north polar region is informally named Mordor Macula. Amateur astronomers with large telescopes have their best opportunities to spot Charon when it lies farthest from Pluto. NASA/JHUAPL/SwRI



Top: This naked-eye view shows the stars of Sagittarius to magnitude 6.2. Pluto spends July in the northern part of this constellation, within a group of 3rd- and 4th-magnitude stars: Rho[1] (ρ^1), Pi (π), Omicron (o), and Xi[2] (ξ^2) Sagittarii. *ASTRONOMY*: ROEN KELLY
Above: This binocular view shows stars to magnitude 8.7. Use it to pinpoint magnitude 8.2 SAO 187913, located 1.7° east-southeast of magnitude 2.9 Pi (π) Sagittarii. *ASTRONOMY*: ROEN KELLY

The orbital diagram at the bottom right of the opposite page will help you figure out where Charon lies relative to Pluto on any July night. The adjacent table lists the times of the moon's greatest northern elongations. The current geometry of the system places the satellite farthest from Pluto when it is either north or south of the dwarf planet, though its orbit appears nearly circular from our vantage point.

Once you decide when to hunt for Charon, you'll need to calculate how much time has elapsed since its previous elongation. For example, if you plan to observe at 11 P.M. EDT on July 10 (the night of Pluto's close pass to SAO 187913), you'll find Charon's previous northern elongation occurred July 5 at 10 P.M. EDT, so 5 days and 1 hour have passed since greatest elongation.



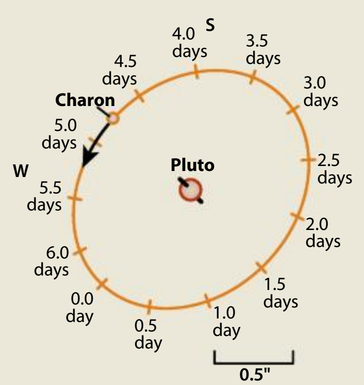
Pluto moves slowly westward this month, passing 29" north of the magnitude 8.2 star SAO 187913 the night of July 10/11. This telescope view shows stars to magnitude 15.0. *ASTRONOMY*: ROEN KELLY

Then, use the diagram to figure out Charon's approximate location along its orbit. If you see a faint speck there, you've found Charon — if it keeps pace with Pluto as the system moves past the star. The farther from Pluto the moon appears, the easier it is to see. The illustration shows south at the top to match the view through most telescopes when Pluto lies highest in the sky.

New Horizons showed Charon as a stunning world in its own right. A vast system of chasms extends across one of its hemispheres, while a dark, red polar cap surrounds its north pole. Scientists also discovered evidence that the moon may have once possessed a large ocean of liquid water beneath its frozen surface.

Not surprisingly, the magnificent vistas revealed by the robotic probe on both Pluto and Charon remain far beyond the reach of earthbound telescopes. But the mere sight of these faint worlds glimpsed from across the solar system is enough to bring a thrill to any observer. And perhaps your view will also provide a personal answer to the question of whether Pluto is a planet.

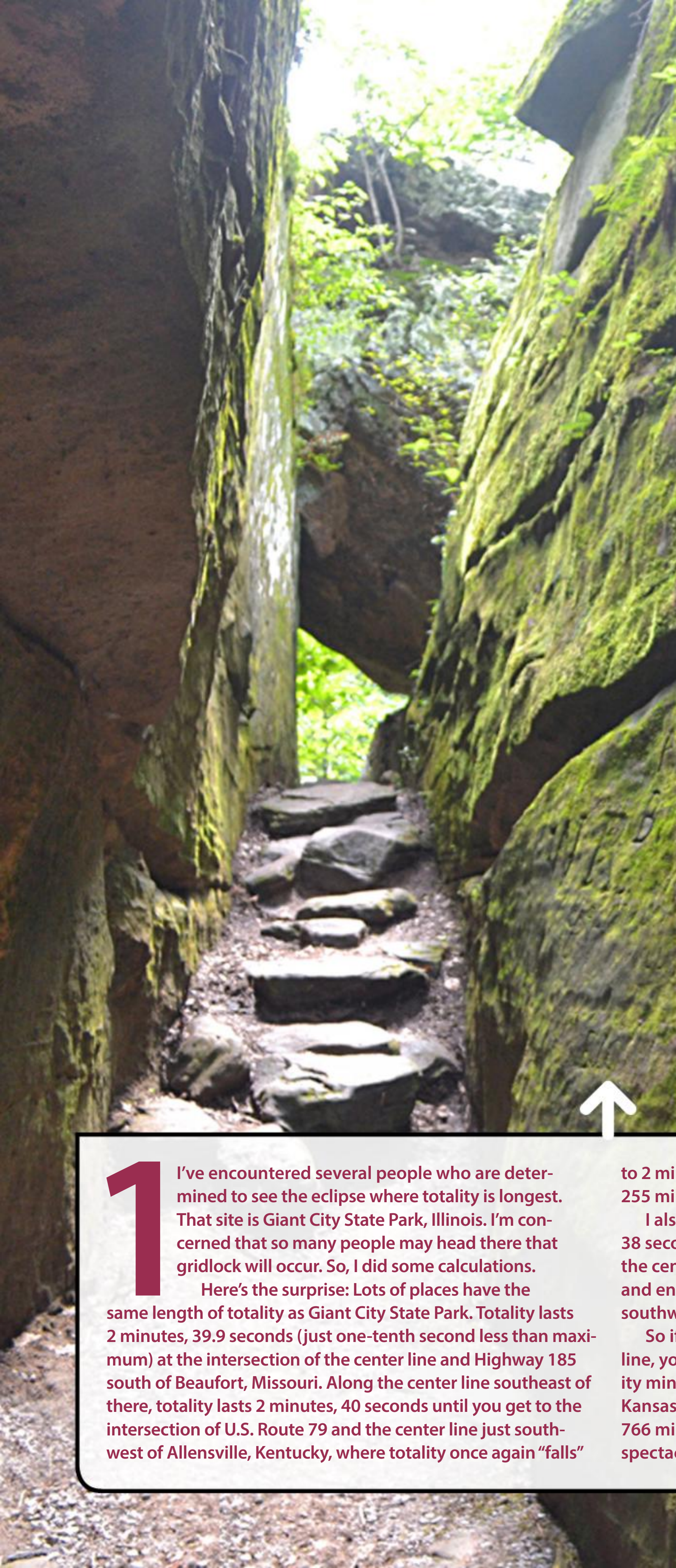
OBSERVE CHARON



DATE	GREATEST NORTHERN ELONGATION
July 5	10 P.M. EDT
July 12	7 A.M. EDT
July 18	5 P.M. EDT
July 25	2 A.M. EDT
July 31	11 A.M. EDT

Track down Pluto's largest satellite, Charon, this month by calculating how far the moon has progressed along its orbit since its previous greatest northern elongation. *ASTRONOMY*: ROEN KELLY

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



KBH3RD

19 big

Be a hit at your next eclipse party with this trivia.

by Michael E. Bakich

IN A BLOG POST DATED JULY 13, 2013, I noted that 1,500 days remained until the August 21, 2017, total solar eclipse. Since then, I've written six eclipse-related stories for the magazine (with at least six more to go), presented more than 60 talks about the coming event, attended a variety of meetings as a member of the American Astronomical Society 2017 Eclipse Task Force, and even written a book about the eclipse.

