SOLAR ECLIPSE! How it really happens p. 34

Astronomy®

The world's best-selling astronomy magazine

MAY 2017

Understanding the strangest stars

50 YEARS OF PULSARS p. 22

DISCOVER 10 WEIRD EMISSION NEBULAE p. 44

Mount Wilson's famous telescope celebrates a century p. 28

A short history of eclipses p. 49

Image the sky with camera and tripod p. 52

www.Astronomy.com

BONUS ONLINE CONTENT CODE p. 4

Vol. 45 • Issue 5

Shot with the EOS 5D Mark IV Camera & EF16-35mm f/2.8L II USM Lens

THE EOS 5D Mark IV. A NEW CHAPTER BEGINS.

For over a decade, nature photographer Alex Strohl has chosen Canon EOS 5D cameras. It's a legacy boldly advanced with the new EOS 5D Mark IV. With a 30.4 Megapixel full-frame sensor, built-in GPS and Wi-Fi® connectivity, and a max ISO of 102400, the features in the Canon EOS 5D Mark IV offer unprecedented flexibility. Perfect for photographers who push the limits. See Legendary.

www.usa.canon.com/5D4Legend

Canon
SEE IMPOSSIBLE

CONTENTS

44

MAY 2017

VOL. 45, NO. 5

DON DIXON FOR *ASTRONOMY*

ON THE COVER

Pulsars — incredibly dense, highly magnetized corpses of massive suns — emit beams of intense radiation that sweep the cosmos.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

ONLINE FAVORITES >>

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

My Science Shop
The perfect gift for your favorite science geeks

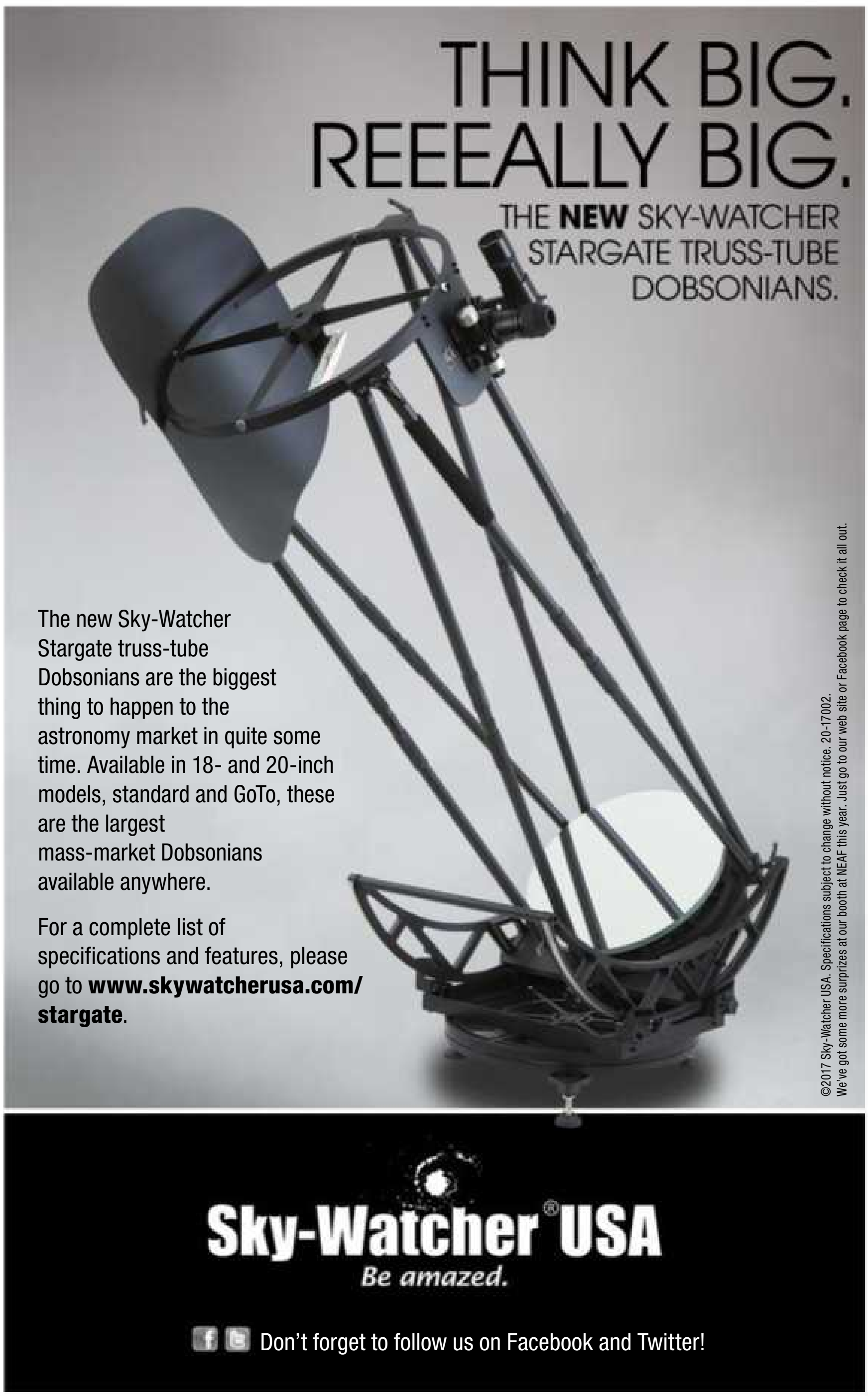
Trips and Tours
Travel the world with the staff of *Astronomy*

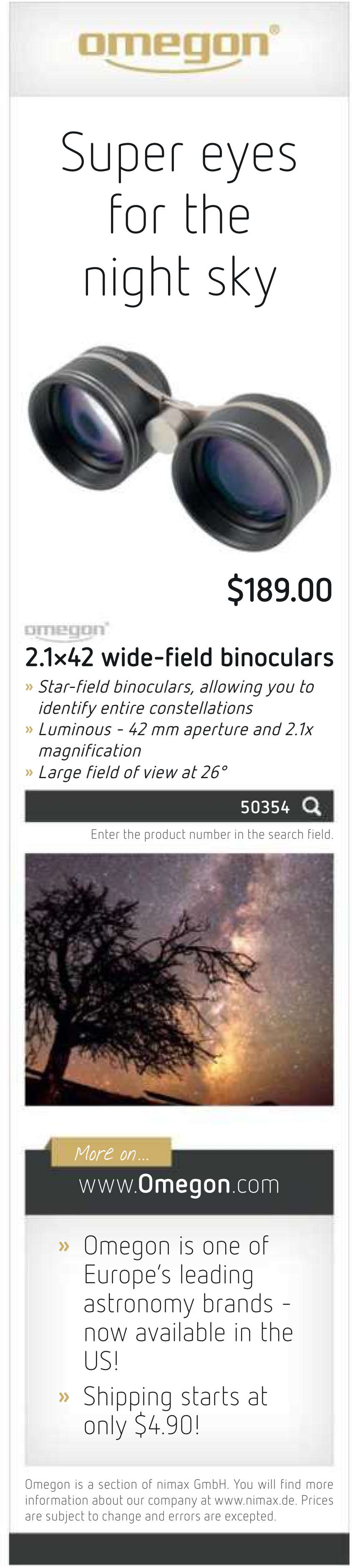
Seasonal Observing
Find great targets in the winter sky

News
The latest updates from the science and the hobby

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.


Get your
eclipse gear at
Great
American
Eclipse.com
eclipse glasses ■ books ■ maps
solar binoculars ■ caps ■ jewelry
shirts ■ posters ■ pins ■ magnets
email greatamericaneclipse@gmail.com for wholesale
Where will YOU be
on August 21, 2017?


THINK BIG.
REEEALLY BIG.
THE NEW SKY-WATCHER
STARGATE TRUSS-TUBE
DOBSONIANS.
The new Sky-Watcher Stargate truss-tube Dobsonians are the biggest thing to happen to the astronomy market in quite some time. Available in 18- and 20-inch models, standard and GoTo, these are the largest mass-market Dobsonians available anywhere.
For a complete list of specifications and features, please go to www.skywatcherusa.com/stargate.
©2017 Sky-Watcher USA. Specifications subject to change without notice. 20-17002.
We've got some more surprizes at our booth at NEAF this year. Just go to our web site or Facebook page to check it all out.
Sky-Watcher® USA
Be amazed.
Don't forget to follow us on Facebook and Twitter!


omegon®
Super eyes
for the
night sky
$189.00
omegon®
2.1x42 wide-field binoculars
» Star-field binoculars, allowing you to identify entire constellations
» Luminous - 42 mm aperture and 2.1x magnification
» Large field of view at 26°
50354
Enter the product number in the search field.
More on...
www.Omegon.com
» Omegon is one of Europe's leading astronomy brands - now available in the US!
» Shipping starts at only $4.90!
Omegon is a section of nimax GmbH. You will find more information about our company at www.nimax.de. Prices are subject to change and errors are excepted.

FROM THE **EDITOR**

BY DAVID J. EICHER

An astronomical workhorse

A handful of instruments stand out as all-time champions in the history of astronomy. The 200-inch scope at Palomar, the refractors at Lowell and Yerkes, and the "Leviathan of Parsonstown" in Ireland come to mind. But none played a more significant role in deciphering the structure of the universe than the 100-inch Hooker Telescope at Mount Wilson Observatory near Los Angeles. And this year, the Hooker scope celebrates a century of existence.

Science writer Ron Voller describes the telescope's historic contributions in his story beginning on p. 28. Vast contributions to understanding the Milky Way Galaxy and the universe at large rolled out of this setting after the telescope saw first light during the latter days of World War I.

Of course, the crowning achievement of this instrument, paid for by Los Angeles steel magnate John D. Hooker, came on what seemed a rather ordinary night in October 1923. A young astronomer interested in "spiral nebulae," Edwin Hubble, trekked up Mount Wilson for an observing run and began capturing exposures of one of his favorite objects, the spiral nebula M31 in Andromeda.

On October 4, he took a 40-minute exposure, despite worrying over somewhat poor seeing, with the resulting turbulent star images. Nonetheless, he developed the glass plate negative and examined it carefully. He found something exciting, a suspected nova — an exploding star.

The next night he imaged the spiral nebula again, believing he had better seeing and might have a superior image. The famous plate he recorded that evening would become one of the greatest ever made. Hubble indeed found the nova again and two additional stars he suspected as novae. He returned to the observatory's offices, down from the mountain, in Pasadena.

Suddenly, examining the plate back in his office, Hubble was dumbstruck. He had not imaged a nova, but a Cepheid variable star, whose luminosity and period were very well known. He recognized the star in other exposures by its unique pattern of brightening and dimming. From the faintness of the Cepheid variable, he could calculate that the spiral nebula in Andromeda must be a million light-years away. At the time, astronomers believed the entire cosmos was only one-third that size.

Hubble had used the workhorse 100-inch Hooker scope to discover the nature of galaxies, and break open the cosmic distance scale. And there was much more to come.

On another note, I'm delighted to welcome two new staff members to *Astronomy*. Associate Editor Alison Klesman brings a solid scientific background along with her writing and editing skills; she has a master's degree in planetary science from the Massachusetts Institute of Technology and a Ph.D. from the University of Florida that focused on active galactic nuclei. Alison is an avid observer and conducted night-sky tours at Spencer's Observatory, a facility near her home in Tucson, Arizona.

The magazine's new editorial assistant, Nicole Kiefert, is a Wisconsin native who is relatively new to astronomy but is already a dynamo at keeping our office procedures running. Nicole is a recent graduate of the University of Wisconsin-Oshkosh, having earned her degree in English along with a journalism minor. She has stargazed only from her backyard, but is anxious to learn all she can about the cosmos.

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 (800) 533-6644
Customer Service Astronomy@customersvc.com
Digital Astronomy.Digital@customersvc.com
Back Issues Astronomy.SingleCopy@customersvc.com

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

Follow *Astronomy*

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

Alliance for Audited Media

KALMBACH PUBLISHING CO.

Please Recycle This Magazine


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 PRODUCTS
Orion® GrandView™ Vari-Angle 20-60x60mm Zoom Spotting Scope #40908 $299.99
Orion® 6" f/4 Newtonian Astrograph Reflector Telescope #10269 $399.99
Orion® 30mm Ultra-Mini Guide Scope #52053 $139.99
Orion® EON 104mm ED-X2 f/6.25 Triplet Apo Refractor #10090 $3,499.99
Orion® Dielectric Twist-Tight Mirror Telescope Diagonals #40901 $119.99 #40902 $189.99
Orion® SteadyPix™ EZ Smart-phone Photo Adapter #5347 $89.99
Orion® GrandView™ Vari-Angle 20-60x80mm Zoom Spotting Scope #40909 $449.99
TELESCOPE OBSERVER'S GUIDE
Orion® Telescope Observer's Guide #51437 $19.99
Orion® EON 85mm ED-X2 f/6.6 Triplet Apo Refractor #10089 $1,999.99
Orion® StarSeeker™ IV 127mm GoTo Mak-Cass Telescope Kit #13163 $599.99
Orion® StarSeeker™ IV 130mm GoTo Reflector Telescope #13160 $499.99
Orion® 60mm Multi-Use Guide Scope with Helical Focuser #13008 $219.99
Orion® Resolux™ 10x50 Waterproof Astronomy Binos #9544 $288.99
Orion® Q70 Eyepieces 26mm 32mm 38mm #24708 $259.99
Orion® StarShoot™ G3 Deep Space Color Imaging Camera #53082 $399.99
Orion® SkyQuest™ XT10g GoTo Dobsonian #10135 $1,299.99
Orion® SkyQuest™ XT6 Classic Dobsonian Telescope Kit #20563 $299.99
Orion® SpaceProbe™ 130ST EQ Reflector Telescope #9007 $309.99
Orion® 1.25" Premium Telescope Accessory Kit #8890 $169.99
SOLAR ECLIPSE USA • 2017
Orion is your one-stop Solar Eclipse Shop
Orion® Solar Eclipse Safe Viewing Glasses, 5-Pack #51907 $12.99
Orion® Solar Eclipse Safe Viewer, 5-Pack #51908 $14.99
NEW PRODUCT 2017
All-American Total Solar Eclipse
Orion® Solar Eclipse Safe Viewer, 5-Pack #51935 $12.99
Orion® SkyQuest™ XT8 PLUS Dobsonian Reflector #8974 $499.99
5.81" ID Orion® Full Aperture Solar Filter #7710 $89.99
4.30" ID Set of Orion® Binocular Solar Filters #20032 $149.99
Retail prices shown are current as of 02/22/17 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:
VISA PayPal DISCOVER
Orders: (800) 447-1001
Customer Service: (800) 676-1343
*We only collect sales tax in CA & PA. See website for details.

QG QUANTUM GRAVITY

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

HOT BYTES >>

TRENDING TO THE TOP

ASTEROID A-GO-GO
NASA approved two asteroid study missions. One probe will visit metal-rich 16 Psyche; the other will look at Jupiter-trailing asteroids.

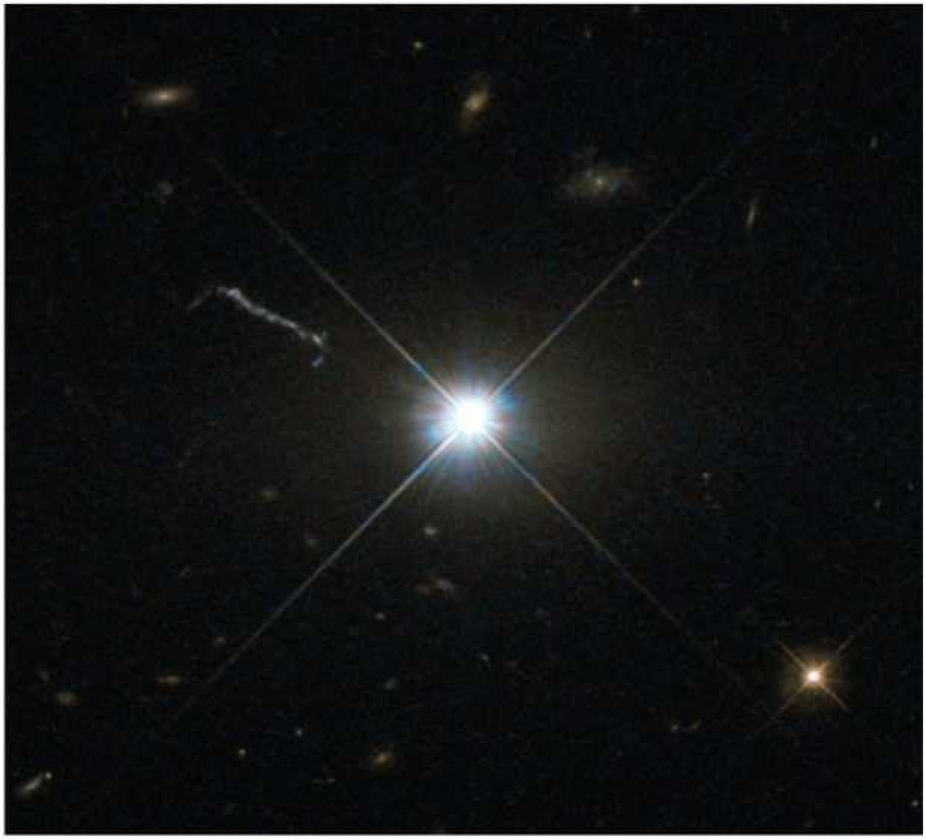
CLOSE ENCOUNTER
The newly discovered asteroid 2017 AG_{13} came within about half the Moon's distance from Earth on January 7.

THIEF!
Eleven stars orbiting far outside the main disk of the Milky Way may have been nabbed from the Sagittarius Dwarf Galaxy, which orbits our galaxy.

SNAPSHOT

The mystery of quasars

Several decades ago, astronomers confronted strange black holes.



This Hubble Space Telescope image of quasar 3C 273 shows the incredibly powerful, distant galaxy blazing as the central "star" in the frame. Material shot outward from the supermassive black hole in the quasar's center is visible as a faint jet to the upper left of 3C 273.

ESA, NASA, AND HUBBLE; TOP FROM LEFT: IMAGE COURTESY OF SOUTHWEST RESEARCH INSTITUTE; *ASTRONOMY*: ROEN KELLY; NASA, ESA, AND THE HUBBLE HERITAGE TEAM (STScI/AURA), ACKNOWLEDGMENT: Y. MOMANY (UNIVERSITY OF PADUA)

In the early 1960s, astronomer Maarten Schmidt had a problem. Along with other researchers, this fixture of the California Institute of Technology had been studying mysterious radio sources discovered in the 1950s.

These strange objects, the two most notable designated 3C 48 and 3C 273, appeared tiny on the sky but were extremely energetic sources of radio waves. They didn't fit any logical explanation of what astronomers understood at the time. (The designation 3C came from the Third Cambridge Catalog of Radio Sources, produced at Cambridge University.)

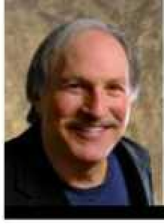
A precise position of 3C 273, using the 200-inch (5.1-meter) Hale Telescope on Palomar Mountain in California, finally allowed Schmidt to record the object's spectrum, the signature of its light, for the first time. This, in turn, produced a 1963 paper declaring that the strange radio object lay at the impressive distance of 2.4 billion light-years. Yet in Earth's sky, the object appeared merely as a faint star, leading Schmidt to name this new thing a "quasi-stellar object," or quasar.

How could something so far away be so incredibly energetic? At first, the notion completely baffled astronomers.

And then the mystery deepened. Over the years to come, astronomers found a series of strange, distant, highly energetic objects far beyond the Milky Way. Using a wide range of the electromagnetic spectrum, a rogues' gallery of super-energetic, distant objects emerged. They came to include quasars, Seyfert galaxies, BL Lacertae objects (or "blazars"), and radio galaxies. For nearly a whole generation, this array of weird objects seemed to represent a complex puzzle of unrelated oddities in the astrophysical zoo.

Eventually, astronomers learned that these strange high-energy objects were similar beasts viewed from different angles. They were all some form of high-energy galaxy, called active galactic nuclei, with centers harboring supermassive black holes. Material cascaded around the black hole — but not swallowed up — was slingshot outward for astronomers to see.

And the first step in resolving the mystery of quasars was complete. **— David J. Eicher**



STRANGE**UNIVERSE**

BY BOB BERMAN

A perfect circle

The most round objects ever found may just be a few million miles away.

The sky is dominated by two seemingly perfect circles: the Sun and Moon. When safely behind the right amount of partially obscuring fog or low clouds, the Sun's shape is obvious. Its equator's tiny bulge throws it out of round by a mere 6 miles (9.66 kilometers) in its 864,337-mile (1,391,015km) width. If the Sun were modeled as a basketball, the difference between its equatorial and polar diameters would be half the width of a human hair. Circular perfection!

But perhaps this perfection is not unexpected. The sphere is the universe's most common shape. Kids may wonder why stars never resemble cubes or diamonds. Answer: Every spot on a sphere lies the same distance from the center. A sphere also has the minimum surface area of any geometric shape. You'd use much more paint to cover a cube than to cover a ball of equal volume. So when a newborn star contracts from its own self-gravity, it pulls itself into the littlest form — always a sphere.

If the object spins quickly and its midsection bulges, it gets thrown out of the ball club. Through backyard telescopes, fast-spinning Jupiter and Saturn are clearly ovals.

But the Sun is different. Its slow rotation preserves its roundness. Our lethargic Moon, which has a similar spin of just under four weeks, differs from a perfect sphere by just 1.24 miles (2km). To the eye, the Full Moon is indistinguishable from a perfect disk.

Ancient cultures, which revered the circle as nature's supreme shape, never saw flawless spheres here on Earth. Only in the heavens was such perfection beheld.

Early astronomers watched the Moon's flawless disk fully shift against the background stars in one hour. The Sun's disk moved its diameter in one day. It was easy to be a circle groupie.

Our language retains this legacy with countless phrases like "inner circle" and the widespread use of "around." And if something returns to where it started, like blood, we say it "circulates," even if its path isn't round. Early astronomers desperately wanted the planets to follow circular orbits to jibe with their belief that the realm "up there" was divine.

THE SPHERE IS THE UNIVERSE'S MOST COMMON SHAPE.

They created complex mathematical systems of epicycles and deferents to circularly explain planetary motion. Dissention was not OK. Abandoning the circle usually brought a penalty that went beyond merely losing tenure.

Reality ultimately intruded. As it turned out, only Venus' orbit would look circular to an alien studying it from a distance, with other planets displaying varying degrees of elliptical shapes. And fair enough: Ellipses rule if you're a planet trying to maintain a stable orbit against the Sun's pull. It's easy to learn to love that shape.

Venus, thanks to its slow rotation rate, is a nearly perfect sphere. A year on Venus is shorter than a single day on the planet. It takes Venus 224.7 days to orbit the Sun, but 247 days to rotate once on its axis. NASA

Until a few months ago, astronomers assumed the most perfect spheres would be neutron stars, the nearest of which is a few hundred light-years away, not far from the North Star. Each of these ultra-heavy balls has a density equal to an entire freight train crushed down to the size of the period at the end of this sentence. As super-hard globes 12 miles (19.31km) wide, they'd be too dense to have bulges.

Then our secret admiration of circularity got a boost. Late last year, an international research team using the Kepler spacecraft announced finding the roundest-ever celestial object. Located 5,000 light-years away, it wasn't a neutron star but a common type-A star resembling Vega and Altair, but with a strangely slow 100-day spin. Using a unique oscillation-detecting method, they announced that this star, with the catchy name KIC 11145123, has an equatorial diameter just 2 miles (3km) longer than its polar dimension. The researchers claim it's the roundest thing in the universe.

But is it really? Have they forgotten about Mercury and Venus, located a million times closer to Earth? Thanks to the fact that someone forgot to wind up those innermost planets, slowing them to a crawl, they are perfectly round, like tires balanced by an obsessed mechanic. No bulges.

But unlike wedding rings and our other circle-shaped infatuations, Venus and Mercury appear telescopically round only in their "full" phase, when farthest away and hence smallest in apparent size. During this, they're also behind the Sun, lost in solar glare. The one exception happened during the recent Venus transits, when we saw Venus' perfect roundness as it glided in front of the Sun. Alas, when the next transit occurs in 2117, none of us will be around.

(Sorry about that. Really.)

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

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

ASTRO**LETTERS**

An unforgettable sunrise

This morning, I was watching the sunrise on approach to Denver, altitude about 20,000 feet. As the horizon grew brighter, the first hints of the Sun began to glimmer over the horizon. But this was unlike any other sunrise I had seen!

A thin line of crimson beads, more than a degree across, shifted and shimmered with the motion of the aircraft for at least five minutes before the Sun actually rose over the Great Plains. It was mesmerizing. I have seen flattened and distorted sunrises and sunsets before, but nothing like this!

Have any readers seen anything like this before? Could it have been just a simple temperature inversion, or something more complex?

Thank you for inspiring me to always be on the lookout for such beautiful and fascinating optical effects. You made my morning flight so much more enjoyable!
— Ryan Hofmann, Denver

Useful information

Thanks for the article "Sizing Up Planetary Nebulae" in the January issue (p. 44). As a budding astroimager, I sometimes find it difficult to determine what nebulae may look like in my f/10 scope. Now I have a good estimation of what will fit on my camera's sensor and what may be too small to properly resolve. The size of optimized internet images can be deceptive, especially when they come from big observatory scopes. Thanks again! **— Jim Mayercak,** Zanesville, OH

Evolution as a gift giver

In his column "In a shark's eye" in the December issue (p. 14), Jeff Hester describes the evolutionary arms race that gifted the shark with its efficient burst of speed and other reactions attuned to its environment. However, Hester has also stated that evolution has no destination.

Thus, Hester's evolution cannot be a

© CBPIX | DREAMSTIME.COM

bearer of gifts. For instance, what makes a shark a shark (or any other species what it is) is the information that is found in its DNA. The shark's intricate design (which allows it to be attuned to its environment) shouts out the necessity of an intelligent source. Only in this light can evolution be a bearer of gifts.

Any alternative explanation creates a paradox as physicist, cosmologist, and astrobiologist Paul Davies points out: "How did nature fabricate the world's first digital information processor — the original living cell — from the blind chaos of blundering molecules? How did molecular hardware get to write its own software?"
— Paul Kursewicz, Epping, NH

Jeff Hester responds

As I discussed in my July 2015 column, "It's genetic," the process of evolution is nothing more or less than a statement of logic, as unavoidable as 1 + 1 = 2.

The more that scientists and engineers have explored just what that unthinking, unguided algorithm can accomplish, the more amazed they have become. The reader's assertions are clearly heartfelt, but then Ptolemy sincerely believed that the Earth sits unmoving at the center of Creation. If science has any lesson, it is that reality doesn't care what we think.

The reader's assertions, made without any evidence apart from the fervency of his conviction, do not accurately reflect the way evolution works. Paul Davies poses questions to which fascinating answers are emerging; the origin of life is itself an evolutionary process. In the words of evolutionary biologist Richard Dawkins, "Evolution has no long-term goal.… In the case of living machinery, the 'designer' is unconscious natural selection." **— Jeff Hester,** contributing editor

The February 2017 issue stated that Katherine Johnson was from Virginia. She is from White Sulphur Springs, West Virginia.

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.*

NEXT DOOR. ESO's Very Large Telescope has been enlisted in an effort by Breakthrough Initiatives to find planets in the Alpha Centauri system. Breakthrough wants to use laser propulsion to deploy probes there.

FLIP THE SCRIPT. Neutron stars can exhibit a wide range of behavior, but it's not often that they behave like two objects in one. This illustration of a magnetar shows the strong magnetic fields that give the dead star husk its name. A recently discovered object, J1119, acts like both a magnetar and a pulsar at different times, the latter of which involves regularly timed radio pulses. ESO/L. CALÇADA

THIS NEUTRON STAR CAN'T MAKE UP ITS MIND

You might as well call PSR J1119–6127 sasquatch because it seems to be a "missing link" in neutron stars, according to astrophysicist Walid Majid of NASA-JPL.

Majid, who presented his findings in January at the annual meeting of the American Astronomical Society, said that PSR J1119–6127 (J1119) seems to split its time between two known states of neutron stars: a pulsar, a rapidly spinning neutron star that sends out radio emissions; and a magnetar, a kind of pulsar with emissions driven by a decaying magnetic field instead of the spin of the star.

Neutron stars are ultra-dense remnants of massive stars. They are one of two supernova outcomes, with the other being black holes. All neutron stars have magnetic fields, which are thought to cause much of their emission.

J1119 doesn't have a regular pulse. Sometimes it behaves like a normal pulsar, keeping a regular rhythm. Other times, it's not pulsing in the same frequency at all, but bursting forth with magnetic activity.

"Basically, this object is normally a pulsation-powered pulsar in its normal state, but it begins to show clear magnetar-like behavior," Majid said.

Of the 2,500 known pulsars in the Milky Way, J1119 is the first to display this kind of behavior. But it may not be all that uncommon. Instead, it may just be part of the life cycle of a neutron star.

"I think that what we're showing is that there's a spectrum of neutron stars or pulsars over time," Majid said. **— John Wenz**

WHAT IF OUR MOON WERE A PLANET?

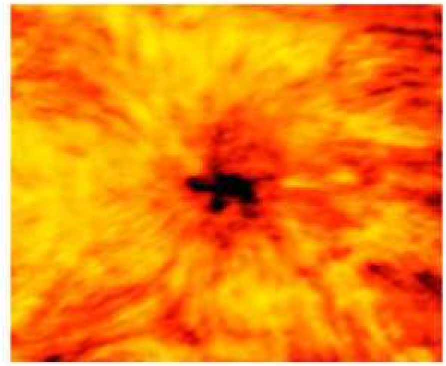
ADAM MONCRIEFF (MAIN SCENE); NASA (MARS AND JUPITER)

NEW MOON. If Earth didn't have the Moon, here's how a new companion would look if it were at the Moon's distance, but as large as Mars or Jupiter. **— Michael E. Bakich**

A sphere the size of Jupiter could hold 1,266 Earths.

FAST FACT

Solar turtles



ALMA (ESO/NAOJ/NRAO)

STARING AT THE SUN. The Atacama Large Millimeter/submillimeter Array (ALMA) in Chile turned up a turtle-shaped sunspot twice the size of Earth. ALMA is in the process of an upgrade that will increase its solar observing capabilities, making it easier for the radio telescope array to measure solar activity in amazing detail. At millimeter wavelengths, ALMA can see stellar activity beyond the reaches of other solar observing telescopes. **— J. W.**

BRIEFCASE

ELEMENTS OF LIFE

The Sloan Digital Sky Survey (SDSS) and the Apache Point Observatory Galactic Evolution Experiment (APOGEE) spectrograph have produced the most precise catalog to date listing the abundance of several elements present in more than 150,000 stars in the Milky Way. These elements include carbon, hydrogen, nitrogen, oxygen, sulfur, and phosphorus — the six most common elements found in living organisms on Earth and considered the building blocks of life. The results not only shed light on the composition and history of the galaxy, but aid in the search for potentially habitable extrasolar planets as well.

•

MINERVA COMES ONLINE

The Albert Einstein Institute at the Max Planck Institute for Gravitational Physics in Potsdam, Germany, recently brought its new supercomputer, Minerva, online. Minerva's 302.4-teraflop performance offers more than six times the computing power of its predecessor, increasing the speed with which astronomers can calculate numerical solutions to Einstein's field equations. Analyzing data from observatories like the Laser Interferometer Gravitational-Wave Observatory to separate real signals from the background noise enables a deeper understanding of the complex astrophysics governing our universe.

•

PULSAR TAILS

Pulsars are rapidly spinning neutron stars emitting radiation that sweeps over Earth, signaling their presence to astronomers. Depending on the star's orientation and the charged particle nebula that surrounds it, different signals may be seen or missed from Earth. Recent studies of the pulsars Geminga and B0355+54 using the Chandra X-ray Observatory and published in the December and January issues of *The Astrophysical Journal* have revealed the shapes of the nebulae surrounding these exotic stars. Differences in the nebula shapes point to varying geometries that could explain these pulsars' separate classifications. **— Alison Klesman**

TURN IT DOWN. FO Aquarii, an "intermediate polar" double-star system in which a white dwarf feeds off a lower-mass star, was found to exhibit strange dimming events. They might be caused by starspots.

Red nova explosion predicted for 2022

In 2022, there will be a spectacular sky show. Two stars will merge into one, pushing excess gas into an explosion known as a red nova. At magnitude 2, it will appear as bright as Polaris. The collision in the constellation Cygnus will be visible for up to six months.

That's pretty impressive. Even more impressive: We've never been able to predict a nova before. Lawrence Molnar, a professor of astronomy and physics at Calvin College in Grand Rapids, Michigan, was able to find a pair of oddly behaving stars giving an indication of what might happen.

The objects, discovered by the Kepler planet-hunting spacecraft and termed KIC 9832227, are contact binaries, two objects that are so close that they touch. The expected outcome is a merger of the two stars that will put on quite a show. Because both are low-mass stars, the anticipated temperature is low, with Molnar calling it a "red nova."

How does Molnar know what will happen? It's "a very specific prediction that can be tested, and a big explosion," he says. He and his team have an example to look at: V1309 Scorpii. First observed in 2008, astronomers were able to watch the light curve as the event unfolded. First, there were a few "booms" in the sky. Then, a spectacular light show began. Using existing data, astronomers were able to trace the evolution from 2001 onward, providing a big picture of the decade of progression of the event.

How did they know it was a merging star? "V1309 was [brightening] before the explosion," Molnar said at the 229th meeting of the American Astronomical Society. "It isn't doing it today. That's the smoking gun of a merging star."

Using Kepler data, Molnar found that KIC 9832227 fits the light curve of V1309 almost perfectly. All radial velocity measurements seem to indicate a contact binary, and by aligning the light curve to the period in time, he and his team concluded that the merger would complete in 2022.

"We don't know if it's right or wrong, but it's the first time we can make a prediction," Molnar says. At 2nd magnitude, it will be easy to see if the prediction was correct.

"You won't need a telescope in 2022 to tell me if I was wrong or I was right," he says. — **J. W.**

NASA, ESA, H.E. BOND (STScI) AND THE HUBBLE HERITAGE TEAM (STScI/AURA)

EXPLOSIVE RESULTS. V1309 Scorpii was a nova that resulted from the merger of two stars. A Kepler-discovered object called KIC 9832227 seems to be repeating that scenario. Thanks to the data of V1309, astronomers have predicted when 9832227 will explode.

ESO

Stellar birthplace

A COSMIC VISTA. The Orion Nebula (M42) and Orion A's molecular clouds, which form part of the sword in the bright constellation of Orion the Hunter, are imaged in the near-infrared part of the spectrum on the VISTA survey telescope at Paranal Observatory in Chile. Orion A's pre-stellar disks, small star clusters, and even galaxy clusters beyond the Milky Way are visible at these longer wavelengths. This vivid photo gives observers a new foundation for future studies of stars and how star clusters form, all while showing off the power of the VISTA telescope. — **Nicole Kiefert**

QUICK TAKES

CONSTANTLY CONSTANT
The Arecibo Observatory in Puerto Rico determined that the fine structure constant (proton-to-electron mass) of the universe changes little over time, only 1.3 parts per million over 3 billion years.

DON'T OPEN THAT DOOR
Researchers have spoken out about geoengineering efforts, saying they could adversely affect telescope instruments while doing little to ultimately improve climate change outcomes.

COMET FLINGING
HD 172555, a 23 million-year-old star, shows evidence of vaporized comets. Their paths indicate the presence of a yet-unseen giant planet.

THAT'S MASSIVE
Researchers determining the mass, including dark matter, of the Milky Way are narrowing in on a number between 4.0×10^{11} and 5.8×10^{11} solar masses.

OLD IS NEW AGAIN
49 Librae, a star once thought to be 2.3 billion years old, is actually 12 billion years old. 49 Lib siphoned gases off a dying companion, which made it appear brighter and younger.

COSMIC WEB
This January, the Keck Observatory was outfitted with the 5-ton Keck Cosmic Web Imager, which is tasked with mapping the "cosmic web" that binds galaxies together.

ANCIENT ASTEROIDS
Research of meteorite dust falling to Earth over time reveals that much of it likely came from a single asteroid impact 466 million years ago.

ONWARD!
In the quest for the Google Lunar XPrize, the Moon Express team has raised enough private funding to afford its trip to the Moon.

