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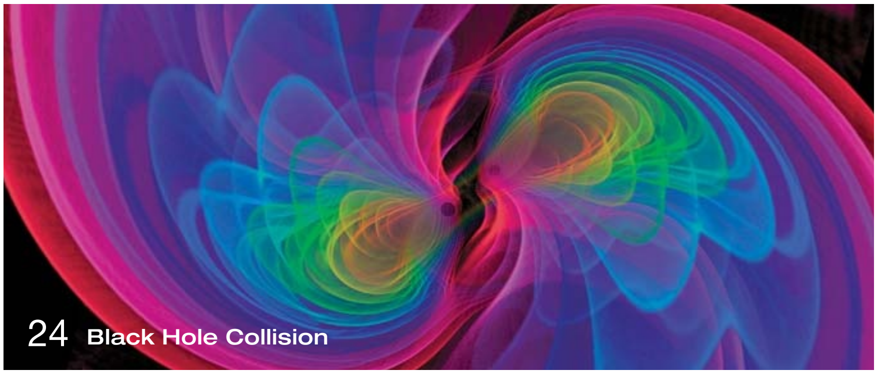

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ON THE COVER

A blue tint marks winter's arrival at Saturn's south pole.

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Periodicals postage paid at Boston, Massachusetts, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 420235, Palm Coast, FL 32142-0235. Printed in the USA.

Mission Extraordinaire

IT'S A BITTERSWEET MOMENT as the Cassini spacecraft prepares to plunge into Saturn on September 15th. Twenty years have passed since it launched atop a Titan-Centaur rocket from Cape Canaveral, and 13 since it entered orbit around the ringed planet, the first spacecraft ever to do so. In that time, as our photo essay starting on page 16 reveals, Cassini and its sidekick probe Huygens have delivered a phantasmagoria of jaw-dropping snapshots of Saturn, its rings, and its moons.

We've seen in radiant technicolor the now-famous geysers that Cassini discovered shooting from the south polar region of Enceladus. We've peered beneath the thick blanket of haze on Titan to uncover vast lakes of methane and ethane. We've marveled at the sea sponge–like surface of Hyperion and the ravioli shape of Pan. On Saturn, we've watched as a massive storm that began in 2010 spread around the entire planet, eventually covering 300,000 km (190,000 miles). The myriad photos we've enjoyed of the storied rings display a Mondrian-like precision, beautiful beyond description. Cassini even shot the stills that became the first video of lightning discharging on another planet.

Yet if there's one thing more impressive than the images, it's the science done with them and other data beamed home. In Saturn's E ring, which is fed by those plumes from ice-encased Enceladus, Cassini detected silica nanoparticles that can only form where liquid water and rock interact at temperatures above 90°C (about 200°F). This is one clue that the frigid moon's internal liquid ocean might host scalding hydrothermal vents akin to those in our own seas. From this mission, we've learned that Saturn's polar storms feature eyewalls just like those in our hurricanes, that its rings hold "particles" kilometers across, and that Titan *rains* hydrocarbons, among countless other findings.

Titan's surface, as captured by the Huygens lander.

ESA / NASA / JPL / UNIVERSITY OF ARIZONA

As expected, the discoveries have spawned questions. Why is the distinctive six-sided jet stream observed around Saturn's north pole not replicated in the south? Where does all the methane in Titan's atmosphere come from? Why does the rotation rate of Saturn's magnetic field appear to have varied since Cassini began measuring it? Perhaps most tantalizing of all: Does Enceladus's subsurface ocean harbor life?

Altogether, the terabytes of data transmitted by Cassini and Huygens will ensure decades' worth of research and analysis. In the meantime, we can return again and again to the pictures and savor them anew. Many of us likely have a personal favorite. Mine — perhaps curiously considering the flashy competition — has always been the comparatively ho-hum image above. Ho-hum? *It's the surface of Titan!* What's yours?

Peter
Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

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Newsstand and Retail Distribution: Curtis Circulation Co., 201-634-7400.

My Town, Our Planetarium #195 / #196

GOTO

Decades Later – Bringing New Life

GOTO INC has always loved the excitement of building a brand new planetarium – of bringing the sky to a community in a whole new way. But we also love pumping new excitement into older, existing planetariums through dynamic renovation projects. In 2016, GOTO was proud to have been chosen to revitalize two decades-old planetariums which re-opened to the public in April of 2017.

The 23-meter diameter Saitama City Space Theater originally opened in 1987. The 18-meter Osaki Lifelong Educational Center was built in 1997. One of these planetariums originally chose a GOTO HELIOS star projector, and the other chose a competitor's machine. Unlike today's video equipment which has lifetimes of only a handful of years, opto-mechanical projectors such as GOTO's can be maintained and operated for 30 years or more. And true to form, both Saitama's and Osaki's opto-mechanical planetarium projectors gave decades of solid service, teaching children and families all about the sky.

But finally, it becomes time to retire all old machines and to look for new opportunities with new equipment in total renovations of all domes. This time, both Saitama and Osaki chose the GOTO CHIRON III opto-mechanical planetarium projector to last for their next 30 years. A truly superb sky, the ability to project in tilted or horizontal domes, LED illumination, and intense and accurate sun, moon and planet projectors make the CHIRON III today's choice to be the dependable, solid core of any planetarium.

As part of their renovations, both planetariums chose to synchronize their CHIRON III with GOTO VIRTUARIUM fulldome video systems. The resulting GOTO HYBRID planetarium systems, with their versatile manual control consoles allow both stimulating and educational live programming as well as dynamic and spectacular automated programs.

So whether it's a new planetarium just being born, or an older planetarium that needs a new breath of life, GOTO INC stands ready to provide the equipment and know-how to make your planetarium and its programs come alive!

Saitama City Space theater

Osaki Lifelong Educational Center

GOTO INC

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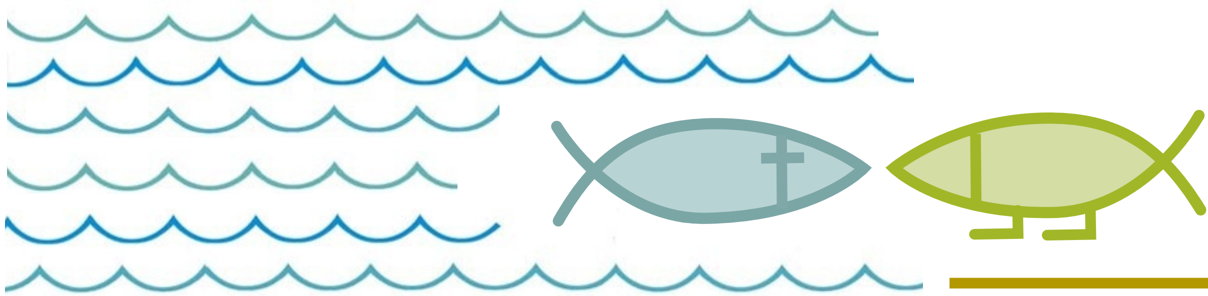

Faith and Science at a Crossroad

Thanks very much for the Focal Point by Camille Carlisle entitled "Two Routes to the Truth" (*S&T:* June 2017, p. 84). I immensely enjoyed the author's personal insight about science and faith. It is a difficult and sensitive subject, and I know that you will also receive letters to the contrary. I have always felt closer to God through my pursuit of this wonderful hobby, and the article helped me probe why I have felt this way. I still don't have a good answer, although I think it has something to do with my personal discoveries and learning, the time spent alone under the stars, and perhaps simply having a VIP seat to the beauty and wonder of the skies above.

Gary Imm
Onalaska, Texas

I was dismayed to read the final essay in your June 2017 issue. Although Focal Point appears to provide a forum for various views, a scientific publication like *Sky & Telescope* should not publish articles that represent personal religious views. The American public already has difficulty accepting scientific facts about climate, evolution, and the age of Earth. Your publication should be supporting critical scientific thinking and not supernatural theories of the universe.

Additionally, the author is in error by suggesting that science seeks "truth." Science seeks knowledge supported by observation and experiment. "Truth" is a term for philosophers and metaphysicians.

Don Waters
Birmingham, Alabama

I much appreciated Carlisle's article. A very similar viewpoint was espoused by physicist Charles H. Townes, who shared the 1964 Nobel Prize for the invention of the maser/laser. He gave a number of popular talks on science and religion, one at a well-attended evening meeting at Harvard in June 2005. During his presentation, he said without comment, "I feel a spiritual presence." The next morning, as we shared a cab to the airport, he remarked on how beautiful the sunrise was. When I asked him if he could elaborate on his comment about feeling a spiritual presence, he replied, "No, I just feel it."

It seems that we all have different capabilities, talents, and sensibilities — like artists who perceive reality in ways many cannot.

By the way, Townes also won the 2005 Templeton Prize for "Progress Toward Research or Discoveries about Spiritual Realities."

Edwin Erickson
Sunnyvale, California

If Carlisle is serious about non-reality-based paths to the truth, I presume she is prepared for a very long journey down a nearly infinite number of routes, for that is surely the course that lies ahead of any honest astronomer wishing to place religion on a par with observable, testable, predictable science.

Therefore, I assume that next month we'll get an article on the differences between the universes created by Shiva or Ptah, or perhaps by the Flying Spaghetti Monster — unless, of course, Carlisle has already narrowed her acceptable "truth" down to just one religious faith, in which case I detect a bias in her data.

Perhaps *Sky & Telescope* can stick with science?

Daniel Molitor
Pasadena, California

I have been an astronomer for more than 50 years and a Presbyterian pastor for nearly 40 years. I stand in a long tradition of astronomers who were also theologically trained and rooted — Copernicus, Kepler, Tycho, T. W. Webb, and others. Still, people are often surprised at how I can be both a pastor and an astronomer.

I often explain that my faith is as different from the religion commonly portrayed in the media as astronomy differs from astrology. It is the common thread of a search for truth, one that weaves its way through the fabric of both, that binds me to both astronomy and theology. Carlisle expressed the two routes to the truth very well. So kudos to *S&T* for publishing her well-thought-out article.

Rev. Dr. W. Maynard Pittendreigh
Orlando, Florida

As a new subscriber, I wish to criticize the editorial failure that led to the publication of the Focal Point essay in the June issue. Carlisle's religious testament has nothing to do with either sky or telescope, and it is as inappropriate in your journal as would be a cooking recipe, a political endorsement, or pornography.

Jack Harris
Troy, New York

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The "Two Routes" article was a mistake. We readers want to know about astronomy, not religion. Granted, it was an opinion piece, but there's such a thing as editorial control, and whoever thought this was a good idea missed the mark. Does the appearance of this article mean that it's a good idea to submit my opinion on how great astrology is? Or why I don't believe we ever landed on the Moon? I can stomach one of these articles, but if another one like this appears, my subscription will do the opposite.

Terry Barker
Richmond, Virginia

Peter Tyson replies: *I asked Ms. Carlisle to write this piece. Not being religious, I was curious how an editor whom I respect so highly for her science-based skills and sharply rational mind could square faith and science, and I felt many readers would also be interested to hear her explanation. Her opinions are her own and not those of* S&T, *and I've no intention of running further articles that touch on religion. But my fellow editors and I will continue to strive to provide intellectually stimulating and provocative content in these pages.*

Never Too Young

Just sending a note of thanks for the fine observing articles penned by Steve Gottlieb, Sue French, and Howard Banich in the May 2017 issue. I'm sure deep-sky observers everywhere appreciated the stories as much as I did.

In his article on interacting galaxies, Gottlieb mentions NGC 6621, discovered by 14-year-old Edward Swift on June 2, 1885. His father, Lewis, spotted the fainter component of the pair, NGC 6622, the same evening. One imagines that Edward alerted his father to the brighter galaxy and that, when taking a look to confirm it, Lewis discovered the fainter galaxy — certainly a heartwarming example of father-son collaboration.

This was not Edward's first deep-sky discovery. Exactly two years earlier, he spied a spiral galaxy now cataloged as NGC 6382. Edward was 12 at the time, making him far and away the youngest contributor to J. L. E. Dreyer's seminal *New General Catalogue.*

Mark Bratton
Limerick, Saskatchewan

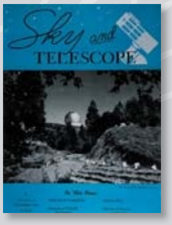
FOR THE RECORD

- In Jerry Oltion's column on DIY solar filters (*S&T:* June 2017, p. 40), the upper caption should note that eclipse glasses provide a "one-power" (1×) view.
- The aperture of the WIYN telescope (*S&T:* July 2017, p. 34) is 3.5 meters.

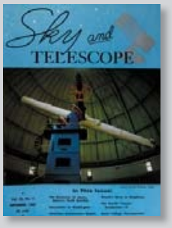
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; published letters may be edited for brevity and clarity.

75, 50 & 25 YEARS AGO by Roger W. Sinnott

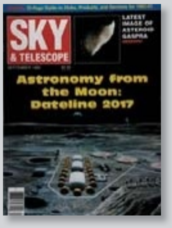
1942



1967



1992



September 1942

War Delays "A continuous flow of inquiries is received as to progress being made on the 200-inch telescope . . . Dr. J. A. Anderson [of] California Institute of Technology has written in part:

"'Last year, even before Pearl Harbor, it became necessary for our personnel to turn their attention to defense work . . . In the optical shop we keep the 200-inch mirror . . . but the last interval on the grinding of the mirror was in April, so we may as well say that no work is now being done on the optical parts. . . . A full year's work will be required to finish the job, when the war is over.'"

The Hale 200-inch telescope wasn't fully operational until 1949.

September 1967

Mirrors in Space? "According to a statement from the White House, the government has discontinued feasibility studies of large orbiting mirrors that would illuminate extensive areas of the earth's night side with full-moon brightness . . . This announcement came after . . . the National Academy of Sciences made public [a critical, fact-finding analysis that] stated, 'The Committee sees no scientific value in a satellite reflector system that is in any way commensurate with the costs and nuisance to science of such a system.'

"Several independent studies of possible systems for Project Able had been made. These ranged from as many as 12 reflectors 400 feet across to a single mirror half a mile in diameter."

Astronomers sighed in relief. Early in the Space Age, this concept and other threats to dark skies never gained traction.

September 1992

Mystery in Monoceros "Located just ¾° southwest of 4th-magnitude Delta Monocerotis, the planetary nebula NGC 2346 is an easy target for amateur telescopes. The object has long been of interest to astronomers because its 11th-magnitude central star does not produce enough energy to make the nebula shine. The notion that [energy from] an unseen, hot companion powered the nebula was confirmed by observations made with the International Ultraviolet Explorer satellite in the early 1980s.

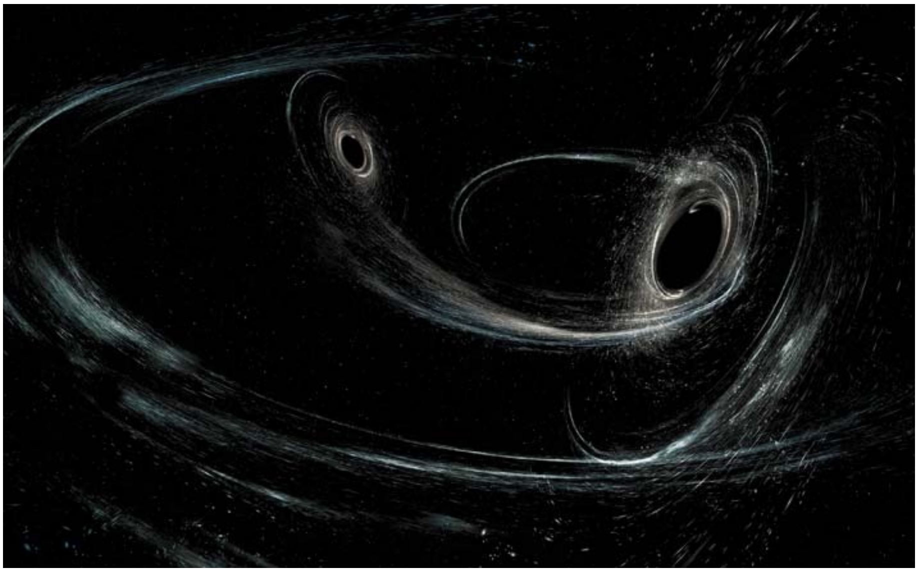
"The central star became even more intriguing during the winter of 1981–82 with the sudden onset of periodic eclipses. According to a study conducted by Hao Xiang-liang (Beijing Observatory), in 1985 the star faded by about 3½ magnitudes during each eclipse. [By 1987 the star was back to normal.]

"Amateurs would be well advised to add NGC 2346 to their regular observing rosters in case the eclipses begin again."

They haven't yet, but two abnormal fadings occurred in 1996 and 2004, each lasting about a year. This behavior suggests material ejected by the hot companion causes the occasional dimming and almost always hides the ongoing eclipses.

PHYSICS

LIGO Detects Third Black Hole Merger



▲ Artist's concept of two black holes about to merge, spinning on axes that are tilted with respect to their orbital plane.

LIGO / CALTECH / MIT / SONOMA STATE (AURORE SIMONNET)

SCIENTISTS WITH the Laser Interferometer Gravitational-Wave Observatory (LIGO) have announced their discovery of another black hole merger, revealed when the spacetime ripples it created squeezed and stretched the two LIGO sites' arms by approximately 1⁄1000 the width of a proton.

The newly announced event, designated GW170104, was detected on January 4th during LIGO's second observing run. The larger of the two merging black holes had a mass between 25 and 40 times that of the Sun; the smaller, between 13 and 25 Suns. The resulting black hole has a mass of roughly 50 solar masses, with a couple of solar masses carried away as gravitational radiation, the collaboration reports in the June 2nd *Physical Review Letters*.

This is the third firm detection of gravitational waves. LIGO scientists detected the previous two events in September and December 2015, announcing each of them last year (see page 24). The final mass of the black hole produced by the latest merger lies betwixt those of the previous two LIGO discoveries. Based on how "loud" the signal was, it happened roughly 3 billion light-years away, approximately twice as far from us as previous events. However, the team cannot pinpoint its exact location; it could lie anywhere in a long, skinny region on the sky spanning roughly 1,200 square degrees.

Scientists derive things like the black holes' masses, spin, and distance based on a careful breakdown of the gravitational-wave pulse. Its frequency, for example, is inversely proportional to the total mass of the black holes: Higher frequency means lower mass.

One aspect of GW170104's signal has astrophysicists excited: the black holes' spins. Although the team can't determine the exact direction and speed of the two black holes' spins before the merger, it does appear that at least one of the objects was spinning in a direction opposite that of its orbital motion.

The reasoning goes something like this: If the two black holes were spinning exactly aligned with the axis of their orbit, they would have needed to shed some of the system's total rotational energy before they could merge. Such a merger would take a few more orbits than if the spins weren't aligned, explains LIGO deputy spokesperson Laura Cadonati (Georgia Tech). But the team didn't see this "hang-up" effect, so they think at least one black hole wasn't perfectly lined up.

This hint of a misalignment is tantalizing. If the two black holes formed from two stars that began life together as a binary system, then they'd likely be spinning at roughly the same angle as their orbital motion. But if the black holes joined up after they formed — say, by sinking to the center of a dense stellar cluster — then their two spins could easily be totally different. "This is an important clue in understanding how black holes form," Cadonati says.

The spin values themselves might provide another clue. All three of the final black holes whose birth LIGO has detected spin at rates that are about 70% of the maximum allowed. This result matches recent calculations by Maya Fishbach (University of Chicago) and others, suggesting that when black holes of similar masses merge, the resulting object will have a rotation period around this 70% value. If this correlation holds up, then whenever we find a black hole with this spin rate, we might be able to say that it's the product of a merger.

■ CAMILLE M. CARLISLE

STELLAR

Potential "Failed Supernova" Discovered

ASTRONOMERS MIGHT have watched a star collapse directly into a black hole without going supernova.

Scott Adams (Caltech) and colleagues caught the rare event using the Large Binocular Telescope in Arizona. They were using the paired 8.4-meter telescopes to monitor a million aging stars in 27 nearby galaxies, waiting for the stars to go pop.