Going in, I knew everything there was to know about such events — at least, that's what the voices in my head kept telling me. But in fact, a great many facts lay outside my knowledge base.

Here, I present just a sampling of eclipse facts. I've also mixed in a few general misconceptions I've encountered as I've spoken to people and a couple of interesting facts you might use to impress your friends. Just remember, it doesn't matter how much you know about the upcoming eclipse; what matters is that you experience totality. It's all about totality!

1 I've encountered several people who are determined to see the eclipse where totality is longest. That site is Giant City State Park, Illinois. I'm concerned that so many people may head there that gridlock will occur. So, I did some calculations.

Here's the surprise: Lots of places have the same length of totality as Giant City State Park. Totality lasts 2 minutes, 39.9 seconds (just one-tenth second less than maximum) at the intersection of the center line and Highway 185 south of Beaufort, Missouri. Along the center line southeast of there, totality lasts 2 minutes, 40 seconds until you get to the intersection of U.S. Route 79 and the center line just southwest of Allensville, Kentucky, where totality once again "falls" to 2 minutes, 39.9 seconds. That's a straight-line distance of 255 miles where totality lasts 2 minutes, 40 seconds.

I also figured out where totality lasts 2 minutes, 38 seconds or longer. That stretch begins just east of where the center line crosses Raccoon Road in Hiawatha, Kansas, and ends just west of where it crosses Hale Ridge Road southwest of Pine Mountain, Georgia.

So if you position yourself along the eclipse's center line, you can experience the maximum duration of totality minus no more than a measly 2 seconds from Hiawatha, Kansas, to Pine Mountain, Georgia, a straight-line distance of 766 miles! Indeed, there's enough shadow for us all to have a spectacular time.

eclipse surprises

2 I've thought that communities can profit from the eclipse, but until recently, I had no proof. Whether or not a certain location will see a net revenue increase depends on one thing: How many people will show? Discussions about this have been fast and loose, but so far, just about everyone seems too afraid to suggest numbers.

I happen to know someone who helped a community prepare for an eclipse. Australian Terry Cuttle described to me what happened in North Queensland during the November 12, 2012, total solar eclipse.

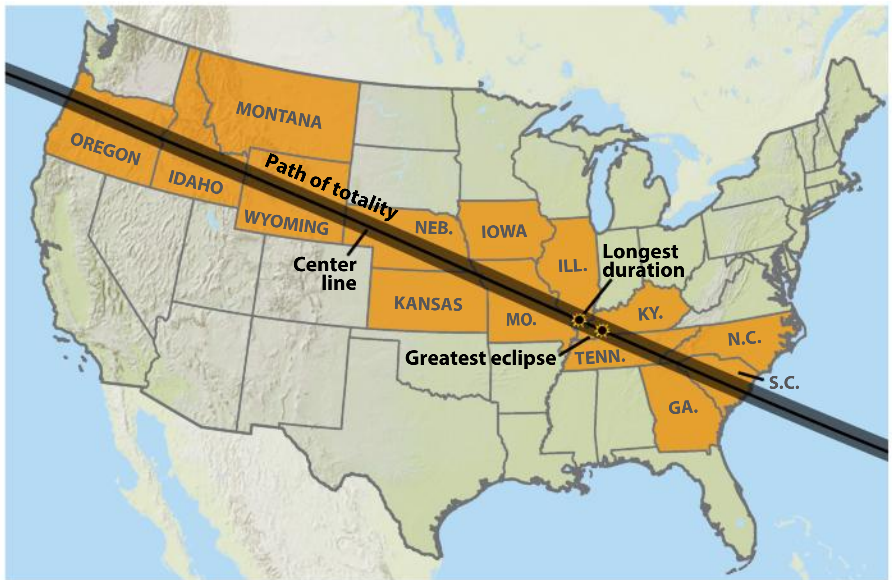
More than three years before the event, Cuttle alerted the Queensland government to the opportunities the eclipse presented. They showed little interest. He then focused on the community of Cairns, assisting its task force and supporting requests to the state government for resources. No such support came.

In the end, the Cairns Regional Council (CRC), which was the main authority affected, managed within its own budget. After the eclipse, two of the CRC's members made a follow-up report.

The report is a public document, but here's the bottom line: The CRC spent in excess of $200,000 (Australian dollars, not U.S.). And the payoff? The committee estimates the direct economic benefit to the region was between $100 million and $130 million. That's right, $100 million of benefits for an outlay of $200,000.

The report also talks about the long-term benefits, especially the increased awareness of the region and its attractions, and the expected increase in visitors that will result. Wow!


KEITH COOPER



ASTRONOMY: ROEN KELLY

3 Many sources say that totality in 2017 passes through 12 states. The number actually is 14, but I can understand why 12 is the number most often given. The amount of land covered by the umbra in the two outliers — Montana and Iowa — is minuscule. Perhaps the best way to use the number 12 is to say, "The eclipse's center line passes through 12 states."

4 The number of people living in the path of totality is 12.25 million. This number comes from Michael Zeiler, who used the 2010 U.S. census population data at the city block level, which is the best available data. He used ArcGIS software to derive the number in the path by computing which centroid positions are inside the umbra and then doing a statistical summary on that table. He also did similar calculations for each 100-mile increment from totality. What did I find stunning? Two out of every five people in the continental United States live within 300 miles of totality! That's scarcely a four-hour drive on an interstate highway.

5 The Moon's umbra will cover 5.5 percent of the total area of the continental U.S. That works out to about two and a half times the area of Missouri, which seems like a lot to me.

People won't observe totality from much of this area because it's relatively inaccessible — especially the mountainous regions in Oregon, Idaho, and Wyoming. Farther to the southeast, areas might be accessible, but people still won't be there because those sites are heavily wooded, and the view will be terrible.