SECOND GENESIS
Conditions on Earth may have been ripe for life at two separate times. Selenium deposits in soil suggest a 1-billion-year gap between the first and second period, when life finally took hold. — **J. W.**

ASTRO**NEWS** **DEATH KNELL.** Researchers have found that some galaxies may fail to form new stars because clouds of plasma sweep cosmic dust away from the protogalaxy, leaving its supermassive black hole with little to feed on.

Is the universe expanding faster than expected?

IN THE BACKGROUND. These are the five best gravitationally lensed quasars seen by the H0LiCOW team. Such quasars were used to independently calculate the Hubble constant, which tells us how fast the universe is expanding. ESA/HUBBLE, NASA, SUYU ET AL.

The Hubble constant (H_0) tells us how fast the universe is expanding. It's also used to estimate the age and size of the universe, the amount of dark matter in the cosmos, and much more.

Researchers from the H0LiCOW collaboration recently released an independent measurement of the Hubble constant using gravitationally lensed quasars. The result agrees with other measurements obtained from the local universe, but discrepancies between these measurements and those based on other methods hint that there may yet be some physics missing from our current model of the cosmos.

Gravitational lensing occurs when a massive object, such as a galaxy, lies between Earth and a very distant object. Due to the effects of general relativity, light from the background object is bent, creating several bright images around the lens. Factors such as the shape of the lensing galaxy and the position of the quasar behind it cause the light to follow varying paths and arrive at Earth at different times.

Quasars are inherently variable; by noting when each image of a lensed quasar flickered, the H0LiCOW team measured the delays due to differing light paths. These delays are directly related to the Hubble constant. "Our method is the most simple and direct way to measure the Hubble constant, as it only uses geometry and general relativity, no other assumptions," explains project co-lead Frédéric Courbin from EPFL in Switzerland. The result was a measurement of the Hubble constant to a precision of 3.8 percent.

The measurement (H_0 = 71.9±2.7 km/s/Mpc) is consistent with others obtained in the local universe using the Hubble Space Telescope (H_0 = 73.24±1.74 km/s/Mpc). But these values don't agree with measurements using the cosmic microwave background (CMB) radiation left over from the Big Bang. Using the CMB, the ESA Planck satellite measured a value of H_0 = 66.93±0.62 km/s/Mpc. This value fits the current cosmological models of the universe very well, but the higher values obtained from local universe measurements don't fit quite so nicely.

Why might these values differ? Sherry Suyu, the leader of the H0LiCOW collaboration and associated with the Max Planck Institute for Astrophysics in Germany, the Academia Sinica Institute of Astronomy and Astrophysics in Taiwan, and the Technical University of Munich, says, "The expansion rate of the universe is now starting to be measured in different ways with such high precision that actual discrepancies may possibly point towards new physics beyond our current knowledge of the universe." — **A. K.**

Young galaxies trap their photons

Researchers studying some of the youngest galaxies visible with today's technology have discovered that these galaxies grab and hold onto their photons, letting very few escape — something that could have happened in the early Milky Way as well.

Teams led by David Sobral at the University of Lancaster and Jorryt Matthee at the University of Leiden surveyed nearly 1,000 distant galaxies using the Isaac Newton Telescope in the Canary Islands. They searched for Lyman-alpha emission, which is associated with hydrogen gas, and measured both the amount of emission produced and the emission's exit points from each galaxy.

They found large, faint halos of Lyman-alpha photons around the galaxies, which they compared with predictions of where and how Lyman-alpha photons should be produced. In a paper published in the January issue of *Monthly Notices of the Royal Astronomical Society*, the astronomers revealed that only 1 to 2 percent of Lyman-alpha photons escape the dense centers of these early spiral galaxies to form the halos they detected.

THE BLOB. Lyman-alpha blobs are clouds of glowing hydrogen gas that hide young galaxies within them. This composite image shows the Lyman-alpha blob LAB-1 from data taken with the FORS instrument on the Very Large Telescope. ESO/M. HAYES

This small escape fraction means that most Lyman-alpha emission is "blocked" by interactions with gas and dust along each photon's path, causing an endless series of absorptions and re-emissions that dramatically slow the photons' progress to the edge of the galaxy. Instead of traveling in a straight line, the photons continually knock into particles as they move from inside the galaxy outward.

"We now need to understand exactly how and why that happens," says Sobral. The soon-to-be-launched James Webb Space Telescope can study these halos in even more distant galaxies, which will tell astronomers how the escape fraction of Lyman-alpha photons changes over time. — **A. K.**

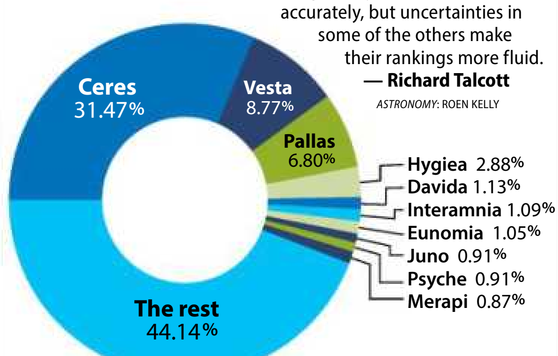
$40 billion a day

The amount of money a solar storm-induced power failure would cost Americans.

WEIGHING THE ASTEROID BELT

MINOR PLANET MASSES. When astronomers discovered Ceres on January 1, 1801, they thought they had found the "missing planet" between Mars and Jupiter. But more discoveries followed, and scientists now know of several hundred thousand objects in the asteroid belt. Astronomers currently classify the largest, 1 Ceres, as a "dwarf planet." It holds nearly one-third of the belt's total mass. The masses of the four largest objects are known quite accurately, but uncertainties in some of the others make their rankings more fluid. **— Richard Talcott**

ASTRONOMY: ROEN KELLY



FAST FACT The masses of all the objects in the asteroid belt add up to just 4 percent that of Earth's Moon.


LUMICON COMET USA


Astronomy


CAMERA QUARK!

ASTRONEWS

MINERAL MOVES. Not all Earth-size planets could support Earth's tectonics, simulations suggest. High-silicon planets, for instance, are also rich in garnet — a much stiffer mineral than the olivine that drives most of Earth's plate movement.

Astronomers find source of fast radio burst

Fast radio bursts, or FRBs, are intriguing high-energy events believed to originate outside the Milky Way. At the 229th meeting of the American Astronomical Society in January in Grapevine, Texas, astronomers announced they'd pinpointed the location of an FRB for the first time. The work was published in the January issue of *Nature* and in *The Astrophysical Journal Letters*.

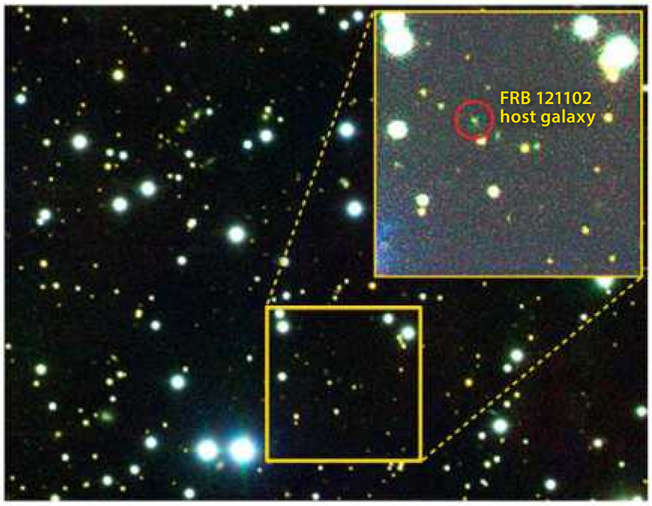
FRBs, which are extremely bright and brief, have stumped astronomers since they were discovered in 2007. In the decade since, over a dozen more FRBs have been identified. Each releases as much energy as our Sun emits in an hour, or even a year. But here's the catch: An FRB releases this astounding amount of energy in just a few milliseconds before it goes dark once more, hence the name "fast."

As of January 2017, scientists have cataloged only 18 FRBs. Just one, FRB 121102, has recurred several times. FRB 121102, named for its initial detection on November 2, 2012, occurred nine times over the course of 83 hours (in a six-month span) of observing time on the Very Large Array (VLA) in 2016.

This unprecedented repeating behavior enabled astronomers to do something they couldn't do with other FRB detections, which have all been made with single-dish radio telescopes. Using the VLA and later the Gemini North 8.1-meter optical telescope, astronomers have finally found the source of an FRB. FRB 121102 originates from a dwarf galaxy 2.5 billion light-years away in the constellation Auriga. It's also suspiciously close (within 100 light-years) to a persistent source of weaker radio emission, leading astronomers to believe the two may be related.

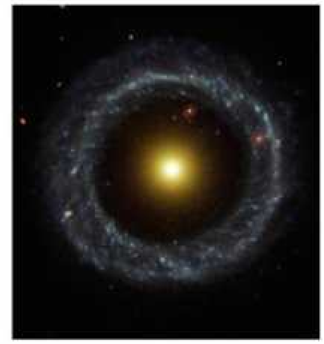
Not only has FRB 121102's behavior enabled researchers to track down its host galaxy, it has also confirmed that at least some FRBs can't be the result of a cataclysmic event, which would leave nothing behind to create repeated bursts.

"The FRB was extremely generous to us," says Casey Law, a co-author on the *Nature* paper. Even so, FRB 121102 is unique among a very small sample, so astronomers don't yet know if other FRBs will repeat, or if there are several types of FRBs. Only time and more observations will allow for better constraints and better models of these events. — **A. K.**



GEMINI OBSERVATORY/AURA/NSF/NRC

FOUND YOU. Fast radio burst FRB 121102 originates from this galaxy. The detailed directional information obtained via its multiple radio outbursts enabled astronomers to pinpoint its location in optical follow-up images.



GALACTIC RING TOSS. The prototypical ringed galaxy, called Hoag's Object, was discovered by Art Hoag in 1950. Researchers found that PGC 1000714 has not one, but two rings of stars circling its nucleus. NASA AND THE HUBBLE HERITAGE TEAM (STScI/AURA); ACKNOWLEDGMENT: RAY A. LUCAS (STScI/AURA)

Our first look at a rare galaxy

Astronomers have taken their first step toward understanding PGC 1000714, a strange, never-before-seen specimen within an uncommon class of "ringed" galaxies called Hoag-type galaxies.

Hoag-type galaxies display a red, relatively old inner core of stars surrounded by a ring of bluer, newly formed stars, with no visible structures to connect them. PGC 1000714 contains both of these, but it also has a second inner ring that is older, more diffuse, and redder than the outer ring.

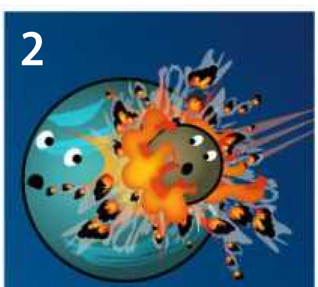
Burcin Mutlu-Pakdil, a graduate student at the Minnesota Institute for Astrophysics at the University of Minnesota, is credited with the galaxy's discovery, which was detailed in a paper in *Monthly Notices of the Royal Astronomical Society* in November. To find this inner ring, Mutlu-Pakdil, a co-author of the paper, modeled the central red component of the galaxy and subtracted it from the images to search for additional features.

The stars in the inner ring are older than those in the outer ring and likely represent an earlier epoch of star formation. Mutlu-Pakdil and her co-authors speculate that PGC 1000714's strange structure may be due to the incorporation of a gas-rich dwarf galaxy in the past. But, Mutlu-Pakdil says, "it's impossible to know how the rings of this particular galaxy were formed" based on current observations. With more data, and if more galaxies like this one are found, a clearer picture could emerge. — **A. K.**

THE BIG SMASH

PILEUP. Most astronomers think the Moon was formed from a primordial planet called Theia smashing into Earth and kicking up molten material that coalesced into the Moon. No one is sure about how this exactly happened, but there are three competing scenarios. — **J. W.**

Theia sideswiped the Earth, picking up some of the Earth's materials in the process, like the paint transfer between cars in a fender bender. A molten Theia – plus the bits of Earth it's now carrying with it – became our Moon. This doesn't explain, though, why the Earth and the Moon seem to be made entirely of the same materials.



A head-on collision mixed materials between early Earth and Theia, kicking up one or two moons. In this scenario, Earth and Theia would have combined thoroughly in a molten state. This explains why Earth and the Moon have similar isotopes. The theoretical second moon would have merged into the one we see today.

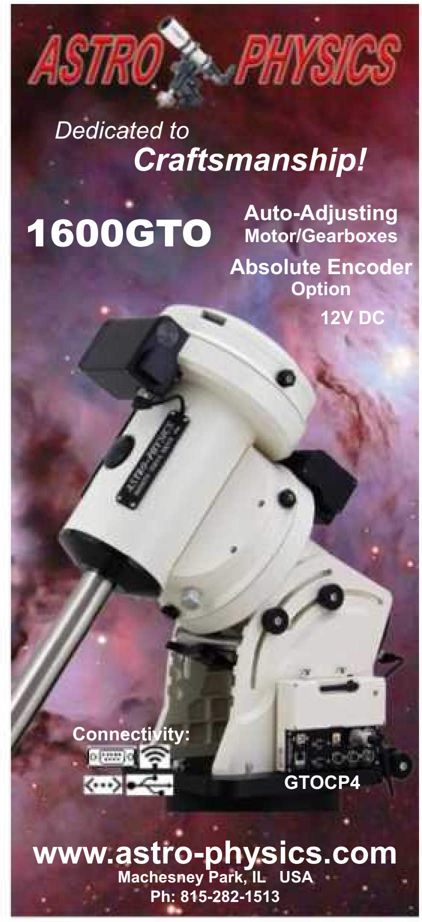
Rather than a primordial Earth and a Mars-size world, two planets at sizes in-between smashed into each other. Both planets were compositionally similar, which accounts for why Earth and the Moon seem to be made of the same stuff.

ASTRONOMY: KELLIE JAEGER

FAST FACT

There may have been several moons that coalesced into the satellite we see today.


DAWSON SPRINGS
KENTUCKY
2 MINUTES & 32 SECONDS
FOLLOW THE TRAIL TO TOTALITY
08.21.2017
Experience the eclipse in the heart of western Kentucky
August 21, 2017
Approximately 2 minutes & 32 seconds of totality!
Affordable Family Atmosphere Campsites
Entertainment & Cultural Displays
Eclipse Flotilla on Lake Beshear
Hammock Hotel & Primitive Camping
Low Sky Glow for Observation
MADISONVILLE
READY. AIM. FUN.
HOPKINS COUNTY TOURIST & CONVENTION COMMISSION
Make your reservations now!
TRAILTOTOTALITY.COM
Kentucky
UNBRIDLED SPIRIT


ASTRO-PHYSICS
Dedicated to
Craftsmanship!
1600GTO
Auto-Adjusting
Motor/Gearboxes
Absolute Encoder
Option
12V DC
Connectivity:
GTOCP4
www.astro-physics.com
Machesney Park, IL USA
Ph: 815-282-1513


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

OBSERVING**BASICS**

BY GLENN CHAPLE

Shadow transit double header

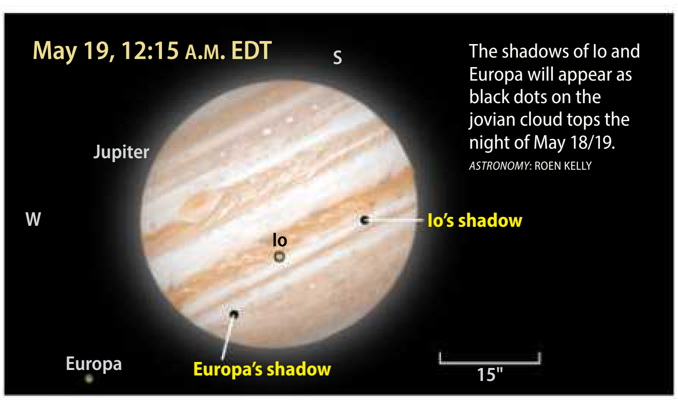
Catch a solar eclipse — on Jupiter.

In the coming months, the buzz surrounding the August 21 total solar eclipse will reach a fever pitch. It will culminate in a cosmic spectacle that will captivate millions across the United States from Oregon to South Carolina. What would this event look like if we viewed it from the Moon? Satellite images showing the Moon's shadow crossing Earth's surface during previous solar eclipses give us a pretty good idea. But did you know that you can view an eclipse shadow in person, and in real time, by observing what astronomers refer to as a shadow transit of one of Jupiter's moons?

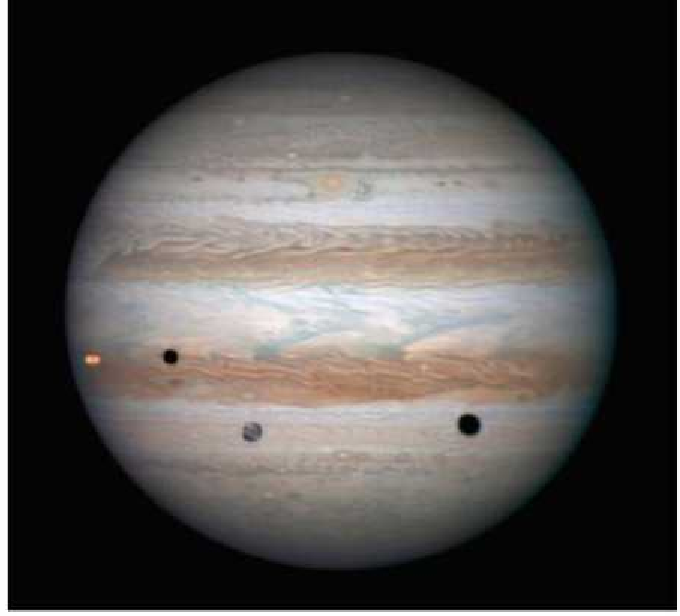
In their orbital waltz, Jupiter's four large satellites — Io, Europa, Ganymede, and Callisto in order of their orbital distances — frequently pass between the big planet and the Sun. When they do, they cast shadows that appear as small black dots traversing Jupiter's cloud tops. Because of the moons' relatively short orbital periods (1.8, 3.6, 7.2, and 16.7 days, respectively), shadow transits occur on an almost nightly basis. Callisto is the only one whose shadow can miss the planet. The outermost moon began a transit hiatus last year that will continue through late 2019. On occasion, two (and rarely three) moons simultaneously cast their shadows on the gas giant.

This month and next, a series of such double shadow transits are in the offing. The events below come from the Royal Astronomical Society of Canada's *Observer's Handbook 2017*, which provides the date and Universal Time for the moment when the second shadow first touches the cloud tops — the official beginning of the double transit. I've dropped those events not visible from North America and converted Universal Time to Eastern Daylight Time.

- May 11 at 9:59 P.M.
- May 18 at 11:54 P.M.
- May 26 at 1:47 A.M.
- May 27 at 8:16 P.M.
- June 2 at 3:42 A.M.
- June 3 at 10:21 P.M.
- June 19 at 10:04 P.M.



The shadows of Io and Europa will appear as black dots on the jovian cloud tops the night of May 18/19. ASTRONOMY: ROEN KELLY



The dark shadows of Io (left) and Ganymede cross Jupiter's expansive disk the night of March 23/24, 2016. The moons themselves appear as brighter disks to the left of their respective shadows. DAMIAN PEACH

All but the double shadow transits of May 27 and June 3 involve Io and Europa. The Io-Europa double transits are brief (6 minutes) at first, lengthen to 130 minutes June 2, and then shorten again to 34 minutes for the final event. The May 27 and June 3 double transits featuring Io and Ganymede last 24 minutes and 120 minutes, respectively.

Viewing a shadow transit doesn't require visiting an observatory. If seeing conditions are favorable, you can get a ringside seat with a common 60mm refractor and a magnification of 100x. You'll get an even better view through a 4-inch or larger scope at magnifications of 150x or more.

Shadow transits — even doubleheaders like the ones I've highlighted — aren't exactly what I'd call "wow!" events. A tiny black dot on Jupiter's surface is hardly a pulse-pounding spectacle. Nevertheless, there's something compelling about watching that dot move slowly across the jovian disk. The motion becomes especially obvious when you observe at 10- or 15-minute intervals. A single shadow transit typically takes between two and three hours.

Wouldn't it be nice to travel to Jupiter and witness a solar eclipse on an almost daily basis? Before you decide to stow away on the next Jupiter-bound spacecraft, consider that such an exotic eclipse wouldn't be nearly as spectacular as the earthly counterpart. By happenstance, our Moon shares the same angular size (about 30') with the Sun. It barely covers the solar disk, allowing for stunning all-around views of the Sun's spectacular corona.

From Jupiter, the solar disk measures a mere 6' across, and all four big moons have larger angular sizes. Jupiter's nearest moon, Io, spans 36' (slightly bigger than our Moon from Earth). Both Europa and Ganymede appear half that size, and Callisto covers 9'. All you would see of the corona is a fairly small section of it at the beginning and end of totality.

If you've never seen a Jupiter shadow transit, take the time to check out one of the double headers listed. For a timetable of other shadow transits and satellite phenomena during 2017, consult the *Observer's Handbook*.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Make a lunar atlas with a small scope and cellphone.

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

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

ASTRO**NEWS**

CRYING WOLF. Observations of Wolf 1061c, an exoplanet 14 light-years away, suggest that although it is in the habitable zone of its home star, its orbital changes could cause it to heat up rapidly and cool too much to support life.

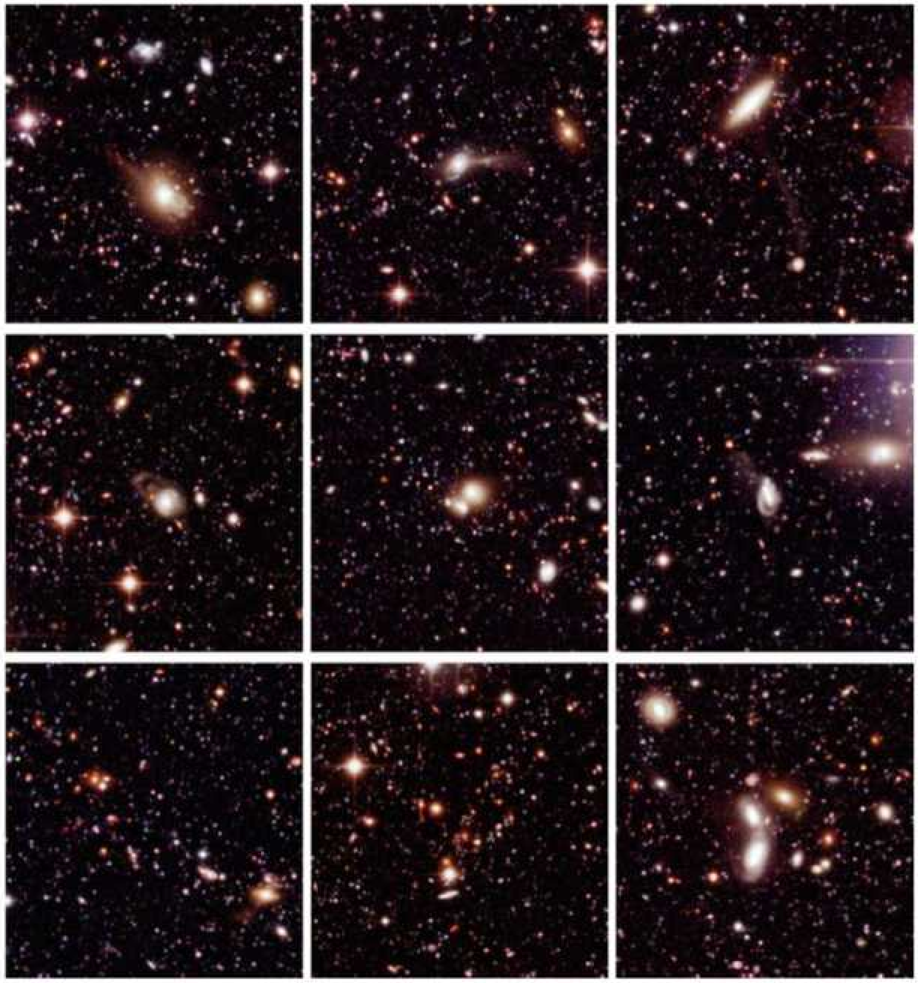
Chandra snaps a deep-field X-ray image

Hubble has its iconic deep field filled to the brim with galaxies. Now the Chandra X-ray Observatory has one, too, peering at ancient galaxies and their massive black holes in an area just 60 percent the size of the Full Moon.

Over 81 days, Chandra looked at 1,055 black holes in this small region, and was able to see energetic events caused by black holes at the center of galaxies visible only in X-rays. It marks, to date, the best survey of active galactic nuclei in the universe and leads to an even bigger estimate: There are 1 billion active galaxies in the night sky, though many are hiding behind city lights or are simply too faint to view with even the best ground-based telescopes.

"The density of these black holes is the deepest we've ever seen in the sky," W. Niel Brandt, the Verne M. Willaman professor of astronomy and astrophysics at Pennsylvania State University, said in a news conference at the 229th gathering of the American Astronomical Society.

The dataset, called the Chandra Deep Field-South, has some of the best resolution of distant supermassive black holes ever, but it reaches a redshift of only 10. The galaxies range in age from 3.5 billion to 12.5 billion years old, leaving a little over a billion years of galaxies yet uncharacterized in a period called the Epoch of Reionization, during which the first galaxies ignited neutral hydrogen in the universe and cleared away the opacity it caused. **— J. W.**



IN DEEP. The Chandra Deep Field-South image captured 1,055 galaxies in an 81-day observing campaign, some stretching back to near the beginning of the universe; these are just a select few of its finds. ESO

SOLAR SYSTEM SEASONS

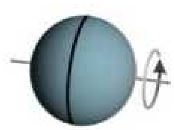
TILT MATTERS. The tilt of a planet's rotational axis plays a major role in the weather it experiences throughout the course of its year — most especially its seasons. **— A. K.**

MERCURY
0°
season length
0 Earth months

With an axis tilt of essentially 0 degrees, Mercury doesn't have seasons at all. In fact, the temperature in some areas at the poles is quite stable throughout its year (about 2.9 Earth months), and astronomers have spotted water ice in its permanently shadowed polar craters.

EARTH
23.4°
season length
3 Earth months

Earth's moderate tilt of 23.4 degrees causes the four seasons we experience, which last about three months each. Because Earth's orbit around the Sun is nearly circular, it has very little effect on the intensity of the sunlight received throughout the year.

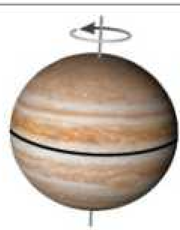


URANUS
97.8°
season length
21 Earth years

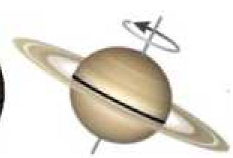
With its equator inclined at 97.8 degrees to its orbital plane, Uranus is essentially rotating on its side. Portions of its surface receive nothing but direct sunlight (or sit in complete darkness) for a quarter of its year (84 Earth years), meaning each season on Uranus lasts about 21 Earth years and each pole receives 42 Earth years of consistent light or darkness.

VENUS
177.3°
season length
1.8 Earth months

MARS
25.2°
season length
7 Earth months



JUPITER
3.1°
season length
3 Earth years



SATURN
26.7°
season length
7 Earth years

NEPTUNE
28.3°
season length
41 Earth years

PLUTO
122.5°
season length
40-80 Earth years

ASTRONOMY: ROEN KELLY

FAST FACT

The orbits of Uranus' rings and moons have led astronomers to believe that the giant planet was hit by not one, but at least two Earth-sized (or larger) objects as it formed.

SECRETSKY

BY STEPHEN JAMES O'MEARA

Uncommon bino galaxies

Looking for a challenge from a dark site? Target a few of these faint fuzzies with both eyes open.

If you find yourself under a dark sky this spring with handheld binoculars, and if you're up for a challenge, why not try some galaxy hunting? The spring night sky contains a veritable haystack of galaxies, and some, especially the brighter Messier ones, are common sights for binocular users. But a deeper layer of uncommon targets also lurks among the multitude. Some require at least 10x50 binoculars to see, but many objects you may have written off are, indeed, available to you through such optics.

The task requires a level of enthusiasm usually found only in a true hobbyist's heart — someone who can get excited over seeing a handful of ill-defined motes of extragalactic "fluff." Your success, on the other hand, may depend largely on the darkness and clarity of the night and your skill as an observer. The latter includes knowing exactly where to look, using averted vision, and having the patience and persistence necessary. My inspiration for this column was *Astronomy* reader Scott Harrington of Evening Shade, Arkansas, who has been cataloging galaxies visible through 7x35 and 8x56 binoculars with great success.

A dark-sky journey

We start off gently by looking only 40' northwest of Chara (Beta [β] Canum Venaticorum) for an eviscerated barred spiral called the Cocoon Galaxy (NGC 4490). Shining at magnitude 9.8 and lying only 25 million light-years distant, this tidally disturbed galaxy is relatively easy to see, appearing as a small, ill-defined haze.

Now hop over to Cor Caroli (Alpha [α] CVn), then make a 2° sweep to the east-southeast. We will then dive 70 million light-years into space as we search for the magnitude 9.8 spiral NGC 5005 and its slightly dimmer neighbor, NGC 5033 (magnitude 10.2), which lies about 30' to its southeast. Both are diminutive oval flecks of pale light requiring much patience and attention; NGC 5005 has a more condensed core, making it slightly easier to see.

For our next target, swing westward to Tania Australis (Mu [μ] Ursae Majoris), and look 45' to its west (and 36 million light-years away) where you'll find a magnitude 9.8 spiral called the Little Pinwheel Galaxy (NGC 3184). It's a smooth diffuse dot 10' east of a 6th-magnitude star. If you succeed, drop some 15° southward to find its near-twin, the Sliced Onion Galaxy (NGC 3344) in Leo Minor. To spot this tight magnitude 9.9 spiral wonder some 20 million light-years distant, concentrate on roughly the midpoint between 40 and 41 Leonis.

Now locate the magnitude 5.6 star 31 Virginis, and look 2° west-northwest for the magnitude 9.7 lenticular known as the Hairy Eyebrow Galaxy (NGC 4526) — a challenge mainly because it is trapped between two 7th-magnitude stars. Therefore, you'll need to make intermittent glances alternating between averted and direct vision to see it. I find it's best to look at a point midway between M49 (which glows 1.3 magnitudes brighter) and NGC 4526, but focus my attention on NGC 4526. The galaxy itself is a minute star with a hint of "fog" around it.

Our final object is another resolution challenge. First, find magnitude 4.2 Tau (τ) Virginis, then look approximately 4° north-northwest for the magnitude 10.1 irregular galaxy NGC 5363. It glows as brightly as NGC 4526, though it's slightly more compact, being almost stellar. However, it lies only 4' southwest of a magnitude 8.5 star. In essence, you're looking for the southwest component of a binocular double.

As always, let me know what you see — and don't see — at sjomeara31@gmail.com.

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

NGC 5033 glows weakly at magnitude 10.2 in Canes Venatici. At least it lies high in the sky for northern observers, making it a bit easier to spot through binoculars. R. JAY GABANY

The Sliced Onion Galaxy (NGC 3344), at magnitude 9.9, barely reveals itself through binoculars from a dark site. Keep your eyes peeled for a tiny, circular fuzz ball. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

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

IN DISGUISE. Observations of Ceres' surface taken with the Stratospheric Observatory for Infrared Astronomy suggest it is covered in shattered bits of asteroids that have cloaked its nature as an icy dwarf planet for hundreds of years.

Our galaxy's center creates planet-sized swarms of gas

At the center of the Milky Way lies Sagittarius A* (Sgr A*), a supermassive black hole. Stellar tidal disruption events, during which stars are torn apart as they approach Sgr A* too closely, likely happen in its vicinity every few million years. Rather than swallowing the star completely, Sgr A* rips it apart. The end result: about 10,000 Jupiter-size swarms of gas. These "planets" then flee at a high velocity.

So, how will we find one? "What will make them distinguishable from normal planets is how fast they're moving," Eden Girma, a sophomore at Harvard University who worked on a project to detect these gasballs, said at the annual meeting of the American Astronomical Society in January.

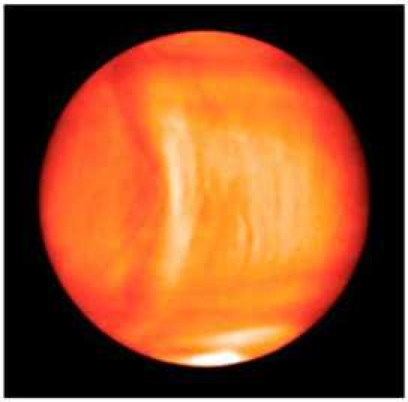
Girma's work focused on how close one such object might have come to our solar system. Simulations suggest that most (95 percent) are tossed out of the galaxy entirely, while a few may have stayed bound to Sgr A*. But a small number (about 5 percent) of these objects are spewed back into the galaxy at large, and the closest one to encounter Earth might have been 700 light-years away, according to Girma's simulations.

Finding such objects might be difficult because "by the time they reach us, they'll be extremely cold," Girma says. This also might make it more difficult to characterize them. Although they will be Jupiter-mass, they won't form by the typical mechanism of planets, where layers of gas accumulate over time. Instead, the timescale of formation could be measured in years instead of millions of years.

WELL, SPIT IT OUT. Sagittarius A* is a voracious, though largely dormant, supermassive black hole that rips apart anything near its grasp. That includes stars, which can be shredded and slowly eaten while much of the gas escapes into Jupiter-sized balls of gas, as illustrated here. MARK A. GARLICK/CFA

They would be abundant in hydrogen and helium, thanks to their stellar origins. Although the gas may be gravitationally bound, it may not have the density typically expected of a planet.

Even if such a planet-like object is found through a microlensing event, it could be hard to distinguish it from planets that formed through traditional mechanisms and were ejected out of their solar system. — **J. W.**



JAXA

Making waves

JAXA's Venus probe, Akatsuki, discovered something spectacular: a 6,200-mile (10,000 kilometers) structure in Venus' upper atmosphere. The entire bow-shaped wave stretched pole-to-pole and lasted about four days. The leading hypothesis is that it's a gravity wave, an atmospheric distortion caused by the interaction of wind and surface features. This hypothesis, put forth in a *Nature Geoscience* article January 16, suggests that winds interacting with Venus' mountains have accumulated into a bulging megastructure in the atmosphere. — **J. W.**

In memoriam: Piers Sellers, Gene Cernan

Piers Sellers, meteorologist, NASA astronaut, and deputy director of the Earth Science Division at NASA's Goddard Space Flight Center, died December 23. He was 61.

Sellers began working at NASA/GSFC in 1982, researching the relationship between Earth's biosphere and atmosphere. After being denied entry to the astronaut program in the 1980s, Sellers became an American citizen in 1991 and was selected as an astronaut candidate in 1996.