Typically, a star more than eight times as massive as the Sun ends its life with a bang. Yet simulations suggest that some massive stars will never explode. "The 'explodability' of a star seems to be dependent on the density

EXOPLANETS

Mini-Flares Might Threaten Life Around Red Dwarf Stars

Illustration of an exoplanet orbiting a red dwarf star

A NEW STUDY of data archived from the Galaxy Evolution Explorer (GALEX) spacecraft reveals how hard life might be on exoplanets orbiting red dwarfs.

Worlds recently discovered in or near the habitable zones around these dim stars have captured our imagination, from the seven planets of the TRAPPIST-1 system to LHS 1140b (*S&T:* Aug. 2017, p. 12). But there's one problem: the host stars. *M* dwarfs are known to throw tantrums in their youth, unleashing intense flares and winds.

With this in mind, Chase Million (Million Concepts) combed through archived GALEX data for flaring red dwarfs. The stellar eruptions release radiation across a wide range of wavelengths, from X-rays to radio, but they peak in the ultraviolet, with a significant fraction of the energy released in the same bands that GALEX observed. Quiet red dwarfs, on the other hand, are relatively dim in the ultraviolet — a contrast that enables a satellite like GALEX to easily pick out flares.

Using specially created software, Million and colleagues studied several hundred *M* dwarfs and found dozens of smaller flares that had evaded detection. This result, announced June 6th at the summer meeting of the American Astronomical Society in Austin, Texas, will help astronomers determine whether the TRAPPIST-1 exoplanets and others like it are truly habitable.

Early indications are that far more low-energy flares occur than high-energy ones. But even low-energy flares might add up to produce inhospitable environments. Moreover, flares lose energy as they travel through space, so planets in a red dwarf's close-in habitable zone are likely to be hit harder than planets, like Earth, that orbit farther away.

■ SHANNON HALL

• More at https://is.gd/galexmdwarfs.

IN BRIEF

TRAPPIST-1h Is Real

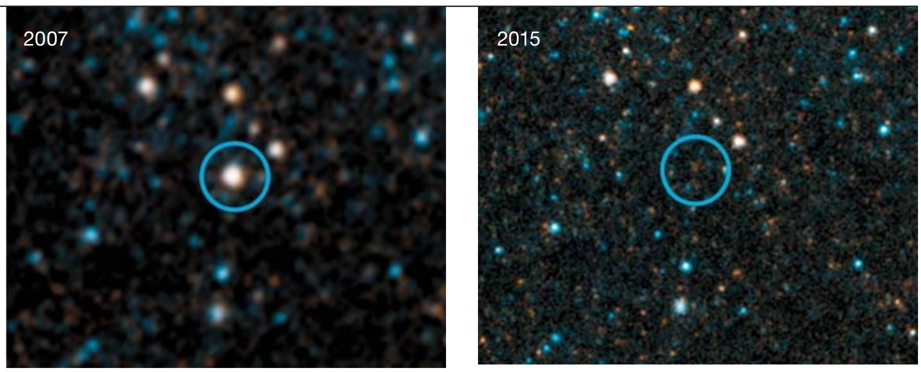
Rodrigo Luger (University of Washington, Seattle) and colleagues have confirmed the existence of the seventh planet around the ultracool dwarf star TRAPPIST-1 (*S&T:* June 2017, p. 12). The team used more than 70 days of data from NASA's repurposed Kepler spacecraft, taken as part of its K2 mission. The craft detected the planet, TRAPPIST-1h, crossing in front of its star four times, with an orbital period of 18.77 days — just what the researchers were expecting, based on previous observations, the team reports May 22nd in *Nature Astronomy*. The transits reveal that planet h is 75% as wide as Earth, or about 40% larger than Mars. Furthermore, starspots in K2's data enabled the astronomers to clock the dwarf's rotation period at 3.3 days, considered middle-of-the-road for nearby, ultracool dwarf stars. Kepler also didn't reveal much stellar activity, but it did catch at least one notable flare. Based on the spin and activity level, the authors estimate that the star's age is between 3 and 8 billion years.

■ CAMILLE M. CARLISLE

• Read more at https://is.gd/trappist1h.

of the layers just outside of the iron core," Adams explains. If the star is too dense, then when the heavy, inert core gives way to gravity, the star will collapse quietly.

Reporting in the August *Monthly Notices of the Royal Astronomical Society*, the team has found a star in the Fireworks Galaxy (NGC 6946) known as N6946-BH1 that seems to have done just that. The star's light stayed roughly constant over a decade before it changed suddenly in 2009, brightening to become 1 million times more luminous than the Sun for several months. (Core-collapse supernovae become another 10,000 times brighter than that.) Then the star's visible light disappeared. But Spitzer Space Telescope images reveal a faint infrared glow — there's still something there. The glow could come from warm stellar debris falling back onto a newly formed black hole. Or it could instead emanate from dust enshrouding a surviving star, perhaps one that just experienced an extreme outburst and ejected material.



▲ Before and after shots of N6946-BH1 by the Hubble Space Telescope

If with time the infrared glow starts to brighten, then we might be seeing a surviving star emerging from an expanding cocoon of dust. But if it continues to fade, then we're more likely seeing stellar remnants feeding the black hole, the team suggests.

■ MONICA YOUNG

DWARF STAR ILLUSTRATION: NASA / ESA / G. BACON (STSCI); SUPERNOVA: NASA / ESA / C. KOCHANEK (OSU) (2)

RADIO

Homing in on a Fast Radio Burst

▲ This artist's impression shows the radio dishes of the Very Large Array receiving the signal of FRB 121102.

THREE NEW PAPERS, published on the open-access site arXiv.org in late May, present surprising results on the only known repeating fast radio burst, dubbed FRB 121102.

Astronomers previously pinpointed this FRB's location in a remote dwarf galaxy and near a faint, persistent source of radio energy (*S&T:* Apr. 2017, p. 10). Now, ground- and space-based observations by a large international team of astronomers reveal that the bursts originate in an active, compact star-forming region some 4,500 light-years across on the outskirts of the tiny galaxy. According to team member Jason Hessels (Netherlands Institute for Radio Astronomy), this location strongly suggests that the source of the bursts is a relatively young object, perhaps a recently formed neutron star.

However, X-ray observations have detected nothing from FRB 121102, and a powerful pulsar should emit X-rays. The Crab pulsar, for example, emits both giant radio flares (albeit roughly 1/500,000 as powerful as FRB 121102) and is a conspicuous X-ray source, too. Nor is it clear whether the bursts have a pattern.

Still, Hessels believes that the culprit must be a young stellar remnant — maybe a rapidly spinning *magnetar* (a strongly magnetized neutron star). The faint, persistent radio source could be the shock wave from the original supernova explosion. Then again, known magnetars also produce powerful bursts of X-rays and gamma rays, which have not (yet) been observed in the case of FRB 121102.

■ GOVERT SCHILLING

SOLAR SYSTEM

Earth's "Xenon Paradox"

XENON ISOTOPES measured by the European Rosetta spacecraft suggest that comets delivered nearly a quarter of Earth's atmospheric xenon.

Xenon is a noble gas with nine stable isotopes, created at different stages in a star's life. Our solar system formed with a mix of these, recycled from earlier stars. But scientists estimate that the levels of heavy isotopes in Earth's primordial xenon mix (referred to as "U-xenon") were lower than those in the solar wind and asteroids.

Flying daringly close to the nucleus of Comet 67P/Churyumov-Gerasimenko in May 2016, Rosetta identified seven isotopes of xenon. The ratio is markedly different from that seen in asteroids and the solar wind — but similar to the predicted U-xenon ratio of primordial Earth. Reporting in the June 9th *Science*, Bernard Marty (CNRS, France) and colleagues conclude that comets contributed 22% of Earth's current atmospheric xenon — the first definitive link between the compositions of comets and Earth's atmosphere.

■ DAVID DICKINSON

MISSIONS

NASA's Lunar Orbiter Takes a Hit

On October 13, 2014, as NASA's Lunar Reconnaissance Orbiter scanned the landscape 1,834 km (1,139 mi) below, a tiny bit of space rock struck the camera's big, scoop-shaped radiator and created this brief vibration. The attacking particle was just an estimated 0.8 mm across (no bigger than a pinhead) and 1⁄1000 of a gram, but it was moving very fast — perhaps 7 km/s (16,000 mph). No other sensors recorded an anomaly, and LRO personnel back on Earth might never have known about the strike were it not for this swatch of zigzag jitter. The cameras build up images one line at a time as the spacecraft coasts high above the lunar surface. As shown here, the image scan started fine (top) but then briefly recorded a zigzag pattern about 10 pixels wide. That corresponds to an angular jitter of roughly 1 arcsecond (1⁄3600°). At the time, LRO was recording a strip of lunar terrain on the Moon's farside, just northwest of Mare Orientale.

■ J. KELLY BEATTY

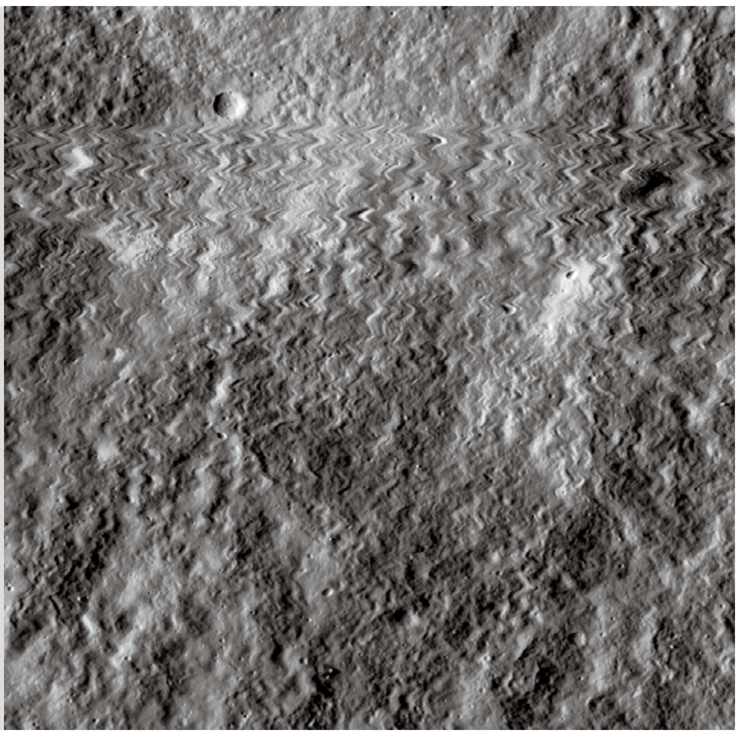
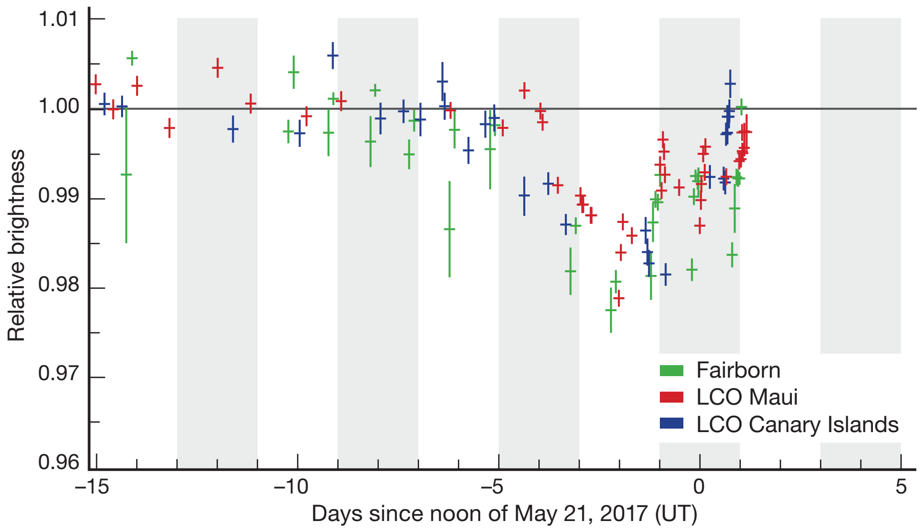


ILLUSTRATION: DANIELLE FUTSELAAR; MISSIONS: NASA / GSFC / ARIZONA STATE UNIVERSITY

STELLAR

Tabby's Star Dims on Cue



OFFICIALLY KNOWN as KIC 8462852, Tabby's Star dimmed substantially in late May, dropping in brightness by 2% before recovering (see graph above). KIC 8462852 has previously exhibited deep dips over days and weeks, a 4-year-long dimming trend, and possibly a century-long fade — behaviors that are difficult to explain (*S&T:* June 2017, p. 16).

The latest dip was the first seen since NASA's Kepler spacecraft stopped monitoring the star in 2013, as well as the first seen since the star attained notoriety in 2015. Notably, the event did *not* come as a complete surprise: In 2016 Tabetha Boyajian (Louisiana State University) and colleagues predicted that, if the strange pattern arises because a circumstellar object — such as a giant comet in an elliptical orbit — is passing in front of the star, then a dimming event would happen in May 2017.

A bevy of telescopes slewed toward Tabby's Star during its temporary fade, including both ground- and space-based instruments and professional and amateur telescopes. Unfortunately Kepler only detects changes in a star's brightness, not its appearance across multiple wavelengths. Nor could it measure how the star's spectrum changed throughout a dip's evolution. Such observations will be crucial to zeroing in on an explanation. For example, *if* a giant comet circles KIC 8462852, then the dips will look different at different wavelengths, because the coma won't block all wavelengths equally.

While the 2% dip ended on May 22nd, further observations in mid-June showed additional changes. Expect analysis of these observations, and perhaps an answer to the star's mysterious behavior, soon.

■ MONICA YOUNG

• **For more information about KIC 8462852's dramatic dimming, see https://is.gd/tabbymay2017.**

MISSIONS

Early Psyche Launch

ORIGINALLY SLATED to launch in 2023, NASA's mission to asteroid 16 Psyche will now start its journey a year earlier, in the summer of 2022. The decision comes as a result of a new, optimized trajectory that doesn't require an Earth gravity assist — and arrives a whopping four years earlier than planned, in 2026. The new trajectory also stays farther from the Sun, meaning the craft will need less heat protection, but it does require more power, which will be provided by a pair of five-panel, X-shape solar arrays.

■ JANINE MYSZKA

IN BRIEF

Jupiter Impact Spotted

On May 26th, amateur astronomers recorded a rare impact flash in Jupiter's north polar region. It's the sixth time that Jupiter has been beaned (that we know about). Corsica amateur Sauveur Pedranghelu detected it live on video between 19:24.6 and 19:26.2 Universal Time. A second video by Thomas Riessler of Dettenhausen, Germany, showed an identical pinpoint flash between 19:24.6 and 19:25.0 UT. From the two videos, the fireball lasted between 0.7 and 0.87 second and was about the size of Europa when seen in transit; Pedranghelu's detection also displayed two brightness peaks. Follow-up observations did not turn up any traces of impact debris.

■ BOB KING

• Read more at https://is.gd/jupiterhit6.

Two New Jupiter Moons

A pair of moonlets found orbiting Jupiter brings the planet's total satellite count to 69. Scott Sheppard (Carnegie Institution for Science) and colleagues announced the objects, S/2016 J 1 and S/2017 J 1 ("S" for satellite, "J" for Jupiter), via Minor Planet Electronic Circulars in early June. With magnitudes hovering near 24, these barely-there moonlets must be only 1 or 2 km (0.6 to 1.2 mi) across. As with the vast majority of Jupiter's moons, both occupy *retrograde orbits*, meaning that they move in directions opposite that of the planet's spin. The orbits are also elongated and highly inclined. Such distant, irregular circuits imply that these bodies formed elsewhere in the outer solar system and were captured while passing by early in the planet's history.

■ J. KELLY BEATTY

Hottest Hot Jupiter Yet

The bloated exoplanet KELT-9b is now the hottest gas giant known. With almost triple Jupiter's mass but half its density, the exoplanet orbits an *A*-type star more than twice as massive as our Sun every 18 hours. The constant bombardment of ultraviolet energy toasts KELT-9b like a marshmallow, bringing its daytime temperature to around 4600K (7800°F), hotter than most red dwarf stars and only about 1200K cooler than our Sun's visible surface. The exoplanet is some 1000K hotter than any other known transiting gas giant, Scott Gaudi (Ohio State University) and colleagues report June 5th in *Nature* and at the summer American Astronomical Society meeting in Austin, Texas.

■ DAVID DICKINSON

LEAH TISCIONE / *S&T*, SOURCE: LCOGT AND TENNESSEE STATE UNIVERSITY / CENTER OF EXCELLENCE FOR INFORMATION SYSTEMS ENGINEERING AND MANAGEMENT / FAIRBORN OBSERVATORY

My Rock of Ages

On being immortalized far out in the asteroid belt.

JAROSLAVAV / BIGSTOCKPHOTOS.COM

WHEN I GIVE public lectures I often say that somewhere out there is an asteroid with Earth's name on it. Now I can add that one has my name on it, too.

Recently I learned about the naming of asteroid 22410 Grinspoon. It's pretty cool to have a space rock a few kilometers wide named after me. But the truth is, millions of these "minor planets" exist, more than 20,000 of them with people's names attached. It's not like having an eponymous planet, or even an eponymous feature on a planet. For those, the rules are clear: To earn the honor of having, say, a crater bear your surname, you first have to die, which would seem to take the fun out of it.

Upon hearing the news, I immediately thought of Antoine de Saint-Exupéry's Little Prince, living on his little asteroid called B-612 and pulling up the baobab trees that threaten to overrun it. Today there's an organization, called the B612 Foundation, dedicated to protecting our planet against future asteroid impacts. Indeed, right after emailing family members to share my delight, I checked my asteroid's orbital parameters. What if it was one of the 1,786 potentially hazardous objects detected so far (as of last March)? I could just see the headline: "Grinspoon threatens Earth in 2042!"

> "You're just outside the 3:1 resonance, but far enough from it that you probably won't kill us anytime soon." Phew.

What I found is that it has a semimajor axis, or average distance from the Sun, of 2.57 a.u. That's a little over two and a half times the distance from Earth to our star. It has an eccentricity of 0.0232, making its orbit almost circular, and an inclination of 3.5°, which takes it slightly out of the ecliptic plane. So it's a fairly ordinary main-belt asteroid.

But it's part of a vast reservoir of rocks close enough to Jupiter's orbit that the big planet sometimes perturbs a fragment into a more hazardous orbit. In fact, my asteroid orbits just outside of a large gap in the main belt at about 2.5 a.u. that our largest planet has already cleared out. Anything in that gap orbits three times for every one Jupiter year, and the cumulative gravitational effect of this "3:1 resonance" is to heave those objects elsewhere in the solar system. I checked with an asteroid expert friend, who told me, "You're just outside the 3:1 resonance, but far enough from it that you probably won't kill us anytime soon." Phew.

So, asteroid Grinspoon is no danger to anyone, and probably not of much interest, either — except as one tiny part of a huge swarm that collectively contains important clues to planetary origins and in the future may provide raw materials for all kinds of deep-space manufacturing and mischief. Understanding more about these space outcasts and how to alter their orbits may save our hides one day.

So, future humans, it's okay with me if you grind up "my" asteroid for minerals, use it for terraforming another planet (please request permission from the locals first), hollow it out to live inside it, or even plant a forest of genetically modified, radiation-hardened baobab trees on it.