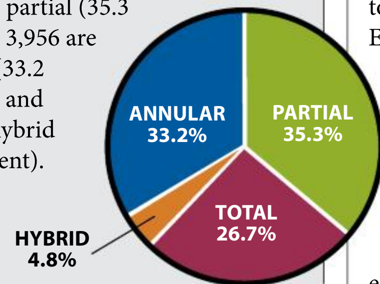
6 In 2017, totality will cross 29 pairs of towns or cities with the same name. The most populated pair is Columbia: Missouri and South Carolina. It will also cover three trios of cities with the same name: Benton in Kentucky, Illinois, and Tennessee; Cleveland in Tennessee, Georgia, and South Carolina; and Marion in Oregon, Illinois, and Kentucky.

7 The Moon's umbra will average 67 miles in diameter in its journey across the U.S. The maximum it can ever achieve is 166 miles.

8 In August, within the continental U.S., the Moon's umbra will travel at a minimum of 1,450 mph (near the point of greatest eclipse) and a maximum of 2,979 mph (at landfall on the Oregon coast).

9 Did you know that you can safely observe the Sun by looking at its reflection off water? I started thinking about this after renowned observer and *Astronomy* contributing editor Stephen James O'Meara submitted a column in which he described observing the Sun's reflection during an eclipse. "Oh, man," I thought, "we can't print this." So, I emailed B. Ralph Chou, professor emeritus of the School of Optometry and Vision Science at the University of Waterloo. He's one of two people responsible for setting the safety standards on all solar filters (think eclipse glasses).

10 Here's a statistic that will make you sound brainy at parties. In the years between 2000 B.C. and A.D. 3000, 11,898 solar eclipses have occurred or will occur. Here's how they break down: 3,173 are total (26.7 percent); 4,200 are partial (35.3 percent); 3,956 are annular (33.2 percent); and 569 are hybrid (4.8 percent).



He answered, "The technique of observing the Sun by its reflection off of water is an ancient one dating back several thousand years. It is quite safe because the reflection in the visible spectrum is of much lower intensity, and the reflected flux of ultraviolet and infrared radiation is extremely small and therefore of no concern. Although the Sun's image is bright, it is not hazardous for the brief observing times that Stephen used. I appreciate your caution, but I believe that what he did was safe, and there is minimal eye hazard involved."

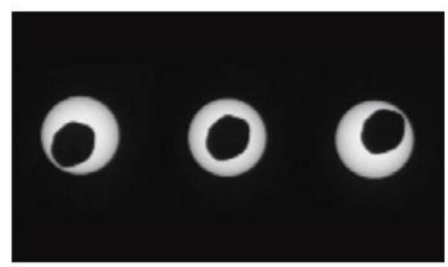
11 The longest totality in 5,000 years will occur July 16, 2186. At maximum, darkness will last an awesome 7 minutes, 29 seconds. The shortest totality happened February 3, A.D. 919. It was only 9 seconds long. The longest annular eclipse was December 7, A.D. 150. Annularity lasted 12 minutes, 23 seconds.

The shortest annular occurs near the end of our span, December 30, 2931. It will last only one-tenth of a second.

12 The larger a body is, the farther into space it will cast its shadow. At Earth's average distance from the Sun, any object casts an umbral shadow (the one that produces totality) 108 times its diameter. This makes Earth's umbral shadow an average length of 855,000 miles and the Moon's umbral shadow approximately 255,000 miles long. Of course, these numbers vary because the distances of these bodies from the Sun change. Still, with them in mind it's easy to see why total lunar eclipses last much longer than total solar eclipses.

13 Guess what? Mars has solar eclipses. It turns out that Mars' moon Phobos revolves around it closer than any other moon around any other planet, only 2.4 percent the distance at which the Moon orbits Earth.

Because it's so close, even this rock, which measures a scant 16 miles long and 11 miles wide, can cast a shadow. Well, an anti-shadow, anyway. Phobos cannot create total eclipses. It can only make partial or annular eclipses, but it makes lots of them. You see, this moon's orbit tilts 1.08° from the plane of Mars' equator. So three



NASA/JPL-CALTECH

© ALEXROZ | DREAMSTIME.COM; *ASTRONOMY*: ROEN KELLY

14 **One of my biggest surprises is that, with regard to eye safety, I've been giving out incorrect information for decades. And pretty much everyone I know has, too. Luckily, it hasn't harmed anyone. What I've been saying is that the reason you shouldn't look at the Sun is not because of the light, but because of the radiation you can't see — the infrared and ultraviolet. Not true.**

Once again, I quote my go-to eye safety expert, B. Ralph Chou, who wrote, "The ultraviolet and infrared levels in sunlight are not a significant factor for solar retinopathy — the injury is primarily due to short-wavelength visible light." So, wow, it is the light alone that does the damage after all.

And here's a fun fact to go with this revelation: You can view the Sun through sunglasses — as long as you stack 13 pairs. Of course, the image through that many inferior optical devices wouldn't be worth looking at, but at least it wouldn't damage your eyes.

times each sol (a martian day), it lines up with the Sun and its host planet, except for those few days when its shadow falls north or south of Mars.

Unfortunately, the annular eclipses Phobos creates take this type of eclipse to a new low. Because the moon moves so fast — it orbits Mars once every 7 hours, 39 minutes — even the longest central annular eclipse lasts a scant 30 seconds.

15 On average, a total solar eclipse reoccurs at a specific location every 375 years. I can't say that was much of a surprise. But did you know that it depends on whether the particular spot is in the Northern or Southern Hemisphere? In the north, the frequency is about once every 330 years. In the south, it's once per 540 years. Here's why.

Although solar eclipses are just as likely to occur in the Northern Hemisphere as in the Southern, each hemisphere sees more of them during the longer daylight hours of its summer — when that part of Earth is tilted toward the Sun. Because Earth is at the farthest point in its orbit in July (during the Northern Hemisphere's summer), the Sun's apparent size in the sky is relatively small then, which means that solar eclipses at that time of year are more likely to be total because the Moon is more likely to appear larger than the Sun. Simply put, observers north of the equator will have more opportunities to see total eclipses.

16 Astronomers categorize each solar eclipse in terms of two properties: its magnitude and the percentage of obscuration. These terms confuse many people. The magnitude of a solar eclipse is the percent of the Sun's diameter that the Moon covers at maximum eclipse. The obscuration is the percent of the Sun's total area covered at maximum.

Here's an example: Let's say we observe a partial eclipse where the Moon covers half the Sun's diameter. The magnitude of the eclipse equals 50 percent. However, the obscuration is only 39.1 percent.

For a total solar eclipse, the obscuration always equals exactly 100 percent. You can't cover more than 100 percent of the Sun. The magnitude, however, can be anywhere from 100 percent, which astronomers would designate as 1.0000, to a bit more than 108 percent, or 1.0805. Magnitudes greater than 100 percent simply mean that the Moon's apparent diameter is that much greater than the Sun's. For our eclipse, the magnitude will be 1.0306.