He flew on three separate space shuttle missions to the International Space Station: *Atlantis* in 2002, *Discovery* in 2006, and *Atlantis* again in 2010. His later career focused on computer modeling of climate systems and meteorology. He also served as first project scientist on the Terra mission. After 559 hours in space, 41 EVA (extravehicular activity) hours, and six spacewalks, he returned to Goddard in June 2011. — **N. K.**

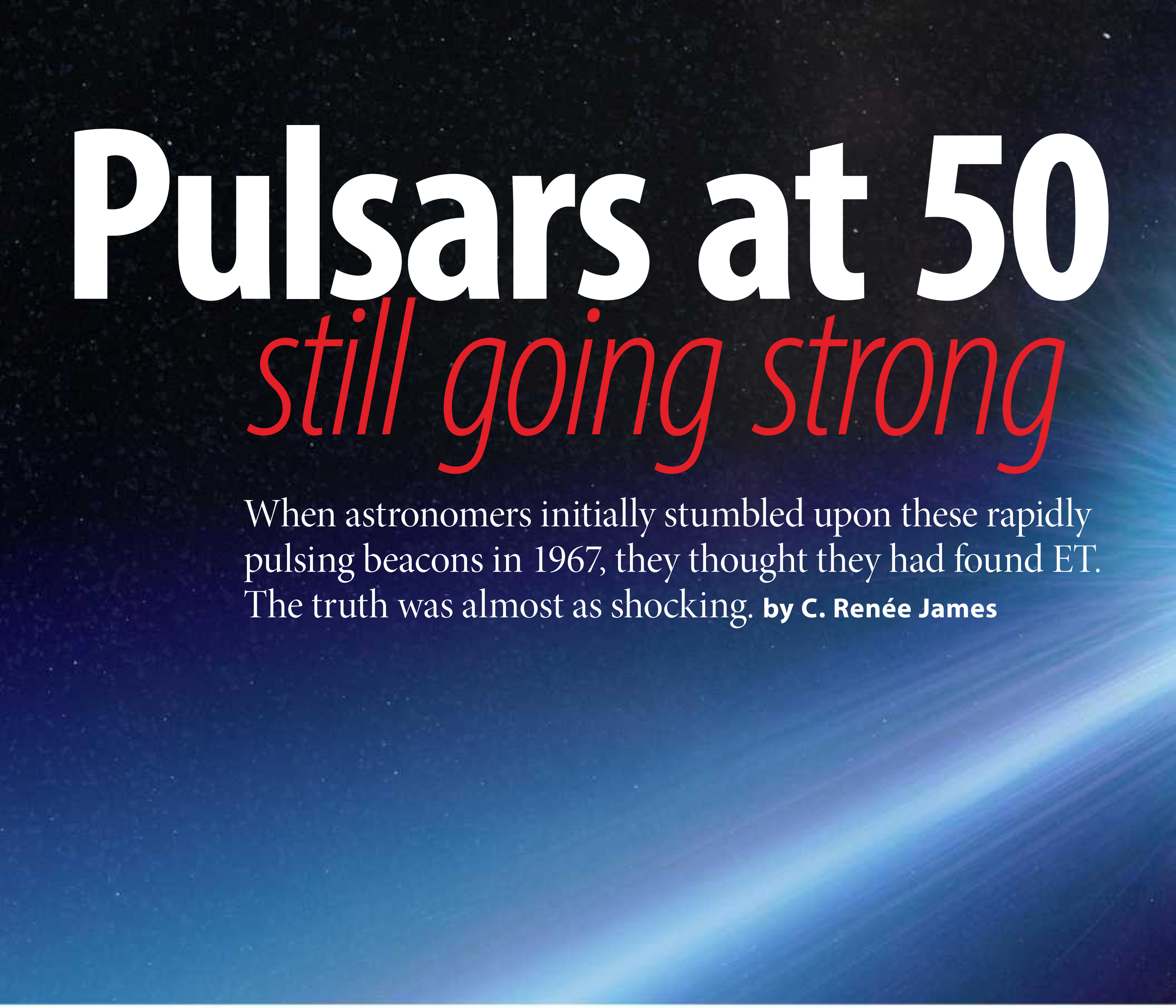
EXPLORATION AND SCIENCE. Piers Sellers (left) and Gene Cernan (right) played important roles in many NASA programs, from manned space flight to climate science. NASA

Eugene "Gene" Cernan, the last man to walk on the Moon, died January 16. He was 82.

Cernan was recruited to NASA in 1963 after serving in the Navy. In 1966 he crewed the Gemini 9A mission with Thomas Stafford, testing technologies for the later Apollo missions.

In 1969, Cernan flew aboard Apollo 10, performing a Moon landing dress rehearsal that paved the way for Apollo 11. He returned to the Moon in 1972 as the commander of Apollo 17, exploring the lunar surface with Harrison Schmitt. Cernan spent 73 hours in total on the Moon. As he returned to the Lunar Command Module, Cernan said, "As we leave the Moon at Taurus–Littrow, we leave as we came and, God willing, as we shall return, with peace and hope for all mankind. Godspeed the crew of Apollo 17."

Cernan continued working for NASA until 1976, when he left to work in the energy industry before becoming an aerospace consultant and ABC news correspondent. — **J. W.**



Pulsars at 50

still going strong

When astronomers initially stumbled upon these rapidly pulsing beacons in 1967, they thought they had found ET. The truth was almost as shocking. **by C. Renée James**

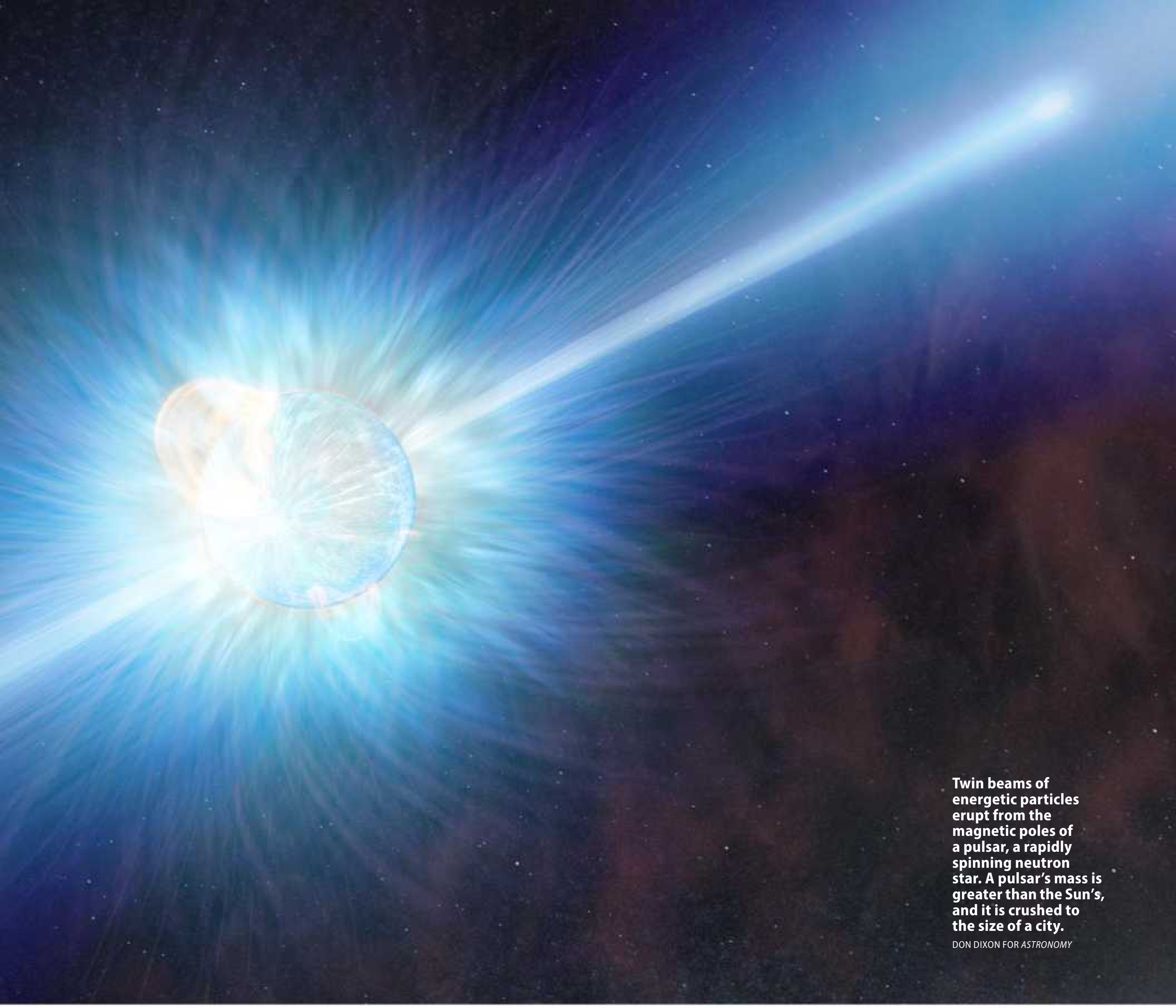
Fifty years ago, an unassuming bit of "scruff" appeared in Jocelyn Bell Burnell's radio telescope data. Although barely noticeable at first, the scruff quickly led to two Nobel Prizes, provided evidence that Albert Einstein's general relativity was right, rode on humanity's first interstellar vehicle, and became the inspiration for a watch, a car, and an album cover.

The objects revealed by the scruff — dubbed "pulsars" — turned out to be smaller than a city but more powerful than the Sun. And if everything goes right, they soon will help us detect the most colossal events in the cosmos and even help us navigate to the stars.

Despite its meteoric rise to fame, the pulsar had an unpromising start. In July 1967, Bell Burnell noticed a quarter-inch-wide radio signal barely rising above the background noise on the recordings. It would have been easy for anyone else to ignore, but Bell Burnell had almost single-handedly strung 120 miles of wire to create the 4.5-acre radio telescope at Mullard Radio Astronomy Observatory near Cambridge, England, making her fast friends with everything it had ever picked up. She was not about to let anything escape her attention, no matter how scruffy.

Fortunately, the scruff showed up more than once. In fact, as she pored over the miles of charts, the keen-eyed graduate student spotted the signal on about 10 percent of the printouts, arriving four minutes earlier each day. Keeping time with the stars, the source definitely was not terrestrial. But what was it?

She persuaded her Ph.D. adviser, Antony Hewish, to speed up the paper feed so she could better scrutinize



Twin beams of energetic particles erupt from the magnetic poles of a pulsar, a rapidly spinning neutron star. A pulsar's mass is greater than the Sun's, and it is crushed to the size of a city.
DON DIXON FOR *ASTRONOMY*

the odd signals. For weeks, miles of charts streamed through. As the piles of paper grew, so did Hewish's frustration. Finally, on November 28, 1967, as they were about to pull the plug on the search, the signal returned.

Now, instead of a bit of scribbly fuzz, a series of regularly spaced shallow bumps appeared, each separated from its neighbors by 1.3373 seconds. These precisely timed, rapid radio blips telegraphed information about uncharted astrophysical territory. Because known stars could not change brightness so rapidly, the scientists knew they were looking at an unfathomably dense, small object. Or did they dare suggest, could it be something artificial?

LGM or not?

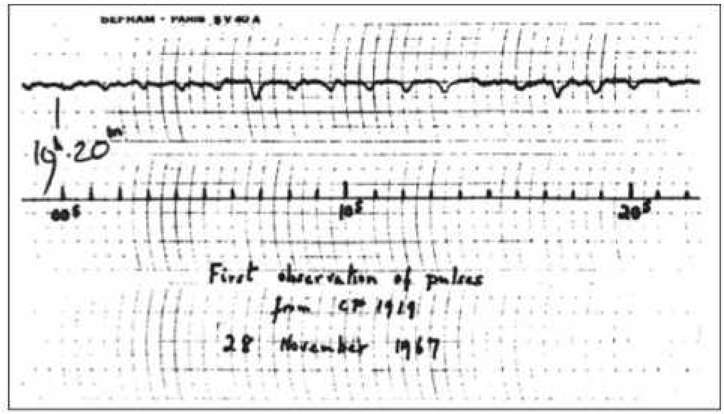
Although Bell Burnell and Hewish agreed that the latter explanation was highly unlikely, unusual signals are a siren song to astronomers. Despite healthy skepticism, most people are open to the possibility that someone, or something, in this vast universe might try to make contact. And so Bell Burnell gave the object the tongue-in-cheek nickname "LGM-1," for "Little Green Men."

The next step was to look for Doppler shifts, telltale changes in the signal's wavelength that let astronomers know an emitting object's comings and goings. These new data would let them know if the signal had been broadcast from a planet orbiting a star. Before that investigation even got off the ground, however, another similarly regular signal joined LGM-1. Then another. And another.

At that point, Bell Burnell recalls, they gave up on the idea of aliens. "It was extremely unlikely that there would be four separate lots of Little Green Men, all, at

C. Renée James *is a science writer and physics professor at Sam Houston State University in Huntsville, Texas. Her latest book is* Science Unshackled: How Obscure, Abstract, Seemingly Useless Scientific Research Turned Out to Be the Basis for Modern Life *(Johns Hopkins University Press, 2014).*

Jocelyn Bell Burnell appears in front of one of the large radio telescopes at Cambridge University's Mullard Radio Astronomy Observatory in 1968. CAMBRIDGE UNIVERSITY



Above: This bit of "scruff" — the slight dips seen in the top row of data — represents Jocelyn Bell Burnell's initial detection of pulses from the pulsar CP 1919+21 (now known as PSR B1919+21) from November 1967. CAMBRIDGE UNIVERSITY

Left: Jocelyn Bell Burnell stands among the more than 1,000 posts and 120 miles of wire and cable that formed the radio telescope she used to discover pulsars in the late 1960s. CAMBRIDGE UNIVERSITY

the same time, signaling to the inconspicuous planet Earth using a stupid frequency and a daft technique," she said.

Although the signal proved not to be an extraterrestrial greeting, it was a tremendous astronomical discovery in its own right. The researchers soon found out that whatever it was, it kept time to better than 1 part in 10 million, either rotating or pulsating (they weren't sure which) more than 60,000 times per day. On top of this, it was emitting enough power across interstellar distances to be detected even by 1967 instruments.

The neutron star connection

This sort of activity required a phenomenal source of energy. Astronomers Fritz Zwicky and Walter Baade hinted at one back in 1934, when they hypothesized that an exploding massive star — they called it a "supernova" — might leave behind a dense core composed mainly of neutrons.

It was a wild idea with seemingly little chance of verification. How would anyone ever detect a city-sized ball of neutrons, even one at a temperature of a million degrees? For the most part, astronomers ignored Zwicky and Baade's prescient paper and quietly assumed that massive stars died by blowing themselves to smithereens.

Then came LGM-1, which soon became CP 1919+21 and ultimately PSR B1919+21. If the object were physically pulsing, growing and shrinking, Bell Burnell and Hewish computed a density equivalent to a mountain squeezed into a thimble: 10 trillion grams per cubic centimeter, the same density as a ball of neutrons.

Since it was a pulsating signal from a stellar source, science journalist Anthony Michaelis christened the object a "pulsar" in 1968. Although scientists were still several months from understanding whether the object was pulsating or rotating, the moniker stuck.

It was admittedly a catchy name. Less than three years after Bell Burnell's discovery, the Hamilton Watch Co. began developing the Pulsar watch, capitalizing on nature's seemingly perfect timekeepers. The first Nissan Pulsar, which was — what else? — a compact car, rolled off the assembly line in 1978.

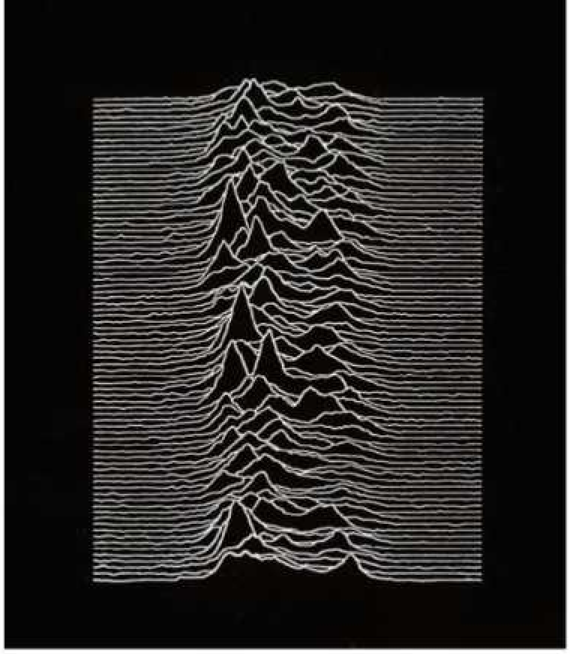
In 1979, pulsars slipped effortlessly and largely unrecognized into popular culture. Next to the entry in the 1977 edition of *The Cambridge Encyclopedia of Astronomy* was an image of successive stacked pulse profiles from PSR B1919+21. The simple but enigmatic portrait of squiggles might have remained in that

AN EARLY WARNING OF PULSARS

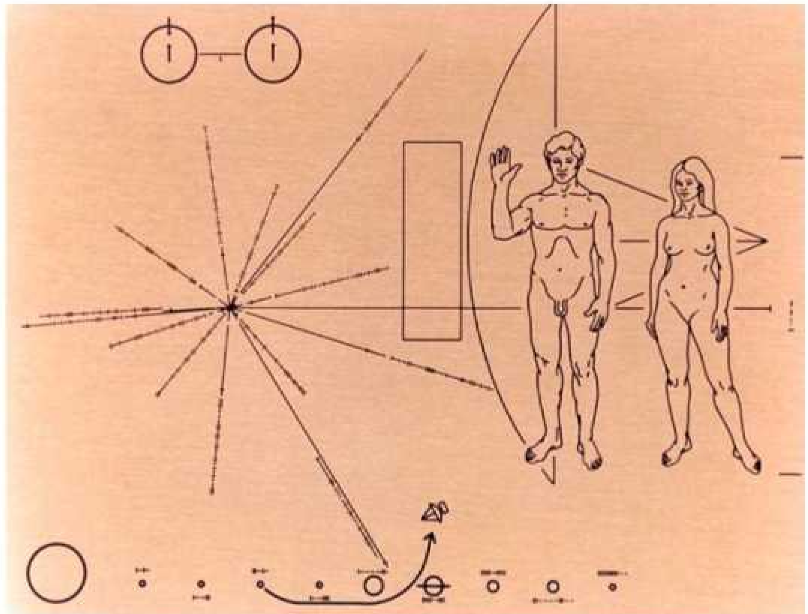
U.S. Air Force Staff Sgt. Charles Schisler knew something was odd in the radar signals he was monitoring. It was summer 1967, and the signal had been showing up for weeks, keeping time with the stars by rising four minutes earlier each night.

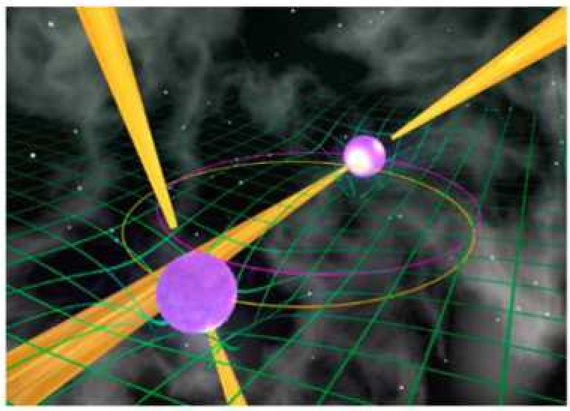
Unfortunately, his employer wasn't at all interested in this sort of signal. The Ballistic Missile Early Warning System at Clear Air Force Station in Alaska was built to detect incoming warheads, not pulsars. As a result, Schisler wasn't at liberty to announce his discovery or do any formal follow-up observations.

It wasn't until 40 years later that information from the Early Warning System became declassified, and Schisler felt comfortable revealing that he had observed not just one pulsar, but a dozen or so. Even then, Schisler was quick to point out that his detections never hinted at the pulsing nature of these sources, a key to understanding the objects responsible for the signals. That honor still goes to Jocelyn Bell Burnell. — *C. R. J.*



These enigmatic squiggles represent pulses from CP 1919+21 recorded with the Arecibo radio telescope. Harold Craft Jr. created this visualization for his doctoral thesis. It became a part of pop culture when Joy Division used it on the cover of the band's debut album, *Unknown Pleasures*. HAROLD D. CRAFT JR.





Top: The Pioneer 10 and 11 spacecraft each carried a plaque describing the Sun's location for any extraterrestrial intelligence that might find the probe. Carl Sagan and Frank Drake used the positions and periods of 14 pulsars (the lines emanating from the star left of center; the horizontal 15th line gives the direction to the Milky Way's center) to mark the spot. NASA

Above Left: PSR J0737–3039 is the only known double pulsar, a binary system in which both objects are pulsars. The two orbit each other once every 2.45 hours. Scientists are using the pair, illustrated here along with the underlying fabric of space-time, to test Einstein's theory of general relativity. MPIfR/M. KRAMER

encyclopedia and in obscure journal articles if it hadn't caught the eye of Peter Saville, who decided that it would make the perfect cover art for Joy Division's 1979 album *Unknown Pleasures*. These days, plenty of people recognize the image that's been featured on everything from T-shirts to tattoos, but few realize it represents the first pulsar discovered.

So what exactly are these objects that have captured the attention of astronomers, watchmakers, car companies, and album art designers? The simplest description is that they are rapidly rotating, highly magnetized, city-sized, collapsed cores of dead, high-mass stars — the neutron stars Zwicky and Baade proposed.

But this portrayal utterly fails to convey the bizarre and extreme character of a pulsar. Nature crams up to three times the mass of the Sun into its tiny volume, making its surface gravity second only to that of a black hole. Its magnetic field strength can be a quadrillion times Earth's, far exceeding anything scientists can create in a laboratory.

This mega-magnetism whips up charged particles in the vicinity, causing them to swarm around the magnetic poles and emit beams of intense radiation. These beams become a sort of lighthouse beacon, sweeping across the universe as the neutron star spins. On the off chance that Earth happens to lie in the beam's path, we see a quick blip with every rotation.

Pulsars are laboratories of extreme physics, and their discovery opened up an entirely new field. The find was so significant that just seven years later, Hewish would share the Nobel Prize in Physics "for his decisive role in the discovery of pulsars." The exclusion of Bell Burnell, who treated even the smallest, most unusual bit of data as significant, has been hotly debated ever since.

Astronomers estimate that up to a billion massive-star remnants should exist in the Milky Way, but only a million or so are pulsars. So far, only about 2,300 have turned up. Pulsars aren't permanent, after all. As the rotation, magnetic field, and local supply of electrons peter out over a few million years, so does the lighthouse beam. During a human lifetime, however, a pulsar's timing is typically as precise as an atomic clock's, changing by about a billionth of a second per year.

The presence of a stellar companion, though, can wind them up and turn them into even better timing devices. In 1982, astronomers discovered the first millisecond pulsars, objects whirling around at more than 100 times per second. The current record belongs to PSR J1748–2446ad, which rotates 716 times per second. Not merely curiosities, these speed demons may help future astronauts find their way.

Toward a pulsar GPS

Astronomers hatched the idea to use pulsars as navigation tools on the heels of their discovery, but in 1972, it literally was etched in gold. As scientists were putting the finishing touches on the Pioneer 10 spacecraft for its journey through the solar system and beyond, they wondered if they could convey the craft's "home" to any extraterrestrials it might come across. If only there were some way to indicate our position relative to

A pulsar spinning 30 times per second powers the emission from the Crab Nebula supernova remnant (M1). The pulsar is the bright dot in the heart of the central, hollowed-out region. This composite image shows visible light as red and X-ray radiation as blue. NASA/HST/CXC/ASU/J. HESTER ET AL.

objects with precisely known properties, like a sort of galactic GPS.

"Pulsars are the obvious answer," Carl Sagan declared. And with just three weeks left to design and etch the gold plaque that would ultimately be affixed to Pioneer 10 and its twin, Pioneer 11, he and Frank Drake created a map of the Sun relative to 14 pulsars. They also included a code indicating universal constants that intelligent aliens should be able to decipher. With the map and the spin-down rate of each pulsar, extraterrestrials would know not only where we are, but also when we launched the probe.

Maybe. "The data for one pulsar on the plaque is wrong, and so the aliens would need to sort that out!" jokes pulsar researcher George Hobbs at Australia's Commonwealth Scientific and Industrial Research Organization.

What about us? Could we ever use pulsar GPS as we leave the safety of Earth? Our current GPS, which uses Earth-orbiting satellites, obviously wouldn't help us navigate to Mars, much less to other star systems. Looking to the future, Hobbs and his colleagues have explored the feasibility of using pulsars as navigation tools.

The idea is straightforward in principle. On Earth, we know when to expect pulses from pulsars. And because light takes time to travel, those arrival times depend on our exact location. Complicating matters is the fact that pulsars, well, pulse — frequently. The universe hosts an infinite number of places where you can expect a pulse from a given pulsar at a particular time, but by observing several pulsars, you can quickly narrow the set of places you might be.

It takes a bit of computational gymnastics to settle on the right one, but Hobbs and his colleague You Xiaopeng have performed those acrobatics with data from millisecond pulsars and successfully pinpointed the location of the 64-meter Parkes radio telescope in Australia to within 0.6 mile (1 kilometer). They even confirmed that Earth revolves around the Sun, just in case anyone was still on the fence about that.

"The main challenge is being able to detect pulsars without a huge telescope," says Hobbs. "Of course, you're not going to launch the Parkes telescope into space!"

Even if you did, it wouldn't be of much use. A single radio dish can observe only one pulsar at a time, but, as is the case with terrestrial GPS, you need simultaneous information from several different clocks. A single X-ray telescope might do the trick, however, and several teams around the globe have jumped on the X-ray pulsar navigation bandwagon.

"The Europeans seem to have a crazy package to see if they can navigate aircraft [with pulsars]," says Hobbs. "And the Americans and Chinese are both undergoing research into deep-space navigation with pulsars."

A time for pulsars

Pulsar timing should prove useful for more than navigation. When he's not wrestling with issues of pulsar GPS, Hobbs and others are looking to these neutron stars to help us listen in on the most gargantuan cosmic events.

We can thank Einstein for the idea that our universe is an interwoven tapestry of matter, space, and time. According to his theory of general relativity, when matter moves, the rest of the tapestry ripples predictably in response. On September 14, 2015, the Laser Interferometry Gravitational-wave Observatory (LIGO) directly detected gravitational waves for the first time. Two black holes, each about 30 times the mass of the Sun, collided over a billion years ago, causing space to literally (and measurably) contract and expand.

But many people aren't aware that pulsars have been whispering rumors about gravitational waves for decades, giving astronomers confidence that they would ultimately detect them directly. In 1974, Russell Hulse and Joseph Taylor Jr. at the University of Massachusetts, Amherst, announced the discovery of a pulsar in orbit around another non-pulsing neutron star. It was the first of its kind: two extreme objects locked in a frantic dance, whirling around each other every 7.75 hours. The system pulls relentlessly at the fabric of the universe, which, in turn, saps energy from the pair. The lost energy spreads into the universe as gravitational waves.

The scenario might sound vaguely familiar. This binary pulsar — PSR B1913+16 — is performing a small-scale version of the tarantella executed by LIGO's famed colliding black holes. Long-term observations show that PSR B1913+16's orbit is shrinking by about 3.2 millimeters per circuit, with the two neutron stars scheduled to collide in just 300 million years. The

THE PULSAR HOUND OF PARKES

Although it was up and running by 1961, the 64-meter Parkes radio telescope in New South Wales, Australia, was not the first to find evidence of pulsars, or even ferret out the first millisecond pulsar. In fact, the radio scope, nicknamed "The Dish," came quite late to the pulsar game.

The telescope — one of the antennas that received the Apollo 11 TV transmissions from the Moon — amassed just eight pulsar discoveries by 1973 and added only about 300 more over the next quarter-century. But once scientists installed a new receiver in 1997 that provided much wider sky coverage, The Dish leapt into action. It would detect more than 100 pulsars per year for the next seven years, outpacing all other radio observatories put together.

The Dish's most significant discovery arguably came in 2004, when it revealed a double pulsar system. A step beyond Hulse and Taylor's pulsar-neutron star binary, the double pulsar allows astronomers to probe Einstein's general relativity further while exploring an eclipsing pulsar system.

All told, The Dish has discovered about two-thirds of the 2,300 or so known pulsars. In addition, it plays a leading role in the International Pulsar Timing Array, the development of pulsar GPS, and bringing pulsar science to a new generation through PULSE@Parkes, an educational program for high school students. — *C. R. J.*

The 64-meter Parkes radio telescope — aka "The Dish" — has discovered about two-thirds of our galaxy's known pulsars. CSIRO

system provides researchers with an extreme gravitational laboratory, one for which Hulse and Taylor received the 1993 Nobel Prize in Physics.

Pulsars probe gravitational waves

Pulsars can do more than merely insinuate the existence of gravitational waves, however. Because rotating neutron stars make exquisite clocks, they can be the endpoints of a galactic LIGO setup. LIGO detects passing gravitational waves by measuring how they compress and stretch the instrument's arms. These waves should do the same to the space between pulsars and Earth. Astronomers would then measure subtle variations in the pulse periods, and those changes would depend on the pulsar's direction. LIGO has only four observational arms: two in Livingston, Louisiana, and two in Hanford, Washington. With pulsars, astronomers can have as many observational arms as there are observed pulsars.

It's an elegant and simple plan, one that officially got underway more than a decade ago with the creation of the International Pulsar Timing Array (IPTA). But IPTA is after much bigger quarry than the stellar-mass black hole mergers seen by LIGO. It's trying to listen in on collisions of supermassive black holes. Paradoxically, this task is even more challenging than detecting the mergers of star-sized black holes.

Paul Lasky, a member of both gravitational wave teams, explains the process: "When two galaxies collide, the black holes in their cores will eventually sink to the center of the merged galaxy, and those two black holes will eventually merge themselves." It would seem that the sheer magnitude of such an event would make it easy to detect, but the resulting gravitational waves would have a phenomenally low frequency.

"The period of the waves is approximately one to 10 years," says Lasky. "This means that you need to observe for that amount of time to actually detect a single period." So even with a decade of observing under their belts, astronomers aren't too concerned that IPTA has yet to detect a merger of supermassive black holes.

There is one puzzling gap in IPTA's results, however. If you throw a large rock into a perfectly calm pond, you will see symmetric ripples radiate from the entry point. But the universe has thrown lots of rocks of varying sizes into the cosmic fabric over billions of years, and that should create a jumble of interacting ripples, or what scientists call the stochastic background. "The fact that we have not seen this stochastic background in more than a decade of observations is slightly at odds with theoretical predictions," says Lasky.

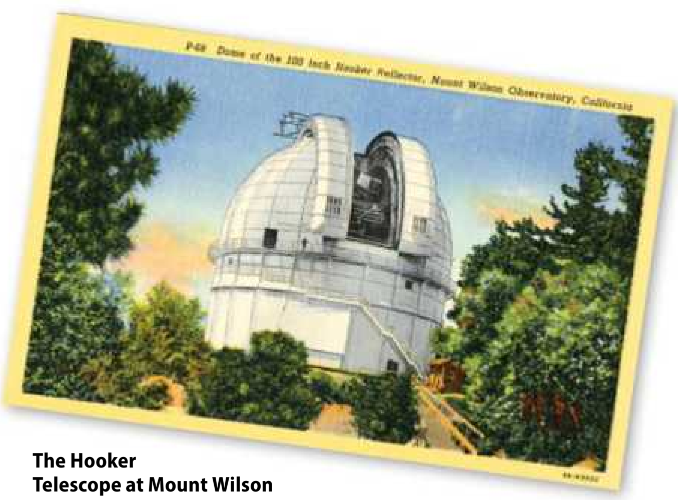
Still, with the resounding success of LIGO, gravitational wave scientists now can look more deeply into phenomena that until recently were on the fringe of observational astronomy, just as pulsars were a half-century ago. And there is every reason to believe that in the next 50 years, pulsars will continue to play a starring role in our understanding of the universe.

Not bad for a bit of scruff.

Mount Wilson's famous telescope celebrates a century

The 100-inch Hooker Telescope, which allowed Hubble to define the size of the universe, was nearly its builder's undoing.

by Ronald L. Voller



The Hooker Telescope at Mount Wilson Observatory was either an engineering feat or a madness-inducing nightmare, depending on whom you ask. Regardless, its first light in 1917 led to new astronomical discoveries. CURT TEICH & CO.

IN DECEMBER 1910, GEORGE ELLERY HALE sat in his Paris hotel room, feverishly going over a telegram he received from across the Atlantic. His assistant, Walter Adams, had cabled with news that hardware tycoon John D. Hooker was once again expressing frustration over delays and a general lack of progress. With Hale as supervisor, Hooker had hoped to finance the successful casting of a 100-inch (254 centimeters) glass disk, one that both men hoped would someday become the primary mirror for the most powerful telescope on Earth, at Mount Wilson Observatory outside Los Angeles.

Inside his hotel room, Hale was being driven mad by the uncertainty over the completion of the disk. "I cannot bind myself to further responsibility at this time," Hooker wrote.

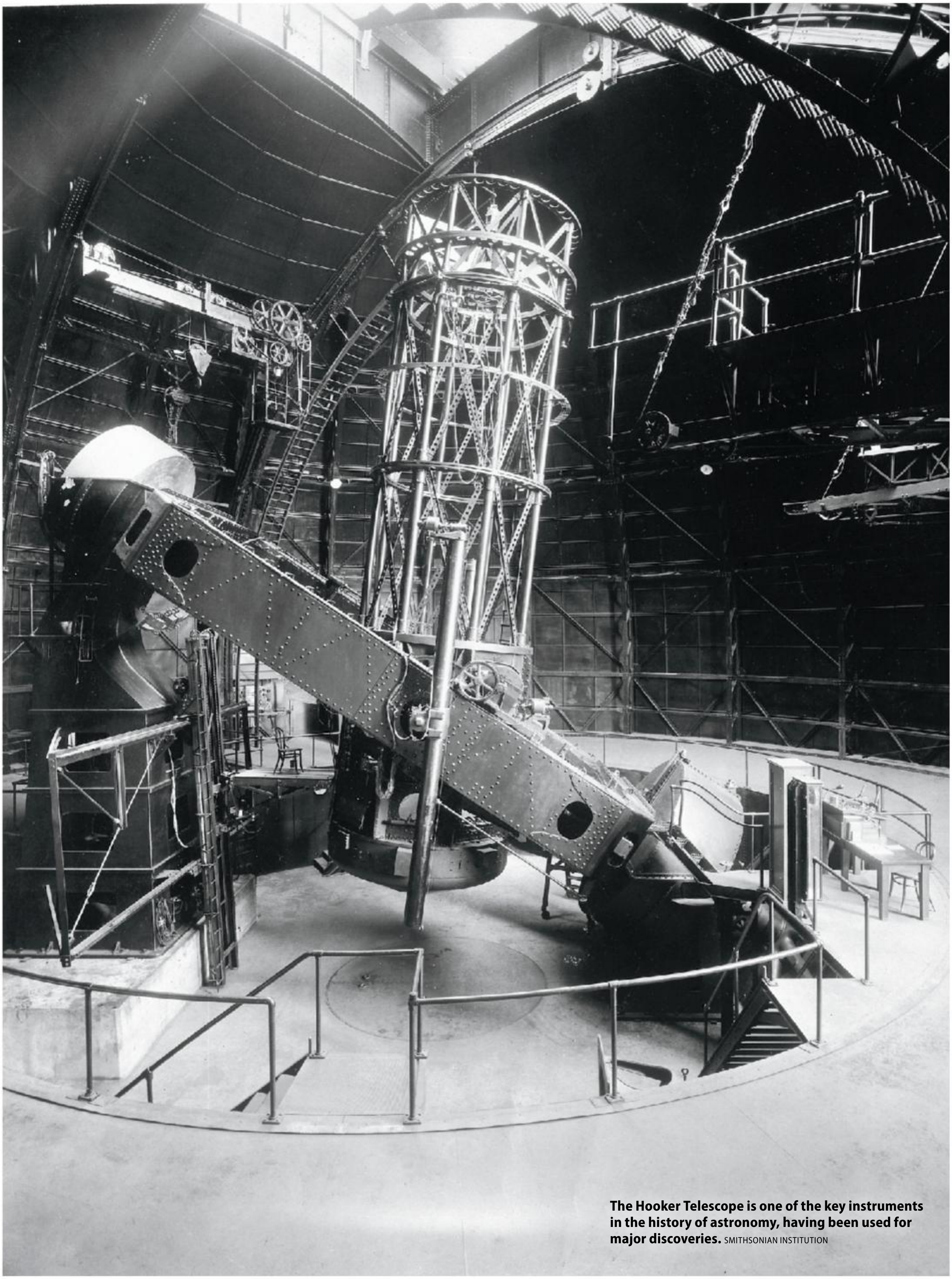
Hale knew that the millionaire's generous endowment of $45,000 to create such a mirror had been exhausted. As problems in casting the mirror persisted, Hooker had agreed to pay an extra $15,000 to send instrument specialists from Mount Wilson to Paris, where the disk was being cast. Now Hooker appeared to be reneging on that offer.

The telegram was the latest in a succession of troubling setbacks that were threatening to derail the observatory founder's ambitious plan. Far more than that, it threatened his mental and physical well-being.