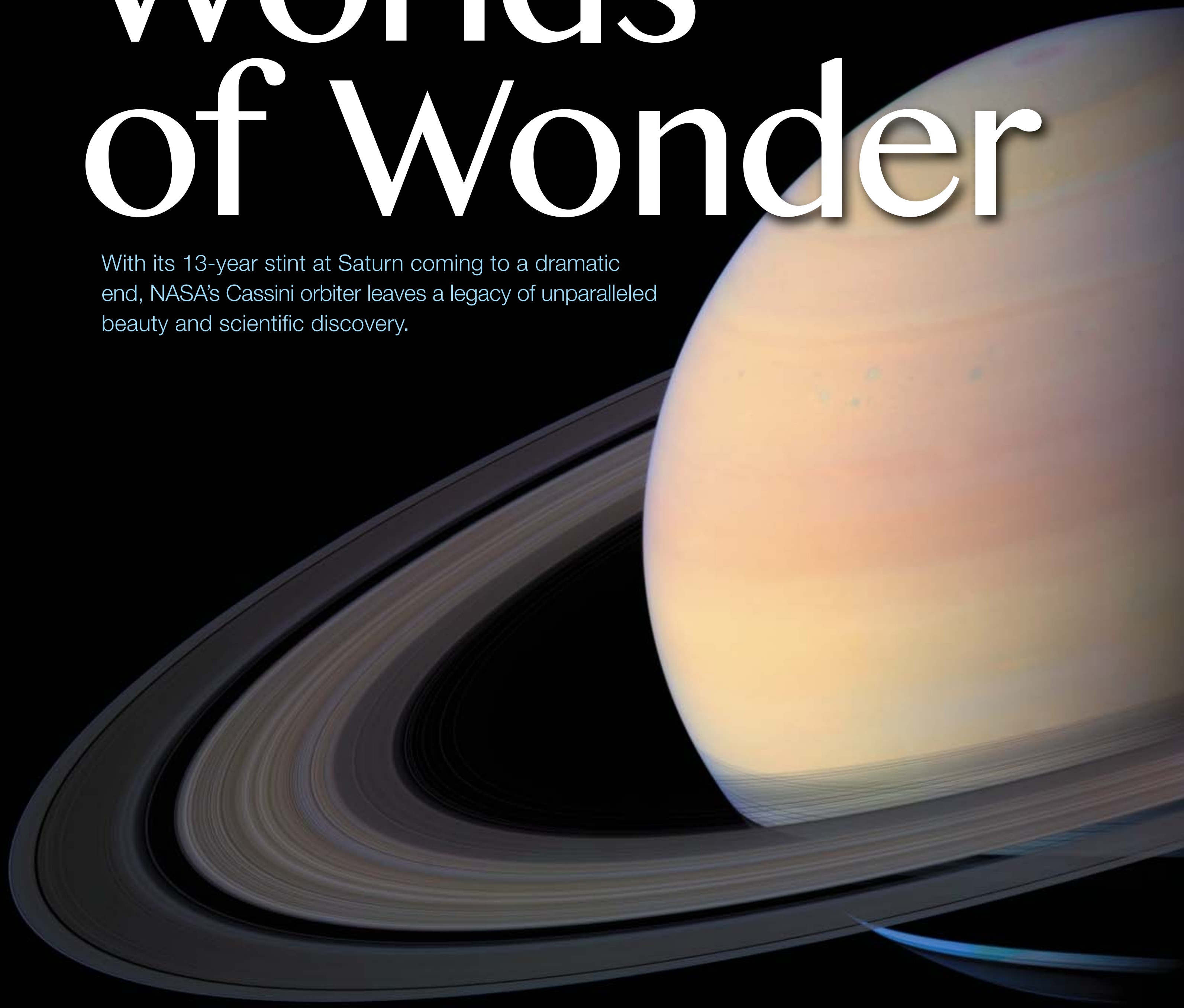
Naming things can provide an illusion of immortality, but all of this is temporary. Whatever happens to 22410 Grinspoon, something else will end up using its atoms. As the poet Joy Harjo wrote, "I know we will live forever, as dust or breath in the face of stars, in the shifting pattern of winds."

DAVID GRINSPOON is an astrobiologist at the Planetary Science Institute. Follow him on Twitter: @DrFunkySpoon.

 by Luke Dones

Worlds of Wonder

With its 13-year stint at Saturn coming to a dramatic end, NASA's Cassini orbiter leaves a legacy of unparalleled beauty and scientific discovery.

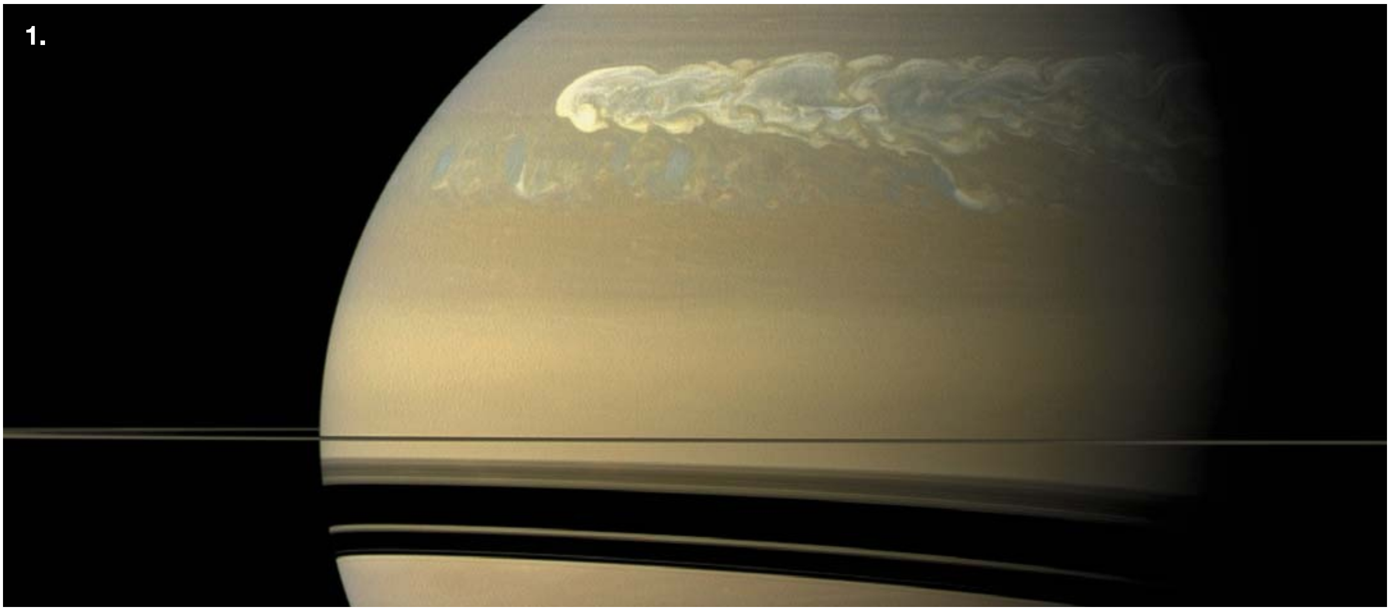


SIMPLY STUNNING Saturn surpasses all other planets for its delicate complexity and surreal beauty. Three months after Cassini arrived, its cameras recorded the mosaic of 102 frames that went into this dramatic vista. Note the tangled interplay of narrow bands in the inner C ring and the shadows they cast on the planet's equator. Below the dense, outer A ring and the complex, even more opaque B ring, blue hues arise from sunlight scattering high in the planet's atmosphere.
NASA / JPL / SPACE SCIENCE INST. / MATTIAS MALMER

The Cassini orbiter, now executing its Grand Finale, has revolutionized our knowledge of the Saturnian system. It's that simple, and that profound.

Launched in 1997, Cassini flew by Venus twice, then past Earth, an asteroid, and Jupiter on its way to Saturn. Finally reaching its destination after a 7-year journey, it went into orbit on July 1, 2004, and later released the European Space Agency's Huygens probe, which sniffed the atmosphere of Titan during its descent and landing in early 2005. Originally planned as a 4-year mission, Cassini will end its 13 years in residence when it plunges into the planet on September 15, 2017.

NASA / JPL



Since its arrival, the spacecraft has witnessed a storm erupt on Saturn; viewed the planet's north and south poles clearly for the first time; observed all of Saturn's inner moons at close range and dozens of "irregular" moons from a distance; partnered with the Hubble Space Telescope to investigate Saturn's auroras; mapped the surface of haze-shrouded Titan; measured the composition of its complex atmosphere; plunged through the watery plumes of Enceladus; and much more.

Titan, a moon bigger than the planet Mercury and cloaked in an atmosphere denser than Earth's, proved to be a fully stocked organic-chemistry lab, featuring giant lakes of hydrocarbons, dynamic clouds and storms, and methane rain.

Saturn's brilliant rings are ever changing, particularly the narrow, multi-stranded F Ring, which inhabits the gravitational "Roche zone" where satellites and rings co-exist.

Cassini — the man — discovered Iapetus, Saturn's distant, third-largest moon, in 1671, and he soon realized that Iapetus has a bright hemisphere and a dark hemisphere. Cassini — the spacecraft — discovered that this object's two-toned appearance results from a feedback loop driven by ice's faster

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1. STORMY SATURN On February 25, 2011, Cassini captured a huge storm churning through the atmosphere in Saturn's northern hemisphere (*S&T:* May 2012, p. 20). By then the storm had raged for about 12 weeks, long enough to become quite extended in longitude and to wrap itself around the planet. The ring system's shadow has a strong seasonal effect on Saturn's atmosphere, so perhaps this storm is related to the change of seasons after the planet's August 2009 equinox. The storm was a prodigious source of radio noise, arising from lightning deep in the planet's atmosphere.

2. ALIEN LANDSCAPE Hyperion has an unusual, spongy appearance that probably results from its low density, only a bit more than half that of water ice. The low density means that Hyperion must be highly porous, causing craters to form in a different way than they would as impacts onto a solid surface. This composite, recorded September 26, 2005, includes images taken through ultraviolet, green, and near-infrared filters.

3. TWO-FACED MOON Iapetus is the most distant of Saturn's "regular" moons and the third largest. Most of the hemisphere shown here is very dark, probably because of infall of material from Phoebe and other irregular moons orbiting farther out. The other half is bright white. An equatorial ridge, standing up to 13 km (8 miles) above its surroundings, gives Iapetus the appearance of a walnut. The ridge probably arose early in the moon's history when a ring system that surrounded Iapetus after a giant cometary impact fell back onto the surface and piled up.

4. CROSSING OVER Cassini crossed from the sunlit to the unlit face of the rings on January 17, 2007. In the top two images, the broad, bright B ring (right half) dominates. The dark — but not empty — Cassini Division separates it from the dimmer A ring (at left), which sports the Encke Gap near its outer edge. Enceladus appears at upper left in the second frame. The bottom two images show sunlight filtering through the rings to their unlit side. Here appearances are reversed: The translucent A ring looks brightest, while the more opaque B ring is dark because very little light filters through.

5. SUNNY GLINT The bright spot in the B ring represents the location of *opposition*, that is, where the Sun is directly behind Cassini (the illumination phase angle is 0°). The size of the spot varies from ring to ring and depends upon the microscopic structure of the ring particles. This *opposition effect* thus provides a way to investigate the structure of the rings on scales far too small to be imaged directly. The fainter C ring is at left in this view recorded June 26, 2005.

6. FLYING SAUCERS Each of these tiny moons orbits within or near one of Saturn's rings. Over time they've accumulated so many ring particles around their equators that they look like enormous "flying saucers" or ravioli. Ring particles seem to cover almost all of Atlas, which orbits just beyond the A ring's outer edge.

7. TOTAL ECLIPSE Cassini recorded the images for this mosaic on September 15, 2006, as the spacecraft briefly passed through the planet's shadow. The narrow G ring and broad E ring, both full of tiny particles that strongly scatter sunlight, lie outside of the main rings. Aegaeon, a tiny moon discovered by Cassini, is a source of the particles in the G ring, while Enceladus's plumes provide the particles in the E ring. Earth is faintly visible at the 10 o'clock position just within the G ring.

NASA / JPL / SPACE SCIENCE INST.

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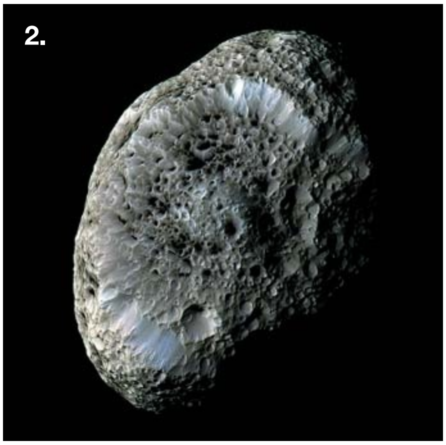

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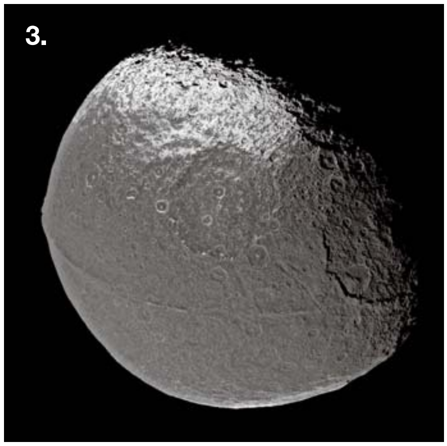

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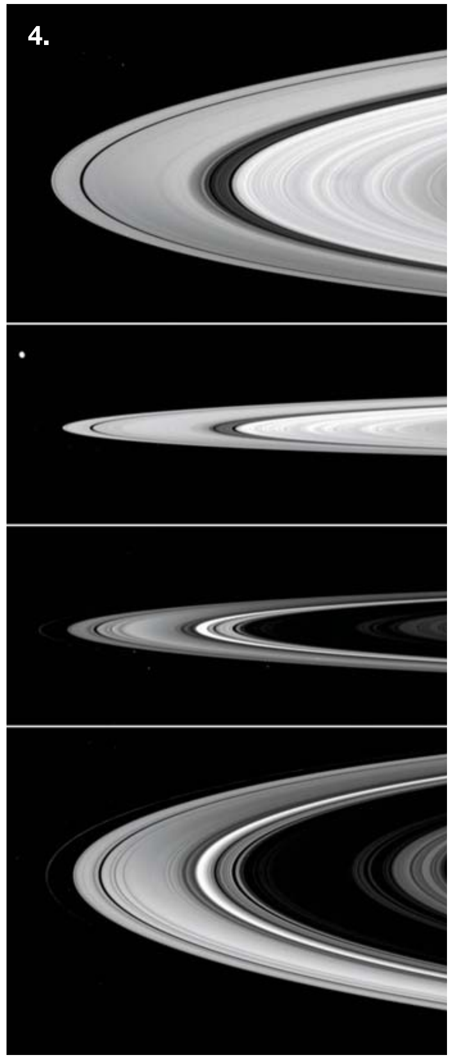

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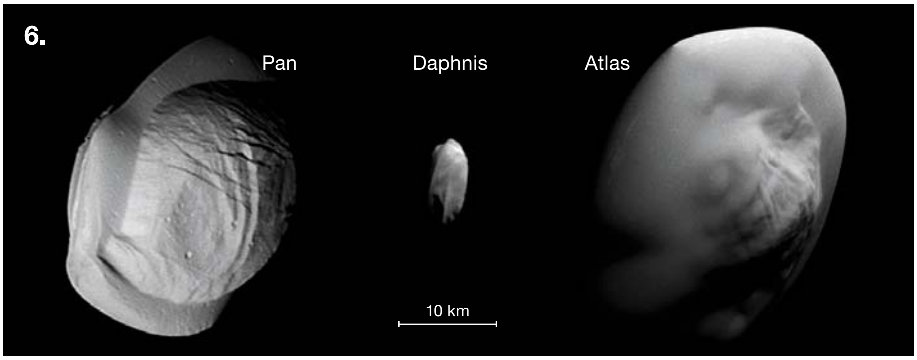

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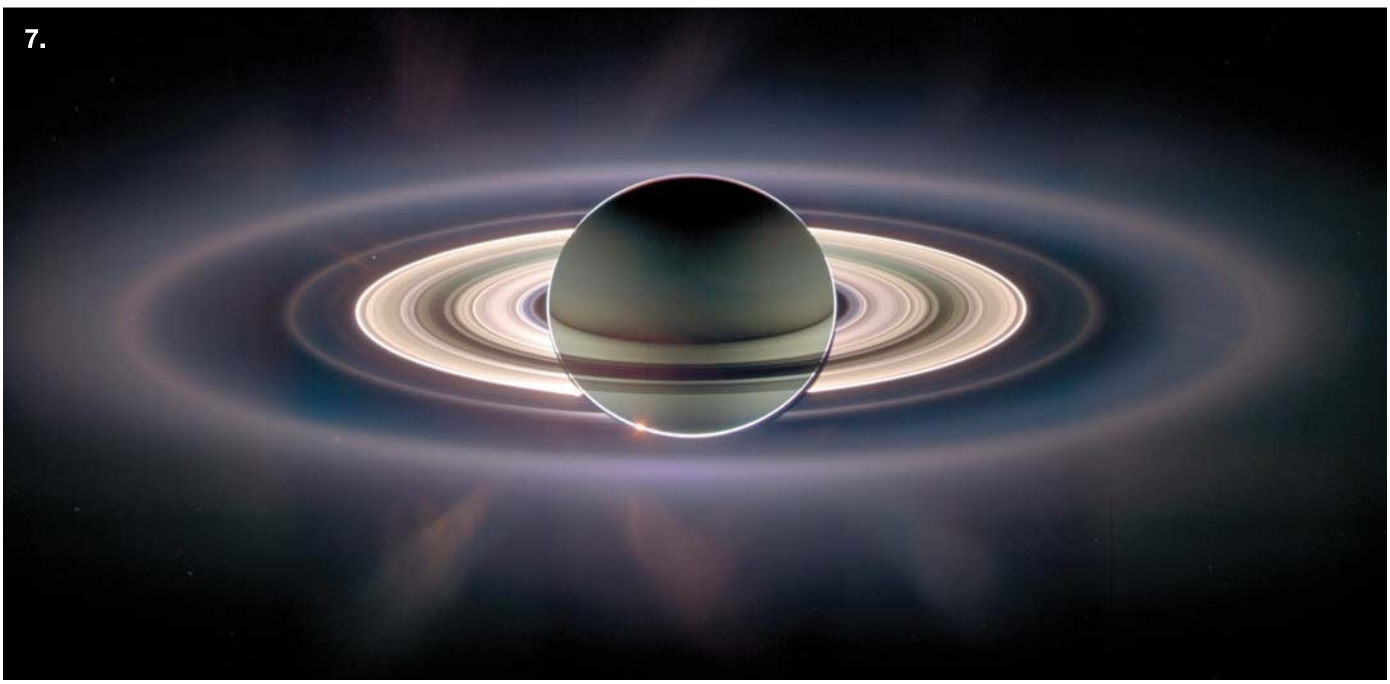
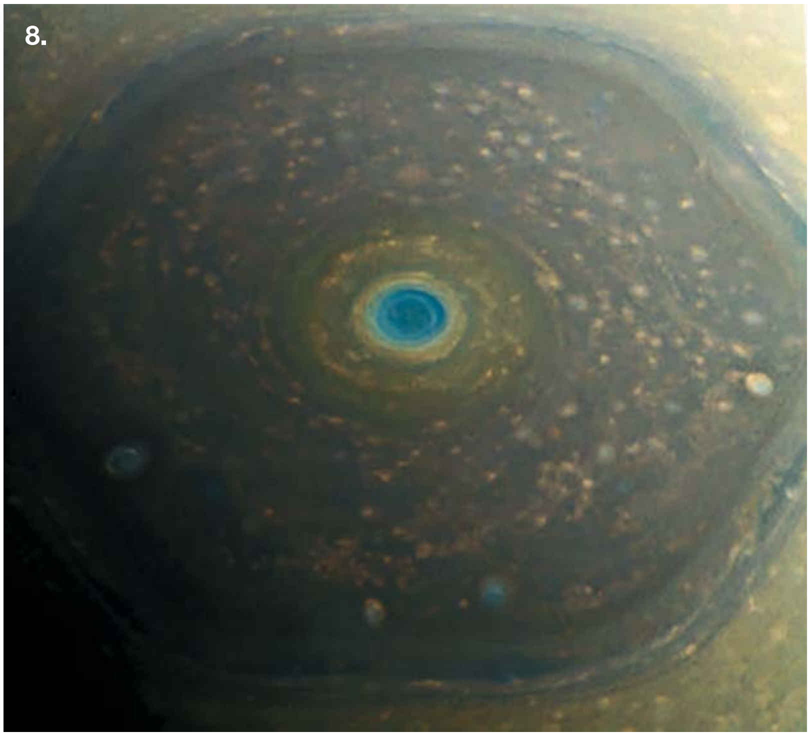
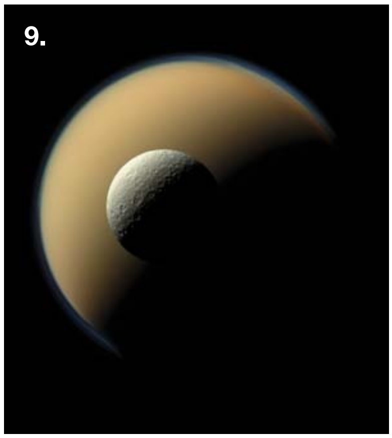


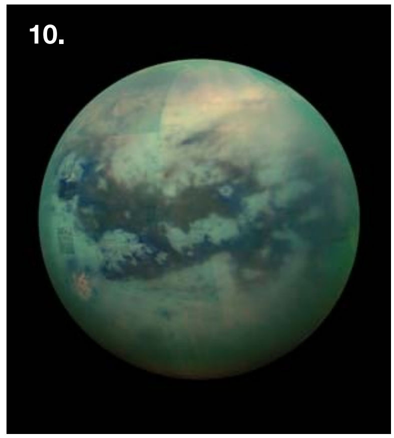
2, 3, 4, 5, & 7: NASA / JPL / SPACE SCIENCE INST.; 6: NASA / JPL / TILLMAN DENK evaporation from dark regions than from bright ones. This "thermal runaway" began billions of years ago, when Iapetus's leading hemisphere was coated with dust blasted from the surfaces of Saturn's even more distant irregular moons, the biggest of which is Phoebe.