MARY BETH SIEBERT

17 **Since late 2013, I've stated in my podcast, in blogs, in published stories, and in my book that if you want to be the first person to experience totality in the continental United States, then be on the waterfront at Government Point, Oregon, at 10:15:57 A.M. PDT.**

On September 13, 2016, my friend and noted eclipse mapmaker Michael Zeiler emailed me to say I was wrong. His calculations (which I trust implicitly) show that first contact with land actually will be at Yaquina Head, just above Newport, Oregon.

He was nice enough to say that it wasn't unreasonable to expect that Government Point (a small peninsula jutting out near the center line of the eclipse) would be first. "But," he continued, "the umbral oval is rotated a bit at landfall in Oregon."

18 You might wonder about the last time totality touched a certain location. I researched past eclipses in the 50 states and the District of Columbia. Amazingly, no part of Delaware (or the area of land that would become Delaware) has experienced totality since July 29, 1478 — 14 years before Christopher Columbus' famous voyage.

And in case you're thinking, "Well, the wait there for the next one can't be all that long," you'd have to linger until October 26, 2144, for the next instance of totality in Delaware.

But the longest wait you'd have in any region of the U.S. would be in the District of Columbia. Our nation's capital won't experience totality until September 12, 2444.

TICHNOR BROTHERS

19 Did you know that a minimum of two and a maximum of five solar eclipses occur each year? Between 2000 B.C. and A.D. 3000, 3,625 years have had or will have two solar eclipses; 877 have three; 473 have four; and only 25 of the 5,000 years contain five solar eclipses. The last time that happened was in 1935. The next time will be in 2206.

Michael E. Bakich *is a senior editor of* Astronomy *who will be hosting the world's largest eclipse viewing party at Rosecrans Memorial Airport in St. Joseph, Missouri.*

Celestron's Inspire 100AZ Refractor Telescope is a great example of an eclipse telescope, but it's far from the only choice. Try to find one with similar specs. CELESTRON

HOW TO choose a telescope for the eclipse

The eclipse will last just a few minutes. The right rig will deliver on the big day.

by Michael E. Bakich

YOU'VE THOUGHT LONG AND HARD about what telescope you should choose to view the eclipse. But you haven't plopped down the money for the scope because you're still a bit unsure which one you should get. I know. All those strange words — *focal ratio*, *aperture*, *catadioptric*, and more — can be confusing if you're reading about them for the first time.

I want to simplify matters. My goal is to help you pick a telescope to view the eclipse, one with which I guarantee you'll have success. What's more, you'll need to understand only three things: focal length, magnification, and field of view. (See the sidebar on the opposite page.)

Now, lest you think that I've hoarded this information until now, the truth is I actually shared it in some detail with four major telescope manufacturers. That happened at the Advanced Imaging Conference that took place in October 2015 in San Jose, California. All four representatives I spoke to thought my idea was excellent. I guess time will show whether any of them followed my prescription.

But even without the "perfect" telescope from one or more manufacturers, you can put together my ideal system with little effort. Here's how.

First, select a small refractor as your scope. It doesn't matter which one. It should be small enough for you to transport and set up easily. You'll also need a way to support it during your observations. The simplest way is to attach it to a camera tripod. Make sure the tripod is sturdy enough for your scope. In fact, check this twice. You don't want wobble, wiggle, or drift.

One note: In nearly all cases, small refractors come with a type of clamp that goes around the scope's tube or a pair of rings that hold the scope. In the case of the rings, a metal bar (sometimes called a dovetail bar because of its shape) connects them together. Either of these clamping systems provides you with a simple way to connect your scope to a tripod. Usually, this is a threaded hole into which you screw the bolt on the top of the tripod.

You could spend more. You could get an astronomical mount with its special tripod for your scope. Honestly, though, if you're only, or mainly, in this for the eclipse, keep things simple and stick with the camera tripod.

Now, you can't just point a telescope — no matter what you've mounted it on — directly at the Sun unless you first cover the front with an approved solar filter. Odds are that the manufacturer of your telescope will have a filter for the model you bought. If not, check out the solar filters sold by Rainbow Symphony. Get the correct size for the front of your tube, and ensure a secure fit by watching the company's video, "How To: Fit a Solar Filter," available on YouTube. Once you have your properly filtered scope and it's set up securely, the only thing left to do is select the correct eyepieces.

When I've used a telescope to view past solar eclipses, I've carefully selected just two eyepieces to combine with it. The high-power one gives a field of view around 1° across. That makes the Sun's disk half as wide as the whole field of view my eye sees. The low-power eyepiece provides a field of view around 2° across, which makes the Sun one-quarter as wide as the field's diameter.

Both eyepieces have specific purposes. I select the high-power one for the partial phases of an eclipse. Through this eyepiece, the Sun is large enough for me to see any sunspots on its surface.

But as totality approaches, I switch to the low-power eyepiece because I want to see most, if not all, of the Sun's corona, which appears as a ring of soft light around the eclipsed disk. Simple math shows that the space around the Sun I'll see through the high-magnification eyepiece will be ¼° across. That's how much distance will be between the edge of the Sun and the edge of my eyepiece's field of view. The low-power eyepiece will show me a ring around the Sun that's ¾° wide. If I want a wider view yet, I switch to binoculars.

So, how do you calculate the true field of view of a telescope/eyepiece combination? The exact calculation is to divide the eyepiece field stop diameter by the telescope's focal length and then multiply that result by 57.3. Ouch!

But there's another way to calculate true field of view that's almost as accurate. Just divide the eyepiece's apparent field of view by its magnification when it's in your telescope. To get this result, you first have to calculate the magnification, which is a simple division. You can find the magnification of any eyepiece in your scope by dividing its focal length (the number on the eyepiece) into the telescope's focal length. To then find the true field of view, you divide that number into the eyepiece's apparent field of view, a number provided by almost all manufacturers. Let's look at an example.

THREE TERMS TO KNOW

Field of view: Apparent: the angle of light emerging from an eyepiece, usually between 45° and 110°. True: the diameter (in degrees) of the circle of sky any eyepiece/telescope combo produces.

Focal length: The distance, usually given in millimeters, from the imaging optic (the main lens of the mirror) of a telescope or of an eyepiece, to where light comes to a focus.

Magnification: The apparent enlargement of an object viewed through an eyepiece connected to a telescope.

A good solar filter is essential for eclipse viewing; otherwise, you could permanently damage your eyes! RAINBOW SYMPHONY

For the upcoming eclipse, you want to see if a certain scope and two eyepieces will work. Maybe it's a scope you're thinking about buying, or perhaps it's one you already own. You'll probably want a unit that's small and one whose mount and tripod (if they came with the scope) aren't huge, either. That makes the system easy to transport.