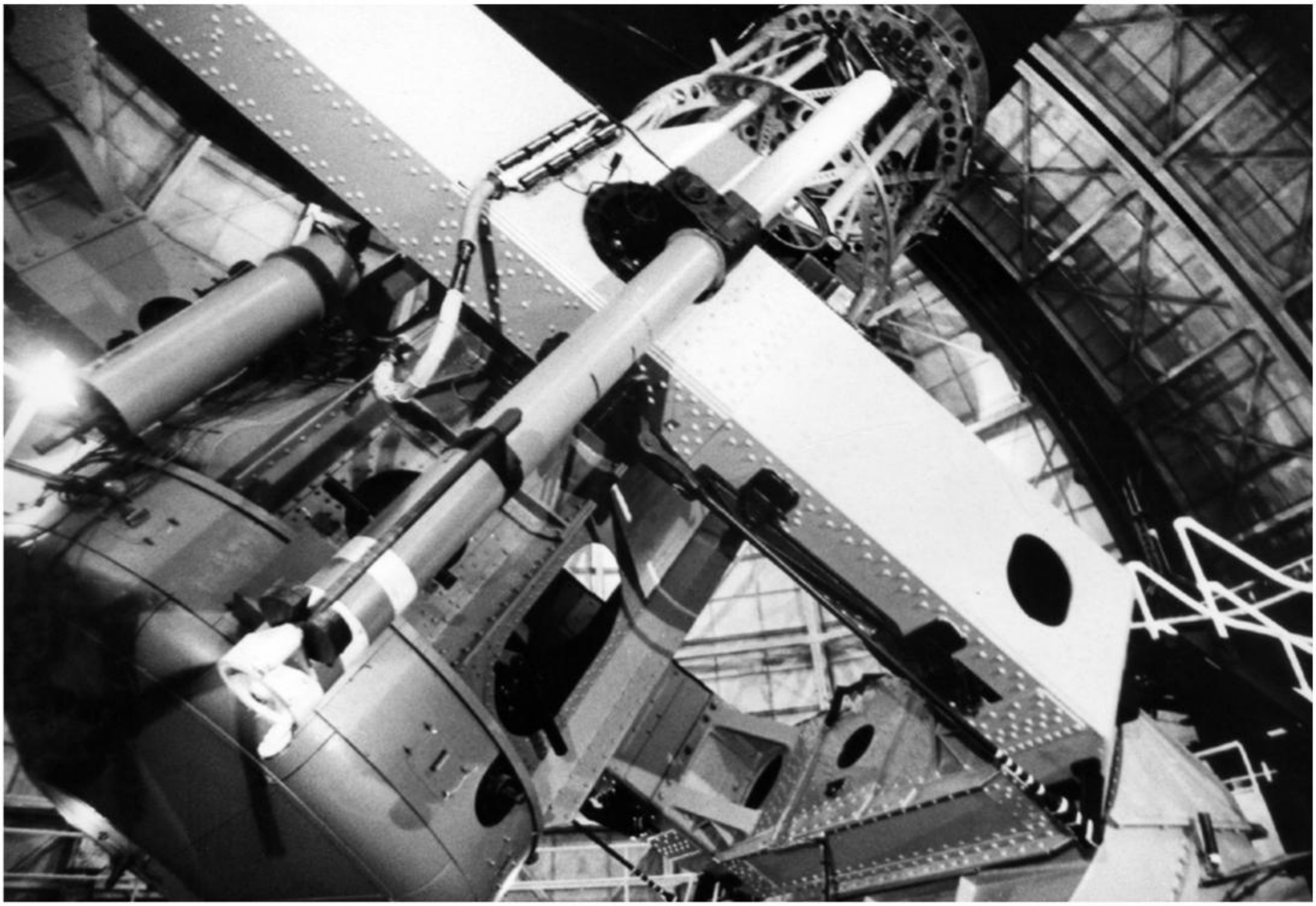
Origin story

The idea to build a 100-inch reflecting telescope had come even as the staff at Mount Wilson was eagerly awaiting the arrival of its first great reflector, the 60-inch (152.4cm) telescope, in 1906. The new telescope's glass disk had been paid for by Hale's father, William Hale Sr. The successful inventor and elevator businessman from Chicago had

Ronald L. Voller *is a writer, historian, and educator in New York City. He speaks frequently to astronomy groups about the Mount Wilson Observatory.*



The Hooker Telescope is one of the key instruments in the history of astronomy, having been used for major discoveries. SMITHSONIAN INSTITUTION



WORLD WIDE PHOTOS/CALTECH ARCHIVES

The Hooker Telescope, which celebrates its centennial this year, gazes toward the stars in this undated photo.

gifted the disk to his observatory director son in 1894. Now, as the director of his third successful observatory in California, Hale had finally found an ideal location for the powerful new telescope.

Hale had already made a name for himself in the astronomical community as founder of the Yerkes Observatory in Wisconsin, part of the University of Chicago. There, he had overseen the creation of the world's largest refracting telescope, with a lens 40 inches (101.6cm) in diameter.

Since then, he had moved his family and his small team of talented engineers and observers to the remote foothills outside Pasadena, California. He was creating a new observatory, one that would rival any astronomical research facility in the world for the next 50 years. Hale's goal was always to attack the problem of stellar evolution. The 60-inch telescope was intended to take that research beyond the Sun and deeper into space.

But even achieving that goal wouldn't be enough for Hale. He had written extensively about his vision for space exploration using instruments developed with ever greater light-gathering capabilities. At Mount Wilson, with an endowment from the Carnegie Institution of Washington, he felt he had the space, the location, and the money to build them.

The first steps

By the summer of 1906, the Hales had become frequent guests of Hooker and his wife, Katherine, at their estate in Los Angeles. Hooker was an amateur astronomer and was intrigued by Hale's vision and stories of the wonders of the heavens.

After dinner one night, Hooker began quizzing Hale about the cost of creating a telescope mirror 84 inches (213cm) in diameter. Hale set the cost at roughly $25,000 for a suitable disk. Being the kind of man he was, Hooker wanted to make sure that any telescope associated with his name would be the largest in the world upon its completion. With that goal in mind, he phoned Hale several weeks later to pledge the funding for a 100-inch mirror.

Hale was both elated and optimistic that the plan would ultimately lead to success. He wrote his friend Robert Woodward at the Carnegie Institution to inform him of Hooker's generous gift. Woodward's response was cautious at best, however. He expressed congratulations to Hale for the gift, but guaranteed no money for the completion of a telescope for the mirror. In the fall of 1906, the 60-inch telescope was still two years from completion and although progress was good overall — the telescope narrowly escaped disaster in the San Francisco Earthquake that April — no one could really be sure it would work properly.

Nevertheless, Hale forged ahead, advising his longtime collaborator and superior telescope designer, George Willis Ritchey, to cable the Saint-Gobain glassworks in Paris to commission the new disk. The firm had cast nearly every disk Hale and Ritchey had created in a partnership that spanned more than a decade. The supervisor of the firm, M. Lucien Delloye, cabled back that casting a disk of the diameter would be a daunting challenge, but one they were eager to undertake.

When it was cast, the 60-inch glass disk weighed nearly a ton. To create it, the team at Saint-Gobain had to build a special mold and oven to handle the massive amount of molten glass in a single pour. The glass blank for the 100-inch mirror would weigh 4.5 tons and test the limits of the glassworks and its capable staff.

Assuming the disk could be cast, there were other problems to resolve as well. The transfer of the disk at port, from ship to train car for the journey west to California, would be difficult because it was too heavy for the machinery at most of the available ports. Once it arrived in Pasadena, the mirror would have to be housed in a new shop with machines designed specifically to grind the glass, all 8,000 square inches (20,320 square cm) of it, true within millionths of an inch. For that purpose, a dust-free environment and the largest, most precise grinding machine ever constructed had to be designed. Finally, the road to the summit of Mount Wilson, which recently had been widened to make way for the 60-inch telescope materials and equipment, would have to be widened still further to accept the heavy materials and supplies for the new telescope and dome.

Ritchey began work designing the new lab, telescope, and dome, as well as overseeing the casting of Hooker's prized disk. Hale dealt with the logistics of getting the 100-inch disk to California safely and seeking suitable engineers, architects, and designers to help build the state-of-the-art instrument that would use it.

He asked his assistant, Walter Adams, to take charge of road construction. At the turn of the 20th century, widening an unpaved mountain pass like this was an arduous task, fraught with difficulties and setbacks such as torrential rains that caused mudslides and delayed the work on the 10-mile path. It was a job that required not just skill in surveying, blasting, and grading enormous amounts of the hillside, but a healthy dose of persistence and patience as well. Fortunately, Adams was endowed with both of these attributes in large proportion.

WELLCOME INDUSTRIES/MOUNT WILSON OBSERVATORY

Images like this picture of NGC 891 taken at Mount Wilson Observatory helped Edwin Hubble determine that several "spiral nebulae" were actually distant galaxies, opening the door to discovering the size of the universe. Later on, Fritz Zwicky would use the Hooker Telescope to find the first evidence of dark matter by observing discrepancies in galaxy rotation rates.

Coming together

By the fall of 1908, everything seemed to be proceeding smoothly. After working through its approach to the problem of casting the large disk, Saint-Gobain sent a cable in the fall of 1907 informing Hale and his team that the hulking disk had been successfully cast and annealed, and was now ready for transport across the Atlantic.

As the 100-inch disk made its way by ship to port in New York, work on the 60-inch reflector was finishing on Mount Wilson. The enormous 100-inch disk finally arrived in Pasadena on December 7, 1908, the same day that the 60-inch mirror was being installed in the new telescope.

The next day, Hale arrived at the lab in Pasadena full of pride. His new reflector appeared to be on its way to a successful completion. The new 60-foot tower for the solar telescope was a complete success, and Hale himself had recently made his groundbreaking discovery of magnetic fields in sunspots. He was also receiving recognition from the scientific community for his work in reviving the National Academy of Sciences, in negotiating the transition of the nearby Throop Institute into the California Institute of Technology, and for creating and organizing the International Union for Cooperation in Solar Research. It had been a good year for Hale and his observatory.

The sense of accomplishment quickly dissipated, however, when Hale and his team opened the crate revealing the newly acquired 100-inch glass blank.

It was a job that required not just skill in surveying, blasting, and grading enormous amounts of the hillside, but a healthy dose of persistence and patience as well.

In order to pour such an enormous amount of glass, they later learned, the craftsmen at Saint-Gobain had engineered three separate ovens, pouring each batch successively into the giant mold. This approach caused bubbles to form in the space between the layers of glass and rise to the surface, creating a frosty seam between them. Because of this, the disk bore resemblance to a giant glass layer cake.

Balking at its apparent lack of homogeneity and overall quality, Ritchey declared the disk useless and walked away in disgust. Hale and Adams didn't feel much better about it. "It is surprising that they sent it," Hale later wrote to Woodward of the Saint-Gobain team.

When he heard the news, Hooker was dismayed. He asked Hale to send Ritchey to Paris to see if he could rectify the mistakes in the initial casting.

During the construction of the disk, Hooker had become jealous and suspicious of Hale, who had garnered much adoration from Hooker's young wife. Ritchey, a devout Christian, was far less charming than the observatory founder, and the hardware magnate respected his skill and experience in the design of precision observing equipment. These attributes likely contributed to a greater trust between the two men than had formed between Hale and Hooker. This dynamic would play out

ruthlessly in the years to come, a product of continued discouraging news out of France for a successful outcome in casting a disk, the rueful grievances of an aging millionaire, and a serious miscarriage of judgment and conduct by Ritchey. All of this increasingly plagued the reputation of the observatory, as well as the mind of George Ellery Hale.

Waiting

Over the next two years, the engineers at Saint-Gobain tried unsuccessfully to cast a new disk. There simply wasn't an oven big enough to hold that much glass, stir it consistently, and pour it into the mold without creating either bubbles or "stones," tiny shards from the mold or pot that chipped away during pouring and affected the homogeneity of the disk. Visits from Ritchey, Hale, and others had produced some hope, but those hopes were dashed by problems in the months-long annealing process, which ended in either broken or blemished disks.

As time wore on, Hooker became increasingly discouraged and took out his frustration on a beleaguered Hale. Hale's already notoriously weak constitution was beginning to let him down under the strain of the bad news out of France. The success of the 60-inch reflector offered some reassurance, but when that telescope's benefactor, Andrew Carnegie, visited in March 1910, Hale was hardly well enough to greet him and his party.

Hale mustered the energy to show Carnegie the telescope and tour the grounds, then collapsed in a fit of exhaustion. In ill health, he attended the meeting of his beloved Solar Union in Pasadena several weeks later. It was a time of anguish and bitterness for Hale, who had dedicated his life to understanding the evolution of the stars. At age 42, he was suffering greatly in the pursuit of his dream.

To make matters worse, Ritchey, with whom Hale had been collaborating for years on the world's most powerful and precise telescopes, committed an act of insubordination that would prove unforgiveable to the director. As the pressure mounted on the observatory team to produce a suitable disk, and as Hooker grew increasingly discouraged, Ritchey began seeking support for an observatory of his own for the sole purpose of stellar photography. In a letter to Hooker, Ritchey expressed what he felt was a mutual idea — that a new observatory would best be used for photography, rather than the more extensive research undertaken at Mount Wilson under Hale's leadership.

Though he was no fan of Hale, Hooker was disarmed by the note and, not sure how to proceed, disclosed the nature of Ritchey's appeal to Hale. The director was understandably outraged. Ritchey had gone behind his back to proposition a known benefactor for his sole profit.

From 1917 until the completion of the 200-inch Hale Telescope in 1948, the Hooker was the world's largest telescope.

His trust in Ritchey broken, Hale began a systematic reduction of the elder craftsman's involvement at the observatory. Francis Pease, Ritchey's longtime assistant in the instrument shop, was put in charge of the design and construction of the telescope's dome, yoke, and cages. Ritchey would be relegated to grinding the disk — should one be cast successfully.

Over the edge

At this point, Hale had to leave all aspects of the daily operation of the observatory in the capable hands of Adams, whom he trusted implicitly. In the wake of Hale's breakdown, his doctor had ordered him to take a leave of absence from Pasadena. Hale's wife, Evelina, booked the family on a trip across the Atlantic to England, where Hale had spent time the year before and had been surprised by his election to the Royal Society of London.

This time, the doctor issued instructions strictly forbidding Hale from taking part in scientific discussion or in the interest of his observatory in any way.

But rest was fleeting for Hale, and his health was in decline. On the day the cable arrived from Adams in London, he looked wearily at the dispatch. "Hooker completes $45,000. Wants release all claims … Shall I sign? Answer." The note sent Hale over the edge. Over doctor's orders, he insisted on leaving London for Paris to deal with the issue himself. In fear for her husband's well-being, Evelina went to his defense. In a note to Adams, she angrily suggested he give Hooker a message from her. "I wish," she said, "that glass was at the bottom of the ocean."

John D. Strong and Ramón Enrique Gaviola, then up-and-coming astronomers, inspect the mirror in 1934 shortly after it was aluminized.
WORLD WIDE PHOTOS/CALTECH ARCHIVES


This view of Los Angeles from Mount Wilson displays the city's intense light pollution, which has affected the Hooker Telescope's observational abilities. ALEX NORIEGA

In Paris, Hale met with Delloye at Saint-Gobain and later fired off a cable to Hooker expressing hope for a successful casting on the next attempt. Despite this assurance, neither Hale nor anyone else associated with the 100-inch project really believed that the glassworks could pull off a successful pour of the massive disk.

Around that time, Hale got a glimmer of hope when he received word from Adams in Pasadena that tests in the lab appeared to show that the original layered disk might be serviceable after all. He recommended that they begin the process of grinding it into shape for a mirror. Hale replied that Ritchey should begin the process in the event that the last attempt to cast a superior disk fell short.

Hale despaired of his predicament. Short on funds for the project, the observatory was dependent on Hooker for financial relief that didn't appear to be forthcoming. They had one marginal working disk for the telescope, and Ritchey was acting defiant, argumentative, and insubordinate. With little hope for a successful casting in the final attempt in Paris, the days became desperately depressing.

Only a visit in January from a longtime family friend and confidant, Daniel H. Burnham, helped to calm his nerves. Burnham had been the lead architect behind the Chicago World's Fair in 1893, where Hale had first displayed his 40-inch refractor. Now Burnham was designing the dome that Hale hoped against hope would be built for his next great reflector.

Following this visit, the family headed south for a tour of Egypt, where Hale was finally spared the near-daily bad news from California. Despite this, he was plagued by remorse, fear, and loathing over the telescope.

Amid this bleary-eyed despondence, he began hallucinating a little imaginary man who badgered him on his decisions, always accompanied by an incessant ringing in his ears. The angry little elf remained with Hale throughout his life, despite his attempts to rid himself of its company, and eventually landed him a brief stay at a mental health facility in Maine.

It was on a train bound for Genoa, Italy, in January 1911 that Hale finally got some good news. While reading a local newspaper, he came across a notice stating that Carnegie had donated another $10 million to his institution and that he had special interest in the Mount Wilson Observatory and the creation of the 100-inch telescope. The news couldn't have come at a better time for Hale. Carnegie, for whom Hale could do no wrong, had once again come to the aid of the great observatory builder.

Coming together

It would be another six years before the great telescope on Mount Wilson saw first light. Ritchey, against his own wishes and in spite of his falling approval with his boss, finished grinding the mirror to perfection. In 1919, after the telescope was put into service, Hale fired him. Pease finished the design and construction of the telescope's pier, bearings, cages, and yoke. Hooker, who died in May 1911 with his promise to the observatory unpaid, would have his namesake telescope in the end.


Albert Einstein peers through the Hooker Telescope in 1931 while on a trip to discuss his theory of relativity with Caltech colleagues. CALTECH ARCHIVES

On July 1, 1917, the great mirror arrived at the foot of Mount Wilson in a heavy crate on the back of a new Mack truck, ready to make the slow climb to the summit. A crowd of spectators, photographers, newsmen, and observatory staff joined the procession. Almost none of these eager citizens had any idea of the pain, suffering, and endless hours of work it took to create the mirror. The parade went on for miles as the crowd followed the truck with its precious cargo up the steep mountain road and into history.

From 1917 until the completion of the 200-inch Hale Telescope in 1948, the Hooker was the world's largest telescope. Astronomers Edwin Hubble and Walter Baade would use it in the discovery of the expanding universe. Their findings, in support of theorists like Albert Einstein, Georges Lemaître, and others, set the course for cosmology for the next 70 years.

Today, the 100-inch Hooker Telescope is used solely for public viewing, having outlived its usefulness as an instrument of research. But on the centennial of its arrival, it is worth remembering that it was almost never completed. Only the foresight and diplomacy of its creator, George Ellery Hale; the incredible sacrifice and experience of craftsmen like Ritchey, Pease, Adams, and those at the Saint-Gobain glassworks; and the zeal and financial might of its benefactors, Hooker and Carnegie, made it possible.

Their hard work and diligence, and that of the many astronomers who used the Hooker Telescope to make discoveries that pushed the frontiers of science, has helped establish our current understanding of the universe.

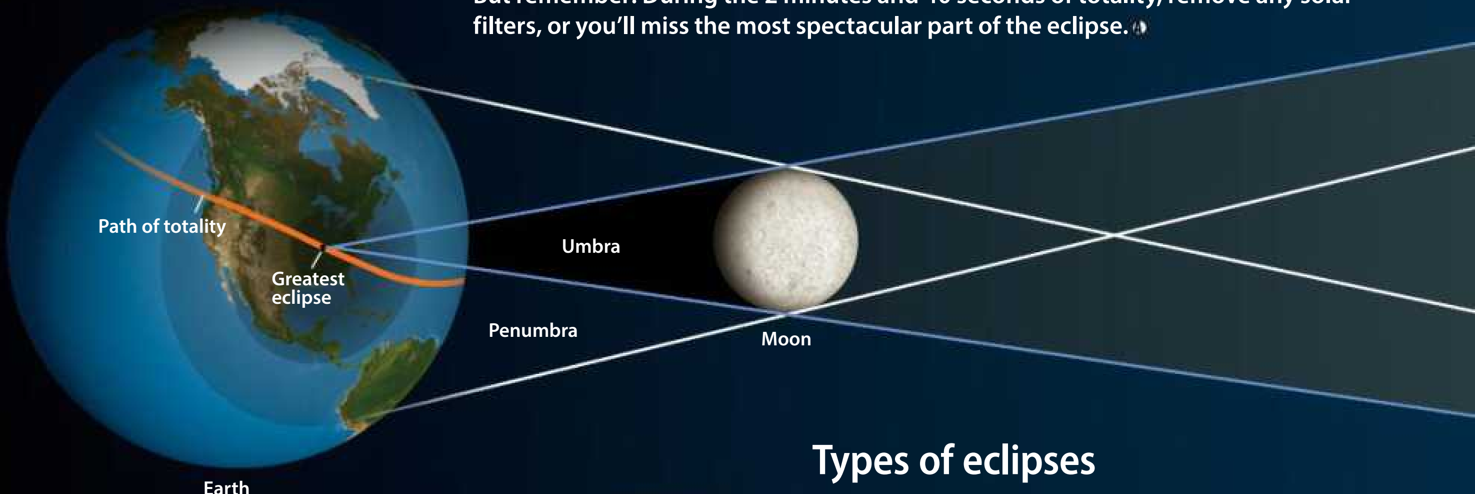
Solar eclipse geometry

What's happening in space and on Earth.

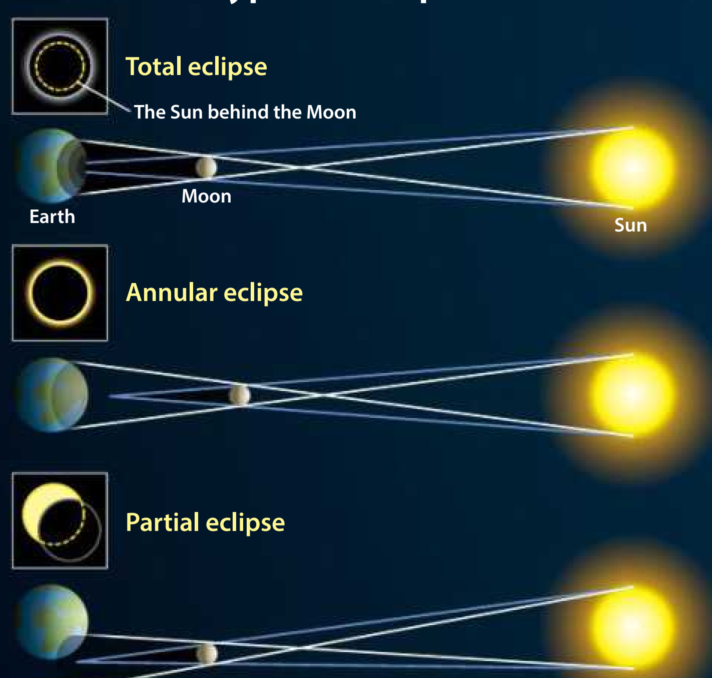
by Michael E. Bakich; illustrations by Roen Kelly

ON August 21, the dark inner part of the Moon's shadow will sweep across the United States, creating a total solar eclipse for regions in 14 states. But, you may ask, the Sun is so much larger than the Moon, so how does this work? While our daytime star has a diameter about 400 times larger than that of the Moon, it also lies roughly 400 times farther away. This means both disks appear to be the same size, so at certain times from certain locations, the Moon can completely cover the Sun.

Be sure to protect your eyes during the partial phases. The simplest way is to buy a pair of solar viewing glasses. Wear them even when 99 percent of the Sun is covered because the remaining part is still intense enough to cause retinal burns. But remember: During the 2 minutes and 40 seconds of totality, remove any solar filters, or you'll miss the most spectacular part of the eclipse.



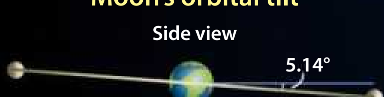
Types of eclipses



The three main types of solar eclipses are total, where the Moon completely covers the Sun's surface; annular, during which the Moon lies too far from Earth (or Earth too far from the Sun) for it to cover the Sun completely; and partial, where the lineup isn't exact and only the Moon's outer shadow touches our planet.

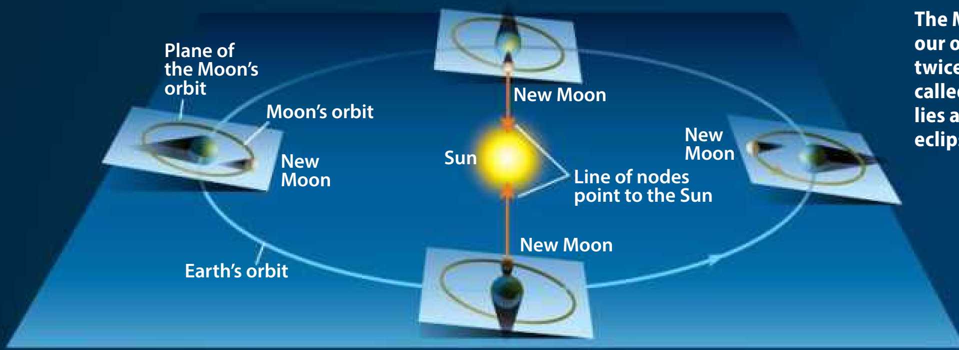
Moon's changing distance

Moon's orbital tilt



Top: Some central eclipses are total and others annular because the Moon's distance from Earth changes. **Bottom:** An eclipse doesn't happen every New Moon because our satellite's orbit tilts more than 5° from the plane of our orbit.

When can eclipses happen?

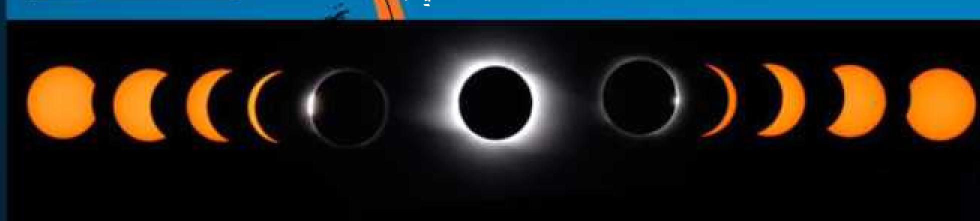


The Moon's tilted orbit intersects our orbit around the Sun only twice in each revolution at points called nodes. Only when the Moon lies at one of the nodes can an eclipse (solar or lunar) occur.

Two types of shadows

If the Sun were a point source, like one of the nighttime stars, the Moon would cast only one kind of shadow. Instead, the Sun stretches 0.5° across, so even during total solar eclipses, some of its light passes either above or below the Moon, creating a less-dense shadow called the penumbra. Only where the Moon blocks all the light from the Sun — in its dark inner shadow called the umbra — can people on Earth see a total solar eclipse. Anywhere in the penumbra, the eclipse will be partial, but the percentage of the Sun covered will increase as you get near the umbra. Unfortunately, the umbra is small, no more than a hundred miles in diameter. On the other hand, the penumbra measures more than 4,000 miles across.

Total solar eclipses during the next 20 years



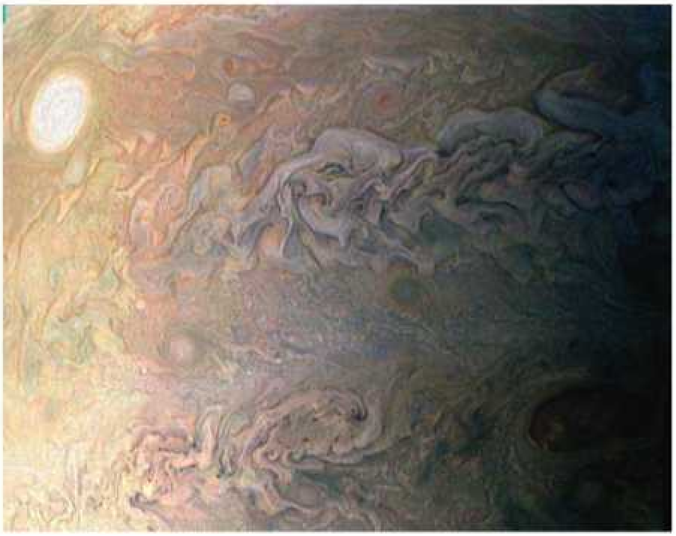
Left: From now until the end of 2037, 12 total solar eclipses will occur. This map shows the paths of totality in orange and each eclipse's center line in black. Below: This sequence shows an entire total eclipse in 11 images. The center shows totality, while the two diamond rings flank it. BEN COOPER/LAUNCHPHOTOGRAPHY.COM

Michael E. Bakich *is a senior editor of* Astronomy *who will be hosting the world's largest eclipse event August 21 at Rosecrans Memorial Airport in St. Joseph, Missouri.*

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

May 2017: Venus dazzles before dawn



While NASA's Juno spacecraft keeps an eye on Jupiter's polar regions (seen here), earthbound observers this month can enjoy exquisite views of the giant planet's cloud tops and moons. NASA/JPL/SwRI/MSSS/ERIC JORGENSEN

You know summer is just around the corner when the Pleiades star cluster sinks low in the west after sunset. May's warmer weather also sees Mars dipping into evening twilight, a prelude to the Sun's light swallowing it in June.

But don't fret: Plenty of planets occupy prime positions this month. Jupiter appears in the southeast in early evening and remains on view nearly all night. Saturn, which rises in late evening, climbs highest in the south before dawn. Early morning viewers also can enjoy Venus blazing in the east. Finally, binoculars should deliver fine views of Comet 41P/Tuttle-Giacobini-Kresak all night long.

Let's start our monthly tour in the western sky soon after the Sun goes down. There you'll find **Mars** glowing at magnitude 1.6 against the backdrop of Taurus. Don't confuse it with nearby Aldebaran, the Bull's brightest star, which has a similarly orange hue. Aldebaran shines about a half-magnitude brighter. The planet appears 7° (about one binocular field) to Aldebaran's right May 1 and passes 6° due north of the star the evening of the 6th. Although Aldebaran becomes lost in twilight by mid-May, Mars' eastward motion relative to the stars keeps it slightly ahead of the Sun all month.

In contrast to Mars' fading glory, **Jupiter** dominates the evening sky. On May 1, the giant world stands 35° above the southeastern horizon an hour after sundown and doesn't set until morning twilight starts to paint the sky. The planet shines brilliantly at magnitude –2.4 early in the month and dims by just 0.1 magnitude during May, keeping it the evening sky's brightest point of light.

Jupiter spends the month among the background stars of Virgo the Maiden, some 10° northwest of 1st-magnitude Spica. Be sure to look for it May 7, when it hangs 2° to the right of a bright gibbous Moon.

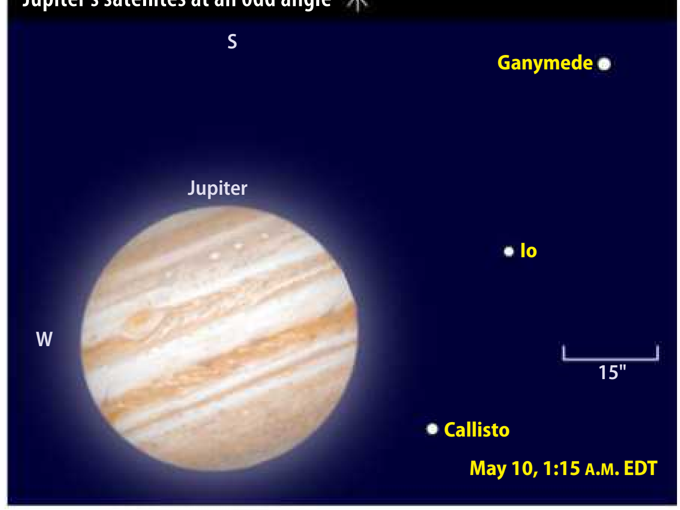
When viewed through a telescope, Jupiter's atmosphere resolves into wondrous detail. The gas giant's disk, which spans 42" at midmonth, sports an alternating series of bright zones and darker belts. The most conspicuous of these parallel bands are two equatorial belts, one on either side of a zone that coincides with the planet's equator. The temperate belts and zones appear more subtle but often harbor noticeable spots.

Any telescope also reveals Jupiter's four large moons. They typically appear in a straight line because all of them orbit in the planet's equatorial plane. But this plane currently tilts enough from our point of view that the two outer moons, Ganymede and Callisto, can appear oddly out of line. Check out the scene the night of May 9/10, when Io, Ganymede, and Callisto appear in a straight line angled some 40° to Jupiter's equator. The closest alignment occurs between roughly 1:00 and 1:30 A.M. EDT.

Yet there's more to viewing Jupiter's moons this night than one unusual configuration. All four perform an intricate dance with the planet and each other. A telescopic view in early evening reveals only three satellites because Jupiter's shadow completely engulfs Ganymede. The solar system's largest moon emerges from this eclipse at 10:55 P.M. EDT some 30" southeast of the planet's limb. Also note Europa slightly west of Jupiter. It passes behind the giant world's limb at 11:45 P.M.

Following the odd lineup of Callisto, Ganymede, and Io, Callisto coasts north of Jupiter while Io sets its sights on the planet's midsection. The latter moon crosses in front of the gas giant's eastern limb at 2:47 A.M. Like Jupiter, Io also casts a shadow, and it touches the planet's cloud

Jupiter's satellites at an odd angle



Although the Galilean moons usually line up east to west, three of them look decidedly askew the night of May 9/10. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

Pickin' up good librations

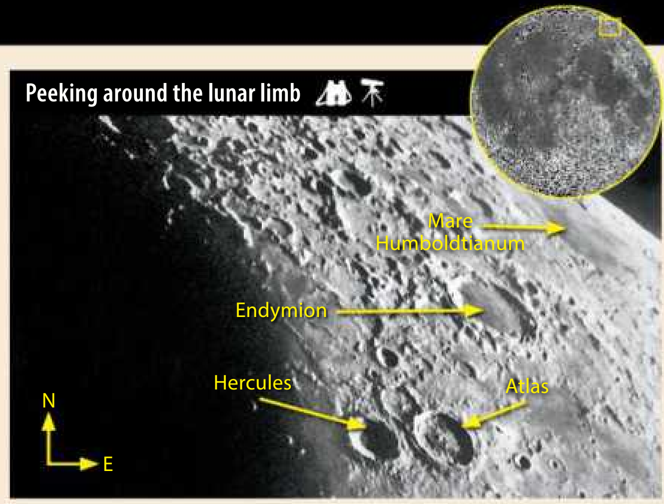
Have you ever watched someone roll their head? Although you still can't see the back of their head, you'll notice more than just the front half. The Moon performs a similar maneuver, called "libration," over a 27-day period. It lets us see 9 percent more of Luna than the 50 percent that normally faces Earth.

Binoculars allow you to track this motion easily. And the timing this month is just about perfect. In most lunar months, at least one of the lunar edges angled toward us ends up in darkness. In May, the Sun illuminates each section of the limb as our worlds dance through space.

The month opens with the northeastern limb displaying the lava-filled Mare Humboldtianum. Inward from there lies the lovely oval crater Endymion, with the striking pair of Atlas and Hercules not much farther inside. To the south, the dark patches of Mare Smythii and Mare Marginis sit near the limb while Mare Crisium resides a fair distance away. The lunar highlands much farther south are their usual white, but that won't last long.

As we approach the May 10 Full Moon, notice how our satellite seems to roll back to the northeast. Endymion almost reaches the limb, and Atlas and Hercules are not far behind. The southern highlands show a gray shade as Mare Australe rotates into view. Note how far north Tycho lies — six months from now, the crater will appear much closer to the southern limb. Also check out the western limb, where Grimaldi sits a bit more than one crater-width from the edge. Meanwhile, Oceanus Procellarum extends right to the limb.

And keep watching after Full Moon — binoculars let you follow libration even past sunrise. Grimaldi now rolls away from the limb, and each passing day reveals more of Procellarum's white coastline in the northwest.



Early May offers great views of the maria and craters that typically hug the Moon's northeastern limb. *CONSOLIDATED LUNAR ATLAS*/UA/LPL; INSET: NASA/GSFC/ASU

tops starting at 3:30 A.M. Six minutes later, Europa exits Jupiter's shadow some 20" off the southeastern limb. The night's final satellite events come when Io leaves Jupiter's disk at 4:58 A.M. followed by its shadow at 5:41 A.M. Although the planet sets in the eastern half of North America before the conclusion plays out, those in the western half should enjoy excellent views.

Saturn rises shortly before 11:30 P.M. local daylight time at the beginning of May and some two hours earlier by month's end. It climbs highest in the south during the wee hours of the morning and remains conspicuous until twilight is well underway.

The ringed planet will reach opposition and peak visibility in mid-June, but the view in May suffers little in comparison. You'll be hard-pressed to notice the world growing brighter because its magnitude increases

— *Continued on page 42*

METEORWATCH

A brief window of opportunity

May's annual gift to meteor watchers is the Eta Aquariid shower. The shower peaks the night of May 5/6, but it typically produces at least half its maximum rate (50 meteors per hour) from May 3 to 10. Although the waxing gibbous Moon interferes this year, observers have a clear shot once the Moon sets — around 4 A.M. local daylight time on the 6th and an hour earlier each day before then.