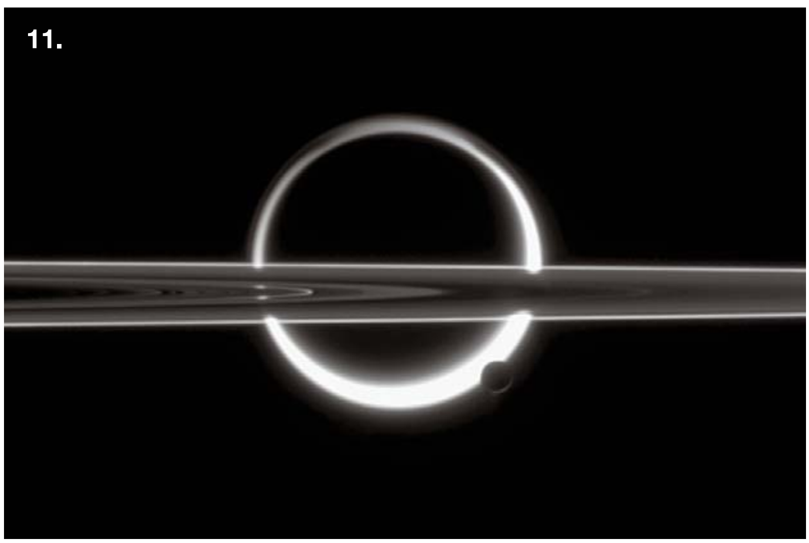
Cassini flew close to Phoebe during its initial approach to Saturn and measured the moon's density, which is higher than is typical of Saturn's ice-dominated satellites. By implication, Phoebe must have a rock-and-ice composition more like that of Pluto, suggesting that this moon originally orbited the Sun before being captured by the planet's powerful gravity.

Like Earth, Saturn has auroras near its poles produced by the interaction between its magnetic field and the solar wind. The auroras cause Saturn to emit radio waves whose strength varies as the









8. GEOMETRIC ODDITY Discovered by Voyager 2 in 1981, the huge, hexagon-shaped cloud pattern surrounding Saturn's north pole remains an enigma. Here's how it looked to Cassini on November 27, 2012. Computer simulations have shown that a shallow eastward-moving jet near the pole, like one of the jet streams in Earth's atmosphere, can develop into a hexagonal pattern.

9. RHEA IN TRANSIT Saturn's two largest moons, Titan (5,150 km across) and Rhea (1,528 km), appear to be stacked on top of each other in this true-color scene recorded June 16, 2011. Titan's dense, nitrogen-dominated atmosphere sports a detached haze layer (seen at upper right) known as the North Polar Hood.

10. TITAN REVEALED Cassini visited Saturn's biggest moon often, making 127 flybys in all. Ordinarily cloaked by opaque haze, the surface of Titan emerges into view when seen at infrared wavelengths. This view shows terrain that is mostly on the moon's Saturn-facing hemisphere. Several places show more details than elsewhere because the spacecraft took those images when closer to Titan during its November 13, 2015, flyby. The scene features the dark, dune-filled regions named Fensal (toward north) and Aztlan (closer to equator), which together form a crude, sideways H.

11. BACKLIT BEAUTY Saturn's backlit rings, gauzy Titan, and Enceladus created this dramatic scene on June 10, 2006. Hazes in Titan's thick atmosphere scatter sunlight to encircle the disk. The crescent of Enceladus encroaches slightly along its lower-right limb, with eruptive plumes faintly visible at its bottom. In this viewing geometry, the brightest parts of the rings are otherwise tenuous features that are rich in tiny, forward-scattering particles.

12. LIGHT & SHADOW Cassini arrived during late summer in Saturn's southern hemisphere, and this view from May 2005 shows the planet's natural tawny color. The bluish tinge near the top results from sunlight striking the northern part of the globe more obliquely, resulting in Rayleigh scattering. Note the interplay of Saturn's delicate, translucent A ring and its finely striated shadow on the planet's disk.

8: NASA / JPL / SPACE SCIENCE INST. / JASON MAJOR; 9 & 11: NASA / JPL / SPACE SCIENCE INST.; 10: NASA / JPL / UNIV. OF ARIZONA / UNIV. OF IDAHO

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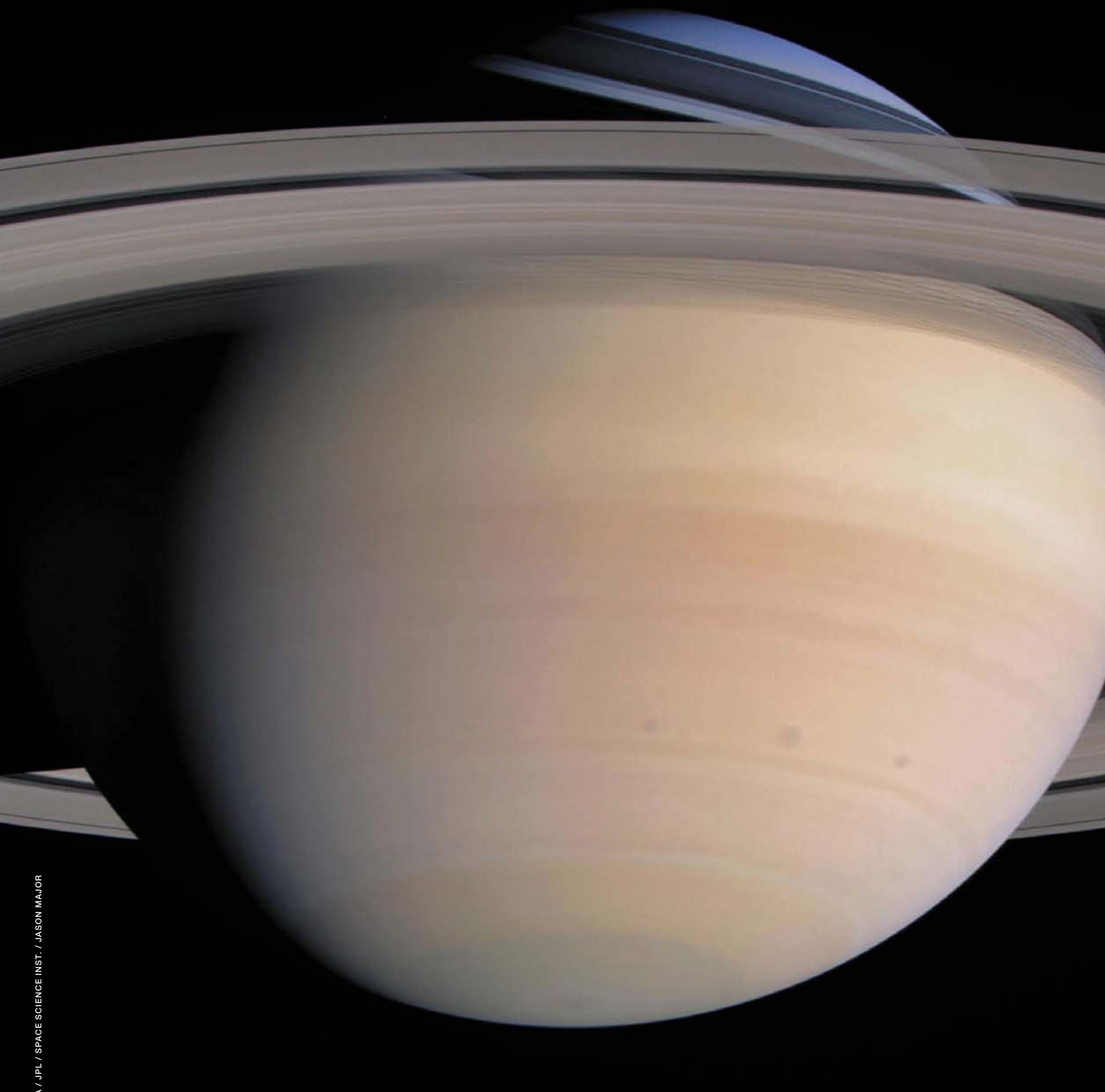

NASA / JPL / SPACE SCIENCE INST. / JASON MAJOR

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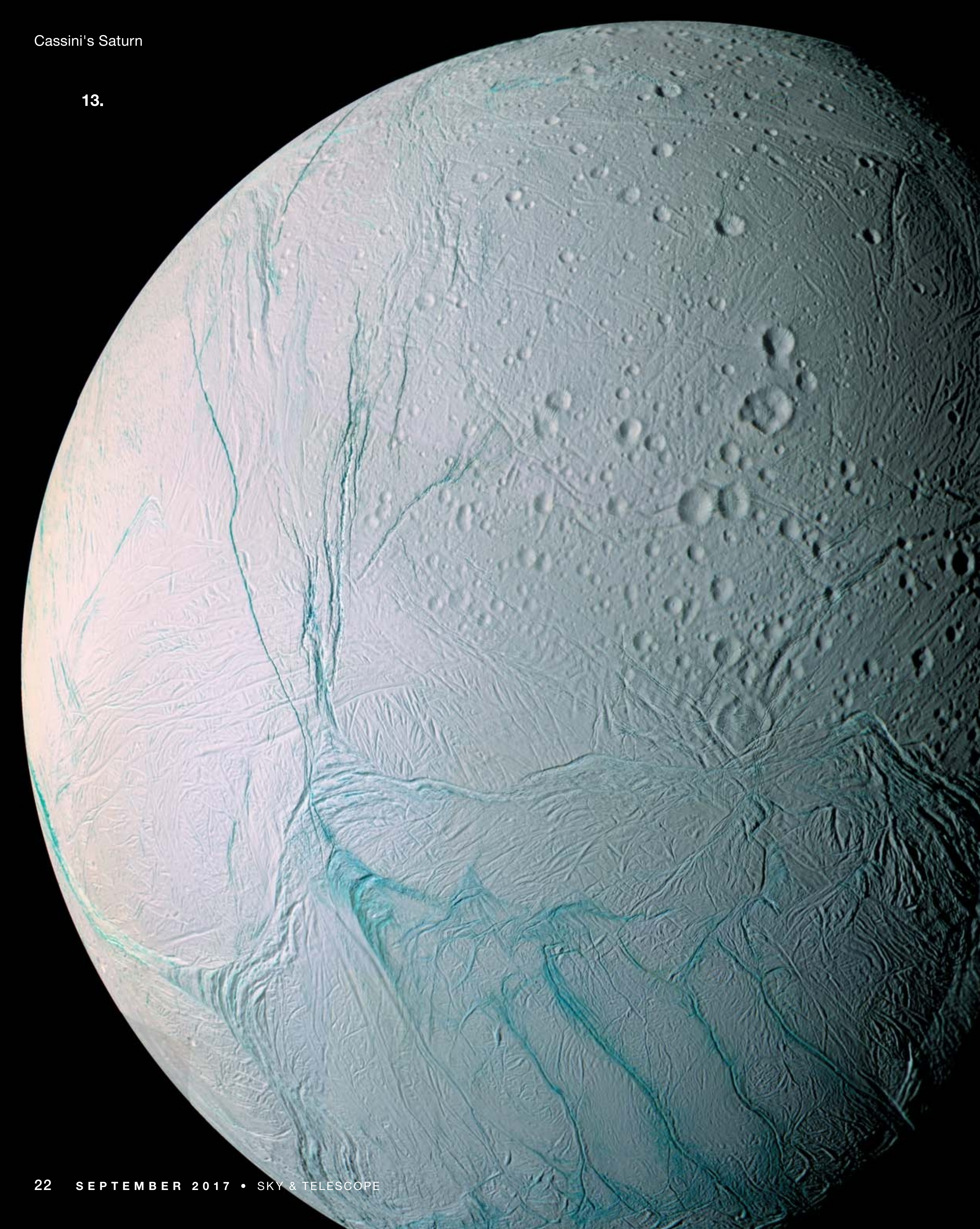
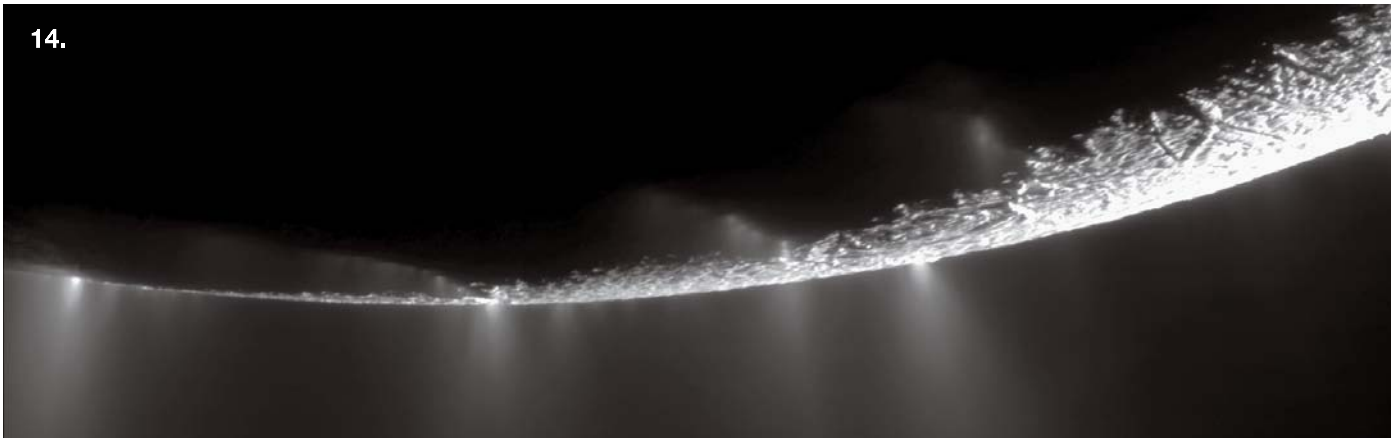




planet rotates. Mission scientists once thought that the period of this variation was synced with the spin rate of the planet's interior and should not change with time. But Cassini has found complicated variations in the radio emission, so the planet's true spin period remains unknown.

Perhaps the most spectacular discovery of the Cassini mission is that Enceladus, the second smallest of Saturn's "classical" satellites, sprays thousands of tons of salty water each day into space from geysers near the moon's south pole. Beneath its icy shell, Enceladus harbors an ocean, the source of the observed plumes. The plumes contain both solids — ice grains and small silica particles — and gases, including methane, nitrogen, hydrogen, and carbon dioxide. On Earth, primitive microorganisms known as archaea use the chemical reaction of carbon dioxide and hydrogen into methane as an energy source. Enceladus's ocean might even contain such simple lifeforms, though that will only be determined by a future mission.

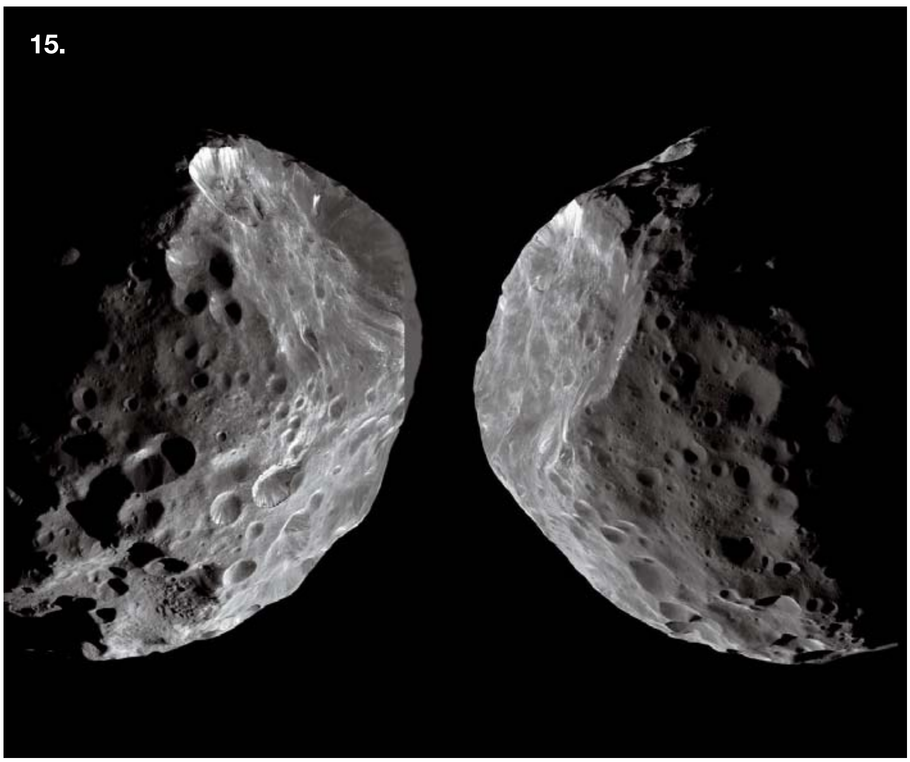
These are but a few of the discoveries by the 12 science instruments of the Cassini spacecraft. All have provided troves of observations that will fuel scientific discovery for decades. Here we have showcased some of the almost 400,000 images taken with Cassini's narrow- and wide-angle cameras and what they've taught us about this incredible destination.

■ **LUKE DONES**, a member of Cassini's imaging team, explores planetary rings, the dynamics of comets and asteroids, and the impact history of the solar system at Southwest Research Institute in Boulder, Colorado.

13. CRACKED ICE Much of Enceladus has a smooth-yet-fractured surface, a telltale hint that its interior is churning with activity. This enhanced-color view, made from images taken in ultraviolet, visual, and near-infrared wavelengths during close flybys in March and July 2005, reveals a system of large cracks (dubbed "tiger stripes") in the moon's southern hemisphere.

14. COLD GEYSERS Dramatic plumes of water vapor and microscopic particles jet into space from the "tiger stripes" near the south pole of Enceladus. These eruptions, seen clearly in this backlit view taken on November 27, 2005, likely originate from a salty ocean deep within Enceladus. The ocean's geochemistry might resemble that of hydrothermal vents in Earth's oceans.