As our example, let's look at Celestron's Inspire 100AZ Refractor Telescope. This 4-inch scope has a focal length of 660mm, and it comes with two eyepieces: a 20mm, which provides a magnification of 33x, and a 10mm that gives 66x. Both eyepieces have apparent fields of view of 50°.

For this example, we didn't even have to calculate the magnification. Celestron lists that on this scope's webpage under "Specifications."

Actually, the field of view wasn't listed for either eyepiece, but a quick look around the web told me each has an apparent field of view of 50°. So, for the 20mm eyepiece, 50° (that's the apparent field of view) divided by 33 (the magnification) equals 1.5°.

That means, for this telescope/eyepiece combo, your field of view would be 1½°. That would make the ½° diameter of the Sun's disk one-third as wide as the view through the eyepiece, and there would be a ½° ring around it. Not too shabby for viewing the total phase of the eclipse.

The second eyepiece Celestron provides for this scope has a focal length of 10mm. Let's make this easy: A 10mm eyepiece has twice the magnification of a 20mm. So this eyepiece provides 66 power. And it also has an apparent field of view of 50°, so 50° divided by 66 equals 0.76°, which we'll call ¾°. Through this eyepiece, the Sun would appear two-thirds as wide as the field of view. Any decent sunspots visible on eclipse day will show up well.

So, according to my criteria, this telescope will work fine for the eclipse. And, at $289.95 for everything, it won't break the bank. Remember, though: You will need a solar filter for the front of it.

Finally, let me share one more piece of advice to first-time eclipse watchers. Keep things simple. Don't bring more than two eyepieces for eclipse viewing. This will make the transition from your high-power to low-power views foolproof. You won't grab the wrong eyepiece or be looking down to be certain you get the right one. Remember: Maximizing your viewing time — and here I'm talking about the maximum of 2 minutes and 40 seconds of totality — will be the most important thing!

Michael E. Bakich *is a senior editor at* Astronomy**.**

OBSERVING**BASICS**

BY GLENN CHAPLE

Hitching a ride

Before buying a new piece of equipment, be sure to test-drive it.

During my college days in the late 1960s, I didn't own a car and often had to hitchhike to get from place to place. Nowadays, I would never recommend this mode of travel (I'm older and perhaps wiser, and understand the sheer number of crazies on the highways), but I do advocate hitchhiking via a different mode of transportation — the telescope. Not only does telescope hitchhiking take you to destinations far beyond anything you could access on the freeway, it might save you hundreds of dollars when it comes to purchasing astronomy gear.

When the first 100° wide-angle eyepieces appeared on the market, I knew I had to have one. Sure, the price was astronomical (pardon the pun), but after four decades as a dedicated backyard astronomer, I felt worthy of the luxury.

Fortunately, I belong to a vibrant astronomy club: the Amateur Telescope Makers of Boston. At one of the club's observing sessions, member Steve Clougherty was using one of these eyepieces to view deep-sky objects through his 18-inch Dobsonian. When I heard this, I had to hitch a ride on his scope! To my surprise and dismay, I couldn't take in the full 100° apparent field of view — not without moving my head up and down and side to side. I returned to my scope and inserted one of my 82° wide-angle eyepieces. Peering in, I could just capture the whole field without any head movements. This was more like it! To spend hundreds of dollars for a slightly wider apparent field would have been a waste of money.

Now, I'm not suggesting that you avoid buying a 100° wide-field eyepiece. Several members of my club own such eyepieces and describe their performance in three words: amazing, amazing, amazing! And your eye may be able to take advantage of the wider view. What I am suggesting is that, whenever possible, try out a telescope or telescope accessory before purchasing one. Hitching a ride on a telescope allows you that opportunity.

That's one reason why I recommend joining a local astronomy club. Not only will you get the chance to talk with people who share your passion for the sky, but you'll also have an opportunity to try out other members' equipment. I've never encountered someone who wasn't eager to let me peer through his or her telescope. In fact, more often than not, the owner invited me to look. In the process, I got to experience a variety of telescope types and accessories. Not only did they teach me what not to buy, but they also paved the way for some worthwhile purchases. I bought that 82° eyepiece I mentioned earlier with confidence after I looked through one at a club get-together.

Telescope hitchhiking might save you hundreds of dollars when purchasing astronomy gear.

Children line up to observe the Moon through an 18-inch Dobsonian telescope and its 12x75 finder scope at southeastern Virginia's Back Bay Amateur Astronomers sidewalk viewing session in April 2012. Such events provide ample opportunities to try new equipment on for size. TED FORTE

Time to party

Astronomy conventions and public star parties also provide great opportunities for telescope hitchhiking — there you'll find amateur astronomers fairly begging you to take a peek through their scopes. A few years ago, I helped out with a star party being held at a local elementary school. One of the volunteers was working with a refracting telescope he purchased from a company that offered such scopes for an insanely low price. I thought the quality would be iffy at best, but I hitched a ride anyway. The image of the Orion Nebula (M42) through it was so crisp that I wound up ordering the same telescope model for myself.

At this year's annual Stellafane Convention in Springfield, Vermont (which takes place July 20–23), I plan to wander around the observing field hitching rides on as many different scopes as I can. I really don't need a new telescope, but I'll be asking the owners about the eyepieces they're using. A backyard astronomer can never own enough eyepieces! Make sure the scope you're hitchhiking with is similar to your own, though. The performance of an eyepiece coupled with a short-focus reflector may differ dramatically from its performance when used with a long-focus refractor or catadioptric scope.

Don't get me wrong — there are drawbacks to telescope hitchhiking. For one thing, a cursory glance may not allow you enough time to truly evaluate a telescope or accessory. Fortunately, my astronomy club has a loaner program. A room in the clubhouse stores a variety of donated telescopes, eyepieces, and accessories, and club members can take any of them out on temporary loan. If you borrow before you buy, you can almost guarantee that your purchase will deliver years of enjoyment.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: August's spectacular total eclipse!

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

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

BINOCULARUNIVERSE

BY PHIL HARRINGTON

Summertime clusters

One of my favorite warm-weather activities as a kid was flying a kite. Even today, I enjoy watching kites soar high in the sky. There is just something very relaxing, almost cathartic about their graceful movements.

That fascination for kites continues into the night sky, where we find a celestial version of a kite in the form of Boötes. This constellation dates back to the second century A.D. when astronomer Claudius Ptolemy included it as one of his 48 constellations in his monumental work, *Almagest*.