The meteors appear to radiate from the constellation Aquarius, which rises a couple of hours before twilight begins. The meteoroids hit our atmosphere at 41 miles per second, one of the highest velocities among all showers. The high speed and low radiant mean Eta Aquariid meteors often leave long trails.

The waxing gibbous Moon sets before dawn May 6, affording viewers a brief period of dark skies to enjoy spring's finest meteor shower.

Eta Aquariid meteors

Active dates: April 19–May 28
Peak: May 5/6
Moon at peak: Waxing gibbous
Maximum rate at peak: 50 meteors/hour

OBSERVING HIGHLIGHT Track Venus through a telescope this month and you'll see its size shrink from 38" to 25" across while its phase waxes from 27 to 48 percent lit.

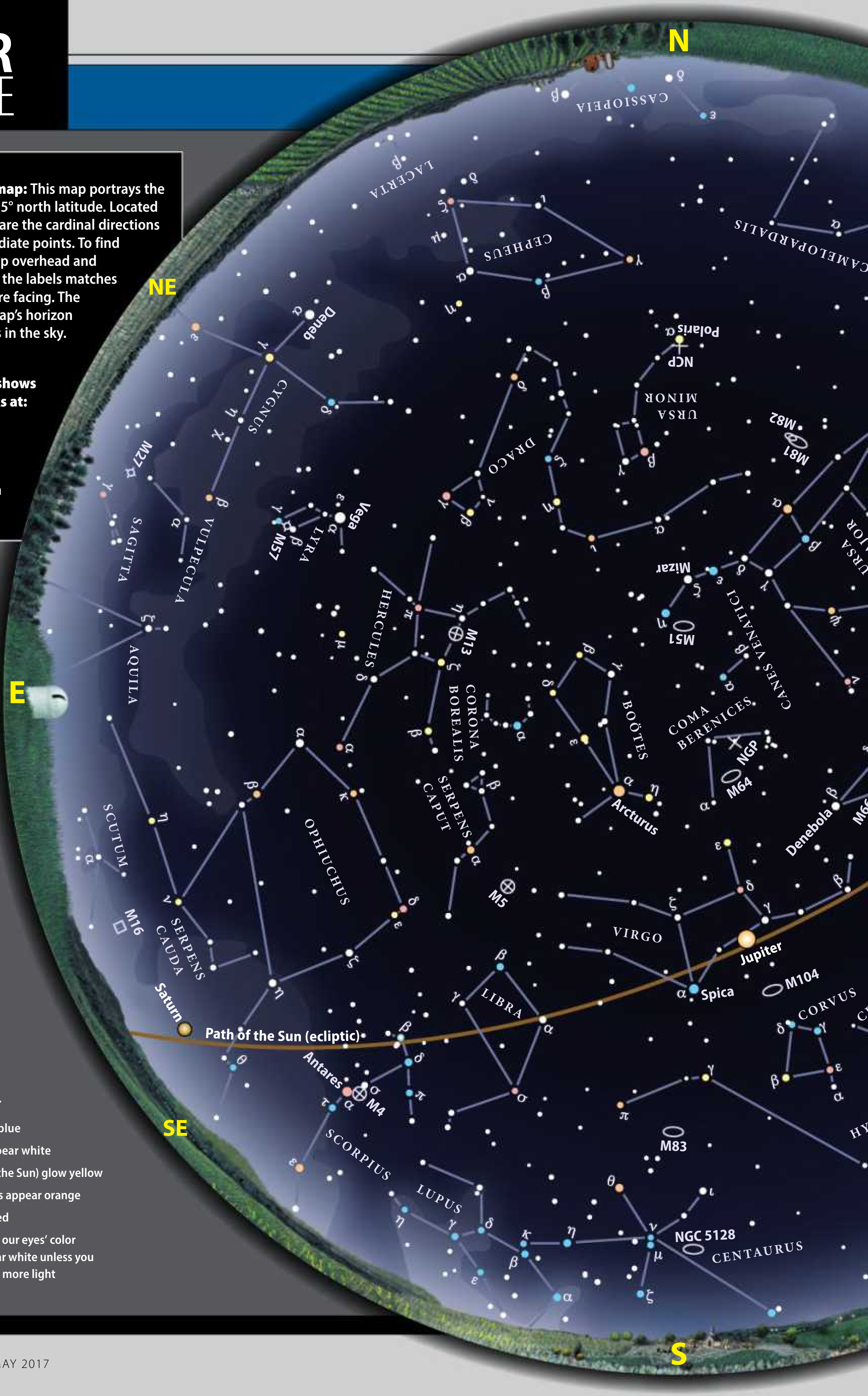
STAR DOME

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 May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth



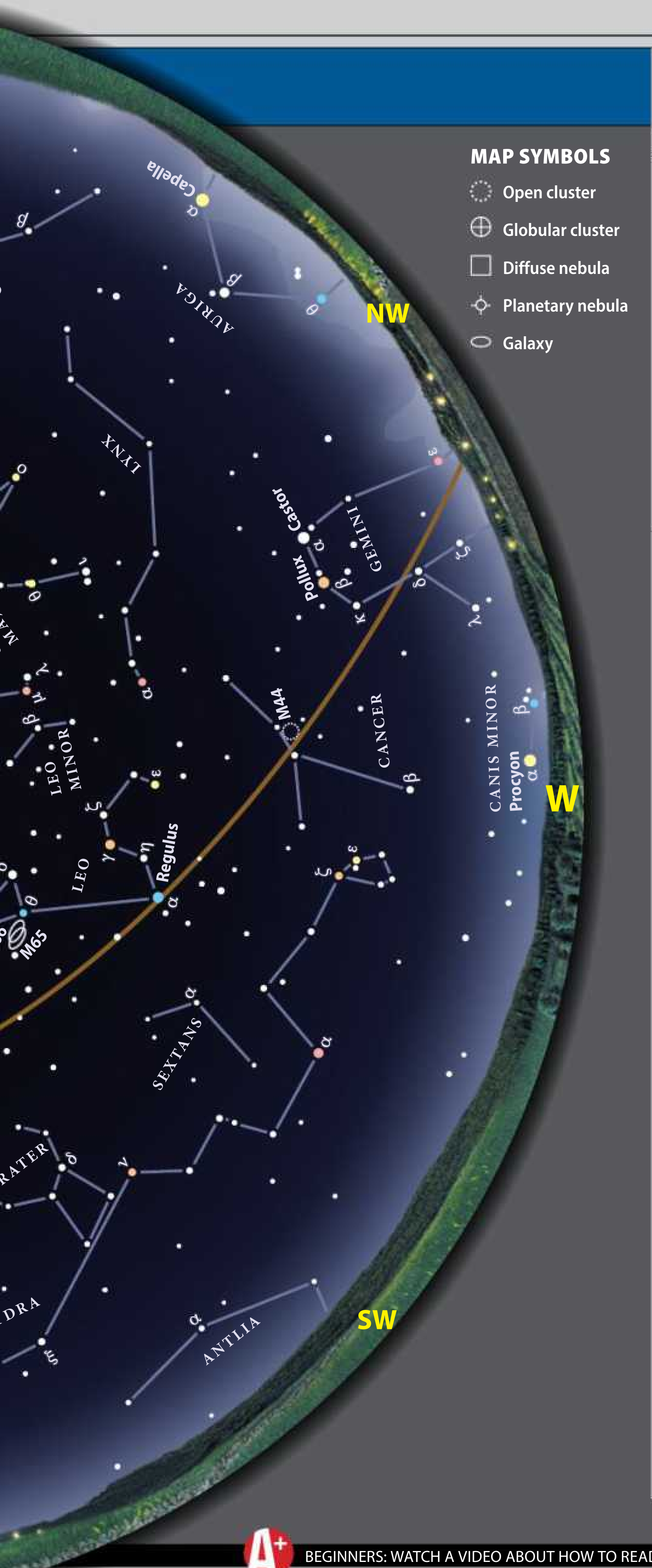
STAR MAGNITUDES

- 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

MAY 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

2 Mercury is stationary, 10 A.M. EDT

First Quarter Moon occurs at 10:47 P.M. EDT

4 The Moon passes 0.5° south of Regulus, 6 A.M. EDT

SPECIAL OBSERVING DATE

6 The Eta Aquariid meteor shower peaks before dawn. Observers have a brief viewing window after the waxing gibbous Moon sets and before twilight begins.

7 Mars passes 6° north of Aldebaran, 3 A.M. EDT

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

Mercury passes 2° south of Uranus, 7 P.M. EDT

8 Asteroid Juno is stationary, 4 A.M. EDT

10 Full Moon occurs at 5:42 P.M. EDT

12 The Moon is at apogee (252,407 miles from Earth), 3:51 P.M. EDT

13 The Moon passes 3° north of Saturn, 7 P.M. EDT

17 Mercury is at greatest western elongation (26°), 7 P.M. EDT

18 Last Quarter Moon occurs at 8:33 P.M. EDT

20 The Moon passes 0.5° south of Neptune, 2 A.M. EDT

22 The Moon passes 2° south of Venus, 9 A.M. EDT

23 The Moon passes 4° south of Uranus, 1 A.M. EDT

The Moon passes 1.6° south of Mercury, 9 P.M. EDT

25 New Moon occurs at 3:44 P.M. EDT

The Moon is at perigee (221,958 miles from Earth), 9:21 P.M. EDT

26 The Moon passes 5° south of Mars, 10 P.M. EDT

31 The Moon passes 0.3° south of Regulus, 1 P.M. EDT

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

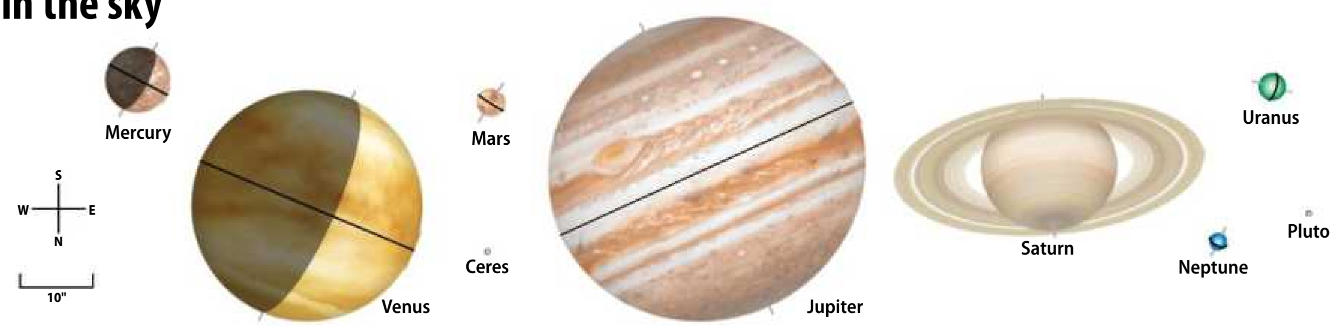
PATH OF THE PLANETS

The planets in May 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.

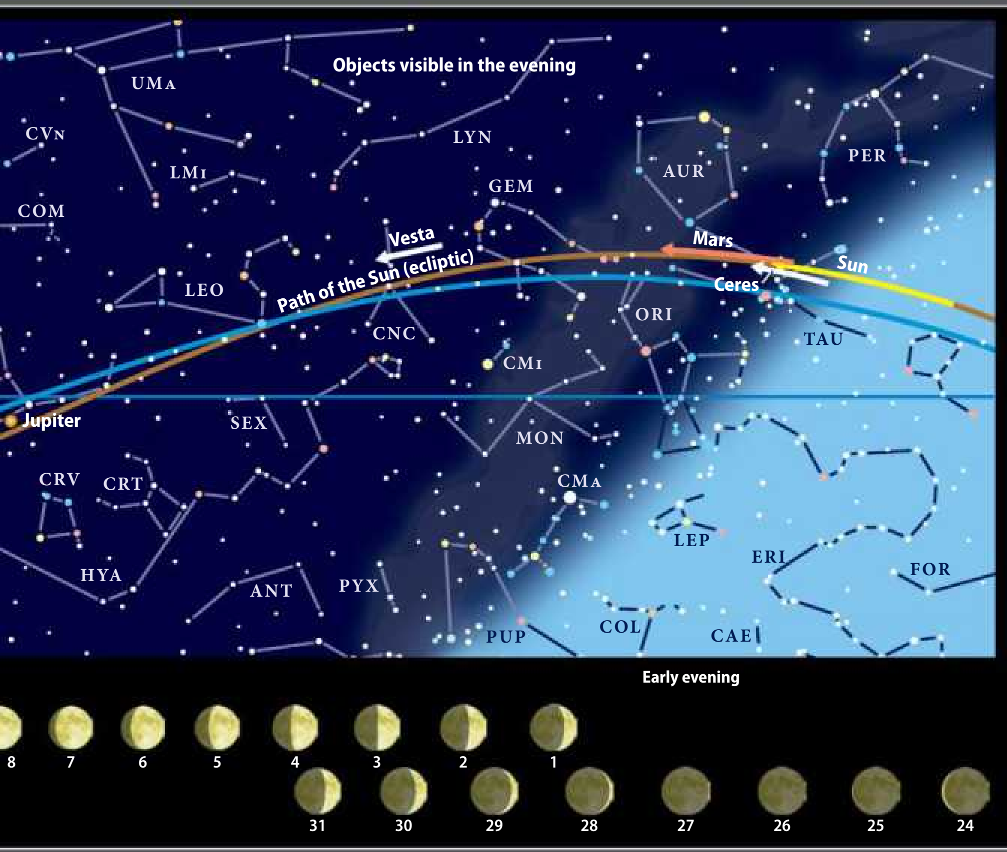
The planets in the sky

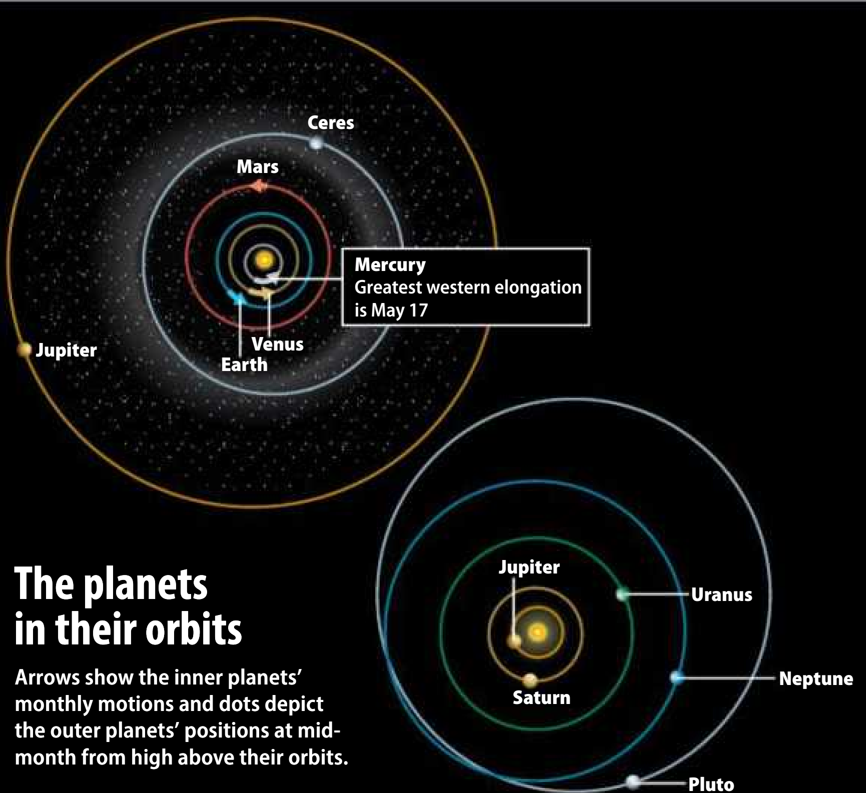
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	May 15	May 15	May 15	May 15	May 15	May 15	May 15	May 15	May 15
Magnitude	0.6	–4.6	1.6	8.8	–2.3	0.2	5.9	7.9	14.2
Angular size	8.7"	30.6"	3.8"	0.4"	42.5"	18.1"	3.4"	2.3"	0.1"
Illumination	35%	38%	99%	100%	100%	100%	100%	100%	100%
Distance (AU) from Earth	0.775	0.545	2.462	3.707	4.644	9.188	20.812	30.273	32.736
Distance (AU) from Sun	0.457	0.727	1.569	2.727	5.455	10.057	19.927	29.949	33.328
Right ascension (2000.0)	1h51.7m	0h37.8m	4h58.4m	4h17.8m	12h53.7m	17h44.4m	1h37.0m	23h01.4m	19h21.8m
Declination (2000.0)	7°58'	3°18'	23°27'	20°00'	–4°07'	–22°01'	9°30'	–7°12'	–21°15'

Astronomy magazine



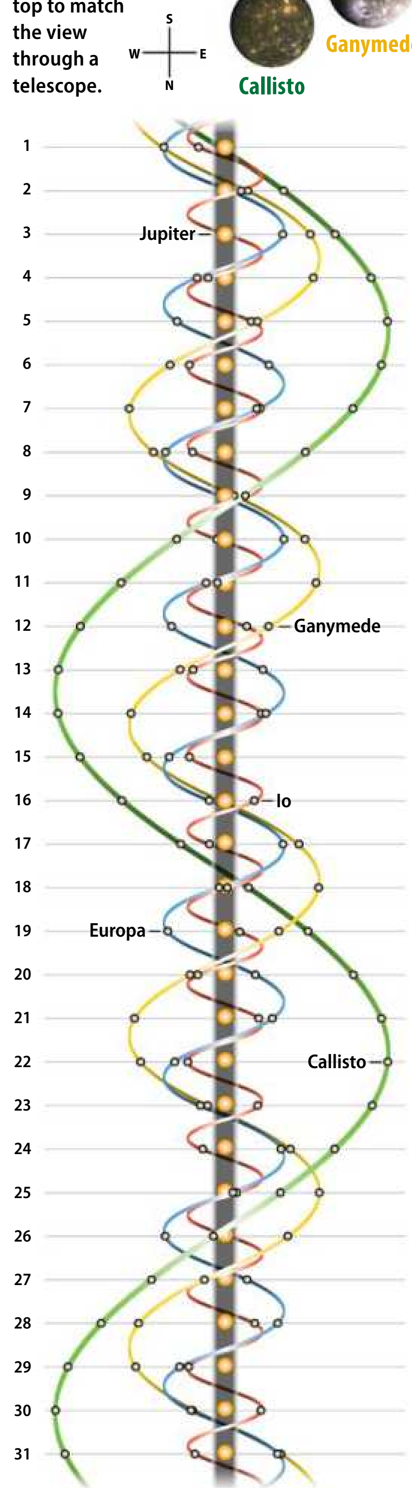


The planets in their orbits

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

Jupiter's moons

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



ILLUSTRATIONS BY ASTRONOMY: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

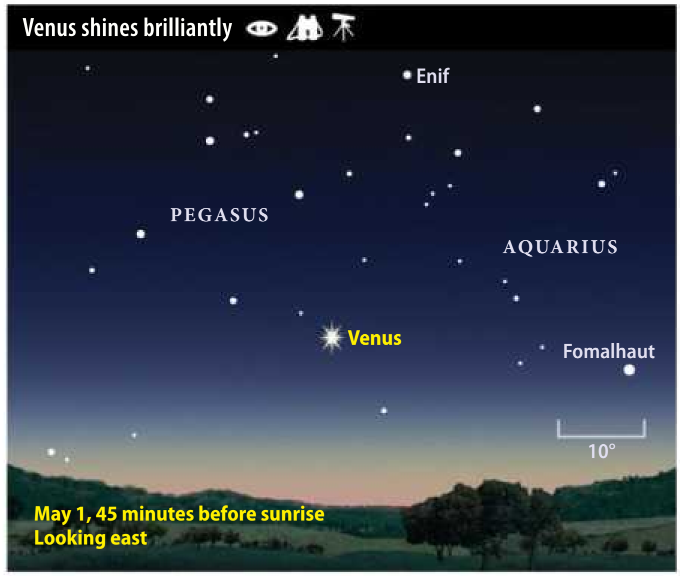
EVENING SKY	MIDNIGHT	MORNING SKY
Mars (northwest)	Jupiter (southwest)	Mercury (east)
Jupiter (southeast)	Saturn (southeast)	Venus (east)
		Saturn (southwest)
		Uranus (east)
		Neptune (southeast)

only from 0.3 to 0.1 during the month.

Once you soak in the view with your naked eye, target Saturn with binoculars. The ringed planet nestles among the rich star clouds of the Milky Way, not far from the galactic center. Saturn drifts slowly westward during May, starting in Sagittarius and crossing into Ophiuchus on May 18. You'll see the misty glows of the Trifid Nebula (M20) and its neighbor, the open star cluster M21, some 5° east of the planet. The spectacular Lagoon Nebula (M8) lies less than 2° south of these splendid deep-sky objects. Also look for the fine open cluster M23 about 5° northeast of Saturn. Avoid the mornings of May 13 and 14 when a bright gibbous Moon passes a few degrees from Saturn.

Of course, nothing compares to the view of Saturn through a telescope. The planet's disk, which measures 18" across at midmonth, may show the subtle shading of an equatorial belt and some darkening toward the poles during moments of good seeing. But the rings are what put Saturn in a class by itself. They span 41" and tip 26° to our line of sight, a large enough tilt to reveal fine ring structure. Notice in particular the dark Cassini Division that separates the outer A ring from the brighter B ring.

Small telescopes also reveal several of the planet's moons. Perhaps the most intriguing of these observationally is distant Iapetus, which glows some five times brighter when it lies farthest west of the planet than when it is farthest



The brightest celestial object after the Sun and Moon, Venus gleams at magnitude –4.7 in early May, its peak for this morning apparition.

COMETSEARCH

Comet viewing the whole night through

Comet 41P/Tuttle-Giacobini-Kresak is perfectly placed for Northern Hemisphere observers this month. The periodic visitor remains visible from dusk to dawn as it slides southward through eastern Hercules. The comet appears in the vicinity of brilliant Vega, which makes a convenient signpost for finding the dirty snowball. Astronomers expect 41P could reach 6th magnitude in early May, and it should be a fine target through binoculars and telescopes if you're far from city lights.

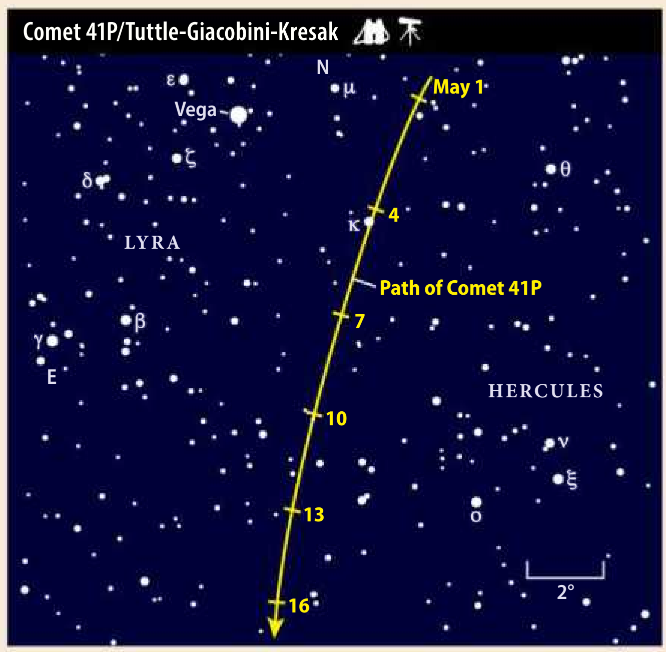
The comet's brightest part should be the slightly oval, yellow-white ball of gas and dust known as the coma, or head. Look for a greenish gas tail extending from the coma. If the comet performs like it did at its last observed apparition, this tail should resolve into multiple strands when viewed through a telescope. The comet's dust tail curves westward from the head.

Comet 41P should be a finalist for comet of the year, but if its nucleus cracks as it did in 2001, it may rank as the comet of the decade. That previous outburst caused 41P to brighten by a factor of 100.

Spring 2017 is shaping up as a golden age for binocular comets. Another 6th-magnitude gem — Johnson (C/2015 V2) — treks south through eastern Boötes this month and also remains on view all night. This first-time visitor to the inner solar system should deliver a nice show for both visual observers and astroimagers as its tail transforms from a wedge shape into a knife-edged saber in a few weeks.

If two bright comets don't satisfy you, maybe a third will. The 7th-magnitude Comet PANSTARRS (C/2015 ER61) lies low in the east before dawn, just a few degrees from Venus.

Be sure to enjoy this comet bounty while it lasts. By the time autumn rolls around, we'll be back to our standard fare of less-than-spectacular 10th-magnitude faint fuzzies.



Riding high in the sky among the background stars of Hercules, this periodic visitor should put on a nice show from dusk to dawn.

The Moon slides past Venus

A waning crescent Moon passes within 2° of brilliant Venus before dawn May 22, mimicking this evening scene from November 26, 2011. JOE ROMANSKI

east. It reaches a favorable greatest western elongation May 9, when it stands 9' from Saturn. Iapetus then shines at 10th magnitude as its bright hemisphere faces Earth. It fades slowly as it heads eastward along its 79-day orbit. The moon glows at 11th magnitude when it passes 2' north of the planet May 29.

The other visible moons lie much closer to Saturn. The brightest is 8th-magnitude Titan, whose distance from the planet ranges between 1.3' and 3.1' during its 16-day orbit. Look for Titan due north of Saturn May 7 and 23 and due south on May 15 and 31.

A trio of 10th-magnitude moons orbit inside of Titan. Rhea circles Saturn in 4.5 days, while it takes Dione 2.7 days and Tethys only 1.9 days. Enceladus hugs the planet's rings, taking just 1.4 days to complete a circuit. This moon glows at 12th magnitude and hovers so close to the rings that the glare makes it hard to see.

The two most distant major planets in the solar system, Uranus and Neptune, join with the two closest, Mercury and Venus, in May's morning sky.

The first to rise is outermost **Neptune**. This ice giant world resides in Aquarius and pokes above the eastern horizon around 3 A.M. local daylight time in mid-May. To locate Neptune, first find magnitude 3.8 Lambda (λ) Aquarii and then scan 2.2° east-northeast to the 6th-magnitude star 81 Aqr. The planet spends the month within 20' of this star and passes 9' due south of it on the 14th. You'll need binoculars to spy magnitude 7.9 Neptune and a telescope to see its 2.3"-diameter disk.

Dazzling **Venus** rises about two hours before the Sun. Once it does, it dominates the eastern sky. The inner planet reached greatest brilliancy in late April, but it remains the same brightness (magnitude –4.7) in early May and dims only 0.2 magnitude by month's end. Be sure to catch the waning crescent Moon when it slides 2° south of the planet May 22.

Venus now lies relatively close to Earth, and this means that its appearance through a telescope changes dramatically during the course of the month. On May 1, the planet appears 38" across and about one-quarter illuminated. By the 31st, its disk spans 25" and nearly half of it is lit.

Venus also serves as a guide to distant **Uranus**. Wait until the end of May, when the two rise together just as morning twilight begins. On the 31st, magnitude 5.9 Uranus lies 3° to the left of its much brighter neighbor. Binoculars will frame the pair nicely, though you'll need a telescope to see Uranus' 3.4"-diameter disk. Although the outer planet soon gets lost in the growing twilight, Venus remains conspicuous until shortly before sunrise.

Start looking for **Mercury** around the time of its May 17 greatest elongation. The innermost world then lies 26° west of the Sun and climbs 4° high in the east a half-hour before sunup. The planet shines at magnitude 0.5 and will be tough to find with the naked eye. Mercury becomes easier to find late in the month, as it brightens to magnitude –0.3 while maintaining its predawn altitude.

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**

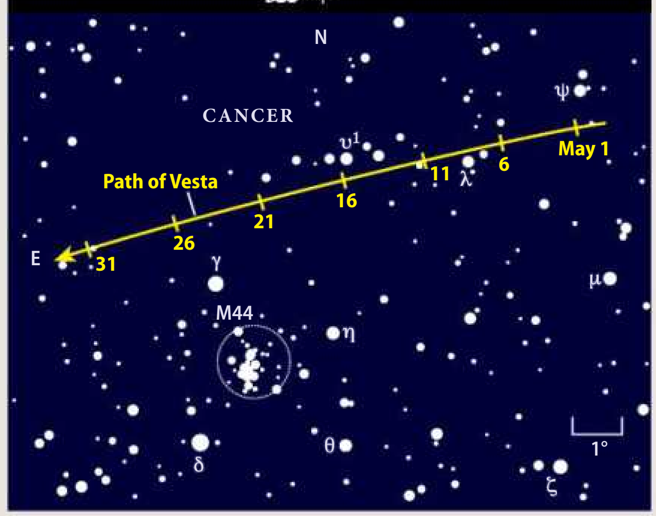
The Crab welcomes the brightest asteroid

Whether you prefer an easy search with a telescope from the suburbs or a more challenging hunt with binoculars under a dark sky, asteroid 4 Vesta is the target of choice this month. Start your quest with the great Beehive star cluster (M44) in Cancer. Then slide north to magnitude 4.7 Gamma (γ) Cancri, the brightest star close to the asteroid in May.

Vesta reflects nearly 40 percent of the sunlight that strikes it, making it one of the shiniest asteroids in solar system and, not surprisingly, one of the brightest. Although now fading from its peak, Vesta still registers a respectable 8th magnitude. And because it is moving away from the crowded Milky Way, there are fewer background stars to complicate the hunt.

During May's first week, Vesta plies the empty space between the 6th-magnitude stars Psi (ψ) and Lambda (λ) Cnc. To find it then, sketch four or five stars in your field of view and then return a night or two later to pick out the one that moved. In mid-May, Vesta glides just south of a zigzag line of stars anchored by magnitude 5.7 Upsilon^1 (υ^1) Cnc. Vesta outshines everything in its vicinity during the month's final week, so identifying it then should be a snap.

Vesta buzzes the Beehive



Look for this 8th-magnitude space rock as it tracks westward against the backdrop of Cancer the Crab.

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

The large emission nebula IC 1396 in Cepheus is faintly visible to the naked eye under very dark skies and a glowing mass in telescopic fields of view. NEIL FLEMING

Discover 10 weird

These clouds of gas, in the process of gravitationally collapsing into new stars, offer spectacular sights for owners of medium and large telescopes. **by Stephen James O'Meara**

emission nebulae

Emission nebulae are glowing clouds of interstellar gas excited by hot, young stars within their folds. Because much of the emitted light is caused by intense ultraviolet radiation stripping electrons from hydrogen atoms of nebulae, they glow in the red part of the spectrum, putting visual observers at a disadvantage unless the nebulae are bright. This is why so many are a photographer's delight and a visual observer's nightmare.

Most emission nebulae are the sites of recent star formation, where hot, energetic radiation streaming from the newborn stars sculpts a nebula's bright and dark clouds into intriguing (and sometimes mystifying) shapes. These shapes have led to many of these objects' fanciful monikers, such as the Lagoon Nebula or the Pillars of Creation.

In this way, all emission nebulae are wonderfully weird, as they reveal nature's artistry across intangible tapestries. But some can be considered weird for other reasons, as we will explore in this list of 10 spectacles hovering above the horizons in May. Note that almost all of these nebulae are best seen with ultra-high-contrast or Oxygen-III filters, which can boost the contrast between the nebula and the sky background.

Sometimes called the Monkey Head Nebula, NGC 2174–5 in Orion contains a cluster and is edged by dark nebulosity. MARK HANSON

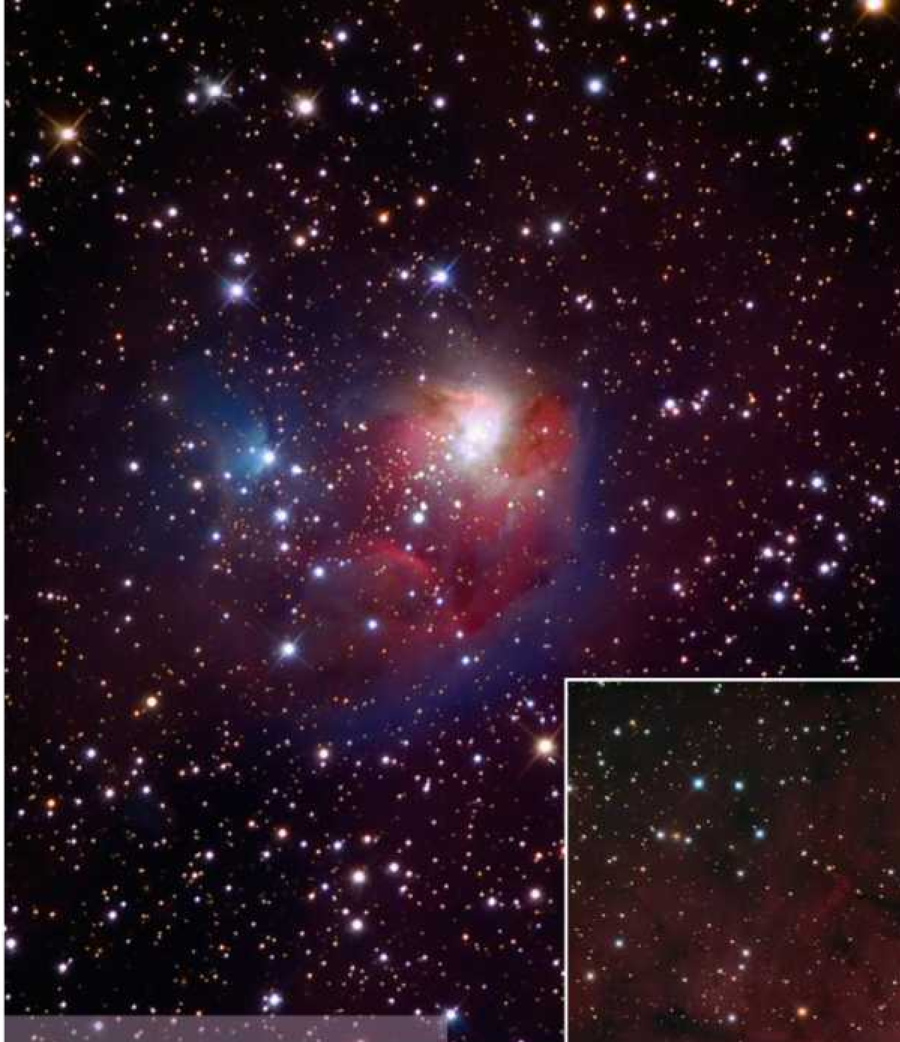
Early May: early evening

NGC 2174–5. Popularly known as the Monkey Head Nebula, **NGC 2175** is a 30'-wide nebulous cluster 6,400 light-years distant in the hinterlands of the Orion Milky Way. In visible light, NGC 2175 is a rosebud of rippling emission excited by a magnitude 6.5 star and centered on what appears to be an embedded cluster. But recent observations have shown this is an illusion, as the NGC 2175 cluster is actually not a star cluster but an extended stellar group of four cluster components within the Gemini OB1 association. The cluster complex formed within **NGC 2174** during a lingering starburst event some 5 million years ago. Infrared views of the largely spherical nebula's dense western edge show a ragged ridge of dust and gas sculpted into a tiered landscape of dark foothills and misty mountaintops where star formation is most likely still happening.

You'll find this exotic wonder about 1° east and slightly north of Chi^2 (χ^2) Orionis, near the northern foot of Gemini. The ghostly glow is most comfortably viewed through binoculars under a dark sky. Look for an irregular sphere of misty "moonlight" seen against a rich Milky Way background.

What's weird about this object is that the enormous nebula's brightest patch, NGC 2174, requires a telescope to see, as it is but an itsy-bitsy (3' wide) enhancement on NGC 2175's northern rim. This swab of gas lies just 10' north-northwest of the embedded cluster's magnitude 6.5 central star and covers a tight gathering of 11th- to 12th-magnitude stars arranged in a north-south line. Large sweeps across the nebula's face with a large telescope will also show the nebula's faint alternating bands of dark and light.

Sharpless 2–235. This peculiar kidney bean-shaped star-forming region lies some 6,500 light-years away in the Perseus spiral



The bright emission nebula NGC 1931 appears like a miniature Orion Nebula and offers something for observers with any size telescope. AL AND ANDY FERAYORNI/ADAM BLOCK/NOAO/AURA/NSF

Sharpless 2–235 in Auriga lies near the bright open cluster M36 and appears as a wavy cloud of gas with lanes of dark nebulosity over its face. AL KELLY

One of the emission nebulae most distant from the galactic center, NGC 1491 in Perseus appears like a lopsided cloud with ripples, folded curtains, and dusty pillars. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA

arm of our Milky Way. It lies in the direction of the galactic anticenter, just north of open cluster M36 in Auriga.