15. IRREGULAR MOON Phoebe is the biggest of Saturn's *irregular satellites*, so called because of their noncircular and highly inclined orbits. These views came during the craft's initial approach to Saturn in 2004. Dynamicists think the irregular satellites of Jupiter, Saturn, Uranus, and Neptune initially orbited the Sun but were captured by their host planets. Cassini observations indicate that Phoebe's density is higher than usual for the Saturn system and akin to those of Kuiper Belt objects, supporting the capture idea.



13–15: NASA / JPL / SPACE SCIENCE INST.

3 Cosmic Chirps &

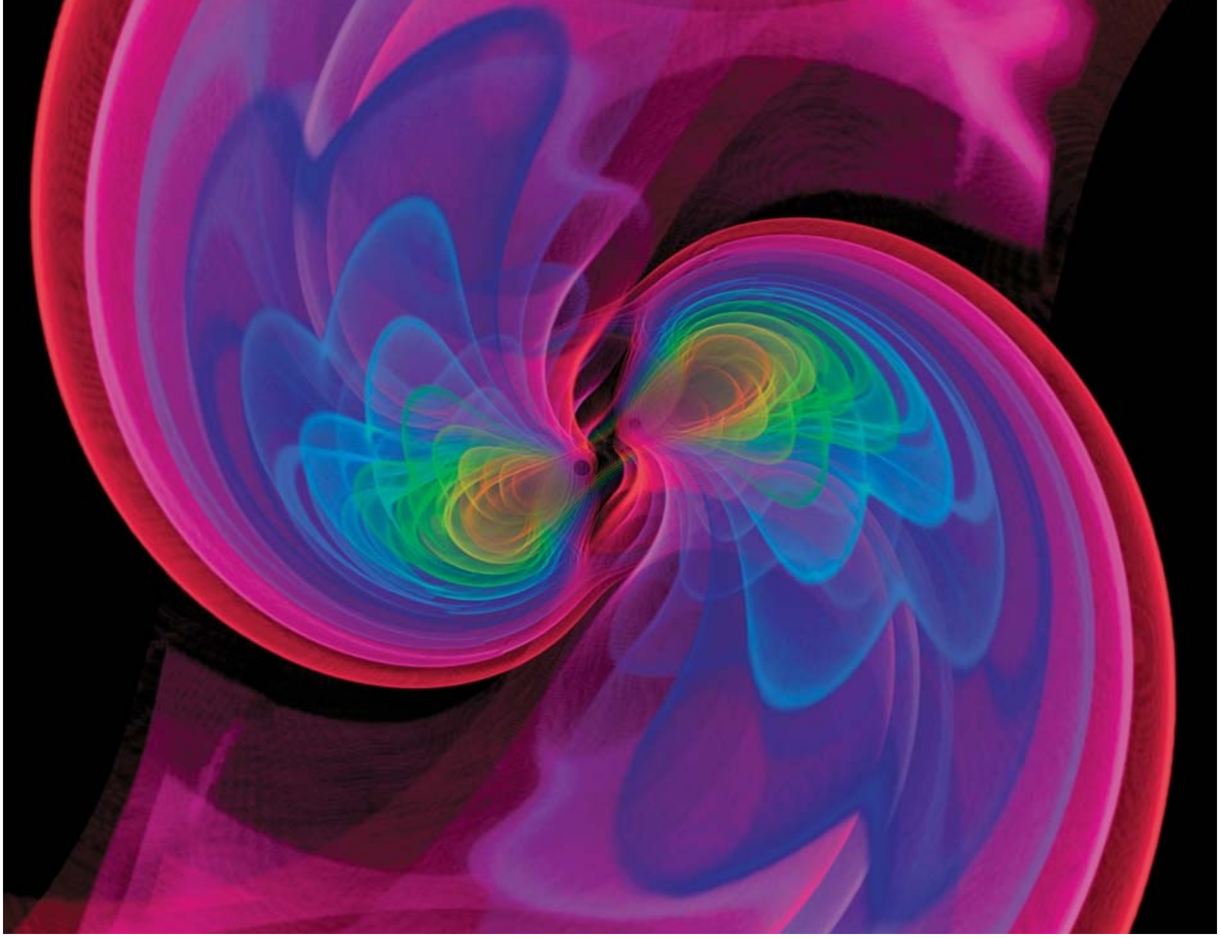
From the first discovery to subsequent finds, **gravitational-wave signals** from the universe's most exotic objects are transforming physics and astronomy.

There are events in everyone's life that are so transformational, they freeze into memory even the most mundane circumstances around them. The detection of ripples in the fabric of spacetime was just such an event. That Monday, September 14, 2015, started as a rather ordinary day for all the scientists involved in the Laser Interferometer Gravitational-Wave Observatory. LIGO is a giant pair of L-shaped detectors, each arm 4 kilometers (2.5 miles) long, built to sense the infinitesimal stretching and squeezing of spacetime created by a passing gravitational wave (*S&T:* Dec. 2015, p. 26).

> Until the end of his life, Einstein was clear about one thing: It would never be possible to confirm that gravitational waves exist.

For most of the last century, that goal seemed like a pipe dream. Albert Einstein published his theory of general relativity in 1915, and a year later he penned the theory's implications for the existence of gravitational waves. These spacetime disturbances propagate at the speed of light, like electromagnetic waves (except the latter are oscillations of electric and magnetic fields). However, until the end of his life, Einstein was clear about one thing: It would never be possible to confirm that gravitational waves exist. Any astrophysical signal would be far too weak and the technological limitations incredible.

Even waves created in our own galaxy by merging two black holes, the universe's most compact objects, would only momentarily expand and contract Earth's diameter by the size of the uranium nucleus. That's equivalent to a change of one part in one thousand billion billion. No device could ever detect such a tiny effect.



Counting...

Yet, on that Monday, we did it. From that first detection and the ones that followed we confirmed general relativity's picture of black holes, established that pairs of black holes do merge in the universe, and began a journey into the densest side of the universe — all by listening to gravitational waves.

▲ **GRAVITATIONAL DANCE** This frame from a computer simulation reveals the complex pattern of gravitational waves emitted by a pair of black holes, 29 and 36 solar masses respectively, moments before they merge. The simulation reproduces the actual merger that was detected on September 14, 2015.

S. OSSOKINE / A. BUONANNO (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS) / SIMULATING EXTREME SPACETIME PROJEKT, D. STEINHAUSER (AIRBORNE HYDRO MAPPING GMBH)

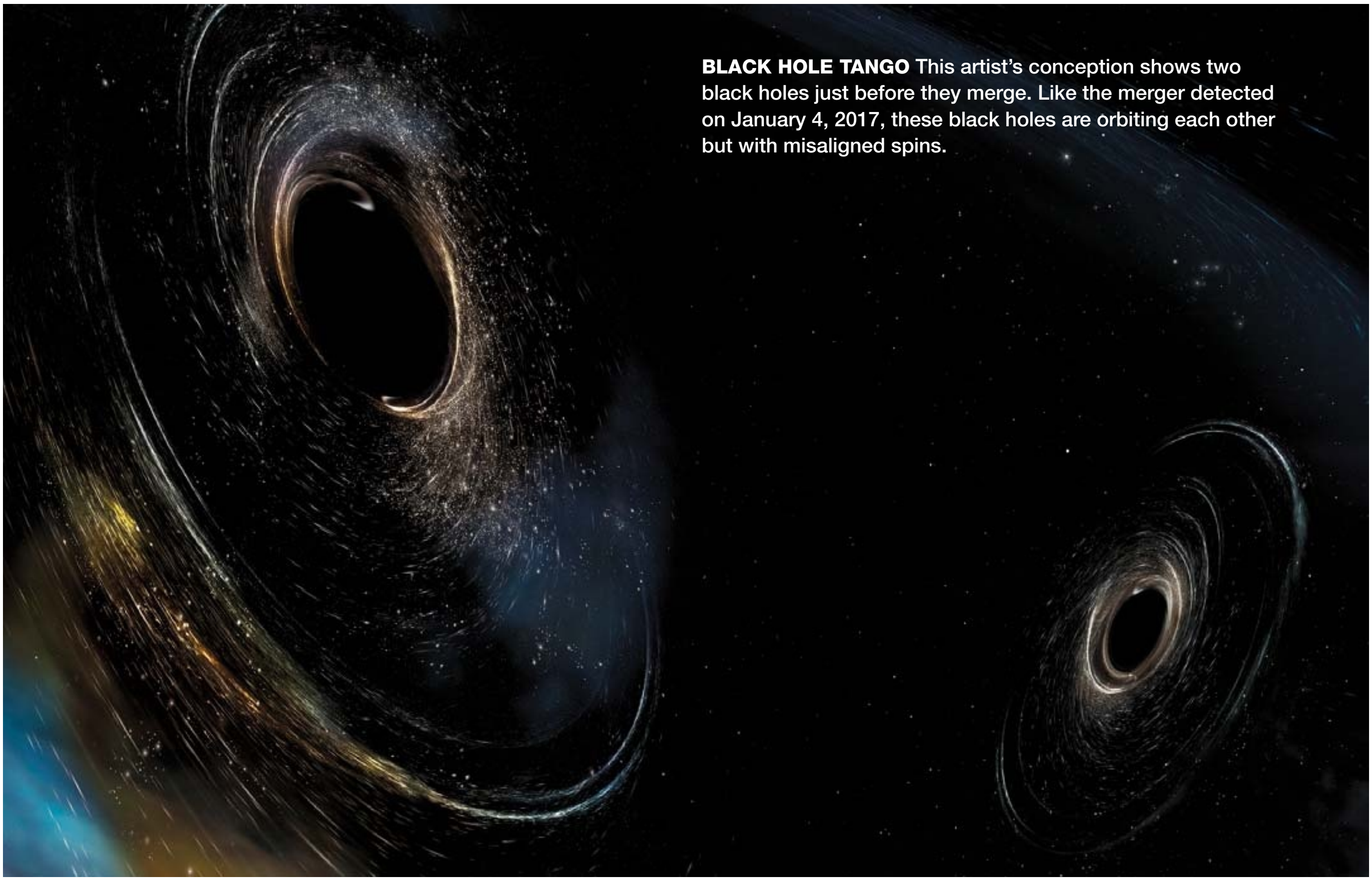
Making Waves

For yours truly, the 14th of September was a hectic day: running children to school and then myself to back-to-back meetings, with no time for lunch and barely even bathroom breaks. While moving from meeting to meeting, I peeked at emails on my phone, but I never had time to read carefully. By midday I could tell something was going on. But Advanced LIGO had just come online three days earlier following major upgrades, and in the rush I thought it was just a test.

At the end of the day, I made it to my daughter's preschool one minute before closing time. My husband was already cooking dinner at home. While preparing the dinner table, I received a text message at 5:42 p.m. (yes, I saved the texts!) from my former graduate student Ben Farr (now a professor at the University of Oregon):

"Have you been keeping up on LSC e-mails today?"
"not yet, what should I catch?" I replied.
"Loud trigger, baby! This could be the one."

I stood there frozen, looking at my screen. Could this be happening?



BLACK HOLE TANGO This artist's conception shows two black holes just before they merge. Like the merger detected on January 4, 2017, these black holes are orbiting each other but with misaligned spins.

LIGO / CALTECH / MIT / SONOMA STATE (AURORE SIMONNET)

Later that evening I hopped onto a Skype chat with Ben. Our research group has been a key contributor to the development of software that takes LIGO candidate signals and extracts information about what types of astrophysical objects could have created them. As pairs of compact objects such as black holes or neutron stars spiral in toward each other, they emit gravitational waves that, if converted to sound waves, would sound like bird chirps. As the two objects drew closer together, those "chirp"-like signals would become louder and higher-pitched until the objects merged — then the signal would fall silent. From such events our calculations can determine the mass of the compact objects involved in the death spiral, how fast they were spinning before they merged, and their distance from Earth.

Ben had already run our codes on the new data, and he showed me his first plots.

"Wow!" I thought. This event looked exactly like it had come from the final stages of two black holes spiraling into each other. The black holes had 29 and 36 times the mass of the Sun, respectively, and their collision took place about 1 billion light-years away.

That is, if it were real.

• Read LIGO's announcements for each gravitational-wave discovery here: https://is.gd/LIGO_discoveries

No way, I told Ben. If we are receiving a real signal just days after the detectors came back online, then these events must be happening frequently — why did we not see them with LIGO's first attempts? And black holes with 30 times the mass of the Sun? No firm electromagnetic measurements of stellar-mass black holes have found such heavyweights, so it would be incredibly unlikely that we would detect a system like that as our first signal.

This must be a blind injection, I said: a scientific fake-out in which only three or four people (out of more than a thousand) in the whole LIGO team know that a simulated signal has been inserted in the data. The rest of the collaboration is tested on handling it as a real signal. But they should have chosen more realistic values — clearly whoever did it wasn't familiar with the existing astrophysical observations, I thought.

Ben was convinced this was the real thing. We agreed to disagree and called it a night.

Now, of course, we all know that I was wrong and Ben was right — this black hole merger did indeed happen.

Only the Beginning

The gravitational waves produced from the merger had been traveling through the universe unimpeded for 1 billion years before they entered our Milky Way about 50,000 years ago, when the Sahara was still wet and fertile. They came from the south to the LIGO detector in Livingston, Louisiana, on

September 14th at 09:50:45 UT. Seven milliseconds later, they hit the LIGO detector in Hanford, Washington. Then they continued past Earth into the cosmos beyond.

Following a pre-existing plan, my collaborators and I on the detection committee and across the whole international scientific collaboration worked around the clock for weeks, laboring through a list of more than 170 checks and questions that needed to be addressed before we could conclude with confidence that the signal was real. We tested the data, hardware, software, and hundreds of thousands of channels recording extraneous noise. We came up empty-handed. There was only one possibility left: This was a bona fide signal. We called it GW150914.

A second signal reached us on October 12, 2015, dubbed LVT151012. It was not nearly as strong — it ended up being what scientists call a 1.7-sigma detection, with only a probability of about 85% that it is of astrophysical nature; there's a 15% chance we're just looking at noise.

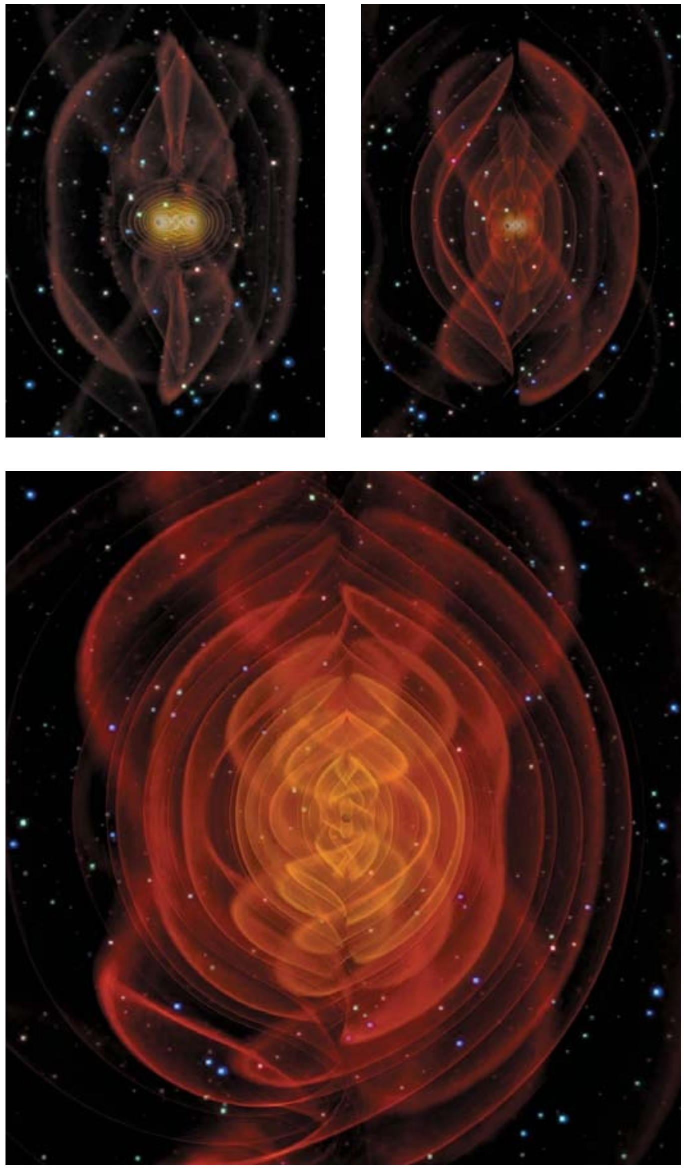
Then another event arrived on December 26, 2015, named GW151226, also from a binary black hole but with smaller members of about 7.5 and 14 solar masses respectively. This event was strong enough to clearly be a real cosmic signal. The chirps were here! We had officially progressed from theory into observational astronomy.

Since then, LIGO has continued to find merging black holes. Both detectors detected an event on January 4, 2017, during the upgraded observatory's second observing run (see page 10). The component black holes, about 30 and 20 solar masses respectively, fill in the gap between the GW150914 and LVT151012 events.

Shaking Up Physics & Astronomy

These cosmic chirps have made it clear beyond a doubt: There is an actual population of merging black holes in the universe. Every chirp that we've detected has lasted about two seconds or less; yet, even though they're so short, these signals have enormous significance for physics and astronomy.

For theoretical physicists, the signals allow us, for the first time, to test general relativity in a regime we've never probed before. Einstein's theory says that what we experience as gravity



▲ **COMPLICATED COALESCENCE** These computer simulations show the complexity of gravitational-wave patterns, which become especially tangled near the inspiraling black holes. The red-colored outer sheets show the expanding wavefront that LIGO ultimately detects.

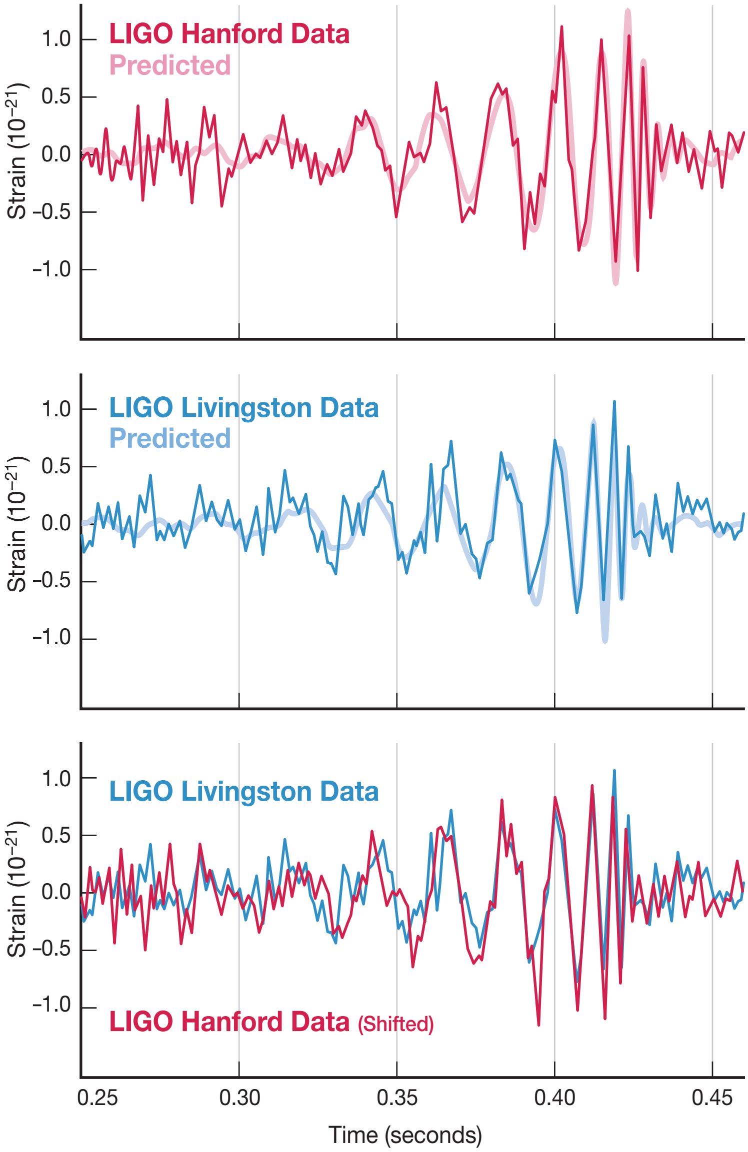
NASA / C. HENZE (3)

The "Sound" of Gravitational Waves

◗ Even though we often discuss gravitational-wave signals as if they were sounds, it's important to realize that they're not, in fact, sound waves. Nevertheless, the analogy is useful for a couple of reasons.