But Ptolemy didn't see a kite when he looked at the stars in his new constellation. Instead, he envisioned an ox driver or a herdsman holding a staff in one hand. Perhaps, but it still looks like a kite to me, as I am sure it does to many others. In fact, if you look carefully, you just might spot the smile on the face of the child who is flying the kite! That smile, formed by a semicircle of stars to the east, is the constellation Corona Borealis the Northern Crown.

Boötes is home to magnificent Arcturus (Alpha [α] Boötis), the brightest star north of the celestial equator. Arcturus puts on a great show through binoculars, beaming with an unmistakable orangish tint. The color demonstrates that its inherent temperature is lower than our yellow dwarf Sun. While Arcturus may be cooler than the Sun, it is significantly larger in diameter.

One reason why Arcturus appears so bright in our sky is that it is fairly close to our solar system, just under 37 light-years away. While most of the stars in the Sun's neighborhood are comparatively modest, Arcturus — along with Alpha Centauri, Sirius, and Vega — really stands out in the crowd.

Arcturus makes a great jumping-off point for finding three globular clusters visible in tonight's binocular sky. One is easy to spot, the second is more difficult, and the third is very challenging even for the largest giant binoculars.

Let's begin with the brightest of the bunch, **M3**. It lies across the border in the neighboring constellation Canes Venatici. The simplest way to find it is to aim your binoculars at the halfway point between Arcturus and the brightest star in Canes Venatici, Cor Caroli (Alpha Canum Venaticorum).

The blazing globular cluster M3 is a gorgeous sight for binoculars in the springtime and early summer evening skies. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

Cor Caroli is just south of the Big Dipper's bowl. M3 will look like a tiny puff of celestial cotton hanging near a 6th-magnitude field star.

Discovered in 1764 by Charles Messier, M3 is one of the brightest globular clusters in the entire sky. More than half a million stars are believed to be held in its grasp, making M3 one of the largest members of the Milky Way's family of globular clusters.

Amateur astronomers everywhere should thank M3, because it was the spark that lit the fire in Messier to compile his now-famous catalog of deep-sky objects. While Messier had made extensive notes on the objects that later became the first two listings in his catalog, legend has it that his discovery of M3 started him on a systematic quest for other comet-like imposters.

Messier's catalog includes a second, more challenging globular cluster 15°, or about three binocular fields, west of Arcturus. Lying within Coma Berenices, **M53** is actually easier to locate than M3, since is less than 1° northeast of 4th-magnitude Diadem (Alpha Comae Berenices). Locating M53 may be simpler, but seeing it is another matter. At 8th magnitude, M53 looks like a round, nebulous disk drawing to a brighter center. Look for a 13'-diameter puff set in an attractive star field. Not one of the 100,000 or so stars that make up M53 is bright enough to see through binoculars.

Lastly, we have a third globular that is probably only visible through giant binoculars, and even then with difficulty. **NGC 5466** lies within Boötes near the border shared with Canes Venatici. It shines at 9th magnitude, so seeing it depends on sky conditions. It's a tough catch through my 16x70s from my suburban backyard, but it becomes much more evident if I travel to darker skies. Look for a dim, gray light just west of a 7th-magnitude field star.

I'd enjoy hearing your success with these three very different globular clusters. Drop me a line through my website, philharrington.net. And if you have a favorite binocular target that you'd like to share with the rest of us, I'd love to feature it in a future column.

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

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

With a condensed core and smattering of stars around its fringe, M53 makes an attractive globular cluster target for binocular observers. AL KELLY

NGC 5466 is a loose globular cluster with relatively few stars and a low surface brightness, making it a challenge for binocular observers. MARTIN C. GERMANO

NEW PRODUCTS

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

Equipment filters

Daystar Filters
Warrensburg, Missouri

Daystar's Universal Solar Lens Filter comes in a number of different sizes. All conform to the ISO 12312–2 safety standard and transmit only one-thousandth of 1 percent of the Sun's light. Each has a spring-folded shape to hold onto various sizes of camera lenses, binoculars, or telescopes.

Price: $12.95 to $39.95
866.680.6563
www.daystarfilters.com

Solar scope

Celestron
Torrance, California

Celestron's EclipSmart Travel Scope 50 is a 2-inch f/7.2 refractor containing permanently attached ISO-certified solar filters to allow direct viewing of the Sun. The kit includes a tripod, star diagonal, Solar Safe finder scope, 20mm Kellner eyepiece, and a nylon backpack.

Price: $99.95
310.328.9560
www.celestron.com

Solar binoculars

Celestron
Torrance, California

Celestron's EclipSmart 10x42 solar binoculars use Solar Safe filter technology for guaranteed safe observation of the Sun. The non-removable 42mm dual lenses provide a 7° field of view and 12.7 millimeters of eye relief. The unit features a weather-resistant rubber-armored aluminum body and includes a soft carry case and strap.

Price: $69.95
310.328.9560
www.celestron.com

Caps

GreatAmericanEclipse.com
Santa Fe, New Mexico

GreatAmericanEclipse.com's Eclipse Caps are durable, embroidered, and come in four colors: denim, charcoal, white, and red. Use the cap as a conversation starter. Explain to your friends that the diagonal stripe in the design is where the total eclipse track travels across the United States. One size fits all.