In optical images, the nebula appears as a small and nearly structureless glowing cloud whose northern half shines more brightly than its southern half. A dark lane of dust separates the two hemispheres, making it look as if the brighter section is being mirrored in a pool of water.

These mismatched clouds actually mark the point where two massive giant molecular clouds have collided. Even stranger: While the main bifurcated nebula's structureless appearance indicates that it is well evolved, three little droplike H II regions — **Sharpless 2–237A**, **Sharpless 2–237B**, and **Sharpless 2–237C** — appear to drip down from the main nebula's dim southern half, forming a roughly 6'-long stream of tears of youthful star formation.

Sh 2–235 is a fine target for those using 10-inch and larger telescopes, which at 100x will show the bifurcated nebula as a pale 10' oval glow with a dark band separating its two disparate halves. But skilled observers have spied the nebula using a 5-inch telescope, so try your luck.

NGC 1931. The Little Orion Nebula is an 8th-magnitude nebulous cluster about 1° west of open cluster M36. Born from a very dense and dusty environment some 7,500 light-years away, the nebula sports a central hollow cleared by radiation from a young, hot trapezium of stars and outer looping bands of dust and gas that glow with molecules of polycyclic aromatic hydrocarbons; these ubiquitous molecules are known to astronomers as the prebiotic roots of life.

So in shape and structure, NGC 1931 resembles a miniature Orion Nebula. Actually, data from the Two Micron All Sky Survey have shown the nebula does not harbor a single cluster but a double cluster: the NGC 1931 cluster and a much fainter stellar gathering to the south near the edge of the hollow. This suggests NGC 1931 is either evolving into an OB association or dissolving slowly into the Milky Way.

Through a 5-inch telescope at powers ranging from 165x to 330x, the nebula has a smooth, milky sheen that gradually, then rapidly, fades away from the bright cluster core. The southern end is more condensed than the northern end, which is partly obscured by the region's large, expansive, and dense molecular cloud.

NGC 1491. This nebula in Perseus is one of the most distant nebulae from the galactic center. It lies in the Perseus arm of the Milky Way, an additional 11,000 light-years farther from the center of the galaxy than our own Sun. This evolved and complex expanse of ionized interstellar hydrogen displays weak, diffuse emission out to at least 1°. NGC 1491 is being excited by a prominent 11th-magnitude central star at the center of a curious "half-ring" of nebulosity immediately to the star's west. The rest of the nebula is indeed odd, having a veritable lopsided appearance — displaying bright ripples like "curtain folds," molecular ridges with dark, dusty pillars and elephant trunks, and a peculiar cavity lying well to the east of the nebula's exciting star.

NGC 1491 is an example of a "blister" type H II region, or one formed in a heterogeneous environment. (In this case, on the lip of a dense molecular cloud.) Intense stellar winds from its hot exciting star are "blowing" a bubble in the gas, which is bursting through the molecular cloud's edge, like a blister, clearing out its environment. The exiting star's ultraviolet radiation is also sending out a rapidly expanding shock wave (the half-ring of light) that's washing through the edge of the molecular cloud like a tidal wave intercepting a coastal plain.

You'll find NGC 1491 about 1° northwest of 4th-magnitude Lambda (λ) Persei. It's visible through a 5-inch refractor under a dark sky as a distinct oval patch of irregular light. High magnifications will show two bright horns of gas northwest of the exciting star against a wider and less-condensed skirt of light.

Late May: midnight hour

NGC 6813. This tiny (2') mote of emission nebulosity all but pleads to be noticed among the rich stellar sands of the Vulpecula Milky Way. Little is known about its true physical nature. It's been classified as an emission nebula, but some databases refer to it simply as "interstellar matter." Nevertheless, it does contain a Westerhout radio source (W54) within a significant star-forming region that includes an infrared cluster cataloged as BDS2003.

You'll find this mystery spot about 2¼° east-southeast of Albireo (Beta [β] Cygni) and about 20' west of a 7th-magnitude star. Amateur astronomers have done admirably in imaging it, and those who have spied it visually have been astounded by its tiny intensity. It is visible to a skilled observer through a 4-inch telescope at 150x, but don't hesitate to pump up the power if you're having difficulty. Its bright center shines around 11th magnitude and has a flattened appearance, oriented east-west.

NGC 6820 in Vulpecula is a large and diffuse object incorporating pronounced pillars of dust. GERALD RHEMANN

NGC 6820. An expansive emission and reflection nebula near 5th-magnitude 12 Vulpeculae, NGC 6820 surrounds the 7th-magnitude open cluster **NGC 6823**, whose Trapezium-like core of hot central stars excites the nebula while clearing away a central cavity. Beyond this central hollow, a battle between light and dark appears to take place on all fronts: A massive jagged slash of dark nebulosity carves across the nebula's faint northwestern flank; a fist of dark matter punches in from the east (with pointy black fingers clawing inward toward the central cavity); and to the south, dark stalagmites of obscuring dust jut from an anemic nebulosity that droops southward like a pouting lip. With imagination, the scene looks like a wilted rose melting in the heat.

Although the nebula has been spied in 15x100 binoculars, its visibility greatly depends on the sky's clarity, light pollution, aperture, and magnification. Through a 5-inch rich-field telescope under a dark sky at 22x, it's but a suspicion of light around the 30'-wide L-shaped cluster, whose halo of fainter stars mingles with the slightly larger (and extremely pale) emission nebula. Others using twice that aperture have reported seeing finer details.

Sharpless 2–82. This small (7') and dim emission and reflection nebula lies some 3,500 light-years away in northwestern Sagitta. In images it's reminiscent of a miniature Cocoon or Trifid Nebula blooming from the center of a long river of dark nebulosity. In terms of color, the scene is most peculiar. The pink emission nebula appears to lie in a nest of blue reflection nebulosity, through which threads of dark nebulae (streaming off the dark river) weave in and out, as if trying to sew the two glows together. Also curious, the dark river's southwestern segment seems to pass in front of and occlude the nebula, while its fainter northeastern extension appears to lurk dimly behind it.

You'll find this little wonder about 2½° west of 4.5-magnitude Alpha (α) Sagittae. Through a 5-inch refractor at 100x, it's a mere hint of a round glow. Telescopes of

Sharpless 2–82 is a small, dim, challenging emission nebula in Sagitta. It appears like a miniature version of the Trifid Nebula in Sagittarius or the Cocoon Nebula in Cygnus. BOB FERA

The Cat's Paw Nebula (NGC 6334) in Scorpius is one of the most complex regions of emission nebulosity in the sky.
THOMAS V. DAVIS

12-inch aperture and greater will show both clouds as mottled textures of rippling light with powers of 150x or more.

IC 5068. You can find this sizable (30') emission nebula about 1° south of the Pelican Nebula in Cygnus. I call it the Black Waterfall because in images, multiple rivulets of dark matter cascade across its face like feathery water. It's an unusual sight, making one wonder about the chaos responsible for causing such visual delight.

IC 5068 is but a ridge of gaseous emission with dark clouds of cool gas invading its borders. It's all part of a single large H II region 1,800 light-years distant that includes the North America and Pelican nebulae. A dark absorption cloud (LDN 935) sweeps through this entire area like a Death Eater from the Harry Potter series, sucking light from distant stars and rendering them invisible.

Through a 5-inch at 22x, IC 5068 is a pale wash of rectangular light sweeping past a 7th-magnitude central illuminating star. Through an 18-inch at 100x, it appears as three irregular parallel strips of pale light stretching roughly east-west and separated by dark nebulosity.

NGC 6334. Popularly known as the Cat's Paw Nebula, NGC 6334 is one visual definition of weird: a bubbling mix of nebulous porridge that just may be one of the most productive star-forming regions in the Milky Way. Astronomers believe this roiling complex, some 5,500 light-years away in the Scorpius Milky Way, is undergoing a tremendous episode of starburst in its central region; tens of thousands of newborn stars may have already "burst" onto the scene along a central radial filament in what astronomers are calling an interstellar "baby boom." The Cat's Paw is visible in 4-inch and larger telescopes and shares the field with the dark nebula Barnard 257. NGC 6334 is a simple sight — essentially three fragmented patches of dim light forming a triangle of uniform glows. The brightest patch surrounds a roughly 9th-magnitude star.

Naked-eye nebula

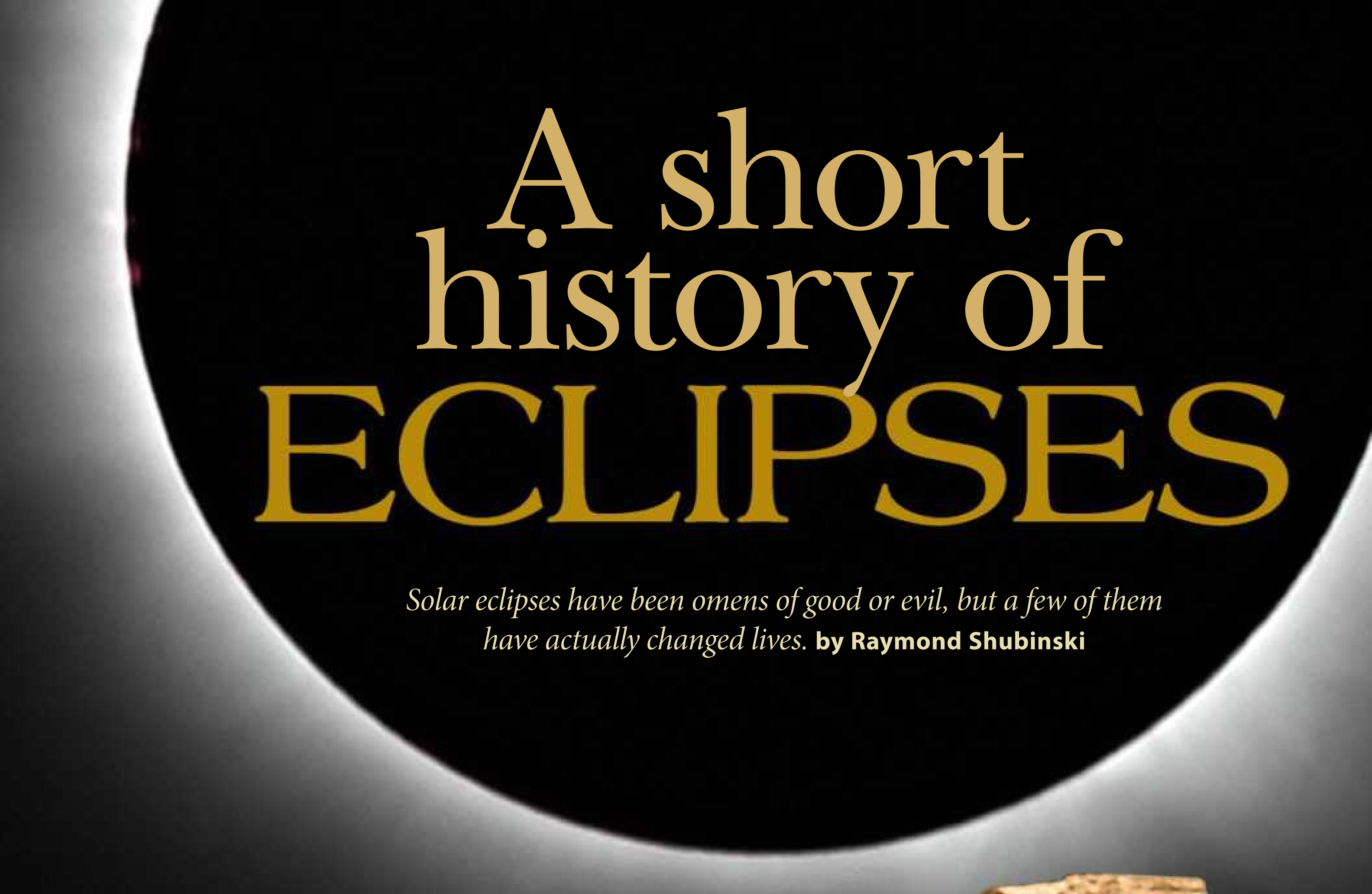
IC 1396. This is one of the largest emission nebulae north of the celestial equator. It's a vast shell-shaped star-forming region (3° wide) nearly 3,000 light-years away in southern Cepheus, just 1½° south-southwest of the 4th-magnitude orange gem Mu (μ) Cephei, also known as Herschel's Garnet Star. The glow encompasses the sprawling open star cluster Trumpler 37, which lies in the core of the Cepheus OB2 association.

Here we have a massive Rosette-type nebula, complete with a central hollow and numerous splotches of dark nebulae littered across its entire face, looking like Indonesian shadow puppets tossed asunder. One of these bleak features is a dark and dense globule on the nebula's western edge known as the Elephant's Trunk. It marks one site of active star formation where radiation and winds from the nebula's hot O-type central star are compressing parts of the cloud and triggering star formation.

Under dark skies, IC 1396 can be seen with the naked eye and somewhat more easily spotted in 7x50 binoculars. Through a 4-inch rich-field telescope, it is a definite telescopic glow, especially if you sweep the scope across the nebula's vast expanse while using averted vision. Observers using larger telescopes have often likened it to a large and very faint Rosette Nebula. Several of its dark nebulae can also be spied through small telescopes under dark skies.

Looking for emission nebulae is like passing through time to see visual traces of uninhibited creation. It is akin to seeing a Monet or Picasso exposed, yet unfinished. Yes, all of this is left to the workings of a visual observer's imagination, but with the remarkable imaging produced by today's amateurs, not to mention by orbiting spacecraft, we have much food for thought. Enjoy.

Stephen James O'Meara *is a longtime* Astronomy *columnist and author of numerous books on astronomical observing.*



A short history of ECLIPSES

Solar eclipses have been omens of good or evil, but a few of them have actually changed lives. **by Raymond Shubinski**

In nature, no event is as dramatic and awe-inspiring as a total solar eclipse. For most of human history these events were mysterious, terrifying, and unpredictable. Some went unrecorded, while others rank as historic.

So, what makes a total solar eclipse historic? It may be the way it affected large numbers of people, or how it led to a scientific discovery, or, perhaps, the way such an event impacted the life of just one individual.

Raymond Shubinski *is a contributing editor of* Astronomy *who observes from sites close to his home in Las Vegas.*

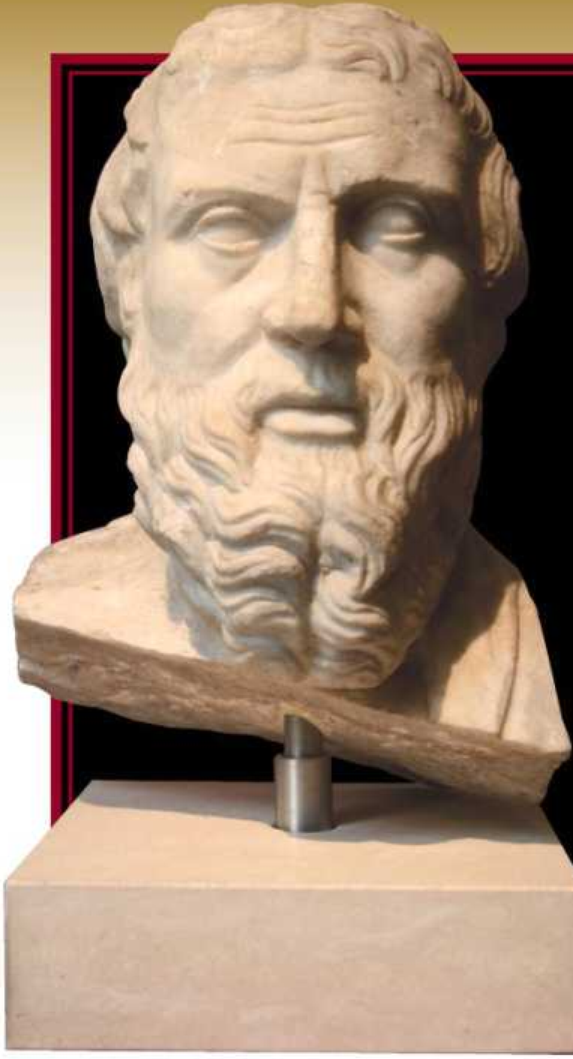
Ancient records

A tablet of the Epic of Gilgamesh

HISTORIANS HAVE RECORDS of eclipses from all over the world. One such place, the ancient city of Nineveh, stood on the east bank of the Tigris River in what is now northern Iraq. Rediscovered in the early 19th century, Nineveh, which now lies in ruins, was the greatest source of cuneiform tablets in the ancient Middle East. These tablets, covered in wedge-shaped characters, describe property listings, names of kings, the Epic of Gilgamesh, and accounts of eclipses. Astronomers have joined forces with archaeologists to use the information contained in thousands of hard-baked clay tablets to help pinpoint historic events.

The Chinese also kept detailed records of solar and lunar eclipses. One such document tells the stories of court astrologers Xi (or Hi) and He (or Ho), who lost their heads for not predicting a solar eclipse in 2100 B.C.

ECLIPSE: MIKE REYNOLDS. TABLET: OSAMA SHUKIR MUHAMMED AMIN FRCP (GLASG)/WIKIMEDIA COMMONS



In the midst of war

HERODOTUS WAS A FIFTH-CENTURY B.C. Greek historian who, among other accomplishments, visited all Seven Wonders of the World. He also collected stories everywhere he traveled. One such story recounted how a total solar eclipse stopped a war and brought about a marriage.

About a century before Herodotus lived, the Lydians and the Medes were fighting a border war for more than five years. On May 28, 585 B.C., the two nations battled near the Halys River, in what is now central Turkey. The day was hot and clear. As the battle raged, the sky began to darken. Soon, the sound of clashing solders slowed and then stopped. Everyone looked skyward to see the Sun blotted from the sky.

Herodotus tells us this was interpreted as an omen to end the war. To seal the alliance between these two groups, Aryenes, daughter of the king of Lydia, was married to the son of the king of the Medes. Herodotus also relates that the Greek philosopher Thales of Miletus had predicted this very eclipse. If he did, the news apparently never reached these two warring armies.

← **Herodotus**

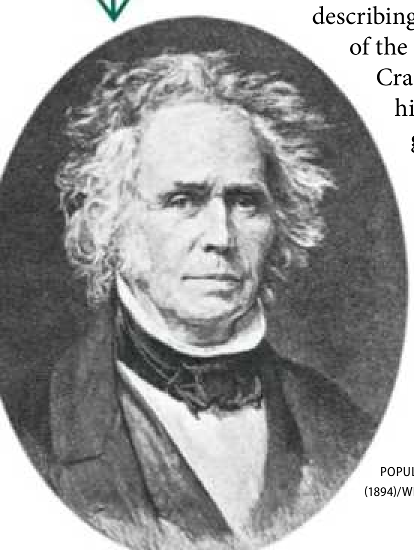
LIVIOANDRONICO2013/WIKIMEDIA COMMONS

Beantown darkens

CALCULATING AN ECLIPSE was once a fool's errand, but as time went on, astronomers were able to predict when the Sun and Moon would be in just the right place. By the 19th century, eclipse predictions were commonplace. In 1806, what became known as Tecumseh's Eclipse swept toward the city of Boston. The 4-minute, 50-second totality had been predicted well in advance.

In May of that year, Bostonian Andrew Newell had published a pamphlet titled "Darkness at Noon," describing the anticipated June 16 eclipse. As talk of the eclipse spread, 16-year-old William Cranch Bond, an apprentice clockmaker to his father, found a rooftop perch that gave him a panoramic view of both the harbor and the town. Experiencing this eclipse changed Bond forever. He became an amateur astronomer and went on to become the first director of Harvard College Observatory. He went on to profoundly affect the direction of American astronomy — thanks to this eclipse.

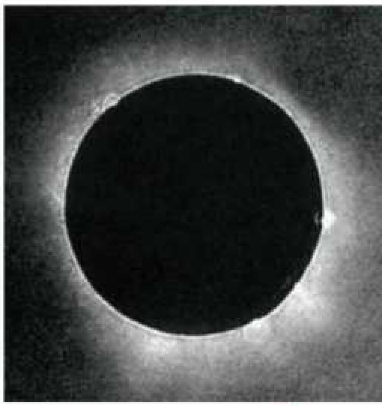
William Cranch Bond ↓



POPULAR SCIENCE MONTHLY VOLUME 47 (1894)/WIKIMEDIA COMMONS

Picture perfect

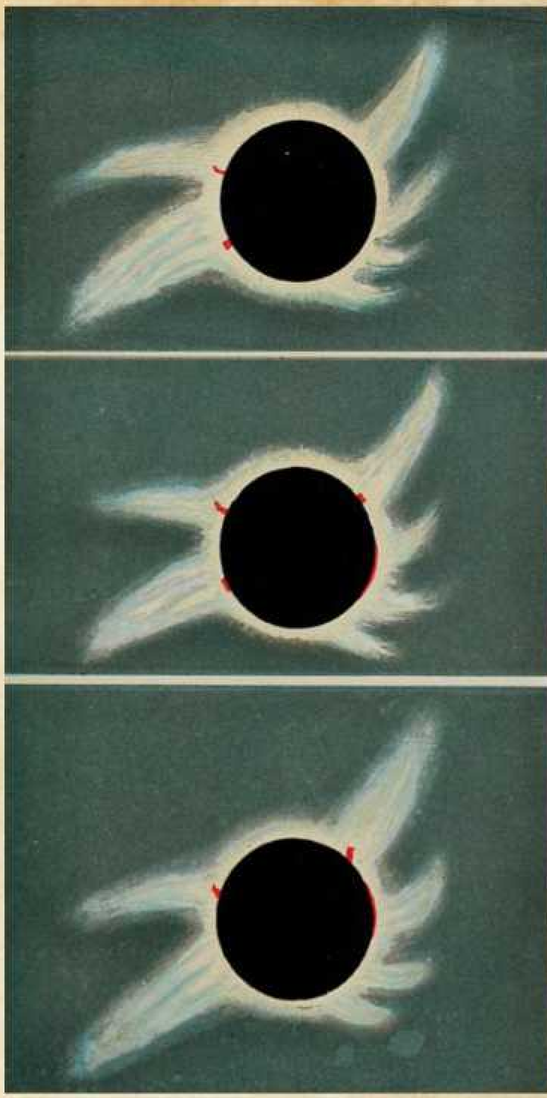
THE SUN WAS FIRST PHOTOGRAPHED in 1845 by Hippolyte Fizeau and Léon Foucault. It was the total eclipse of July 28, 1851, however, that gave us the first useful photograph of the Sun's outer atmosphere.



↑ **The first usable eclipse image**

The path of totality cut across northern Europe, and the Royal Prussian Observatory in Königsberg lay in the zone of darkness. Waiting at the observatory's telescope was a local photographer named Johann Berkowski with his daguerreotype camera equipment. Berkowski faced a common problem among early photographers: contrast. Contrasting between areas of light and dark in eclipse photos was a difficult undertaking in early photography.

Rather than film or glass, a daguerreotype is a silver-plated sheet of copper that has been exposed to fumes of mercury. The plates require long exposures to record images. Berkowski managed to capture the corona in just 84 seconds, marking a monumental first in our studies of the Sun.



MINISTÈRE DE L'INSTRUCTION PUBLIQUE/INTERNET ARCHIVE BOOK IMAGES

Finding fingerprints

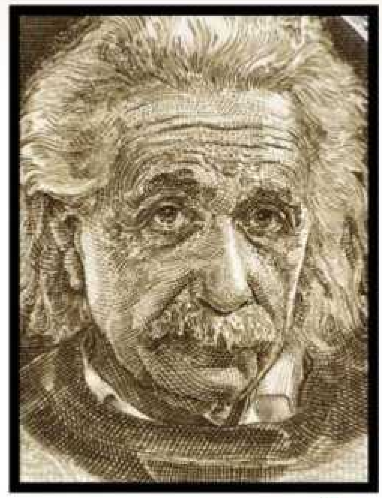
The 1868 eclipse

IN 1868, A TRULY ENLIGHTENING discovery occurred during a total solar eclipse observed by French astronomer Jules Janssen. A few years earlier in Germany, Gustav Kirchhoff and Robert Bunsen had been studying the spectra of various elements heated to incandescence. Their work in identifying the chemical "fingerprints" of elements held promise for astronomers observing distant objects outside of any laboratory. Janssen, who became one of many researchers experimenting with spectroscopy, was working at an observatory in Guntur, India, on August 18, 1868, when a total eclipse gave him the chance to use a spectroscope to observe the Sun's chromosphere. A bright yellow line initially identified as sodium instead became the first recorded discovery of the element helium, a noble gas then unknown on Earth.

JOHANN BERKOWSKI

Einstein's proof

F. W. DYSON, A. S. EDDINGTON, AND C. DAVIDSON



© GEORGIOS I DREAMSTIME.COM

The eclipse of 1919 and Albert Einstein

ONE OF THE MOST IMPORTANT ECLIPSES in history happened in 1919. This particular eclipse cut a path across South America and the Atlantic Ocean, and landed on the west coast of Africa. Waiting on the island of Principe, in the Gulf of Guinea off the west coast of Africa, was a team of astronomers armed with telescopes and cameras and led by English physicist Sir Arthur Eddington.

Amid World War I, Albert Einstein published his groundbreaking paper on general relativity. When the theory was presented in 1915, the press claimed that only three people in the world could understand this new and seemingly outlandish idea. "Only three" may have been an exaggeration, but Eddington immediately realized the theory's importance.

One prediction made by the theory of general relativity was the bending of light in a strong gravitational field, called gravitational lensing. In 1917, the astronomer royal of England, Sir Frank Watson, realized that a total solar eclipse would set up the perfect experiment to test relativity. The upcoming eclipse of May 29, 1919, was the best candidate — if only the war would end in time.

Luckily, the war ended in November 1918. During totality of the eclipse, the Sun would be in the constellation Taurus, near the stars of the famous Hyades cluster. So in February 1919, Eddington took photographs of the Hyades and made exact measurements of each star's position. And in May, Eddington camped on Principe.

The day was clear. During the eclipse, astronomers worked frantically to photograph the stars nearest to the Sun. With his valuable exposures in hand, Eddington sailed home to England and measured the star images on the glass plates. Precise measurements of these stars, especially Kappa (κ) Tauri, showed a defiant deflection from its true position, proving one component of relativity — gravitational lensing — to be true. Overnight, Einstein became a world celebrity, and relativity became a fact of life in the 20th century.

Our next eclipse

IN THE MODERN ERA, astronomers have studied the incredibly high temperature of the corona, ionized gas, and magnetic fields around the Sun during solar eclipses. And they're planning even grander experiments for the eclipse that will cross the U.S. in August. But in addition to returning data, you can bet this event also will send its observers home with stories of amazement and wonder.

With today's imaging software, amateur astronomers can stack (or combine) exposures to create a final image. This image is a stack of 92 30-second exposures with the chapel of Netley Hospital near Southampton, England, in the foreground. (Canon 6D, Canon 16–35mm USM MK.II Super Wide Angle Lens set at 16mm and f/4.5, ISO 400) JOHN GENT

Astroimaging

without a telescope

Do you have a camera? A tripod? Then head outdoors, because you're ready to image!

by Mike Reynolds

MANY PEOPLE LOOK WITH AWE at the spectacular images taken with the Hubble Space Telescope. But today's amateur astronomers are nearly as good, having developed imaging techniques and using equipment only dreamed about 20 years ago. Today's equipment for what's commonly called "star trail photography" (although it encompasses much more) is much like it was when I took my first star trail: a camera, a cable release, and a tripod. And, oh yes, a little creativity. More on that later.

Camera selection

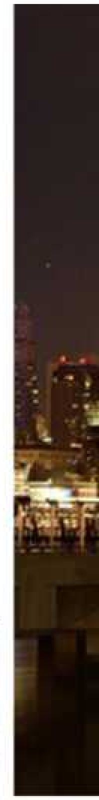
The digital single lens reflex camera (DSLR) has replaced the film cameras I used in my youth. I recommend this type of camera mainly because it allows you to change the lens. If you do not own a DSLR, you can purchase a good-quality entry-level one for under $1,000. Sometimes you can catch deals on used or refurbished models that will cost you much less. These cameras might not have all the features you might desire, but they will get you started. Do some research to determine which camera brand and manufacturer you want to build your photographic platform.

During your search, you will discover that the camera body is only part of the investment. High-quality DSLR lenses can cost as much or more than a medium-priced DSLR. Unfortunately, the major brands and manufacturers use different lens mounts. When I started the switch from film to digital some 16 years ago, I decided to go with Canon. I liked the company's camera body innovations and the design and quality of its lenses.

For star trail photography, you don't need a telescope. A regular lens with a focal length around 50mm will suffice. I use a couple of Canon zoom lenses, and I choose between them depending on the length of the exposure and the subject. If I want to capture a wide field, I use a 16–35mm zoom. When I'm shooting actual star trails, the short focal length and wide angle provide wonderful images of curved star arcs

Astroimaging can be as simple as placing a camera on a tripod and taking a single exposure. This one captures the sky's brightest star, Sirius (Alpha [α] Canis Majoris) with a tripod in the foreground. (Canon 60Da, 35mm lens at f/2.8, ISO 3200, 13-second exposure) MIGUEL CLARO

When you use a camera/tripod setup but don't trail the images, you can capture recognizable constellations. That's what this photographer did to catch Orion above a tree near Zahedan, Iran. (Canon 5D Mark II, Samyang 24mm f/1.4 lens at f/2.8, ISO 4000, 20-second exposure) AMIRREZA KAMKAR



Lots of amateur astronomers enjoy imaging the Milky Way with their camera/tripod setup. (Canon 6D, Tamron 24–70mm lens at f/5, three 3-minute exposures at ISO 5000 for the sky stacked with three 100-second exposures at ISO 3200 for the landscape, taken from Hyalite Canyon near Bozeman, Montana) CARLOS EDUARDO FAIRBAIRN

as they rotate around Polaris. My other lens is a 24–105mm zoom. With it, the longest focal length I generally use for star trails is around 80mm. A longer focal length creates too many issues with star trails for my liking. When I photograph other subjects, however, I generally take many exposures encompassing a wide range of focal lengths. I pick the one I like best later.

Your tripod

Just like when you use a telescope, you will need a solid base to prevent any shaking during imaging. I use a standard metal tripod with extendable legs and a ball (swivel) head. I also often use a carbon-fiber tripod, which is lighter, yet still provides the stability my shots require. You can use either a pan-tilt head or a ball head, your preference.

Here's an important tip that can increase your tripod's stability: If I am in doubt about it, especially when I travel with a lighter tripod, I add a weight in the tripod's center. I've found that an empty gallon milk jug filled with water, sand, or gravel works great, but I have friends who use a 10-pound weight from a barbell set, a small anvil, a large sack of pennies, and other solutions.

Make sure you can securely lock the tripod's extendable legs — not only the leg extensions, but also any spread adjustment the legs will allow. Sometimes a taller tripod is not advantageous; there is more chance of introducing vibrations in the system. Yet you want to be comfortable as you frame and take your exposures, so set it at the height that works best for you, or don't extend it and image while sitting.

Exposure times

Finally, you need the ability to control the length of your exposure. Technically, the device you want is an intervalometer. Canon refers to this as its Timer/Remote Controller, TC-80N3. This is compatible with all Canon DSLRs except the Rebel series.

Regardless of the camera brand and model you use, the intervalometer allows you to set the length of each exposure when your camera is set to "Bulb" on some DSLRs or "Manual" on others. With most intervalometers you also can set the amount of time before the first exposure begins, the time between exposures, and

This astrophoto proves you can capture celestial objects (look to the left side) even when they compete with the colorful lights of the Manhattan skyline. Venus is the brightest object, with Jupiter to its left and Mars to its bottom left. (Nikon D7000, Nikkor 18–200mm lens set at 35mm and f/9, ISO 400, 10-second exposure, taken October 26, 2015, from Hoboken, New Jersey) ALEXANDER KRIVENYSHEV

the number of exposures. Also note that most intervalometers, though well constructed, connect via a cable, and that cable can be damaged. I used my first TC-80N3 so much that the cable's connection to the unit itself became frayed. Now that's a lot of imaging!

Other types of intervalometers are available, including wireless devices. Just make certain the one you purchase is compatible with your camera, and that it lets you easily take long exposures. You do not want to be sitting or standing there, holding some remote button for 30 minutes!

Other considerations

Probably the most important point after equipment selection is that you will need to focus manually; do not engage the lens' autofocus feature. If you do, the lens will search for infinity and never find it. To manually focus, look for the infinity mark (∞) on your lens. On Canon models, look for what looks like an L before infinity. It is crucial that you check focus. Take test shots and get it right. Once you figure out where to set your lens for sharp stars, you can mark it to signify infinity. I've added a small but nice-looking label to the lens showing exactly where infinity is. I still recheck the focus every time I image, but at least I have a starting point.

If your lens incorporates an image stabilizer (IS), turn it off. IS is a terrific feature for many applications, but when taking star trails or long exposures, I've found it drains your battery and provides little benefit.

You have the option to determine your camera's level of sensitivity to the available light through the ISO (also known as ASA). These designations go back to the days of film and established standards. You might think that the higher the ISO, the better, especially with stars as faint objects. Not so fast. Yes, a higher ISO means greater light sensitivity. But along with it comes additional electronic noise, seen on your exposures as small specks that are not stars.

You must find a balance between ISO settings and noise. My Canon EOS 80D has a feature called "Native ISO," resulting in less noise when compared with other similar ISO settings. Generally I image at around 320 ISO. I might push it to 640 or even 1280. Experiment with your camera by taking exposures using varying ISO settings.

You can purchase modified DSLRs that include a camera cooler. It lowers the camera sensor's temperature, thus reducing the noise. However, these modified cameras are more expensive. Think of this as something you might want to look into if you step up to taking images through a telescope. Also, keep in mind that usually you can't use such modified DSLRs for anything but astroimaging.

Two other considerations of star trail imaging are the camera's lens aperture and shutter speed. As you set the aperture, you change the lens opening, which allows more or less light onto the sensor, much like the pupil in your eye. The smaller the f/number, like f/1.4, the larger the aperture and the more light that strikes the sensor.

So why would you even want a smaller aperture? It has to do with having everything in your photo in focus, called depth of field. This is important for regular

Here's a tip to increase a tripod's stability: I add a weight in the tripod's center. An empty gallon milk jug filled with water, sand, or gravel works great.

Set up your camera at a dark site in late winter and you may capture the zodiacal light. This photograph shows that faint region of solar system dust over the Chiricahua Mountains in Arizona. (Nikon D3, 16mm lens at f/2.8, ISO 1250, 60-second exposure) STEVE CULLEN

photography, but not star trails, so open the aperture as large as possible.

Some people thinking of imaging star trails on a regular basis will purchase a fast lens, like the Canon 50mm f/1.4. Even better would be a 50 mm f/1.2 lens. Unfortunately, the difference in retail pricing between these two lenses is about $1,000. And while you can load your camera case with fixed-aperture lenses, many photographers (me included) choose to purchase one or two high-quality zoom lenses instead.

Regarding shutter speed, we are taking long exposures — seconds to minutes. You have a couple of choices: a single long exposure or a number of short exposures that you later stack using image-processing software. Each has advantages and disadvantages.

For the novice unfamiliar with software, start with single exposures. However, taking one long exposure can lead to issues, like unwanted exposure to light by something like a passing car, capturing an airplane's light trail, or even you bumping the camera or tripod.

If you're familiar with image-processing software, taking a series of shorter images and later stacking them as one image is an attractive option. This alternative lessens the seriousness of bad exposures. Because you haven't invested a great deal of time in any one of them, tossing out the bad ones becomes easier.

Be creative! For example, if I'm trying to photograph meteors, I prefer to place a terrestrial object such as a tree, some landscape, or even a man-made object in the foreground.