First, LIGO is sensitive to wave frequencies of tens to thousands of hertz. If these frequencies *were* sounds, our ears could hear them.

Second, and more importantly, the LIGO detectors function more like our ears than our eyes. Eyes — and most electromagnetic telescopes — have pointing capabilities. That is, they can detect a signal as long as they're pointing in the same direction as the signal's source. But LIGO doesn't have strong pointing capabilities. Instead, it detects gravitational-wave signals from almost all around us, just as our ears can hear sounds from any direction — behind us, below us, above us, and in front of us. With two detectors, LIGO can localize sources to narrow strips of sky that nevertheless cover a lot of area. But with more "ears," we can triangulate the signal and better pinpoint its source. That's why the addition of Virgo data to LIGO's two detectors is so vital.



▲ **FIRST SIGNAL** On September 14, 2015, a set of gravitational waves passed through the LIGO detector in Livingston, Louisiana, and 7 milliseconds later, through the detector in Hanford, Washington. The data matched perfectly the brief signal expected from two black holes spiraling toward each other before coalescing into one.

is basically the mass-induced warp in the fabric of spacetime (*S&T:* Dec. 2015, p. 18). This curvature increases rapidly as we get closer to massive, highly compact objects such as black holes. In these regions of strong gravity, the motion a particle experiences as it slides along spacetime's curvature approaches the speed of light. The black holes LIGO detected were zipping around each other at about 50% the speed of light before they merged — about 500 times faster than the speeds relevant to the best observational test before now. This is the regime where, if general relativity were to break down, we might begin to find unexpected effects in the gravitational-wave signal.

Einstein's fans will be relieved to know that, at present, the LIGO data do not support any measurable deviations from general relativity. While some have recently claimed potential evidence for the presence of post-merger gravitational-wave echoes, only possible via quantum modifications to general relativity, members of the LIGO scientific collaboration debate the validity of these claims.

For theoretical astrophysicists, LIGO's discoveries provide the first direct confirmation that close black hole binaries can form in nature and merge within the age of the universe. Mergers are one of two ways in which black holes should grow (the other is by accreting gas), yet we've never actually seen two black holes merge before. Now, we've "heard" it happen multiple times.

The discoveries also reveal the existence of surprisingly heavy stellar-made black holes. Although supermassive black holes of millions or billions of solar masses exist, they didn't form from a single star (*S&T:* Jan. 2017, p. 24). The black holes that LIGO has detected, on the other hand, are probably the remains of individual, albeit massive, stars.

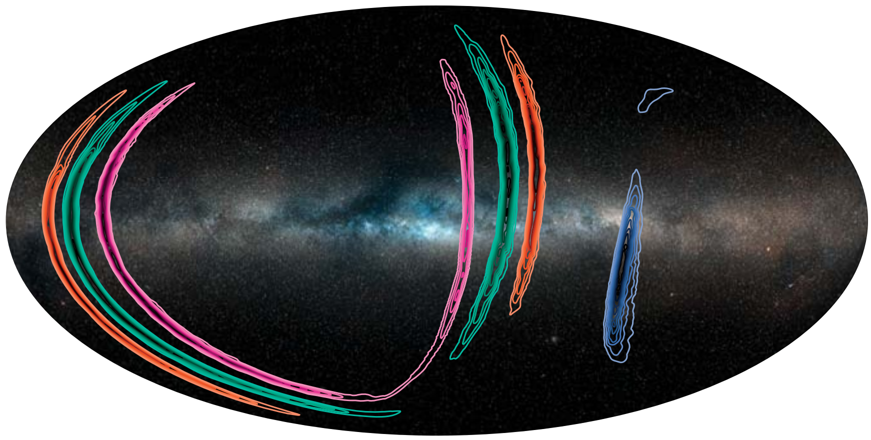
Before LIGO, astronomers could only see stellar-mass black holes when they siphoned off gas from a companion star, heating the plasma to X-ray-emitting temperatures before devouring it. Among these systems, the most massive black hole contained about 20 times the mass of the Sun. The vast majority of theoretical predictions also homed in on this mass as an upper limit. In fact, only since about 2010 have some theorists suggested that stars of low metallicity might produce black holes with masses several tens of times that of the Sun. But these predictions weren't widely recognized — as

Gravitational Waves Detected

Event	Date Detected	Mass of Black Holes	Final Mass	Distance (light-years)
GW150914	Sept. 14, 2015 (O1)	29 M_{Sun}, 36 M_{Sun}	62 M_{Sun}	1.2 billion
*LVT151012**	Oct. 12, 2015 (O1)	13 M_{Sun}, 23 M_{Sun}	35 M_{Sun}	2.5 billion
GW151226	Dec. 26, 2015 (O1)	7.5 M_{Sun}, 14 M_{Sun}	20.8 M_{Sun}	1.2 billion
GW170104	Jan. 1, 2017 (O2)	20 M_{Sun}, 30 M_{Sun}	48.7 M_{Sun}	2.2 billion

O1 and O2 refer to the first and second observing runs, respectively. The masses of merging black holes do not add up to the final mass because some of the mass is radiated away as energy, in the form of gravitational waves. Error bars excluded for simplicity. *Candidate detection.

LEAH TISCIONE / *S&T*, SOURCE: LIGO



◀ **SEEING BLIND** LIGO is often called a "blind" detector in the sense that it can't tell exactly where a signal is coming from, as demonstrated by this sky map of the origins of the four signals seen during the first two observing runs. With only two detectors, LIGO cannot easily triangulate position; the sources of GW150914 (blue), LVT151012 (green), GW151226 (orange), and GW170104 (magenta) lie somewhere in the linear fields marked on the map. The areas of these fields are 600, 1,600, 1,000, and 1,200 square degrees, respectively. Additional data from the Virgo detector in Italy should significantly improve our ability to pinpoint future sources.

made clear by my initial reaction on September 14th.

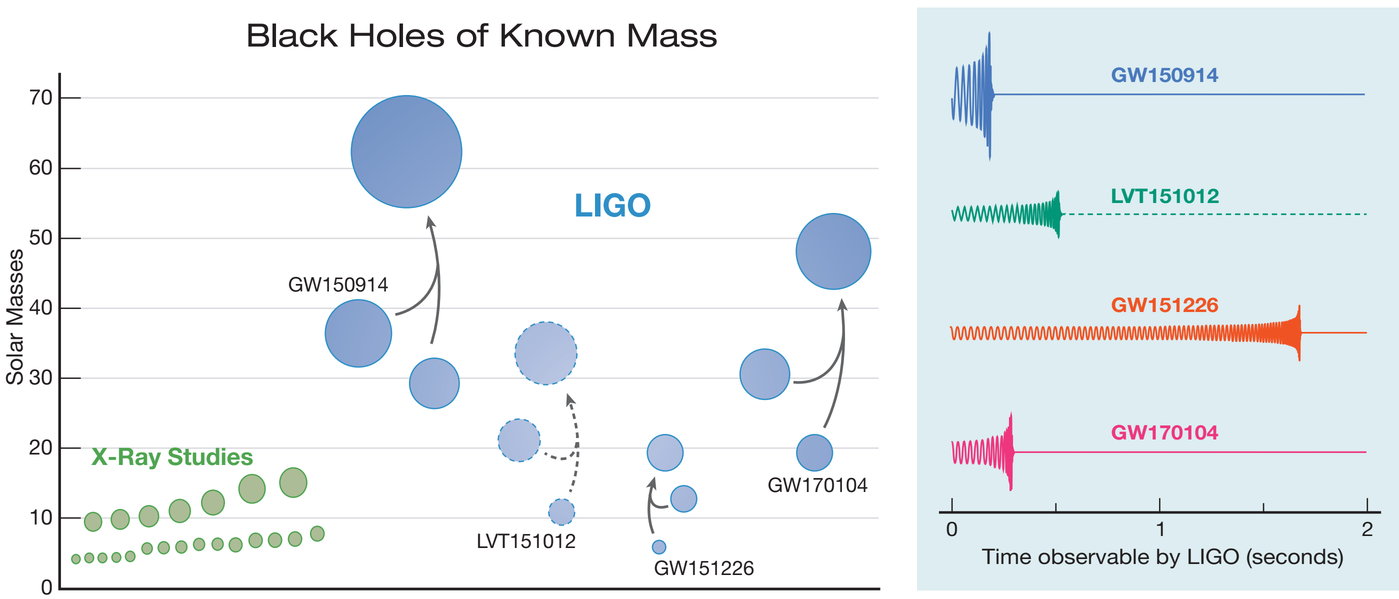
The first LIGO discovery, on the other hand, provided solid observational evidence that black holes more than 25 to 30 times the mass of the Sun form in nature. Mergers of these heavy black holes can create even more massive beasts, with as much as 50 or 60 times the Sun's mass. The newest detection in January 2017 supports this result. These discoveries challenge our understanding of massive stars' evolution.

Coupled with X-ray observations, LIGO's discoveries also indicate that black holes have a wide *range* of masses. Understanding this population, especially the binaries' origins and evolutionary histories, is now one of the most exciting investigations in modern astrophysics.

Finally, for experimentalists and observers, gravitational-wave detections are of historic significance. Since LIGO's inception in the early 1970s, numerous physicists and astrophysicists doubted this measurement would ever be possible. When I joined the collaboration as a young postdoctoral researcher about two decades ago, for example, the majority of my astronomy mentors advised me against it.

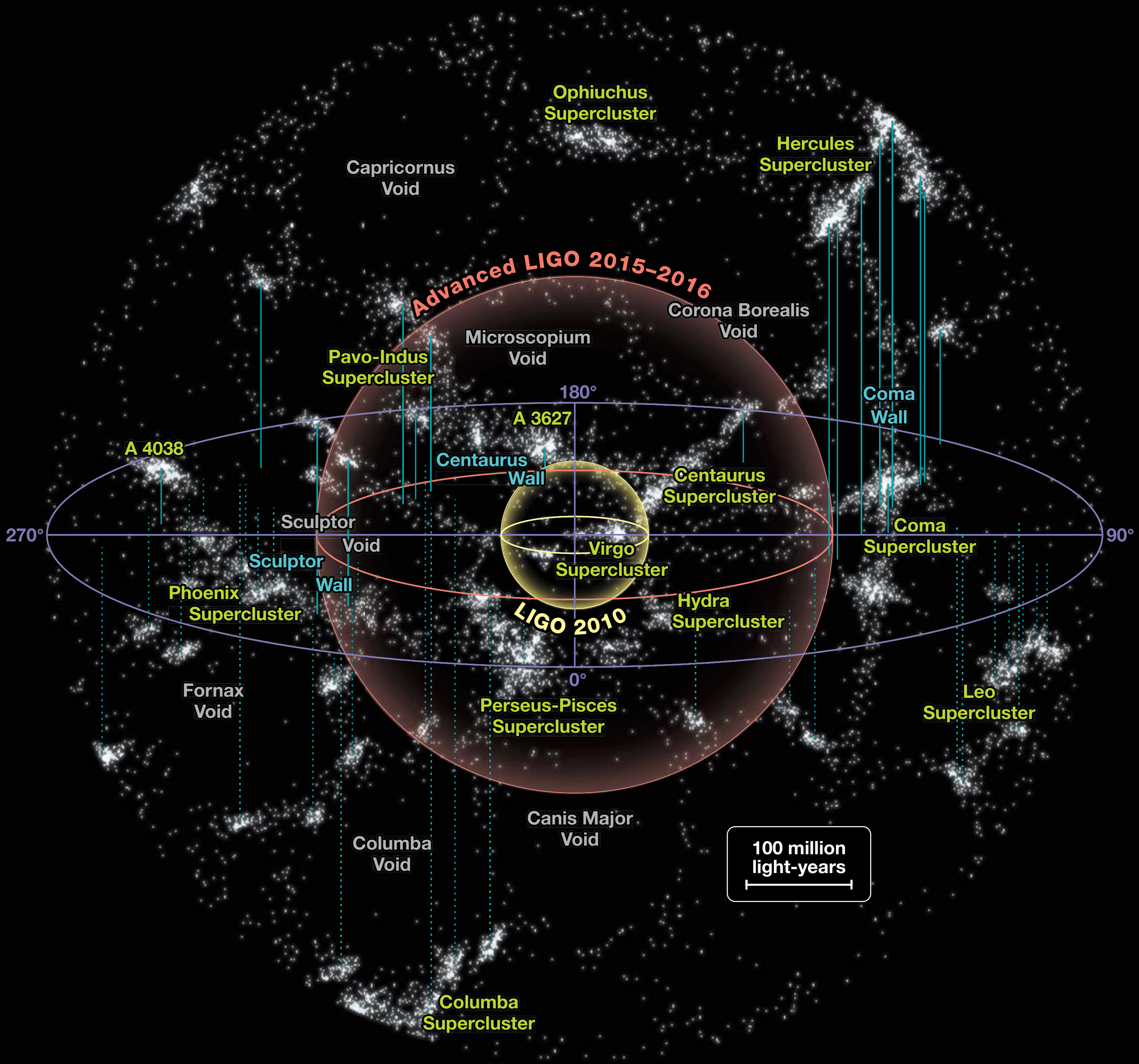
Yet today LIGO's results represent the most precise measurement ever achieved by humans in any field of science and engineering: LIGO detects changes on the order of one part in one thousand billion billion (10^{-21}). And with Advanced LIGO's sensitivity in 2015, we can "hear" black hole mergers out to more than 8 billion light-years. By the time the Advanced LIGO detectors reach their design sensitivity in a few years, we'll gain yet another factor of three in reach.

These discoveries represent a completely new way of observing the cosmos, distinct from the electromagnetic



▲ **MASSIVE DISCOVERIES** *Left:* LIGO's detections have uncovered a population of massive, merging black holes that X-ray observations hadn't revealed. Historically, black holes have made themselves known by the X-rays they emit as they feed on gas pulled from a companion star. LIGO has shown that some black holes are far more massive and electromagnetically silent, having long ago swept up any gas and other potentially X-ray-emitting material. *Right:* This chart shows reconstructions of four gravitational wave signals, three of them confident detections and one more tentative, seen by LIGO's Hanford detector and shown as a function of time. Only the portions of each signal that LIGO was sensitive to (the final moments leading up to the merger) are shown here.

MASS CHART: LIGO / CALTECH / SONOMA STATE (AURORE SIMONNET); TIME CHART: LIGO / CALTECH / MIT / UNIVERSITY OF CHICAGO (BEN FARR); MAP: CONTOURS: LIGO / CALTECH / LEO SINGER, MILKY WAY: AXEL MELINGER



COSMIC REACH For its first eight years of operation, LIGO could “hear” gravitational waves from neutron star mergers out to about 70 million light-years (yellow sphere), and black hole mergers as “loud” as GW150914 out to about 1.9 billion light-years (not shown) — but it found nothing. Once Advanced LIGO came online in 2015, with significant improvements made to its dectectors' sensitivity, the reach quadrupled (red sphere), upping the volume accessible to LIGO by roughly a factor of 40.

LEAH TISCIONE / *S&T*; SOURCES: RICHARD POWELL, MARTYNOV ET AL. 2016, *PHYSICAL REVIEW LETTERS* waves on which modern astronomy has been based for the past four centuries and historic astronomy for several millennia. Now that gravitational-wave astronomy has become a "real" field, it's also ushering in the era of multi-messenger astronomy: the study of the same astrophysical objects using two different "message carriers," namely gravitational waves and electromagnetic waves (see box below).

So far no one has detected a counterpart at any wavelength of light to any of the LIGO discoveries — with the potential exception of a possible gamma-ray burst reported by the Fermi team and associated with the first black hole merger LIGO detected (*S&T:* Aug. 2016, p. 14). However, other observational teams have questioned this claim of association — it may be only a coincidence.

The issue is, we don't expect electromagnetic bursts from black hole pairs. Long before they merge, the orbiting black holes ought to sweep up any surrounding gas or other ordinary matter that could produce radiation. In other words, these merger events should be invisible to all but gravitational-wave detectors. If instead these events were in fact accompanied by gamma-ray or other flashes of radiation, then it would be an unexpected — and exciting — development. Only by continuing to watch the gravitational sky will we find out for sure.

The Future of Gravitational-Wave Astronomy

LIGO is now a true cosmic observatory. By the time Advanced LIGO reaches its design sensitivity in 2018 or 2019, we anticipate dozens of detections a year. These new discoveries will allow us to uncover the range of black hole masses and determine which masses are most common. The signals might even reveal an "intermediate-mass" black hole with hundreds to thousands of solar masses, a hypothesized class without any conclusive examples — yet.

Because the chirps include information about the black holes' spins, we can also begin to probe the role that angular momentum plays in black hole formation and growth. For example, the black holes' initial spins will differ depending on whether they were born in orbit around each other, or if two individual stars instead underwent gravitational interactions, such as via cosmic slingshots and flybys, to become part of a binary pair.

Virgo, a third gravitational-wave detector in Italy, will also join the network this year. The most important impact of having a third detector will be an improved ability to pinpoint a signal's origin on the sky. LIGO could only localize its first event to a long, thin arc covering roughly 600 square degrees, equivalent to the sky covered by the constellation Orion. With Virgo in the mix and with all three detectors at design sensitivity, we may be able to decrease the implicated sky area by more than a factor of ten, facilitating easier follow-up with electromagnetic telescopes.

The opening of this new field of gravitational-wave astrophysics is bound to take us further than black hole mergers. LIGO and Virgo should also detect neutron star mergers, which produce electromagnetic as well as gravitational waves (*S&T:* July 2017, p. 16). Meanwhile, as a network of ground- and space-based gravitational-wave detectors joins the effort, we may soon detect gravitational signals from collapsing stars and their supernova explosions, persistent waves from misshapen, spinning neutron stars, and a broadband humming from the combined noise of many individual sources in the faraway universe. True multi-messenger astronomy is just around the corner.

■ **VICKY KALOGERA** is the Haven Professor of Physics and Astronomy at Northwestern University and the director of CIERA, the Center for Interdisciplinary Exploration and Research in Astrophysics. She has been a member of the LIGO Scientific Collaboration since 2000 and has contributed to the astrophysics research of gravitational-wave sources, the analysis of LIGO data, and the discoveries of black hole mergers.