Price: $20
GreatAmericanEclipse@gmail.com
www.GreatAmericanEclipse.com

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

MARKETPLACE

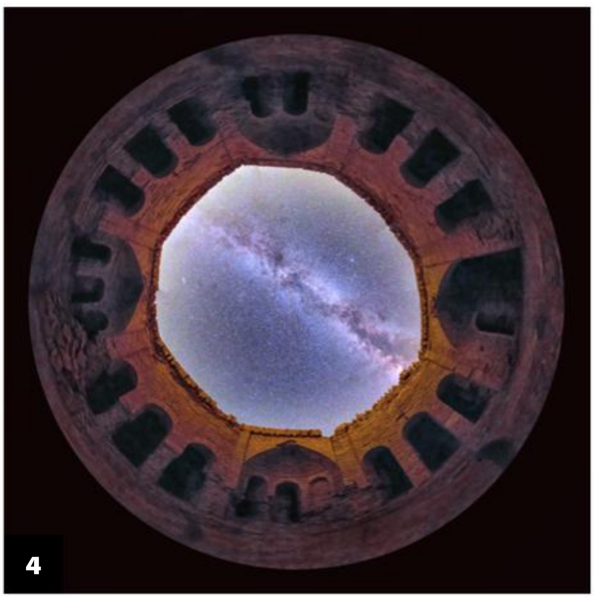
INDEX *of* ADVERTISERS

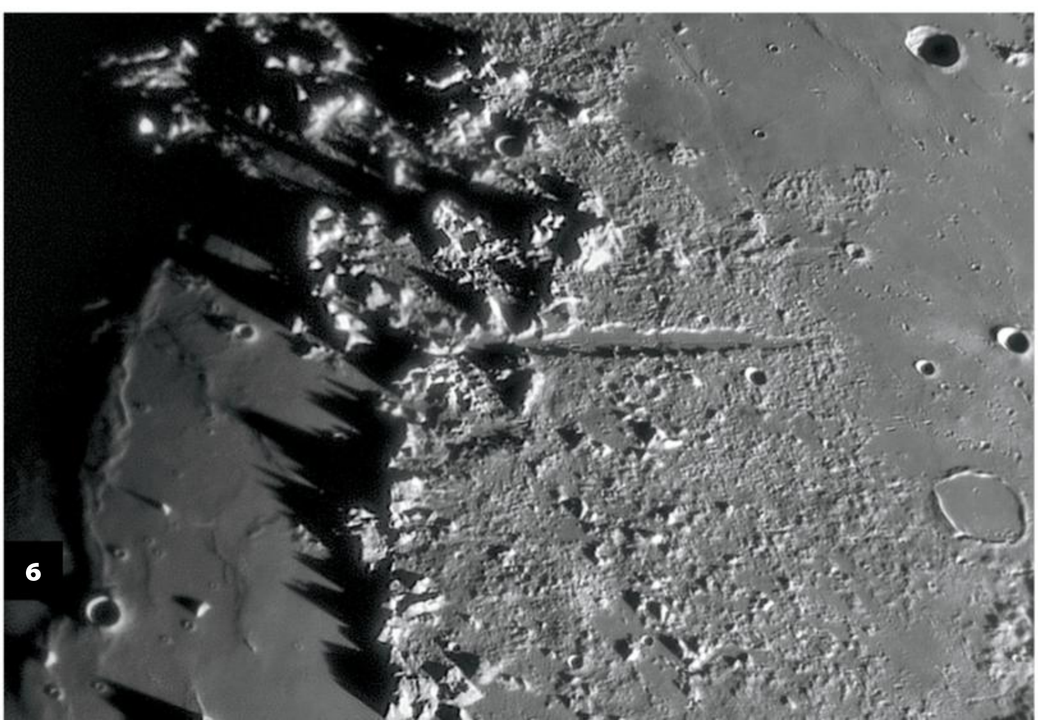
The Advertiser Index is provided as a service to *Astronomy* magazine readers. The magazine is not responsible for omissions or for typographical errors in names or page numbers.

READER GALLERY

1. RUN, CHICKEN, RUN
This region of sky, sometimes called the Running Chicken Nebula and at other times the Lambda Centauri Nebula (IC 2944), combines an open star cluster and a bright emission nebula. The nebula lies about 6,000 light-years away in the constellation Centaurus. • ***Gerald Rhemann***

2. JUST PASSING BY
Comet Tuttle-Giacobini-Kresak/41P glides by spiral galaxy NGC 3198 on March 14. Over Payson, Arizona, the comet exhibited a strong teal color while the galaxy was full of blue and pink knots, indicative of star-forming regions. • ***Chris Schur***





3. THE MUSCLEMAN CLUSTER
Stock 2 is an attractive open cluster of stars in the northern constellation Cassiopeia the Queen. Its designation comes from being included on a list of 24 such objects compiled by Jürgen Stock in the 1950s. • ***Dan Crowson***

4. A ROOF FULL OF STARS
This fisheye image comes from the Deyr-e-Gačīn caravansary near Tehran, Iran. It shows the Northern Hemisphere summer Milky Way stretching across the opening. If you look closely, you can see the three bright stars of the Summer Triangle. • ***Amirreza Kamkar***

5. THE DARK SIDE
Observers have noted this little gas cloud, situated between the North America (NGC 7000) and Pelican (IC 5070) nebulae, and christened it the Skull Nebula. This imager, however, says its shape and stars in the positions of eyes are more suggestive of a storm-trooper helmet from *Star Wars*. One argument against this might be that it lies within our Milky Way and not "a galaxy far, far away." • ***Rodney Pommier***

6. MOON SCAR
This image shows the Montes Alps mountain range on the Moon when it was near the terminator (the line dividing the light and dark sections). The large gorge at center is Vallis Alpes, which stretches for 103 miles (166 kilometers). • ***Chuck Manges***

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

Galaxy with a twist

The rough-and-tumble world of galaxy groups and clusters often reveals itself through wildly distorted galaxy shapes. Other times, the effects prove more subtle. The unassuming galaxy NGC 1055 is a perfect example. Look carefully at the dark dust lane cutting through the center of this edge-on spiral, and you'll notice that it splits in two, with the fainter strand twisting out of the galaxy's disk. Astronomers suspect the slight distortion arises from NGC 1055's interaction with the nearby active galaxy M77. These neighbors dominate a small galaxy group 55 million light-years from Earth in the constellation Cetus the Whale. ESO


ECLIPSMART™
SOLAR SAFE PRODUCTS
by CELESTRON
YOUR PERFECT COMBINATION FOR THE
TOTAL SOLAR ECLIPSE
NEXSTAR SE AND ECLIPSMART SOLAR SAFE TELESCOPE FILTERS
THERE'S NEVER BEEN A BETTER TIME to gear up for the Total Solar Eclipse and a lifetime of amateur astronomy! Pair the 6" or 8" NexStar SE with Celestron's new, ISO-compliant solar filters and you have the ultimate eclipse viewing setup.
Solar Safe 6" Telescope Filter
Actual image taken with filter and point-and-shoot camera
Solar Safe Photo Filter
Solar Safe Glasses
(Included in Deluxe and Ultra Sun Observing and Imaging Kits)
NexStar 6SE
Perfect for nighttime observation of the best celestial objects.
SAFELY OBSERVE
THE SUN ANY DAY
10x25 Solar Safe Binoculars
10x42 Solar Safe Binoculars
Solar Safe Travel Scope 50
SOLAR SAFE™ FILTER TECHNOLOGY
All EclipSmart products are lab tested and certified to the latest ISO standards for 100% safe solar viewing
ISO
Conforms to and meets the Transmission Requirements of ISO 12312-2, Filters for Direct Observation of the Sun
CELESTRON PREMIER SELECT DEALERS
Adorama – 800.223.2500 – www.adorama.com
Astronomics – 800.422.7876 – www.astronomics.com
B&H Photo – 800.947.9970 – www.bhphotovideo.com
Focus Camera – 800.221.0828 – www.focuscamera.com
High Point Scientific – 800.266.9590 – www.highpointscientific.com
OPT Telescopes – 800.483.6287 – www.opttelescopes.com
Optics Planet – 800.504.5897 – www.opticsplanet.com
Woodland Hills – 888.427.8766 – www.telescopes.net
CHECK OUT
other EclipSmart Solar Safe products and customize your own eclipse viewing experience
celestron.com/ECLIPSMART

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

September 2017: Ringed planet evenings

September's most prominent evening planet is **Jupiter**. You can find this world in the western sky as twilight fades, though it loses altitude as the month progresses. The planet remains within 5° of Spica, the brightest star in the constellation Virgo the Maiden, all month. It passes 3° due north of the star September 5 and appears directly to the star's right around midmonth. At magnitude –1.7, Jupiter shines more than 10 times brighter than Spica.