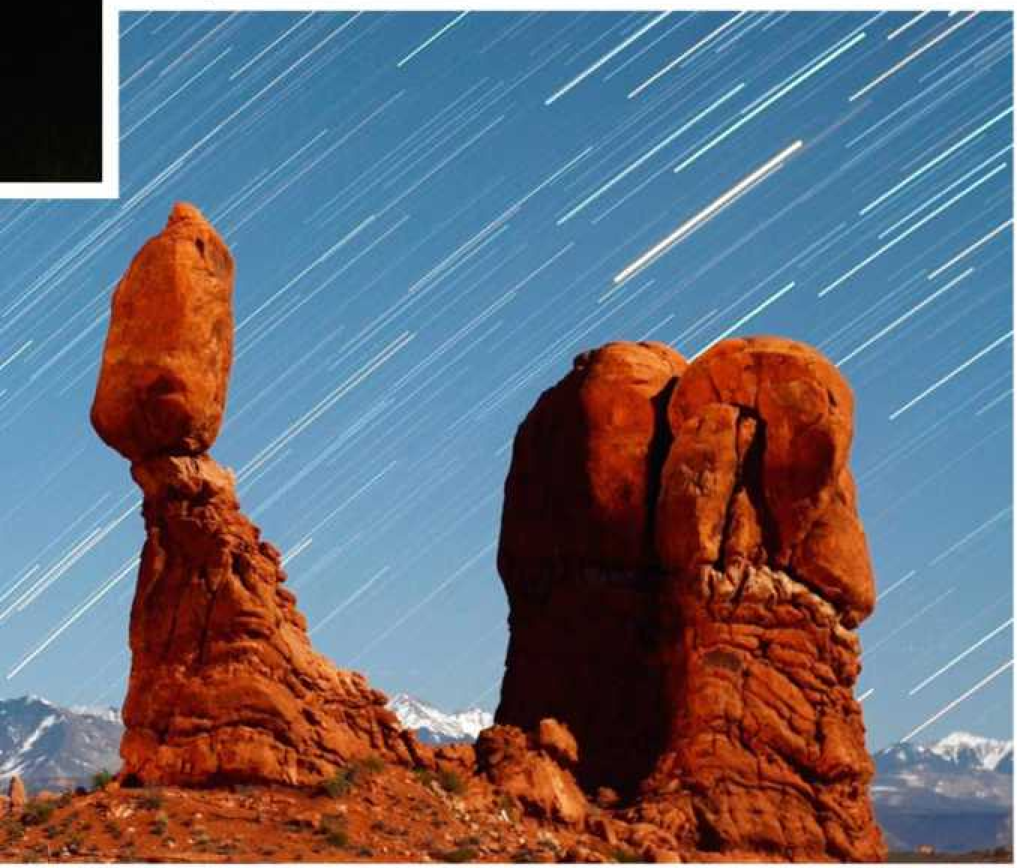
If you stack a series of exposures to create a star trail, you might end up with small gaps between each one. Let's say you take 30 three-minute exposures for a total of 90 minutes. You start the first exposure, stop it, and then take the next one. Here's where an intervalometer really comes in handy: You can set the length of time to be quite small between each exposure. Note that when you're doing this manually, even if it's only a few seconds between each star trail you take, you could end up with a gap, depending on the focal length of the lens. This becomes more

Not every star trail photograph has to center on Polaris. This one — a stack of 100 eight-second exposures taken from Arches National Park in Utah and featuring Balanced Rock — looks to the southeast. The brightest star trail (at right) is that of Antares (Alpha Scorpii). (Nikon D7000, 50mm lens at f/4, ISO 1600) FABRIZIO MELANDRI

problematic with the longer focal lengths, especially toward the top of the range I usually use, 80mm.

One attractive alternative is combining both: Take one short exposure, break for a

A bright Perseid meteor streaks above the city lights of Nanchuan, China, on August 11, 2013. (Canon 5D Mark II, Nikkor AF-S 14–24mm f/2.8G IF-ED lens set at 14mm and f/2.8, ISO 5000, 30-second exposure) JEFF DAI



couple of seconds, then a long exposure. Your final stacked photograph will show stars exposed for the shorter time as star-like. The trails, then, will be longer arcs.

The bottom line

Be creative! For example, if I'm trying to photograph meteors, I prefer to place a terrestrial object such as a tree, some landscape, or even a man-made object in the foreground. This makes for a more compelling result. When I image with a tree, I put it about 10 to 30 feet (3 to 9 meters) from my camera, depending on the size of the tree, of course. I have also used white and red flashlights to illuminate foreground objects during exposures. I don't use the light constantly; it's more like I'm brushing the object with the flashlight. The Moon setting behind you (opposite your target) can also light the foreground object. Just know bright moonlight can wash out your sky and provide too much additional lighting.

I have also imaged sections of sky with a telescope in the foreground. I don't light the scope; I just let it eclipse that part of the sky. And people work well here, too. They just need to be still while you image.

As you master star trail photography, look for other challenges. One of these could be mounting your camera on a small equatorial mount that compensates for Earth's rotation. You'll then essentially be creating your own star maps. Here, the techniques above, such as focusing, using the intervalometer, and setting a correct ISO, will play a big role in your success.

Star trails were my first trip down the path of astroimaging. From there I built my own cold camera, machined a device to hold film in a container with specific gases to increase its sensitivity, and experimented with all types of film emulsions. Yet in a relatively short period of time, those often-difficult techniques have become things of the past. With the tools and techniques now available, you can begin your journey by taking star trail shots that would have been considered works of art when I began imaging all those years ago. So pick up your camera, head outside, and start your journey.

Mike Reynolds *is professor of astronomy at Florida State College at Jacksonville and a contributing editor of* Astronomy.

This oil-on-canvas painting depicts the famous telescope-maker John Dollond, whose company began producing commercially available refractors in the 1750s. BENJAMIN WILSON/WIKIMEDIA COMMONS

Great telescopes of the past

The opticians of yesteryear combined science and art to pave the way for today's masterpieces.

by Mike Reynolds

Professional and amateur astronomers who lived 200 years ago did not have the variety of options to purchase a telescope that we enjoy today. It was far easier to obtain spyglasses than serious astronomical instruments. The few companies that existed, almost exclusively located in Europe, built fine (and correspondingly expensive) telescopes. Most of the instruments sold were refractors because at the time, lens crafters produced better products than mirror-makers.

Still, a few individuals — like Sir William Herschel in England — built and sold reflectors. Let's introduce you to a few of the best-known telescope-makers of the past. By getting to know them a bit, you'll have a better understanding of how today's telescopes evolved and why astronomers chose them to help us all understand the cosmos.

Mike Reynolds, *a contributing editor of* Astronomy, *is a professor of astronomy at Florida State College at Jacksonville.*

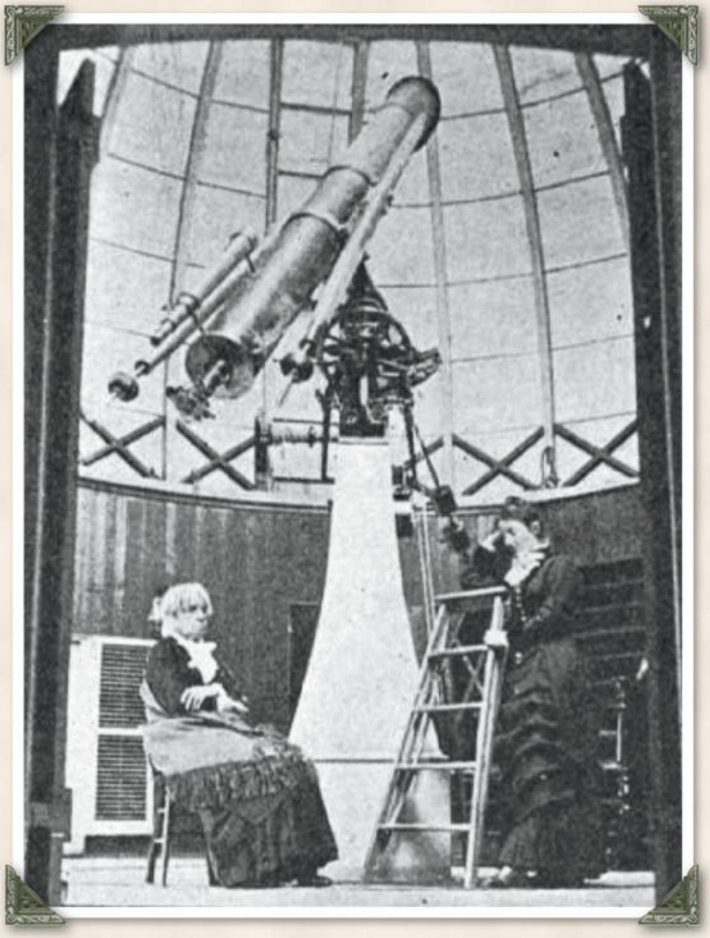
Glass warfare

Besides Herschel, the most famous English optician of the day was John Dollond. He determined specific glass types and combinations that improved the refractor, and he was awarded a patent for this work. The resulting "achromatic" refractor combined lenses made from crown and flint glass, which reduced the color fringing so apparent in earlier instruments.

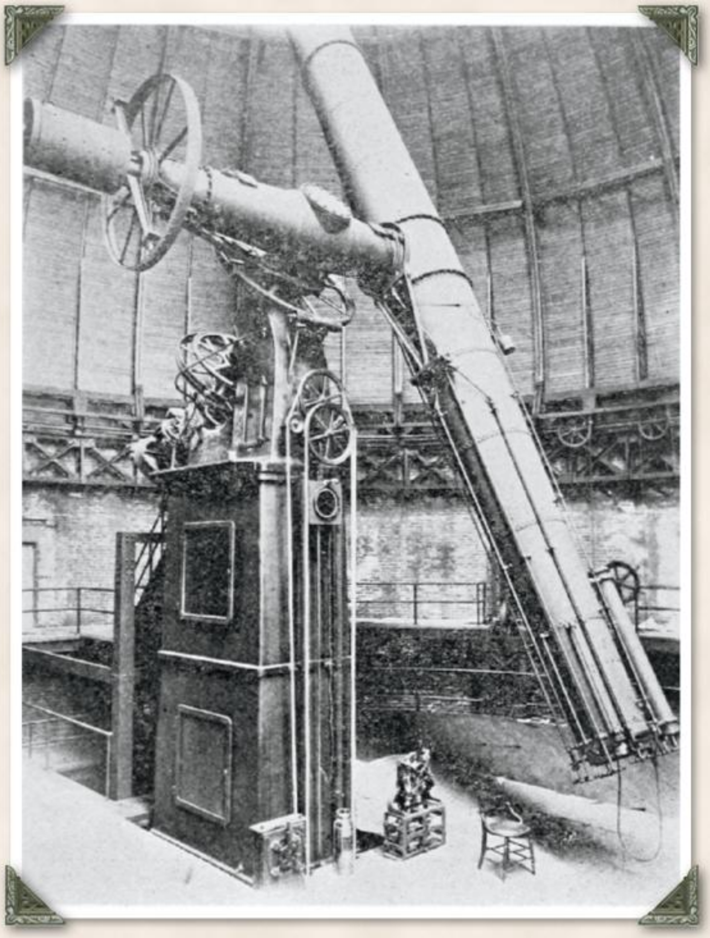
Dollond's company began commercial production of achromats in 1758. In 1763, his son, Peter, who took the reins of the company after his father's death, improved on the optical design by adding a third lens to the objective. The company innovatively marketed it as a "triple achromat," but, in fact, this was the first apochromatic lens. Such an optic makes color fringing virtually undetectable.

Under the terms of Dollond's patent, only his company could commercially make achromatic refractors. With the patent expiration in 1772, other companies came on the scene, producing achromatic refractors at more reasonable prices.

This 4-inch refracting telescope by John Dollond resides in the White Hall of the Vilnius University Library in Lithuania. Dollond made only the scope; another craftsman made the tripod. ALMA PATER; ANTIQUE PHOTO CORNERS © LOUOATES | DREAMSTIME.COM



The telescope-making firm of Henry Fitz made this 12-inch equatorially mounted instrument for Vassar College. Above, American astronomer Maria Mitchell sits while her associate holds the ladder that users often stood on when observing. *HEROES OF PROGRESS: STORIES OF SUCCESSFUL AMERICANS* (1921)



This image from the October 1912 issue of *Popular Science Monthly* shows the 30-inch Thaw Photographic Refractor, the main instrument at Allegheny Observatory in Pittsburgh. The 47-foot-long scope is still in use. WIKIMEDIA COMMONS

Scoping out the Colonies

Across the Atlantic, Henry Fitz became one of the first American commercial telescope-makers. He constructed a high-quality 6-inch refractor in 1845. With the money he earned giving public star parties, he started a telescope-making business. Fitz's firm sold refractors from 1848 into the 1860s, even a few after his death in 1863. Astronomers considered these instruments some of the best available. The lenses compared favorably with those being made in Europe at the time, which makes sense because Fitz learned his techniques there.

From 1840 to 1855, Fitz made 80 percent of all astronomical telescopes sold in the United States. His smaller refractors (those with lenses 4 inches in diameter or less) characteristically had beautiful wooden tubes and are today considered highly desirable and collectible.

But Fitz also made a number of then-large refractors — a total of 30 with lenses 6 to 16 inches in diameter. Some of his better-known ones include a 6⅜-inch for South Carolina College in Columbia in 1851; a 9¾-inch for West Point in 1856; and a 13-inch for the Allegheny Telescope Association in Pittsburgh in 1861.

That 13-inch refractor at the Allegheny Observatory has an interesting story. In 1872, someone stole the objective from the telescope, which was then the main instrument at the Allegheny Observatory. The thief then informed the facility that the lens was being held for ransom. Samuel Pierpont Langley, the facility's first director, was unsuccessful in negotiating the return of the objective.

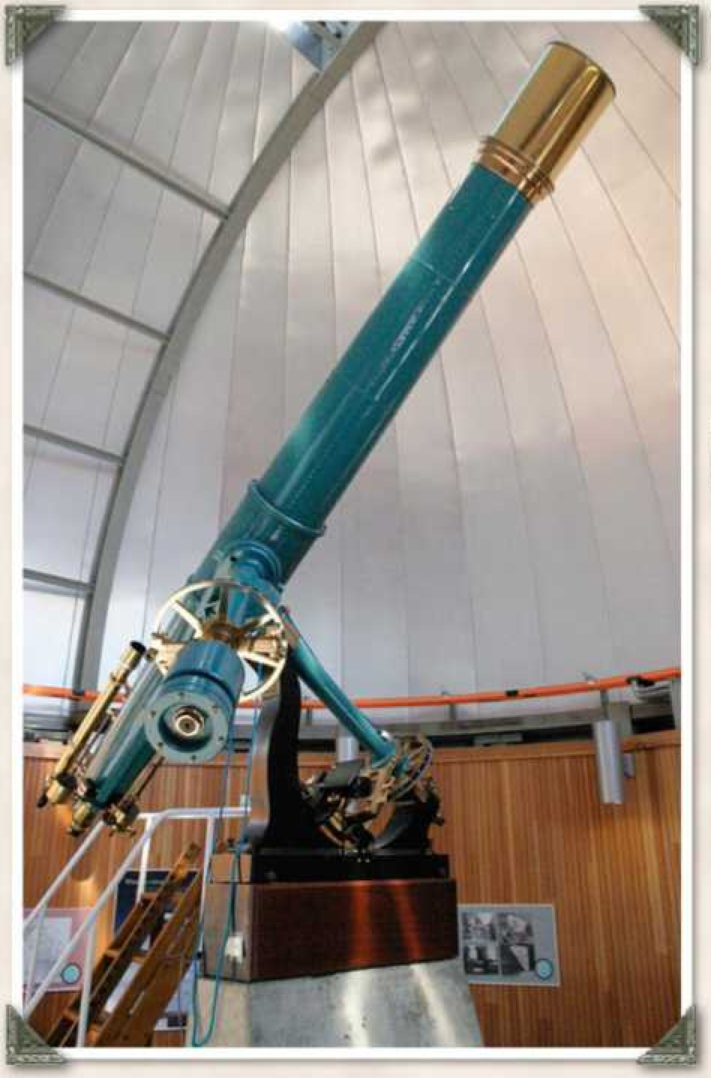
After a few months, it turned up in a hotel's garbage can in Beaver Falls, Pennsylvania, badly scratched. Langley turned to the firm of Alvan Clark & Sons to rework the lens because Fitz had died some nine years earlier. The reworked objective provided higher-quality images than the Fitz original, thus the lens-napping actually led to a better telescope.

Artists in optics

In 1846, a few years after Fitz established his firm, Alvan Clark established Alvan Clark & Sons in Cambridgeport, Massachusetts. As the company name implied, his two sons, George Bassett Clark and Alvan Graham Clark, joined him in the endeavor. By far, the Clarks rank as the most famous American telescope-makers. Often referred to as "artists in optics," the Clarks produced high-quality refractors in a variety of sizes sought by professionals and amateurs alike.

Not only were the optics excellent, the mount and optical tube assembly were outstanding, demonstrating some of the finest craftsmanship of the era. The Clarks were called upon numerous times to build larger telescopes. Five times the firm constructed the world's largest refractor. This culminated in the design and construction of what is still the largest refractor: the 40-inch at Yerkes Observatory in Williams Bay, Wisconsin.

Clark refractors of the era have many interesting stories and discoveries associated with them. Asaph Hall, an astronomer at the United States Naval Observatory, used the 26-inch Clark refractor to visually



Above: "Rachel" is a 20-inch refractor created by Warner & Swasey with optics by noted lens-maker John Brashear. This telescope, located at the Chabot Space & Science Center in Oakland, California, is the largest refractor in the western U.S. regularly open to the public. MIKE REYNOLDS

Left: "Leah" is an 8-inch refractor that also resides at the Chabot Space & Science Center. Alvan Clark & Sons built this instrument in 1883. MIKE REYNOLDS

discover the two moons of Mars in August 1877. Because Mars was so bright, Hall kept the Red Planet just outside the field of view, allowing him to first spot the outer moon Deimos and then the inner moon Phobos.

Another tale involves wealthy Bostonian Percival Lowell, whose interest in astronomy, and in particular Mars, led him to Flagstaff, Arizona, where he constructed an observatory in 1894. The 24-inch Clark refractor, still in use for public observing, was the main instrument Lowell and his staff used to study their primary target, Mars.

Lowell's focus was primarily on the martian "canals," of which he and others produced many sketches over the years. And when you visit Lowell Observatory, you will see not only a historic telescope, but also a reminder of Percival Lowell himself: His mausoleum stands only a short distance from the 24-inch refractor.

Another Clark refractor, this one a 20-inch on a mount built by German-born American inventor George N. Saegmuller, also had first light in 1894. Denver University's Chamberlain Observatory is still in operation, having undergone a major renovation in 2008. Members of the Denver Astronomical Society operate the scope for public outreach events.

The crowning achievement of Alvan Clark & Sons is the 40-inch at Yerkes Observatory. Yerkes was founded in 1897 by astronomer George Ellery Hale and financed by entrepreneur Charles Yerkes. Hale, at the start of his quest for larger and larger telescopes, established Yerkes as a part of the University of Chicago. Astronomers conducted significant research there over the years, and today the observatory is known for its formal and informal science education and outreach.

Clark 2.0

As the 20th century dawned, other telescope-makers started coming onto the scene, most notably John Brashear. Though he became interested in astronomy as a child while looking through a telescope at the Moon and Saturn, Brashear started his career as an accomplished machinist. He could not afford to purchase a telescope, so he made his own, thus starting him on the way to establishing the John A. Brashear Company.

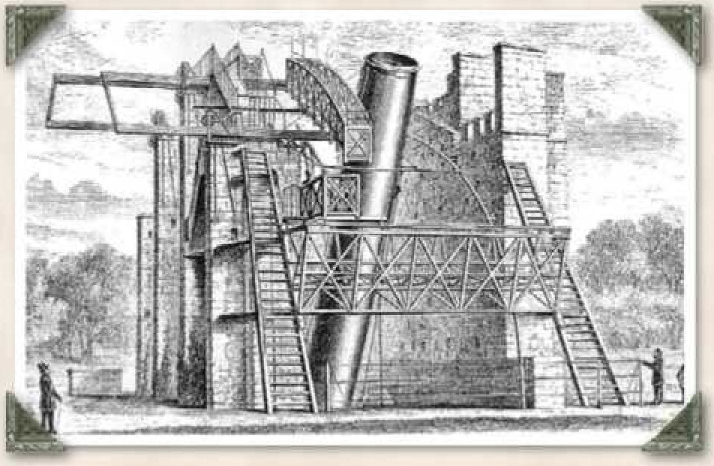
Beginning around 1880, Uncle John, as he was called, became prominent in the manufacture of not only telescopes, but also other instruments. His experimentation also led to the development of a new coating method for depositing silver on glass, the prevailing technique until the implementation of the vacuum-coating process in 1932.

Among Brashear's other scopes is the 30-inch Thaw refractor at the Allegheny Observatory, which was completed around 1914, is still in use. The 20-inch Brashear refractor on a Warner & Swasey mount, originally installed in 1914, is the centerpiece at the Chabot Space & Science Center in Oakland, California. "Rachel," as the telescope is called, was refurbished in 2000 and moved to a better location.

Other great refractors dominated during this era, and each improved the technology. They included the Royal Greenwich Observatory's 28-inch Grubb refractor, which began operating in 1893; 32.7-inch and 24.4-inch refractors at the Paris Observatory (1891); and 31.5-inch and 19.7-inch refractors at the Astrophysical Observatory in Potsdam, Germany (1899).

Mirror, mirror

During the era of the great refractors, designers and engineers were making slow but steady advances in techniques to build big reflecting telescopes. The main issue was the primary mirrors, which were made



Left: The "Leviathan of Parsonstown," a 72-inch reflector, was constructed in 1845 by William Parsons, third Earl of Rosse. Right: One of the original speculum (copper and tin) mirrors is on display in the Science Museum in London. WIKIMEDIA COMMONS

from speculum metal, a mixture of copper and tin with an abysmal reflectivity around 68 percent. Speculum mirrors also needed to be repolished and refigured every few months because they tarnished in the open air, further reducing reflectivity.

Perhaps the two most famous of the great speculum-mirror reflectors were those of Sir William Herschel and William Parsons. Herschel's "40-foot telescope," a 49.5-inch reflector, saw first light in 1787. Truly a giant of the time, it let Herschel make numerous previously impossible observations. Records show it was difficult to use, however, and the weather rarely permitted good seeing. It saw last light in 1815.

The "Leviathan of Parsonstown" in Parsonstown, Ireland, was a reflector with a 72-inch speculum mirror telescope made by William Parsons, third Earl of Rosse. It saw first light in 1845 and was the largest telescope in the world until the Mount Wilson 100-inch Hooker Telescope opened in 1917. In the 1870s, J. L. E. Dreyer observed through the telescope to research objects in his *New General Catalogue of Nebulae and Clusters of Stars*. Workers began to dismantle the Leviathan in 1908. In 1914, they moved one of the two main mirrors Parsons cast to the Science Museum in London.

Advances in the material used for the primary mirrors in reflectors led Hale (who had seen the 40-inch Yerkes Telescope through to its completion) to again step to the forefront in large-telescope construction. Large speculum mirrors had proven to be too challenging to maintain, and the reflectivity was poor. Saint-Gobain, a French glass company, cast a 60-inch mirror blank, which William Hale, George's father, purchased for him. After funding from the Carnegie Institution was secured, construction began in earnest on the new telescope in 1904.

Hale selected Mount Wilson, a 5,710-foot-high (1,740 meters) peak in the San Gabriel Mountains, northeast of Los Angeles. The site remains a high-quality one today because of its steady airflow. The 60-inch, with its silvered surface, saw first light in 1908. The Hale Telescope (with an aluminum coating on the mirror) is still in use today for public outreach.

Yet Hale was already thinking ahead to an even larger telescope. He persuaded elevator magnate John Hooker to pay for the mirror and Andrew Carnegie to fund the observatory and telescope. Saint-Gobain was again selected, this time to provide a 100-inch mirror blank, which turned out to be no easy task.

The Hooker 100-inch went into operation in late 1917, and it was the primary telescope for a number of important advances, such as Edwin Hubble's recognition in 1923 that Andromeda was a galaxy and not a nebula, and Hubble and Milton Humason's 1929 discovery that the universe is expanding and measurement of the rate of that expansion. Like the Hale 60-inch, the Hooker 100-inch is now dedicated to public use.

Hale was still thinking ahead, however, and he would again lead the effort to build another record-shattering telescope, the fourth of his career. Hale wrote an article for the April 1928 issue of *Harper's Magazine* entitled "The Possibilities of Large Telescopes." This was the jump-start for the 200-inch Hale reflector on Palomar Mountain in San Diego County, California.

Through the California Institute of Technology and with funding from the Rockefeller Foundation, work began in 1928 on the mirror, telescope, and observatory. The low-expansion Pyrex mirror blank, made by Corning Glass Works, was far superior to the plate glass one used for the 100-inch telescope.

Unfortunately, Hale died in 1938, prior to the completion of the 200-inch. Yet work continued, though slowed by several challenges and in particular the war efforts of World War II. Finally, on January 26, 1949, Hubble was given the honor of taking the first photograph.

Many large reflectors followed, the first being the Soviet Union's Large Altazimuth Telescope in 1975. And larger, more-complex telescopes dot the astronomical landscape today, including the behemoth 409-inch Gran Telescopio Canarias and, of course, space-based telescopes like Hubble and — hopefully in 2018 — the James Webb Space Telescope.

As telescopes become bigger and more sophisticated, we owe a tip of the hat to pioneers like Henry Fitz, Alvan Clark, John Brashear, and George Ellery Hale. They, and others like them, opened up more of the universe for us to explore.

The 24-inch Clark refractor, still in use for public observing, was the main instrument Lowell and his staff used to study their primary target, Mars.

Stellarvue's Optimus eyepieces tested

Whether you're observing planets or galaxies, this set will make your current equipment setup better. **by Tony Hallas**

Stellarvue released its Optimus eyepiece line with four initial focal lengths. Expect at least a 13mm version this year. STELLARVUE

Vic Maris, the founder of Stellarvue, wasn't happy. Amateur astronomers had a lot of eyepiece choices, but he was convinced that he could do better. So, he set a goal to create eyepieces with apparent fields of view of 100° to 110° that would be ergonomic, lightweight, and offer high performance — all at a reasonable cost.

The current Stellarvue lineup features 9mm and 20mm models with 100° apparent fields of view and 3.6mm and 4.7mm versions that sport 110° fields. The company plans to introduce a 13mm 100° version in 2017. All eyepieces come with 1¼"-to-2" adapters except the 20mm, which only fits a 2" focuser.

A general look

To achieve his goal, Maris spent several years working with the company he chose to manufacture them. And as you read on, you'll see that the end product justified the time and effort spent.

All the eyepieces feature extreme broadband coatings on each glass surface to enhance light throughput and image contrast; special edge-blackening to minimize reflections and increase contrast; tight tolerances on polishing the glass to enhance performance; precision machining to the eyepiece's body to make it easy to handle at night; high-grade rubber for the grips and eye cups to enhance longevity; sealed field and eye lenses to keep moisture out under normal use; and gold badges to designate their focal lengths.

Add all these up, and you get sharp contrasty views right to the edge of the field. Maris designed the eyepieces primarily for refractors, but they also work well with Newtonian reflectors if you add a coma corrector. That additional optic eliminates the defect called coma, which makes stars near the edge of the field of view resemble comets. Using such a device with a fast (short focal ratio) reflector will give pinpoint stars to the edge of the field of view.

Tech timeout

Beyond how well these eyepieces work, I also wanted to know how they work. So, I contacted Roger Ceragioli, an optician and lens designer at the Steward Observatory Mirror Lab, which is part of the University of Arizona. Here's what he told me.

Super wide eyepieces typically have three functional lens groups. The field group (the one at the front of the eyepiece) is usually a multi-element Barlow lens, sometimes called a Smyth lens. This diverges the incoming light rays and counteracts errors inevitably introduced later in the eyepiece.

Next comes a thick meniscus lens, positioned just before the eyepiece's internal field stop. Its purpose is to broaden and flatten the focal surface (field of view).

The third group (at the eye end) comes after the field stop and strongly converges the light cones into parallel bundles. They then move into the exit pupil (where the eyeball goes) at a steep angle to create the visual wide-angle effect.

Under the sky

Comparing eyepieces is tricky business because many factors come into play. Seeing, transparency, and the quality of the telescope all can affect how a person judges their performance. Therefore, I always test eyepieces over several nights with rested eyes to make sure I'm using a level playing field.

During the last Stellarvue Star Party at Likely Place Golf and RV Resort in California, we put a 20mm 100° Optimus eyepiece into my 24-inch f/3.85 Newtonian reflector and added a coma corrector. The popular consensus: "best views ever" of everything we looked at. The wide field of view, combined with pinpoint sharpness, great light throughput, and high contrast, made the Optimus a winner.

But what exactly did that consensus mean? In one instance, we compared the 20mm Optimus to a famous-brand 20mm eyepiece of slightly different (but still wide field) design. Despite the fact that the Optimus had larger true and apparent fields of view, brightness and contrast of objects were as good or better through it compared with the other eyepiece. Furthermore, with a coma corrector at exactly the right setting, stars were pinpoints all the way to the edge. This enhanced the feeling that we were looking through a porthole on a spaceship.

To give you an idea of what some famous, and often viewed, objects look like through this eyepiece, I made some notes. Some of these are my impressions, and others come from various seasoned observers.

The author put Stellarvue's eyepieces to the test using his 24-inch Newtonian reflector and inviting friends to observe through them and comment. TONY HALLAS

PRODUCT INFORMATION

Stellarvue Optimus eyepieces
Focal lengths: 3.6mm, 4.7mm, 9mm, and 20mm
Sizes: 2" (20mm); all others 1¼" (with 2" adapters)
Apparent fields of view: 100° (9mm and 20mm); 110° (3.6mm and 4.7mm)
Number of elements: Nine
Lengths: 6 to 6.75 inches (15 to 17 centimeters)
Weights: 17 to 29 ounces (482 to 822 grams)
Price: $349 each
Contact: Stellarvue
11820 Kemper Road
Auburn, CA 95603
[t] 530.823.7796
[w] www.stellarvue.com

The Andromeda Galaxy (M31) is like nothing I have ever seen before. The wide-field view of the dark lanes is jaw-dropping. They look like railroad tracks planted in front of the galaxy. The ethereal light coming from the nucleus is so bright you lose your dark adaption.

When we swung the telescope toward NGC 206, this star cloud within the galaxy became pronounced. But then the real fun began — many of the star clouds and dark lanes were clearly visible as the galaxy wrapped around itself. You actually could trace the curved end of the galaxy. The 20mm Optimus kept things bright but also magnified the image enough so that small details became visible.

After I attached a UHC filter (which increases contrast by darkening the sky background), the Swan Nebula (M17) looked as though it was illuminated by fluorescent lights. Mottling was obvious as well as many arcs of faint stars. Once again, the pinpoint stars to the edge of the field greatly enhanced the porthole illusion.

The Lagoon Nebula (M8) appeared to be a seething cauldron of light punctuated by dark lanes and bundles of stars. First-time viewers gasped when they saw this sight, hardly imagining anything like this was possible. Like the wizard behind the scenes, however, it was the Optimus 20mm combined with the coma corrector that was the real showpiece.

But what about more subtle views — say, the Crescent Nebula (NGC 6888)? For this one, I selected an Oxygen-III filter to pair with the Stellarvue eyepieces. Whereas the other objects were "in your face," the Crescent showed how the Optimus could deliver on more rarified subject matter. The view revealed a softly glowing nebula surrounded by stars, an ethereal view again enhanced by the large field of view.

Once again using the OIII filter, I aimed the scope at the Veil Nebula (NGC 6960/74/79/92–95) in Cygnus. Everyone saw both sides of it bright and well defined with sinuous strands everywhere. The part of the nebula close to the bright star 52 Cygni was especially poignant, looking like some piece of translucent coral that branched off into the Witch's Broom area.

Love at first sight

In a nutshell, the four eyepieces in Stellarvue's Optimus series have become my go-to eyepieces for viewing larger celestial targets. I look forward to winter views of the Orion Nebula (M42) and the Rosette Nebula (NGC 2237–9/46) and springtime views of galaxy clusters. Once you get used to them (and this doesn't take long), you will not be satisfied with ordinary views ever again.

These eyepieces represent a significant breakthrough in performance for cost. The views through them of common and uncommon celestial targets were jaw-dropping. In every case, whichever Optimus I selected delivered superb definition and sharpness to the edge of the field. To Vic Maris and Stellarvue I can only say: Mission accomplished!

Tony Hallas *is a contributing editor of* Astronomy *and one of the finest astroimagers on planet Earth. He likes equipment, too.*

ASTROSKETCHING

BY ERIKA RIX

Sandpaper blocks

Why would an astro sketcher need a block of sandpaper?

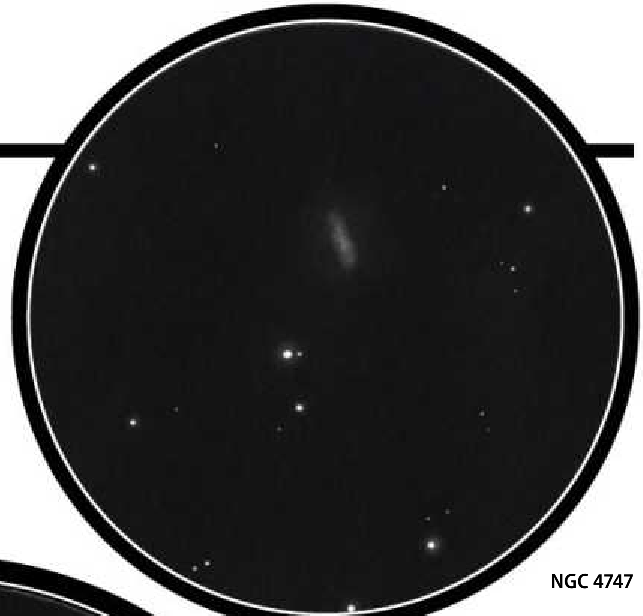
I pondered that very question the first time I stumbled across a small wooden paddle with strips of sandpaper stapled to it while browsing for art supplies. As it turns out, it's so handy that I use it during most observing sessions. I've included sketches of NGC 4747 and NGC 4725, galaxies in the constellation Coma Berenices, to explain how.

Peculiar entry

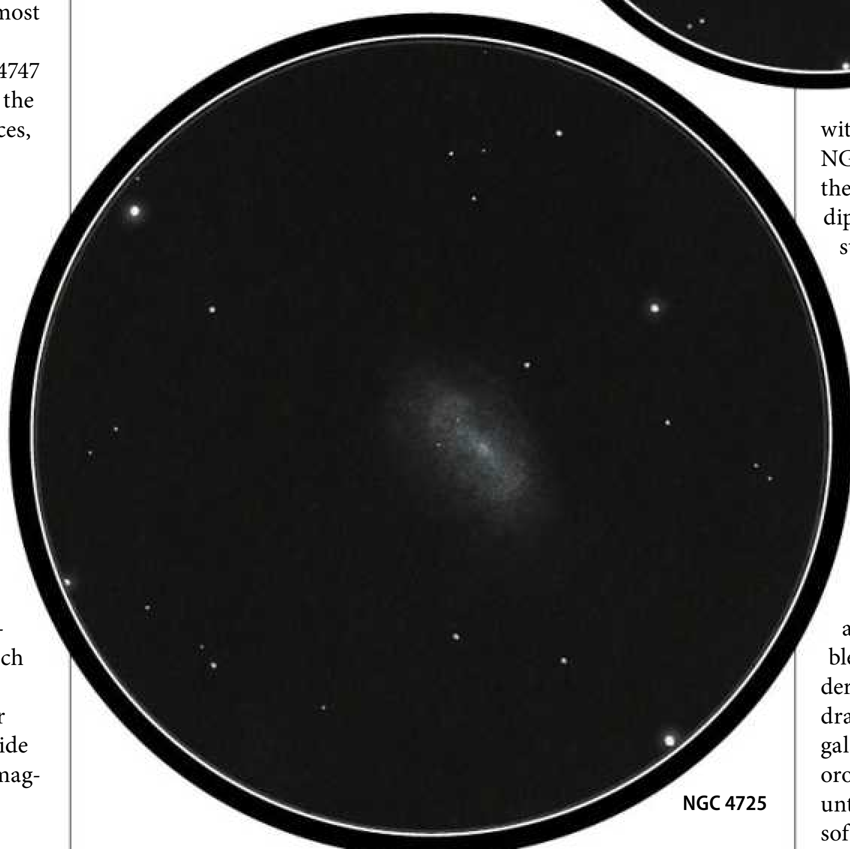
You can locate this duo some 5½° northwest of Beta (β) Comae Berenices. The smaller of the two, NGC 4747, appears as the 159th entry in Halton Arp's *Atlas of Peculiar Galaxies*. It sports tidal tails from its interaction with NGC 4725, which lies 24' farther to the southwest. The galaxy itself measures 3.5' by 1.2' and glows at magnitude 12.3. Through a 10-inch scope, it appears as a faint oblong halo with a brighter center. And you'll find a wide double star (7th and 10th magnitudes) 7' to its south.