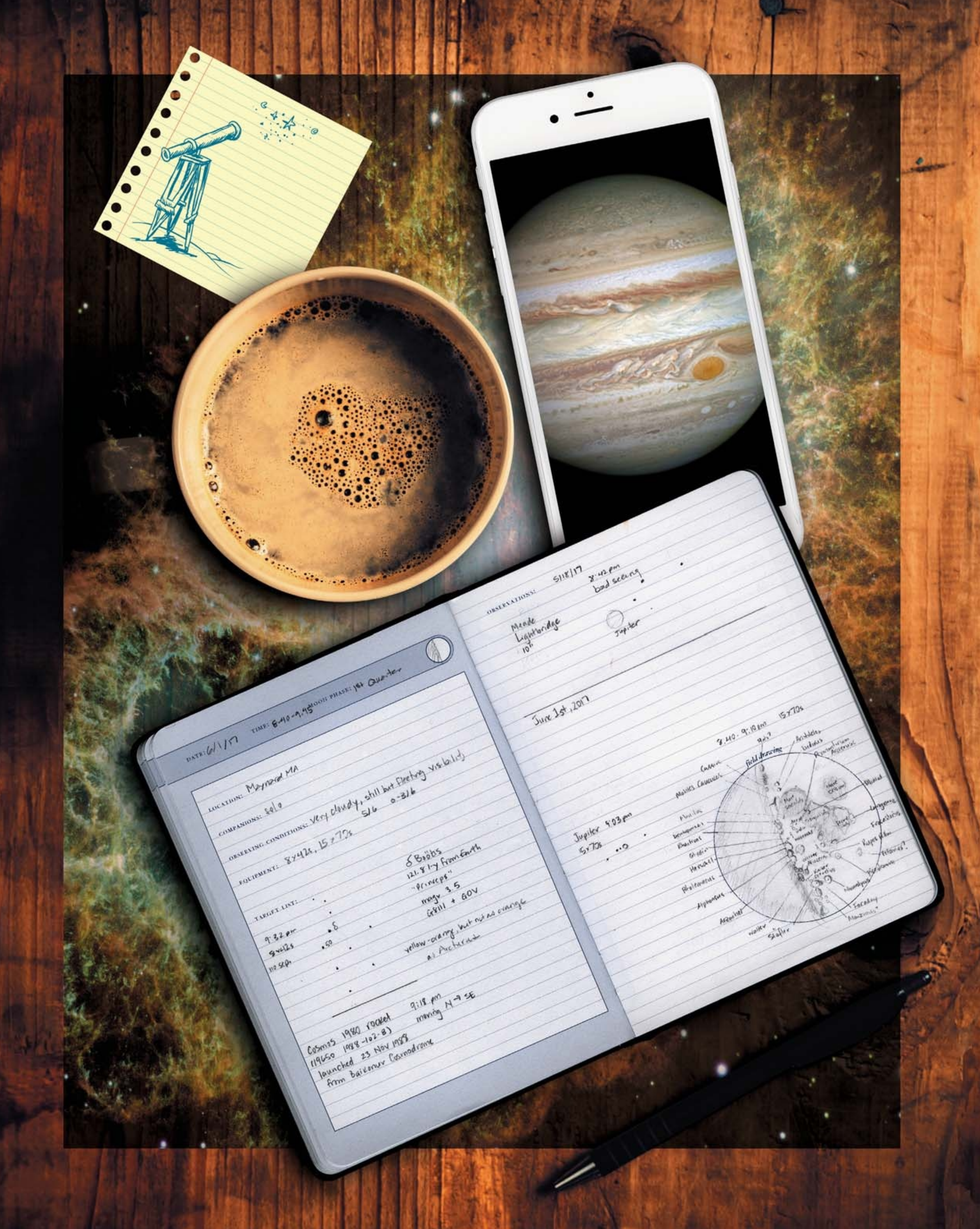
The Light Side of Gravitational Waves

BY GOVERT SCHILLING

If you know the direction of origin of a gravitational-wave signal, then it makes sense to scan that region of the sky in search of electromagnetic counterparts. The main problem: Astronomers can't precisely determine the sky position of gravitational-wave sources. With only two detectors, LIGO scientists can only narrow in on long, thin regions that encompass hundreds of square degrees.

Two new facilities are more or less tailor-made for the electromagnetic counterpart hunt. The first one is the Zwicky Transient Facility (ZTF) at the Palomar Observatory in southern California. It's a sensitive, 600-megapixel camera mounted on the 48-inch Samuel Oschin Schmidt telescope, providing a 47-square-degree field of view. According to project scientist Eric Bellm (University of Washington), ZTF has a response time of less than a minute and is able to reach 21st magnitude in 30 seconds. First light is expected in August 2017.

The second one, in the Southern Hemisphere, is BlackGEM, due to become operational in 2018. Controlled from Radboud University in Nijmegen, the Netherlands, BlackGEM will start as an array of three automated 65-centimeter telescopes, at the La Silla Observatory in Chile. In the future, the array may expand to 15 identical telescopes, each equipped with a sensitive 110-megapixel CCD camera. BlackGEM is very flexible. If the search area is elongated, each telescope in the array can focus on just one part of the banana-shaped region. If the search area is small, or if a counterpart has already been detected, the telescopes can observe in concert, resulting in a much higher sensitivity.



DATE: 6/1/17
TIME: 8:40-9:45
MOON PHASE: 1st Quarter
LOCATION: Maynard MA
COMPANIONS: solo
OBSERVING CONDITIONS: Very cloudy, still but fleeting visibility
EQUIPMENT: 8x42s, 15x70s
TARGET LIST:
yellow-orange, but not as orange as Arcturus
Cosmos 1980 rocket
launched 23 Nov 1988
from Baikonur Cosmodrome
OBSERVATIONS:
5/18/17
8:42 pm
bad seeing
Meade Lightbridge 10"
Jupiter
June 1st, 2017
field drawing

Keeping Track of the Night

An experienced observer describes the benefits and pleasures of keeping an astrojournal.

Recording one's thoughts and actions in writing and pictures — it's an ancient urge, akin to collecting, and humans have been at it since the first cave paintings. I started keeping a diary when I was 12 years old. In loopy, handwritten pencil, I recorded daily temperatures and weather, events at school, baseball games with my friends, and even the first time I held a girl's hand. But the main thrust of that first diary was to record what I saw in the sky at night. All the wonderful little and big events I thought significant, unusual, strange, and beautiful made it into that book. Sometimes a single page wasn't enough, and I had to finish the entry on loose 3×5 index cards.

Tiny sketches of conjunctions and deep-sky objects were squeezed between the words. I was a kid then, with small, steady hands. Little did I know that by keeping this and subsequent observing logs, I was learning to see the sky better. Recording my observations and making drawings of what I saw through the telescope also gave me a sense of accomplishment.

Writing creates a record that may provide a useful data point one day or simply a return path to a pleasant memory. I might recall seeing the total lunar eclipse of October 18, 1967, with my friend Roy, but you know how memory is — full of holes! Writing it down made the experience stick.

Most amateurs I've met keep some kind of record and well we should. You might see something unusual or a change in an object's behavior — variable stars come to mind here. How nice to be able to check back to look for a trend or draw up your own light curve of the changing brightness of a nova or supernova. Some years back, the American Association of Variable Star Observers (AAVSO) sought crucial observations of the variable central star in the planetary nebula NGC 2346. I dug back through my logbooks and gave them everything I had.

Just as important as record keeping is learning how to see the fuzzy stuff just a bit more deeply. Translating the telescopic view onto paper — whether in word or sketch — makes you notice details you wouldn't otherwise catch. When sketching a nebula, for instance, you might start by marking the location and brightness of stars within and near the nebula. As you add the nebulosity, you begin to see subtleties in brightness and shape. The simple act of recording is already working its magic, sharpening your gaze. Note-taking and sketching give us an intimacy and familiarity with our subject that otherwise might elude our perception were we simply to look and move on. Paying attention is no small feat in the 21st century.

> Note-taking and sketching give us an intimacy and familiarity with our subject that otherwise might elude our perception . . .

Photographs often help observers look for details that might be overlooked. Having them at the ready, so easy in our internet era, will increase your expectations and encourage you to dig deeper yet. I'm a big believer in seeing everything you can, the better to appreciate the nature of the amazing

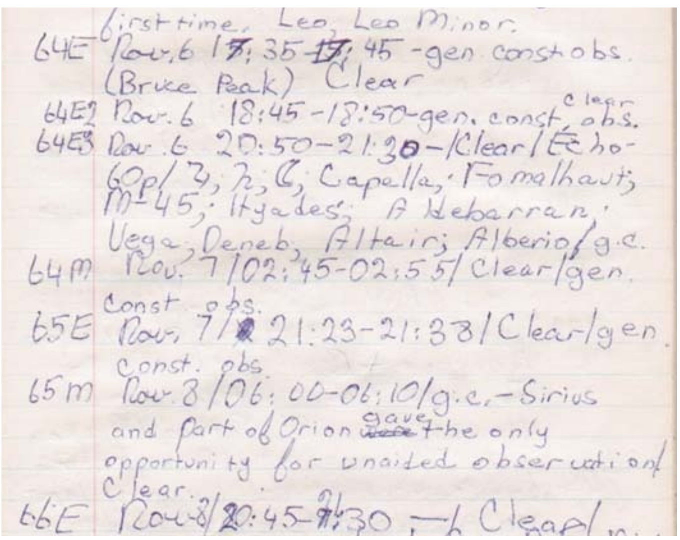
FACING PAGE: PHOTOILLUSTRATION: PATRICIA GILLIS-COPPOLA / *S&T*; BACKGROUND: ©IGOR STEVANOVIC / BIGSTOCKPHOTOS.COM; CRAB NEBULA: NASA, ESA, J. HESTER (ARIZONA STATE UNIV.); NOTEBOOK PAGES: S. N. JOHNSON-ROEHR; IPHONE: EMIL IMARIETLI / BIGSTOCKPHOTOS.COM; JUPITER: NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER); TELESCOPE SKETCH: STARI / BIGSTOCKPHOTOS.COM

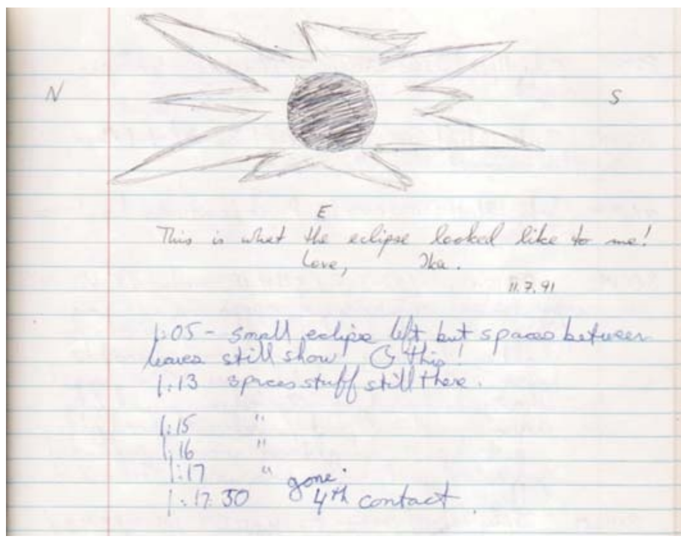
▲ **TOUCH UP** Michael Vlasov captured this view of the Orion Nebula with a graphite pencil sketch on white paper while observing with an 8-inch f/5 Newtonian reflector under a red light. After his observing session, he scanned, inverted, and processed the sketch in Adobe Photoshop.

things we're privileged to behold in this drive-through lifetime of 80-odd years.

While writing and sketching will never go out of style, there are other great options for tracking your observing, too: recording an image or voice with a smartphone; entering a night's observations into specialized computer software; or sketching a view with Photoshop and other digital drawing tools. An advantage of using a computer to track your data and store your sketches is the ease of future searching. Want to find that observation you made of the Orion Nebula eight years ago? Open the file, type "Orion Nebula" in the "find" box, and hit enter. For drawings, I enjoy the software approach, because erasing mistakes and starting over again is so much easier thanks to Ctrl-Z!

It's important to remember that perfection isn't required when writing up an observation. Don't like drawing? Skip it and expand on descriptive writing. Whatever you write, don't sweat verb tenses and sentence structure. Just lay it out there.


first time, Leo, Leo Minor
64E Nov. 6 17:35-17:45 -gen const obs.
(Bruce Peak) Clear
64E2 Nov. 6 18:45-18:50-gen. const. obs. clear
64E3 Nov. 6 20:50-21:30-/Clear/Echo-
[illegible] Capella, Fomalhaut,
M-45, Hyades, Aldebarran,
Vega, Deneb, Altair, Alberio/g.c.
64M Nov. 7/02:45-02:55/Clear/gen.
Const. obs.
65E Nov. 7/ 21:23-21:38/Clear/gen
const. obs.
65m Nov. 8/06:00-06:10/g.c.-Sirius
and part of Orion gave the only
opportunity for unaided observation/
Clear.
66E Nov. 8/20:45-21:30 -/ Clear/


N S
E
This is what the eclipse looked like to me!
Love, [illegible]
11.7.91
1:05 - small eclipse left but spaces between leaves still show (this!)
1:13 spaces stuff still there.
1:15 "
1:16 "
1:17 "
1:17:30 gone: 4th contact

▲ **IN THE BEGINNING Left:** David Levy discovered 22 comets, either independently or with Gene and Carolyn Shoemaker. But his expertise had to start somewhere. This page from Levy's notebooks covers some of his earliest observations, including his first identification of Regulus, the brightest star in Leo. **Right:** Levy has kept a continuous logbook from 1962 to the present. This page features observing notes and a sketch of the totally eclipsed Sun on July 11, 1991. Levy lives by the words of long-time Canadian amateur astronomer Isabel K. Williamson: "Observations not written down are not observations."

ORION NEBULA SKETCH: MICHAEL VLASOV (2); PAGES: DAVID & WENDEE LEVY, JARNAC OBSERVATORY / RASC

> Including these soul-stirring moments as part of the night's entry deepens that inner dialogue we carry on all our lives between us and the Big All.

If you worry about details as if you're writing for posterity, you'll soon quit under the pressure. Let it flow.

Since our hobby can take us to dark and wild places, consider adding some atmosphere to your entries: what animals or insects you heard that evening, night scents, whether the aurora or zodiacal light made an appearance, the temperature, bright meteors seen, unusual satellites, and atmospheric seeing. My scale for seeing is a simple 1–5, from the worst to best. After 50 years of peering through telescopes, I've recorded a handful of 4½ nights, but never a 5.

Everything in nature has the potential to induce wonder and inspire us. It's easy to get swept up in the meaning of it all when you're caught like a fly in the starry web of a globular cluster or during a wave of good seeing when the rings of Saturn settle down and become as still as a painting. Including these soul-stirring moments as part of the night's entry deepens that inner dialogue we carry on all our lives between us and the Big All.

My journal includes successes as well as setbacks. Didn't see that hoped-for comet? No worries — you tried and hopefully will get another shot at it. If you succeed in finding something you've never seen before, give yourself a few exclamation points!

So what are you going to do with all these data? Absolutely nothing, if that's your choice. Remember, this is for your own use. No one else need see it. But if you choose to share what you see, lots of organizations are interested — the Association of Lunar and Planetary Observers (ALPO), the aforementioned AAVSO, and online comet, occultation, and satellite observer lists, just to mention a few.

No matter your style, whether casual or scientific, your observations serve as a chronicle of your progress. Educating eye and heart is what we're about as amateurs. Let the period at the end of each sentence stand as testament to our gratitude for the cosmic bounty that fills our lives with a sense of place and wonder.

Deep-Sky & Planetary Checklist

Record the time and date of your observations. You might think that times aren't necessary for deep-sky objects, but who knows? You might inadvertently sketch the start of a supernova explosion in a galaxy and not even know it. The observation and time would be invaluable in such a case. Or how about a rare nova in a globular cluster?

To help train your eye on what to look for when you bring a favorite planet or planetary nebula in focus, consult the features checklist below. The list just scratches the surface but offers a good start for learning how to focus your vision and deepen your observing skills. If you're not sure what's special

▲ **SCOPE-SIDE SKETCH Top:** Mike Sangster of Duluth, Minnesota, uses a clipboard with a built-in red light to sketch the planet Jupiter as seen in his 4-inch refractor. "I try to get the positions of the belts and moons first, then add in details," he says. Sangster likes to go back and review observations he's made in the past: "It brings me back in time to that night and helps grow my observing skills. When I write down descriptions or make drawings I concentrate and see much more of the object." **Bottom:** Sangster marks the location of Europa's shadow on his drawing of Jupiter. Like many amateurs, he'll make a rough sketch at the telescope and refine it later at home.

BOB KING (2)

about your view or what you want to record, revisit these suggestions for some guidance.

Planets

• **Mars:** Use an online tool such as the *Sky & Telescope* Mars Profiler (**https://is.gd/marsprofiler**) to find out which hemisphere and what dark albedo marking face you at the time of observation. Watch for clouds, limb hazes, and the bright orange clouds that signify major dust storms in progress. Note the expansion or contraction of the polar caps with the changing seasons.

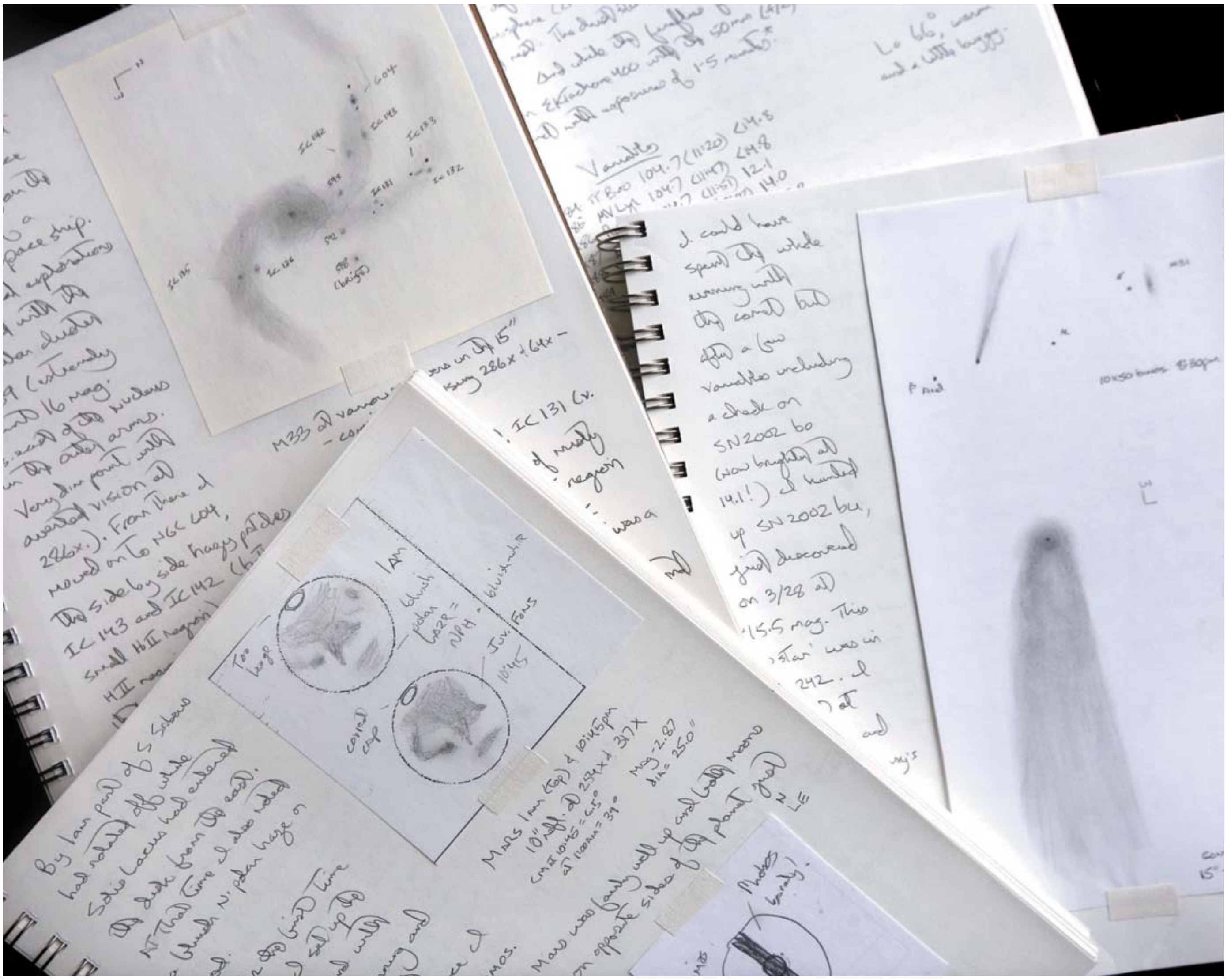
• **Jupiter:** Note the color of the cloud belts and whether they're continuous or broken. Are there any dark curls (festoons) in the broad Equatorial Zone? What color is the Great Red Spot this season, and how do cloud textures vary preceding versus following the Spot? Are the equatorial belts single or double? Does their texture vary with longitude? What's the current position of the planet's moons? Use the *Sky & Telescope* tool to identify them (**https://is.gd/JupMoons**). During shadow transits, examine the size of the shadows and how their paths over the planet vary. Before long, you'll know which moon-shadow is which without even checking.