Even though the giant planet now lies relatively far from Earth, it continues to be a wonderful subject for telescopes of all sizes. You'll easily see its disk, which spans 31" in mid-September and shows plenty of intricate detail in its cloud tops. You'll also spot the four brightest of its 67 known moons. It's best to observe Jupiter early in the evening before it dips too low and you have to view it through thicker layers of Earth's image-distorting atmosphere.

The showpiece planet **Saturn** appears high in the northwest as darkness falls. The ringed world lies at a declination of –22° and is beautifully placed for viewing from the Southern Hemisphere. Saturn drifts slowly eastward against the backdrop of southern Ophiuchus this month, though the magnitude 0.5 planet shines far brighter than any of the Serpent-bearer's stars.

Now that the weather has started to warm up, consider introducing your friends and acquaintances to a telescopic view of Saturn. You won't believe how many "oohs" and "aahs" you'll hear, along with surprised expressions at the ring system's prominence. Even experienced observers never lose their enthusiasm for this planet. In mid-September, Saturn's disk measures 17" across while the rings span 38" and tilt 27° to our line of sight.

At the other end of the night, brilliant **Venus** adorns the predawn sky. Unfortunately, the ecliptic — the apparent path of the Sun across our sky that the planets closely follow — makes a shallow angle to the eastern horizon on September mornings. This means Venus' elongation from the Sun translates more into distance along the horizon than altitude above it. The inner planet's elevation a half-hour before sunrise shrinks from about 10° to 5° during the month. Still, at magnitude –3.9, Venus stands out against the twilight glow. The planet's 12"-diameter disk appears nearly full when viewed through a telescope.

The other morning planets suffer a similar fate. **Mercury** reaches greatest elongation September 12, when it lies 18° west of the Sun but climbs only 3° high in the east 30 minutes before sunrise. You'll need an unobstructed horizon to spot the magnitude –0.4 planet. Your best bet is to use binoculars and scan the area 10° to Venus' lower right.

Mars is even harder to see. On September 30, the Red Planet stands 3° above the eastern horizon a half-hour before the Sun rises. Mars is slowly emerging into morning twilight after its July conjunction with the Sun, and keen observers may be able to spot it through binoculars. Look for the magnitude 1.8 planet's ruddy glow just 3° to the lower right of brilliant Venus. It will be several months before Mars grows prominent in our sky.

The starry sky

Typically, the stars labeled Alpha (α) and Beta (β) within a constellation are the brightest and second brightest, respectively. But a striking counterexample exists in Sagittarius the Archer, which lies high in the northwestern sky as darkness settles in during September.

When I first learned to find my way around the night sky, I quickly noticed that Sagittarius was easy to identify because it features two prominent yet distorted quadrilaterals of stars. The brightest star in the western group is magnitude 1.8 Epsilon (ϵ) Sagittarii, while the brightest in the eastern set is magnitude 2.1 Sigma (σ) Sgr. They rank as the Archer's two brightest stars.

Where do Alpha and Beta Sgr come in? Alpha shines dimly at magnitude 4.0 while Beta comprises two stars, Beta^1 and Beta^2, that glow at magnitudes 4.0 and 4.3, respectively. Both Alpha and Beta reside in the far southern part of Sagittarius, with Alpha at a declination of –41° and the Beta pair some 4° farther south.

Astronomers think that the southerly location of these stars has a lot to do with their hard-to-explain promotion to Alpha and Beta status. We owe the Greek letter designations to German astronomer Johann Bayer, who introduced them in his early 16th-century star atlas, *Uranometria*. Bayer lived in Augsburg at a latitude of 48° north, where Alpha Sgr barely clears the horizon. Even then, Earth's atmosphere dims the star considerably. And residents of Augsburg can never see the Beta pair.

Uranometria covered the entire sky, however. To complete his star atlas, Bayer had to rely on the observations of others who had actually studied the sky from farther south.

It is nearly impossible to imagine Earth's atmosphere dimming these stars significantly, so it seems plausible that Bayer misinterpreted the comments of other observers about the brightnesses of these stars. Indeed, Bayer depicts Alpha and Beta as quite brilliant in *Uranometria*, certainly far brighter than either Epsilon or Sigma.

Although Beta^1 and Beta^2 make a pretty naked-eye pair, they are not a binary system. Beta^2 lies 139 light-years from Earth, some 240 light-years closer than its neighbor.

However, Beta^1 itself is a binary system. The main star has a 7th-magnitude companion located 28" away, making it an easy pair to split through any telescope. Astronomers estimate that the two are more than 3,300 astronomical units (1 AU is the average distance between the Sun and Earth) apart — 110 times the distance between the Sun and Neptune.

STAR DOME

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

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

SEPTEMBER 2017

Calendar of events

4 Mercury is stationary, 16h UT

5 Neptune is at opposition, 5h UT

Jupiter passes 3° north of Spica, 11h UT

6 The Moon passes 0.8° south of Neptune, 5h UT

Full Moon occurs at 7h03m UT

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

10 Mercury passes 0.6° south of Regulus, 12h UT

12 Mercury is at greatest western elongation (18°), 10h UT

The Moon passes 0.4° north of Aldebaran, 13h UT

13 Last Quarter Moon occurs at 6h25m UT

The Moon is at perigee (369,860 kilometers from Earth), 16h06m UT

16 Mercury passes 0.06° north of Mars, 18h UT

18 The Moon passes 0.5° south of Venus, 1h UT

The Moon passes 0.09° north of Regulus, 5h UT

The Moon passes 0.1° north of Mars, 20h UT

The Moon passes 0.03° south of Mercury, 23h UT

19 Venus passes 0.5° north of Regulus, 23h UT

20 New Moon occurs at 5h30m UT

22 The Moon passes 4° north of Jupiter, 8h UT

September equinox occurs at 20h02m UT

25 Asteroid Pallas is stationary, 11h UT

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

The Moon is at apogee (404,348 kilometers from Earth), 6h50m UT

Asteroid Vesta is in conjunction with the Sun, 14h UT

28 First Quarter Moon occurs at 2h54m UT

Pluto is stationary, 8h UT

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