Perhaps the sandpaper block's most common use is to shape the tip of a pencil. Softer graphite and pastel pencils are fragile and break easily when you use a regular pencil sharpener. So instead, do as I've done while sketching NGC 4747: Shave away the pencil's wood casing with either a knife or sharpener, and then use the sandpaper to create a rounded, pointed, or even a diagonally shaped tip. (And here's an extra tip: Save the residual graphite powder in a small container for later use. I'll return to this in a bit.) For example, I often use an 8B graphite pencil with a blunt, rounded tip to render the brightest stars. I then draw the faintest with a sharp 2H pencil.

The author created both sketches while using a 16-inch f/4.5 reflector on a Dobsonian mount with a 12mm eyepiece for a magnification of 152x. She used 8B, 2B, and 2H graphite pencils on white paper to depict the stars and their magnitudes and a blending stump to render the galaxies. The sandpaper block enabled her to keep her blending stump sharp. She then scanned and inverted the sketches in Photoshop. Both have north up and west to the right. ERIKA RIX



NGC 4747



NGC 4725

Single-arm splendor

Next up is NGC 4725. It's a one-armed spiral spanning 10.7' by 7.6' that glows at magnitude 9.2. Through a 6-inch telescope, the galaxy appears as a moderately bright northeast-to-southwest halo with a dense core. Bumping the aperture to 12 inches reveals hints of the broad spiral arm with the brightest arcs northeast and southwest of its faint central bar. Be sure to look for two 14th-magnitude stars twinkling in front of the northeastern quadrant of its halo. You also should spot NGC 4712, a smaller galaxy that lies 12' farther to the west-southwest.

I prefer using the soft, chamois-like texture of a blending stump to render subtle details within intricate galaxies like NGC 4725. So, after drawing the star field for this sketch, I dipped the tip of my blending stump into the container of graphite powder I had created earlier, and then used the coated stump to draw the galaxy's core and bright arcs. Alternatively, you can scratch a patch of graphite outside of the sketch area with your pencil and then rub the tip of the blending stump through it.

The graphite will gradually build up on the tip of the blending stump until it hinders the control needed to draw the soft tonal layers of the galaxy. Simply rub the tip vigorously against the sandpaper until you restore its shape and soft texture, and then continue with the sketch.

Do you use a chiseled eraser to draw dark lanes? If so, you also can use sandpaper to clean and shape erasers. Explore other uses for this handy tool and let me know what you come up with.

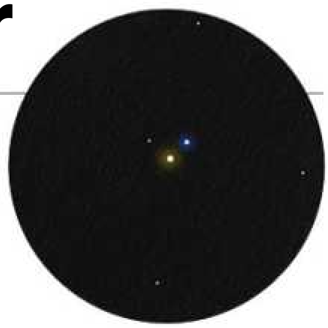
Questions or comments? Contact me at erikarix1@gmail.com.

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

BINOCULARUNIVERSE

BY PHIL HARRINGTON

Deep-sky objects in Cancer



The double star Iota Cancri makes for a binocular challenge for observers of binary stars. This sketch shows a telescopic view made with a 6-inch f/8 reflector at 240x magnification. JEREMY PEREZ

The Beehive Cluster (M44) in Cancer is one of the greatest open clusters in the sky. BERNHARD HUBL

One of the faintest figures lying along the ecliptic, Cancer the Crab often confounds naked-eye constellation hunters in search of new conquests. Even without the extinguishing effect of light pollution, the Crab's stars are just above the limit for most observers.

The Crab's body is drawn from four stars in a trapezoid, while its legs extend north and south. The brightest of the bunch, Beta (β) Cancri, shines at only magnitude 3.5; the rest are fainter.

Binoculars prove helpful to identify the Crab's stars. Aim about halfway between Castor and Pollux, in Gemini, and Regulus, in Leo. There, keep an eye out for the Crab's trapezoidal body. The stars Asellus Borealis (Gamma [γ] Cancri) and Asellus Australis (Delta [δ] Cancri) bound the eastern side; Eta (η) and Theta (θ) Cancri form the western boundary.

Look closely at the colors of the four stars. See any differences? Slightly defocusing them will accentuate the effect. Delta, Theta, and Eta are all spectral type K orange giant stars, larger but cooler than our Sun. The fourth, Gamma, is a type A white subgiant, making it both larger and hotter than the Sun.

Fainter than the Beehive, open cluster M67 nonetheless makes a nice binocular target under dark skies. RICHARD McCOY

These four stars nicely frame one of the finest binocular targets found anywhere in the sky. The Beehive Cluster (M44) is a striking sight at low magnification. Also nicknamed Praesepe, which is Latin for "manger," M44 comes alive in sparkling style through just about any binocular, no matter how large or small, expensive or affordable. That's partly because of the cluster's wide berth. M44 spans 1.5°, or three Full Moons stacked end to end. Telescopic fields are just too narrow.

How many stars actually belong to M44 is open to debate. A 2007 survey published in *The Astronomical Journal* said the true number may exceed 1,000. Part of the confusion surrounds the number of faint red dwarfs lying within. That analysis suggests there could be more than 650.

Of course, we can't hope to see those through binoculars. Most of the 75 or so that we do see are white spectral type A stars. At least four, however, glisten with contrasting tints of red or orange. Again, defocusing a little heightens color saturation.

Many stars in M44 align in interesting pairs or patterns. For instance, five centrally located in the cluster form a V that my eye interprets as either an arrowhead or even a miniaturized version of Taurus the Bull's head.

Look carefully, and you'll see that one of the stars in the V is actually a triple. Cataloged as Burnham 584, the three stars are separated by 45" and 93", respectively.

While Charles Messier added it to his growing catalog of faint fuzzies in 1769, the Beehive was known long before the invention of the telescope. The first person to note it was the Greek poet-turned-astronomer Aratus. He referred to M44 as *Achlus*, meaning "Little Mist," in his poem about the sky, *Phainomaina* (*Heavenly Displays*) in the third century B.C. The true nature of Praesepe didn't come to light until Galileo viewed it through his first crude telescope nearly two millennia later.

Let's use M44 as a jumping-off point for two more targets hidden in the Crab. First, hop 9°, or about 1.5 binocular fields, due north to Iota (ι) Cancri. Whereas M44 is an easy target, this one will prove a challenge — not in finding the star, but in resolving it, because Iota is a binary system. Here, a yellowish, 4th-magnitude primary star is accompanied by a bluish, 7th-magnitude companion separated by just 31". That's doable in steadily supported 8x binoculars, but it takes a sharp eye and steady seeing conditions to pull it off. I can make it out in my 10x50s, but again only if they are secured to a base. With more oomph, my 16x70s and, especially, my 25x100s display Iota as one of the prettiest binaries in the northern spring sky.

Return to M44, but only briefly on your way to one of the Crab's claws, Acubens. Can you see a fuzzy blur less than 2° to the star's west? That's Cancer's second contribution to the Messier catalog, M67. It may not stand out as well as M44, but M67 is still bright enough to be seen through my 7x35s as my own "Littler Mist," even with suburban light pollution. Since none of its 200 stars shines brighter than 10th magnitude, however, we have little hope at resolving them through most binoculars. One or two faint points may just squeak out using averted vision.

M67's location far from the plane of the Milky Way makes it especially interesting to study. Normally, open star clusters are found along the plane, where gravity from other stars causes them to disperse in a matter of a few million years. But M67 is situated away from such influences. As a result, it has outlasted nearly every other open cluster in the Milky Way. From studying its stars, we know M67 is between 3.2 billion and 5 billion years old.

Next month, we go dipper diving. Until then, don't forget that two eyes are better than one!

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

NEW PRODUCTS

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

5-inch refractor

Explore Scientific
Springdale, Arkansas

For Explore's FCD100 127mm, the company combined Hoya FCD100 glass with high refractive index glass to eliminate chromatic aberration. The scope comes in a white aluminum tube and weighs less than 20 pounds (9.1 kilograms). It includes a 2.5" focuser, cradle rings, two extension tubes, and a 99-percent reflective 2" star diagonal.
Price: $1,999.99
[t] 866.252.3811
[w] www.explorescientific.com

Eclipse app

GreatAmericanEclipse.com
Santa Fe, New Mexico
Great American Eclipse announces its new comprehensive free web app, created to help the expected tens of millions of American and international eclipse tourists see the sight of a lifetime. Just head to the front page of GreatAmericanEclipse.com to launch the app. You'll also find an instructional video there.
Price: Free
[e] GreatAmericanEclipse@gmail.com
[w] www.GreatAmericanEclipse.com

6-inch reflector

Orion Telescopes & Binoculars
Watsonville, California
Orion's 6-inch f/4 Newtonian Astrograph Reflector Telescope is only 22.5 inches (57 centimeters) long and weighs a scant 12.7 pounds (5.8kg). It comes with two heavy-duty hinged tube rings, an 8x50 finder scope, a dovetail mounting bar, and a 2" dual-speed Crayford focuser with a 10-to-1 ratio.
Price: $399.99
[t] 800.447.1001
[w] www.telescope.com

Scope controller

Orion Telescopes & Binoculars
Watsonville, California
Orion's StarSeek Wireless Telescope Controller allows wireless control of an Orion go-to telescope with an iPhone, iPad, or Android device running the Orion StarSeek astronomy app. The database contains 31,000 deep-sky objects and 2.5 million stars. Runs on a rechargeable lithium ion battery and includes an AC charger.
Price: $199.99
[t] 800.447.1001
[w] www.telescope.com

SEE REPORTS ON 400+ PRODUCTS AT **www.Astronomy.com/equipment.**

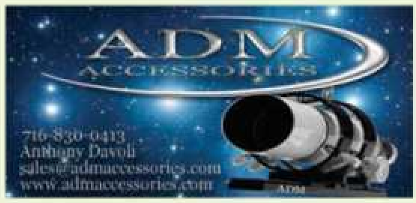
INDEX *of* ADVERTISERS

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.


OBERWERK
Astronomical binoculars and binocular telescopes at down-to-earth prices.
Astronomy 2013 Star Products
BT-100-45
BT-70-45
Available exclusively at www.bigbinoculars.com
ph. 937-253-8010 9:00-5:30 Mon.-Fri.
1861 Wayne Ave., Dayton, OH 45410


OPTIC WAVE O.W.L. LABORATORIES
Optical Coatings
Parabolic Mirrors
Testing
Refiguring
www.OpticWaveLabs.com


SIRIUS ASTRO PRODUCTS
**Computer Caves
**Light Shields
for: Computers, iPhones, iPads, DSLR's....More
www.siriusastroproducts.com


ADM ACCESSORIES
716-830-0413
Anthony Davoli
sales@admaccessories.com
www.admaccessories.com


Bob's Knobs
Meade, Celestron, Intes, Takahashi...and more!
6976 Kempton Rd.
Centerville IN 47330
765-855-5109 USA
www.bobsknobs.com


Keeping it "Beautifully" Simple
Almost Zero Maintenance... Very little to go wrong
Almost Zero Operation Software... No Rotation
Astro Haven ENTERPRISES
domesales@astrohaven.com
949.215.3777 www.astrohaven.com

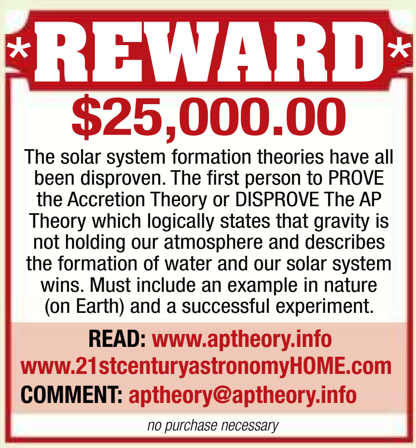

Build Your Own
Custom Astronomical Adapter
www.preciseparts.com
+1 305 253-5707
info@preciseparts.com
PRECISEPARTS


*Follow us on Facebook!
GO TO
www.Facebook.com/AstronomyMagazine


Fine Meteorite Jewelry
In Gold & Platinum
www.JewelryDesignsforMen.com

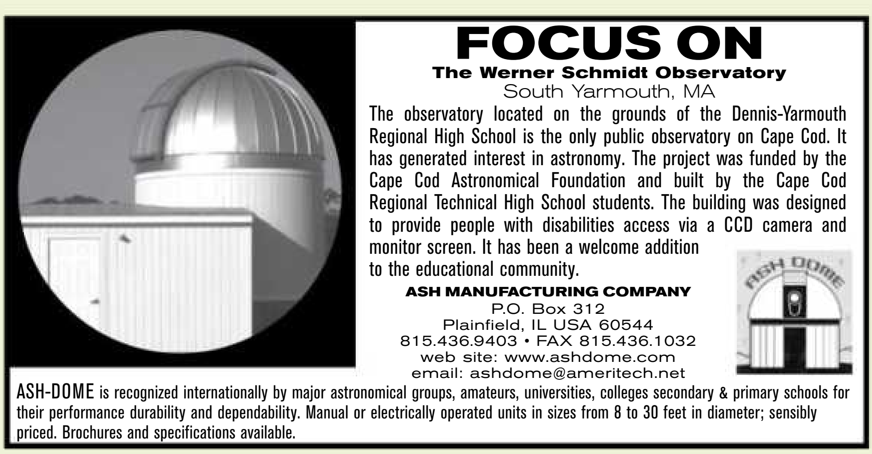

OREGON COAST ECLIPSE TOUR
August 15–24, 2017
Enjoy the BEST of the Oregon Coast— ocean-view hotels, food, tour stops, speakers
www.DeluxeEclipseTours.com
503-914-9769


Step Up To Astrodon Filters
· Highest Throughput guaranteed
· Great durability
· 100% hard sputtered coatings
· Narrowband, Photometric, LRGB
· Quality Made in U.S.A
Astrodon®
www.astrodon.com


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


Sidereal, Martian and Tidal clock movements
Free U.S. shipping
12 hour movements $15
24 hour movements $20
Geppetto Electronics
https://is.gd/astroclocks


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


FOCUS ON
The Werner Schmidt Observatory
South Yarmouth, MA
The observatory located on the grounds of the Dennis-Yarmouth Regional High School is the only public observatory on Cape Cod. It has generated interest in astronomy. The project was funded by the Cape Cod Astronomical Foundation and built by the Cape Cod Regional Technical High School students. The building was designed to provide people with disabilities access via a CCD camera and monitor screen. It has been a welcome addition to the educational community.
ASH DOME
ASH MANUFACTURING COMPANY
P.O. Box 312
Plainfield, IL USA 60544
815.436.9403 • FAX 815.436.1032
web site: www.ashdome.com
email: ashdome@ameritech.net
ASH-DOME is recognized internationally by major astronomical groups, amateurs, universities, colleges secondary & primary schools for their performance durability and dependability. Manual or electrically operated units in sizes from 8 to 30 feet in diameter; sensibly priced. Brochures and specifications available.


LIGHTS OF ALASKA 2018
Join us for an amazing, once-in-a-lifetime Northern Lights adventure, with Bob Berman!
*ask about our Anchorage extension
March 11-16, 2018
(extension 8th-10th)
www.specialinteresttours.com
727.330.7738 info@specialinteresttours.com

1. THE FLY NEBULA
Sharpless 2–237 is an emission nebula about 10,000 light-years away in the constellation Auriga. The brighter stars in this image belong to the young star cluster that has formed out of the gas. • ***Dean Salman***

2. TRIPLE THREAT
The photographer traveled to Cape Chignecto Provincial Park in Nova Scotia to photograph a close gathering of Saturn, Mars, and Antares. You can see the three objects, top to bottom in that order, between the two sea stacks. • ***Barry Burgess***

3

4

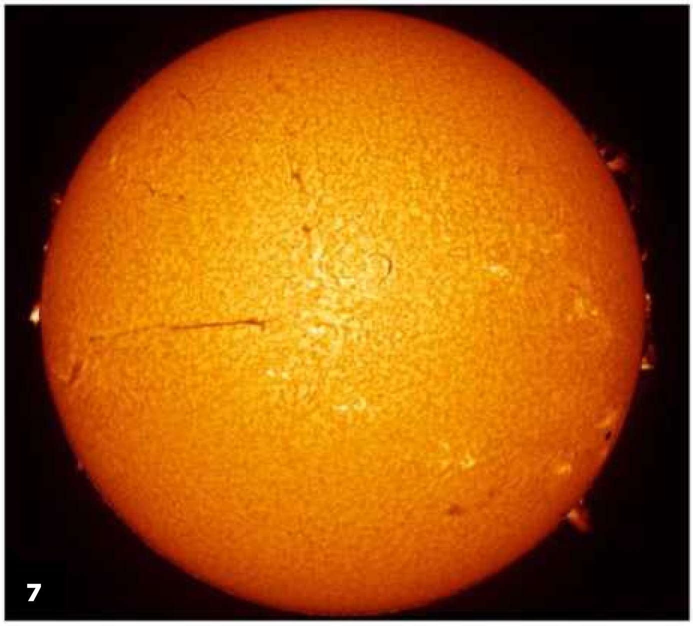
5

3. THE MAGNIFICENT EIGHT
The Perseid meteor shower was quite active in 2016, as demonstrated in this stack of eight images taken from Mourão, Dark Sky Alqueva Reserve, Portugal, on August 13. The red object at the center is the North America Nebula (NGC 7000). • ***Miguel Claro***

4. SUDDENLY STARLESS
The Eta Carinae Nebula (NGC 3372) is the brightest emission nebula in the sky. But what if we could see it without stars? Clever work with astronomical image-processing software allows us to do just that. Notice how certain features (especially the dark nebulosity) seem much more apparent in the right-hand image.
• ***Terry Hancock and John Mansur***

5. A PRETTY PAIR
The Owl Cluster (NGC 457) lies just above the center within this rich star field in the constellation Cassiopeia. But it's not alone. To its lower left is open cluster NGC 436. The brighter cluster lies some 7,900 light-years away and the fainter one 9,800 light-years distant. • ***Ron Brecher***

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.



6. THE ASSOCIATES
NGC 206 is a huge stellar association in the Andromeda Galaxy (M31) and one of the largest star-forming regions within the Local Group. • ***Tony Hallas***

7. ACTIVE SUN
This image of the Sun, taken through a Hydrogen-alpha filter April 1, 2015, shows our daytime star during an active stage. Numerous prominences ring its circumference while bright areas called flares erupt here and there. Finally, we can see several darker lines astronomers call filaments. They show prominences viewed from above (from our perspective on Earth). They appear dark because each is slightly cooler than the surface below.
• ***Knox Worde***

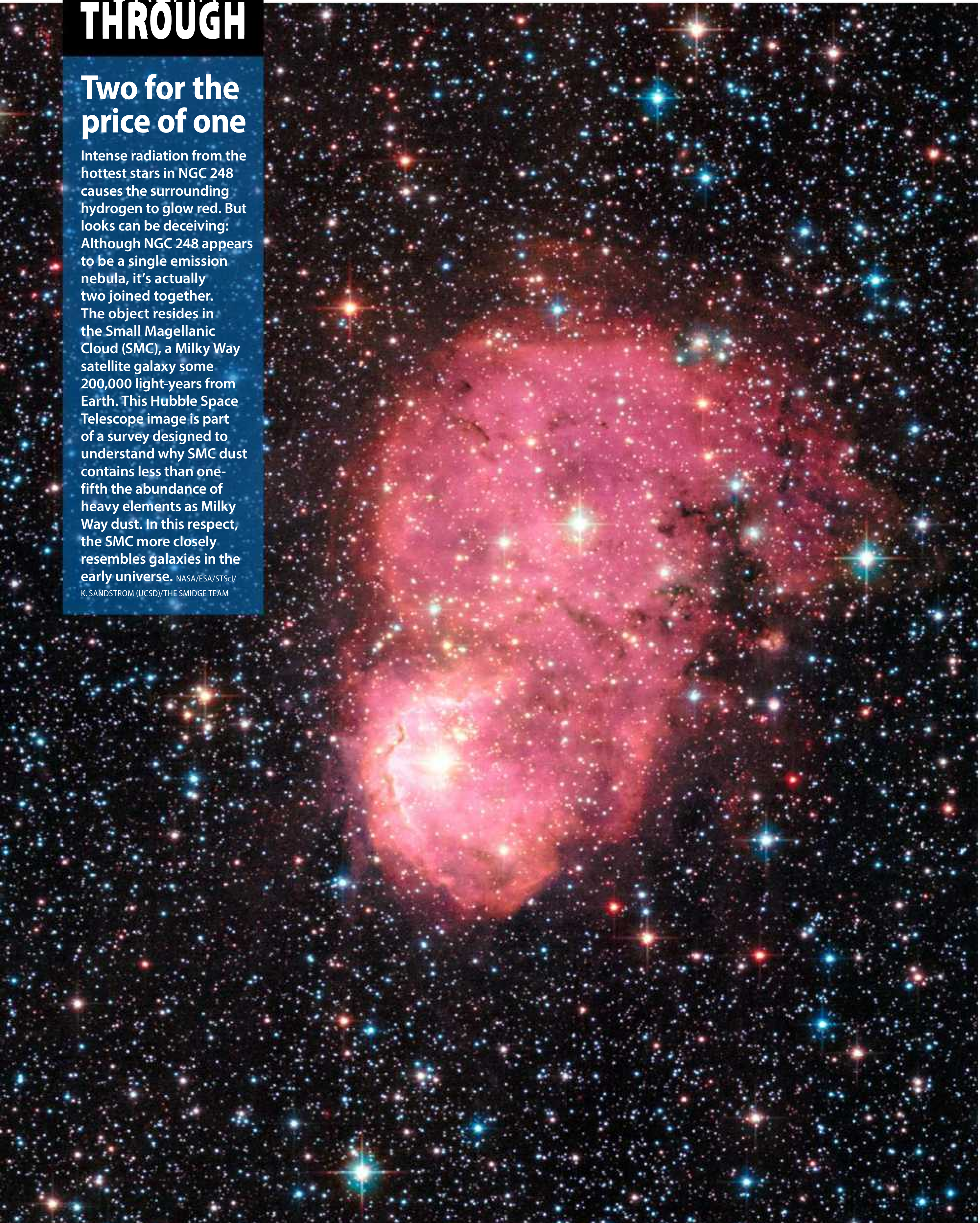
8

9

8. TONGUE TWISTER
Comet 45P/Honda-Mrkos-Pajdusakova is a periodic comet that orbits the Sun every 1,921 days. It approached closest to Earth on February 11 when it stood 7.74 million miles (12.46 million kilometers) away. The photographer captured the comet December 28, 2016, at 18h52m UT. • ***Gerald Rhemann***

9. LIKE NIGHT AND DAY
Globular cluster M4, which lies in Scorpius, and Sharpless 2–9, just over the border in Ophiuchus, provide observers and imagers great diversity. Sh 2–9, a combination of blue reflection nebulosity and a red emission complex, gets the ultraviolet energy to glow from the variable giant star Sigma (σ) Scorpii. • ***Burley Packwood***

Two for the price of one



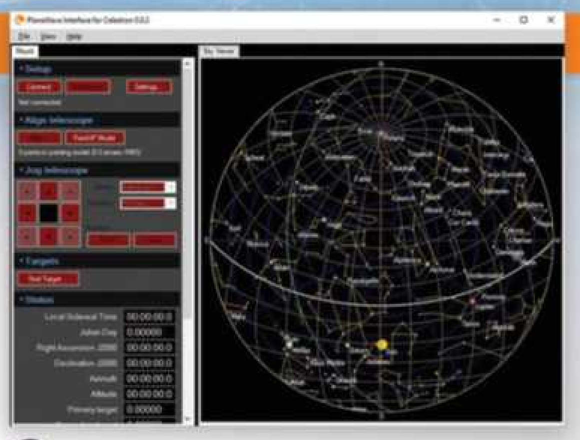
Intense radiation from the hottest stars in NGC 248 causes the surrounding hydrogen to glow red. But looks can be deceiving: Although NGC 248 appears to be a single emission nebula, it's actually two joined together. The object resides in the Small Magellanic Cloud (SMC), a Milky Way satellite galaxy some 200,000 light-years from Earth. This Hubble Space Telescope image is part of a survey designed to understand why SMC dust contains less than one-fifth the abundance of heavy elements as Milky Way dust. In this respect, the SMC more closely resembles galaxies in the early universe. NASA/ESA/STScI/K. SANDSTROM (UCSD)/THE SMIDGE TEAM

CELESTRON

POINTING ACCURACY TRUSTED BY RESEARCH OBSERVATORIES

INCLUDED WITH EVERY CGX AND CGX-*L*

INTRODUCING CELESTRON PWI



TELESCOPE CONTROL SOFTWARE

PlaneWave™ INSTRUMENTS

Celestron and PlaneWave Instruments have joined forces to deliver the absolute best telescope pointing accuracy in the consumer market. Celestron PWI operates on the same software engine as PlaneWave Instruments' professional software that controls up to 1-meter observatory telescopes with the ultimate precision.

+ Add an unlimited number of alignment stars to the pointing model for unparalleled accuracy with Point XP advanced mount modeling
+ Connect directly from your Windows PC to your CGX/CGX-*L* mount via the integrated USB port
+ Navigate the intuitive SkyViewer user interface to select your desired object with ease
+ Access millions of celestial objects in the online SIMBAD astronomical database

CELESTRON PWI IS AVAILABLE EXCLUSIVELY WITH CGX AND CGX-*L*

Designed from the ground up, CGX and CGX-*L* are the sturdiest, most ergonomic mounts in their class.

+ Exceptional load capacity to weight ratio
+ Spring loaded worm gears with belt drives for smooth tracking and minimal backlash
+ Internal cabling; stationary power and accessory ports
+ Home and limit sensors with mechanical hard stops
+ Smoother polar align adjustments and All-Star Polar Align technology
+ Tracks 20° past the meridian so you can image the best part of the night sky

CGX 1100 EDGE HD
TELESCOPE #12057

CGX-*L* 1400 EDGE HD
TELESCOPE #12077

CGX 55 LB CAPACITY
OR UPGRADE TO CGX-*L* FOR 75 LB CAPACITY PLUS EXTRA FEATURES

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

EXPLORE ALL OF CGX AND CGX-*L* AT
celestron.com

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

July 2017: Mercury at its evening best

The evening sky boasts plenty of solar system targets for long winter nights. The most conspicuous is **Jupiter**, which gleams at magnitude –2.0. Its position high in the north as twilight fades only increases its prominence. The planet lies between Virgo's two brightest stars: 1st-magnitude Spica and 3rd-magnitude Gamma (γ) Virginis. It begins the month 4° from Gamma and 11° from Spica, but by the end of July, its eastward motion relative to the background stars has carried it about midway between the two.

Jupiter's high early evening altitude makes that the best time for viewing the planet through a telescope. The giant's equatorial diameter shrinks slightly during July, from 37" to 34", but that's plenty big enough to show nice detail. Even small scopes show two dark cloud belts sandwiched around a brighter zone that coincides with Jupiter's equator.

Despite Jupiter's brilliance, the star of the evening sky has to be **Saturn**. The ringed planet reached opposition and peak visibility in June, but its appearance hardly suffers this month. You can find the magnitude 0.2 world among the background stars of Ophiuchus the Serpent-bearer. During the early evening hours, it lies high in the east and almost directly below the 1st-magnitude star Antares in Scorpius. By late evening, the planet passes nearly overhead.

A telescope delivers splendid views of Saturn on any clear July evening. At midmonth, the planet's disk measures 18" across while the ring system spans 41" and tilts 27° to our line of sight. You should be able to spot the Cassini Division — the largest "gap" in the rings — through even the smallest scope during moments of steady seeing.

A third bright planet joins Jupiter and Saturn in July's second half. **Mercury** puts on its finest evening show of the year when it reaches greatest elongation July 30. It then lies 27° east of the Sun and appears nearly 15° high in the west-northwest an hour after sunset. Shining at magnitude 0.3, it appears noticeably brighter than 1st-magnitude Regulus, which lies 5° below the planet. (The two approach within 1° of each other July 25 and 26, and a slender crescent Moon adds to the scene the evening of the 25th.)

Although Mercury reaches its peak in late July, you can start tracking it around midmonth. On the 15th, the planet stands 8° high an hour after sundown and shines even brighter, at magnitude –0.2, than it does late in the month. A telescope then reveals a 6"-diameter disk that appears two-thirds illuminated. By greatest elongation, the innermost planet spans 8" and shows a slight crescent phase under good seeing conditions.

The morning sky features the brightest planet of all. **Venus** shines at magnitude –4.2 in early July, when it rises shortly before 4 A.M. local time. The brilliant world fades to magnitude –4.0 and rises a little after 4 A.M. late in the month. It spends the first 29 days of July crossing Taurus, passing in front of the Hyades star cluster around midmonth. The planet slides into northern Orion for the month's final two days.

Venus' appearance through a telescope seems a little disappointing after the spectacular views we had in the first half of 2017. The planet measures 16" across in mid-July and its gibbous disk appears two-thirds lit.

Mars is in conjunction with the Sun on July 27, and it remains lost in the solar glare all month. It will return to view before dawn in late September.

The starry sky

On the next clear, moonless night, plan to spend some time examining star colors. Although white and blue-white stars tend to dominate the sky, many others show distinctly different colors. The best-known example in the southern half of the celestial sphere is probably Antares in Scorpius the Scorpion, which sports an obvious orange-red color.

It's important to note that these colors are subtle to the naked eye. Observers over the ages often have quoted colors that are far too specific. Consider French astronomer Camille Flammarion's book *Popular Astronomy*, in which he describes colors including emerald, ruby, topaz, and sapphire. In particular, no greenish stars exist, despite reports that the companion to Antares appears this color.

The color of an individual star depends on its surface temperature — hotter stars shine blue-white while cooler ones glow reddish. But the colors typically don't appear distinct because stars emit radiation across all wavelengths, and this "dilutes" the color of peak emission. Another important consideration is that the human eye doesn't discern colors well under dim lighting conditions.

It's often easier to spot these subtle shades when two stars with different colors lie adjacent to each other. A number of good examples occur in the southern sky. Let's start in the constellation Chamaeleon, not far from the South Celestial Pole. Target Alpha (α) and Theta (θ) Chamaeleontis, which stand 0.6° apart. You should quickly notice that Theta appears slightly more orange than Alpha.

Next, find the constellation Ara the Altar directly south of the tail of Scorpius the Scorpion. Its stars Beta (β) and Gamma appear 0.8° apart and show a clear color contrast, with the somewhat orange Beta quite different from the blue-white of Gamma.

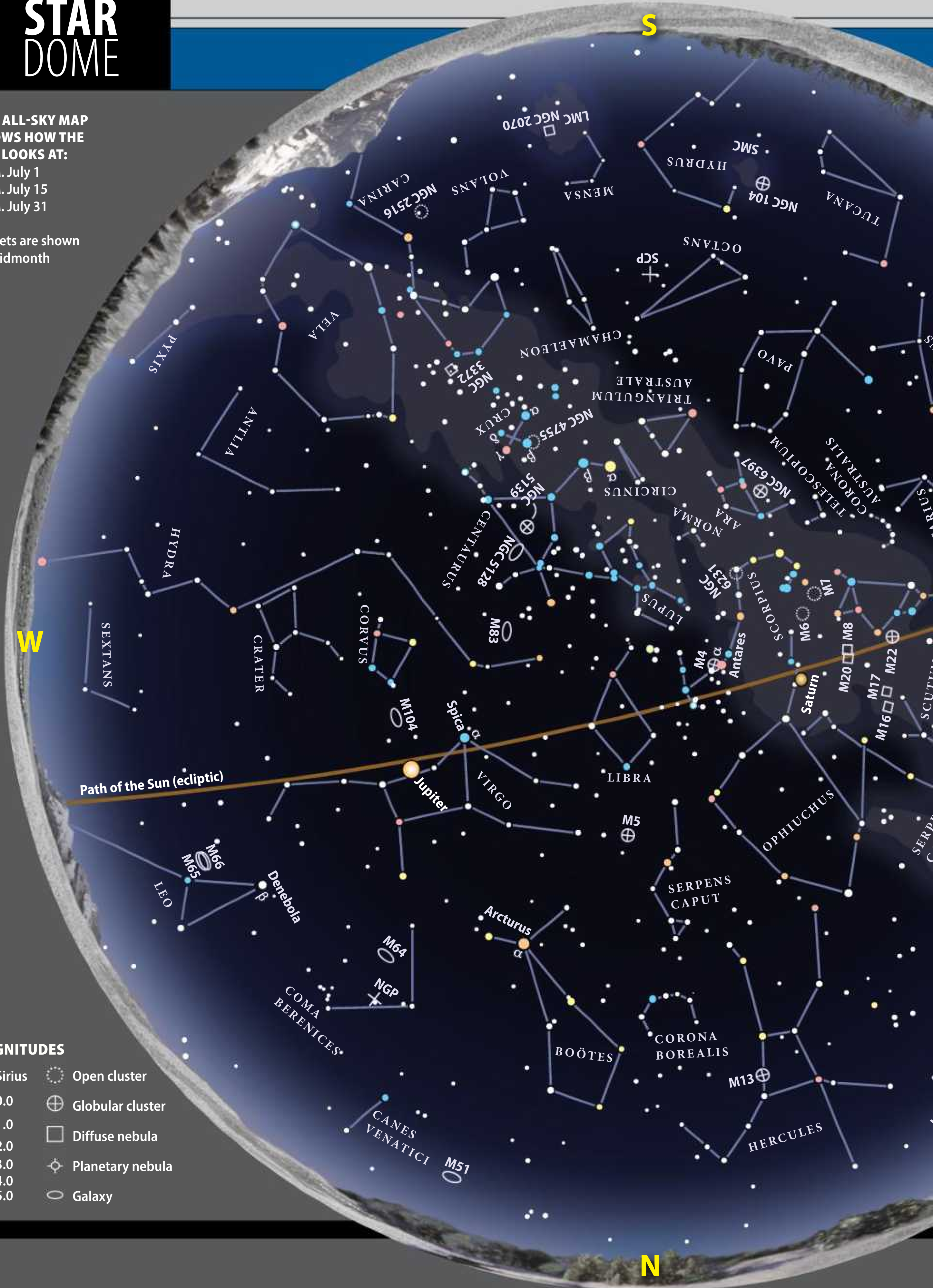
Brighter stars show their colors more distinctly, and its hard to find a better comparison than Alpha and Gamma Crucis, the stars at the foot and head of Crux the Cross, respectively. Gamma's yellow-orange color stands out clearly compared with blue-white Alpha.

Finally, over on the other side of the South Celestial Pole, you'll find Grus the Crane. This constellation's two brightest stars, Alpha and Beta Gruis, make a splendid example of star colors. Alpha's blue-white hue contrasts nicely with the orange-red of Beta.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth



MAGNITUDES

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

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

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

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

Illustrations by *Astronomy*: Roen Kelly

JULY 2017

Calendar of events

1 First Quarter Moon occurs at 0h51m UT

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

2 Asteroid Juno is at opposition, 13h UT

3 Mercury passes 5° south of Pollux, 0h UT

Earth is at aphelion (152.1 million kilometers from the Sun), 20h UT

6 The Moon is at apogee (405,934 kilometers from Earth), 4h28m UT

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

9 Full Moon occurs at 4h07m UT

10 Pluto is at opposition, 5h UT

13 The Moon passes 0.9° south of Neptune, 18h UT

14 Venus passes 3° north of Aldebaran, 11h UT

16 Last Quarter Moon occurs at 19h26m UT

17 The Moon passes 4° south of Uranus, 0h UT

20 The Moon passes 0.4° north of Aldebaran, 0h UT

The Moon passes 3° south of Venus, 11h UT

21 The Moon is at perigee (361,236 kilometers from Earth), 17h12m UT

23 New Moon occurs at 9h46m UT

25 The Moon passes 0.9° north of Mercury, 9h UT

The Moon passes 0.07° north of Regulus, 11h UT

26 Mercury passes 1.1° south of Regulus, 9h UT

27 Mars is in conjunction with the Sun, 1h UT

28 The Moon passes 3° north of Jupiter, 20h UT

30 Southern Delta Aquariid meteor shower peaks

Mercury is at greatest eastern elongation (27°), 5h UT

First Quarter Moon occurs at 15h23m UT