• **Saturn:** Is Cassini's Division visible? How many belts stripe the planet? Can you discern the gray-topped polar regions? Do color filters improve the view of certain features? Search for the five brightest moons using the *Sky & Telescope* Saturn's Moons tool (**https://is.gd/SatMoons**).

Deep-Sky Objects

• **Globular clusters:** Is the core compact or loose? Can you resolve stars in the halo? In the core? How does the cluster change in appearance with averted vision? Some globulars

▼ **RECENT OBSERVATIONS** This sample of entries comes from the author's more recent astronomy journals and includes observations of a close Mars apparition, nebulae in M33, and Comet 153P/Ikeya-Zhang.



BOB KING

display apparent whorls or sprays of stars that give them a very distinctive appearance.

• **Planetary nebulae:** Is the nebula spherical, elongated, or irregular in form? Uniformly bright? Brighter in the center? Darker in the center with a ring shape? Is a central star visible? If a planetary has a faint outer shell, averted vision may help you see it. Compare views with and without a nebular filter.

• **Open clusters:** How many stars does the cluster have? How compact is the cluster? Does it have a distinct central core or is it so loose it's indistinguishable from the background stars? Open clusters have many different shapes depending on your own perception and imagination. What do you see? Look for both double stars and red stars within the cluster. Are cluster stars of similar magnitude, or do they vary widely in brightness?

• **Galaxies:** What's its shape and how elongated is it? Is the core bright and starlike or more extended? Is mottling visible, or is the galaxy's texture smooth? If it's a bright spiral galaxy, use averted vision and a photograph oriented to the telescopic view to help you discern the spiral arms. When viewing edge-on and highly inclined objects, look for dust lanes.

• **Bright nebulae:** Can you see the nebula with direct vision, or is averted vision necessary? What's the shape of it, and do brightness and texture vary across its face? Are there any stars involved in the nebulosity? If you're looking at an emission nebula, ask: Does a nebular filter increase contrast or expand the extent of the nebula?

• **Dark nebulae:** How dark is it? Does the cloud stand out against the starry backdrop in an obvious way or more subtly? How large is the nebula? Does it have a shape? Is it connected to others within or just out of the field of view? Use the Lynd's Scale to determine how truly "dark" the nebula is, rating it from 1 (least opaque) to 6 (most opaque).

Finishing Up

I like making a rough drawing in the field along with notes on what to add later. Then I tidy up the final product in the warm, windless environment of my home.

Remember, none of the above suggestions is obligatory, but when you're stumped, they're a good place to start. Good luck and good observing!

■ An amateur astronomer since childhood and a long-time member of the American Association of Variable Star Observers (AAVSO), Contributing Editor **BOB KING** also teaches community education astronomy and writes the blog *Astro Bob* (**https://astrobob.areavoices.com/**).

FURTHER READING: For more on observing logs, including links to downloadable templates, visit: **https://is.gd/Notebooks**.

▲ **VOICE TO MACHINE** Richard Hudson of Somerset, Wisconsin, uses a voice recorder to compile his observations at the telescope, then keyboards the information into his laptop when he has free time.

HOMEWORK After an observing session, the author re-works the sketch made at the eyepiece in Photoshop. Here he's added color and clarity to a sketch of the "Fish's Mouth" region of the Great Orion Nebula.

BOB KING (2)

 by Robert H. Gray

Searching a Trillion Stars for ET

How I helped shrink the possibility that *really* advanced aliens are broadcasting far and wide.

MORE THAN 100 SEARCHES for extraterrestrial intelligence have been carried out since 1960, when Frank Drake first pointed an 85-foot dish connected to a tabletop shortwave radio receiver at two nearby stars. Many of these SETI efforts viewed only a handful of stars for a few hours. A few ambitious surveys covered much of the sky, but they listened at each spot for only a few minutes.

Some of the most famous SETI experiments have concentrated on a relatively few nearby stars — "few" meaning in the thousands at most — scrutinizing them intently one by one. This approach assumes that the Milky Way is buzzing with thousands or millions of radio-signaling civilizations, *all* of whose transmitters are relatively weak.

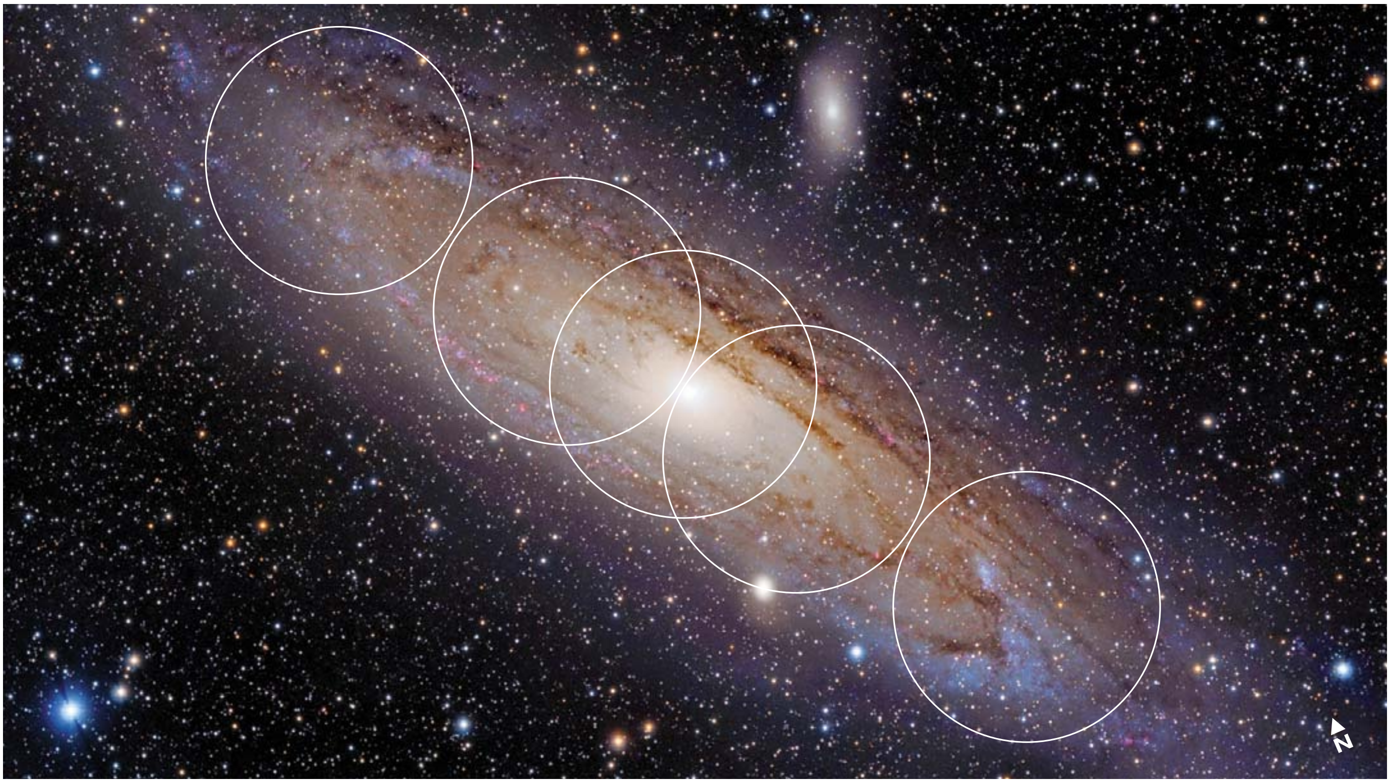
But there's every reason to think that an opposite assumption is the smarter bet: that the strongest signals in our sky, the ones we can most easily detect (assuming any exist at all), come from rare civilizations extremely far away who have harnessed energy on an extreme scale.

With this in mind, I used the Very Large Array (VLA) in New Mexico, one of the world's premier radio telescopes, to examine the nearby galaxies M31 in Andromeda and M33 in Triangulum for artificial, narrowband signals. Between them, they contain roughly one trillion stars.

These stars probably host trillions of planets, including billions of "habitable Earths." Admittedly, they're 2½ million light-years distant. But if even one of those stars hosts

NRAO / AUI

▲ **THE LISTENERS** The Karl G. Jansky Very Large Array in Socorro, New Mexico, consists of 27 radio dishes each 25 meters (82 feet) in diameter. Their data are combined interferometrically to create radio images with the sensitivity of a single 130-m dish, but with much higher spatial resolution.



▲ **ANYBODY HOME?** Overlaid on M31, the Andromeda Galaxy, are the five radio fields of view that the author imaged with the Very Large Array in his search for narrowband artificial signals. Billions of habitable planets should be within the circles. If any of them had radio engineers continuously directing at least a 10^{17}-watt signal to blanket the Milky Way at just the right frequency, he would have found it.

a long-lived civilization that wishes to make itself known to the cosmos, it could plausibly build a transmitter that's bathing our entire Milky Way with a signal strong enough for the VLA to detect.

Choosing a SETI Strategy

Even using today's most sensitive radio telescopes, the only type of alien signal we have much hope of hearing is a deliberate, powerful "beacon signal" — one that somebody or something designs to be detected by far listeners like us. Any plausible "leakage" from a civilization's own internal communications will be much too weak and messy for us to hear across many light-years.

Another key point: Any beacon that we pick up is almost certain to have been broadcasting for millions of years. That's because shorter-lived ones would have only a minuscule chance of overlapping our own moment in cosmic time. So any ETs currently announcing themselves to the cosmos have almost certainly had all the time in the world (literally!) to build up their hailing transmitter to tremendous power.

If this logic is correct, then for listeners like us, playing the numbers game makes sense. (See "Smarter SETI Strategy," *S&T:* Apr. 2001, page 50, or **https://is.gd/setistrategy**.)

Following this logic, Frank Drake and Carl Sagan searched four galaxies in the early 1970s using the 300-meter Arecibo dish in Puerto Rico. They examined frequency channels 1,000 hertz (Hz) wide, narrow enough to screen out natural radio emissions, though not as narrow as alien radio engineers might use for the best stand-out visibility. Drake and Sagan looked at 212 spots covering M33 for about 1 minute each. They could not see M31; Arecibo's big antenna couldn't point far enough away from Puerto Rico's zenith.

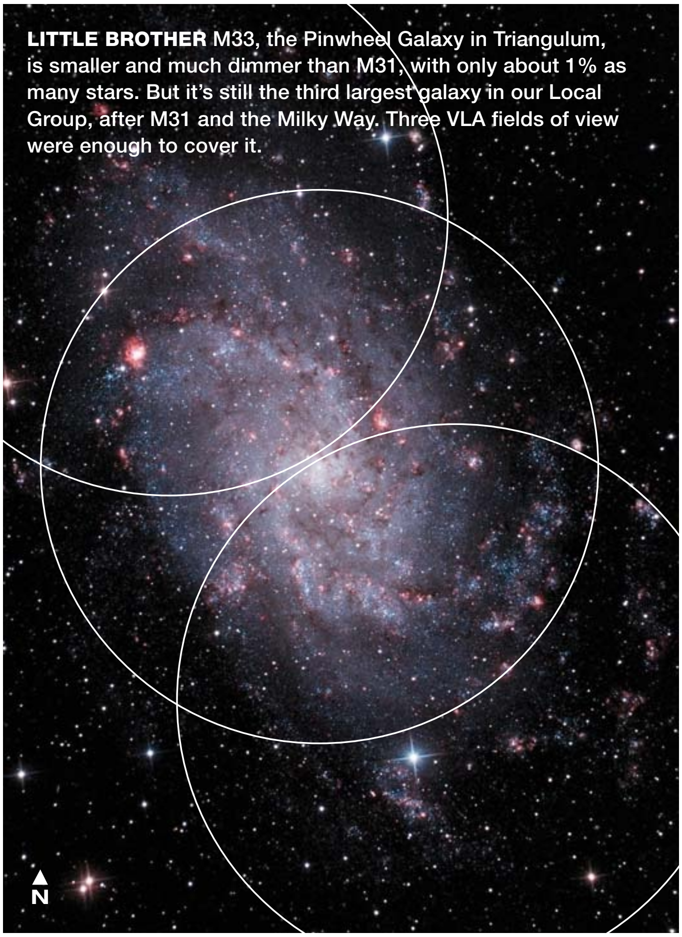
I could point toward both galaxies easily with the VLA's 27 fully steerable dishes. On the visible-light image of M31 above, the five circles show the array's ½°-wide field of view for the five sky areas I observed.

Another daunting issue facing SETI efforts is the vast range of radio frequencies that hypothetical aliens could choose for their beacon: any of about 10 billion channels, if their beacon broadcast is a highly efficient signal 1 Hz wide. Where on this enormous dial should we tune? I chose a narrow range around the ubiquitous hydrogen emission at 21 cm wavelength (a frequency of 1.420 gigahertz), as many SETI projects have done. The hope is that radio astronomers anywhere will think that radio astronomers anywhere else will pay close attention to it.

From Dream to Reality

I proposed this project to the VLA — it is open to anybody anywhere in the world — and somewhat to my surprise, the Time Allocation Committee granted me 12 hours. It's complicated to tell the 27-dish array what you want it to do, but the help staff enabled my observations to go successfully.

Everything in SETI is a tradeoff. I had the array dwell on



LITTLE BROTHER M33, the Pinwheel Galaxy in Triangulum, is smaller and much dimmer than M31, with only about 1% as many stars. But it's still the third largest galaxy in our Local Group, after M31 and the Milky Way. Three VLA fields of view were enough to cover it.

each pointing direction for 5 to 20 minutes, building up the signal-to-noise ratio like a long photographic exposure. I searched two spectral windows near the hydrogen frequency, blueshifted slightly to account for the motions of M31 and M33 toward us. These windows spanned 1 MHz and 125 kHz, admittedly very small slivers of the microwave dial. The hardware divided these frequency windows into 8,192 channels 122 Hz and 15.3 Hz wide, respectively, much narrower than Drake and Sagan's 1,000 Hz but not as narrow as the roughly 1 Hz channels often used in SETI.

To check that this experiment really could detect a weak signal from far away, I pointed the VLA at the most distant *known* transmitter — the Voyager 1 spacecraft. Launched in 1977, it was 130 astronomical units away and its signal power was down to about 10 watts, not much more than a flashlight's. But it came in extremely loud and clear from far out past Pluto.

I spent the next year analyzing the resulting several hundred gigabytes of data using the software package AIPS. Pat Palmer at the University of Chicago advised me on many baffling problems, and Kunal Mooley, a recent Caltech astrophysics PhD, joined the analysis as my co-author using the software package CASA.

After analyzing well over 100,000 radio images, one for each of 8,192 channels per bandwidth per field, we found nothing much stronger than noise.

Too bad — it seemed like *such* a good idea!

The Meaning of a Negative Result

The value of a scientific experiment can often be judged by how meaningful a negative result will be. Mooley and I think we've shown that there are no technological supercivilizations broadcasting very powerfully toward the Milky Way continuously in the 21-cm band from any of a trillion stars.

What's the problem? Maybe there *is* nobody like that in M31 or M33. Or maybe they're not transmitting radio beacons toward the Milky Way, or not in the narrow frequency window we chose, or not strongly enough, or their transmitter wasn't turned on when we looked, or . . . the list goes on.

We can, however, say one thing: There were no easy pickings. Disappointing, but worth knowing.

A more thorough followup should be coming along behind us. Outclassing all previous SETI efforts, if it goes as planned, will be Yuri Milner's $100 million Breakthrough Listen project, now in its beginning stages (see *S&T:* Nov. 2015, p. 10, or **https://is.gd/leapseti**). Breakthrough Listen will, among other things, examine 100 galaxies (including M31 and M33) using many millions of channels across much of the entire microwave spectrum — a search vastly broader and deeper. So the case is far from closed on the possibility that somebody or something is signaling our galaxy from another.

■ **ROBERT GRAY** is author of *The Elusive Wow: Searching for Extraterrestrial Intelligence.* The full report on the VLA project, by him and Mooley, appears in the March 2017 *Astronomical Journal*; read the preprint at **arxiv.org/abs/1702.03301**.

To Build A Really Loud Hailer

BY ALAN MACROBERT

For the author's VLA project to have hit the jackpot, a beacon transmitter in M31 or M33 would have to be continuously emitting at least 10^{17} watts of signal if it were illuminating the entire Milky Way. Is such a thing even conceivable?

Well, we could be building one ourselves in not too many centuries.

If it were built in space, there's really no limit to the power a beacon transmitter could have. We could avoid inconveniencing the Earth by, for instance, assembling a grid of small modules in a close orbit around the Sun that would collect solar energy on one side and emit radio from the other, through small, phased-array antennas. Such an assembly could grow indefinitely large, maybe by robotic manufacturing of modules using asteroids as raw material. If it grew to thousands of kilometers across — and remember, a long-lived civilization has all the time in the world — our own radio equipment today could hear it from as far away as other galaxies.

4–6 **DAWN:** Mars glimmers less than 1° from Regulus, the brightest star in Leo, on these three mornings, with Mercury about 3° right or upper right of the pair. Use binoculars to pick up all three very low in the east, about 16° below or lower left of brilliant Venus.

10 **DAWN:** Mercury, now shining at magnitude 0.0, glows only 1° lower right of 1.3-magnitude Regulus. Dimmer 1.8-magnitude Mars is about 3° lower left of the pair.

DUSK: Find Spica twinkling about 3° lower left of bright Jupiter, very low in the west-southwest in bright twilight.

12 **MORNING:** The waxing gibbous Moon beams in the Hyades. The Moon occults Aldebaran in darkness or morning twilight for Hawai'i and western North America; see page 50.

16 **DAWN:** Look for 1st-magnitude Regulus 4½° below the dazzle of Venus. Binoculars may reveal the close pairing of Mercury and fainter Mars 7° lower left of the star.

17–30 **DAWN:** The zodiacal light is visible in the east 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes. Look for a tall, broad pyramid of light, tilted to the right, with Venus and Regulus in its base.

18 **DAWN:** Venus, Regulus, the hair-thin waning Moon, faint Mars, and Mercury form a nearly vertical line some 12° long, in that order from top to bottom, low in the east as dawn brightens. Bring binoculars.

19, 20 **DAWN:** Less than 1° separates bright Venus and weak Regulus on these two mornings.

22 **AUTUMN BEGINS** in the Northern Hemisphere at the equinox, 4:02 p.m. EDT.

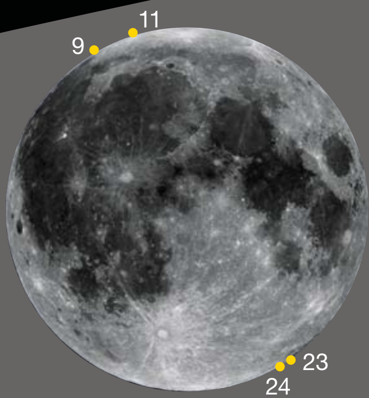
DUSK: The thin waxing crescent Moon hangs about 7° upper left of Jupiter in the west-southwest.

26 **EVENING:** Look southwest to spot yellow Saturn about 3° below the fat waxing crescent Moon.

Discovered by William Herschel in 1798, the intermediate spiral galaxy NGC 6946 lies about 22 million light-years away on the border of Cygnus and Cepheus. Ten supernovae have been detected in NGC 6946 in the past 100 years, prompting astronomers to informally refer to it as the Fireworks Galaxy.

Photo: NASA / ESA / STSCI / R. GENDLER / SUBARU TELESCOPE (NAOJ)

Lunar Almanac
Northern Hemisphere Sky Chart



Yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration.
NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	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

FULL MOON
September 6
07:03 UT

LAST QUARTER
September 13
06:25 UT

NEW MOON
September 20
05:30 UT

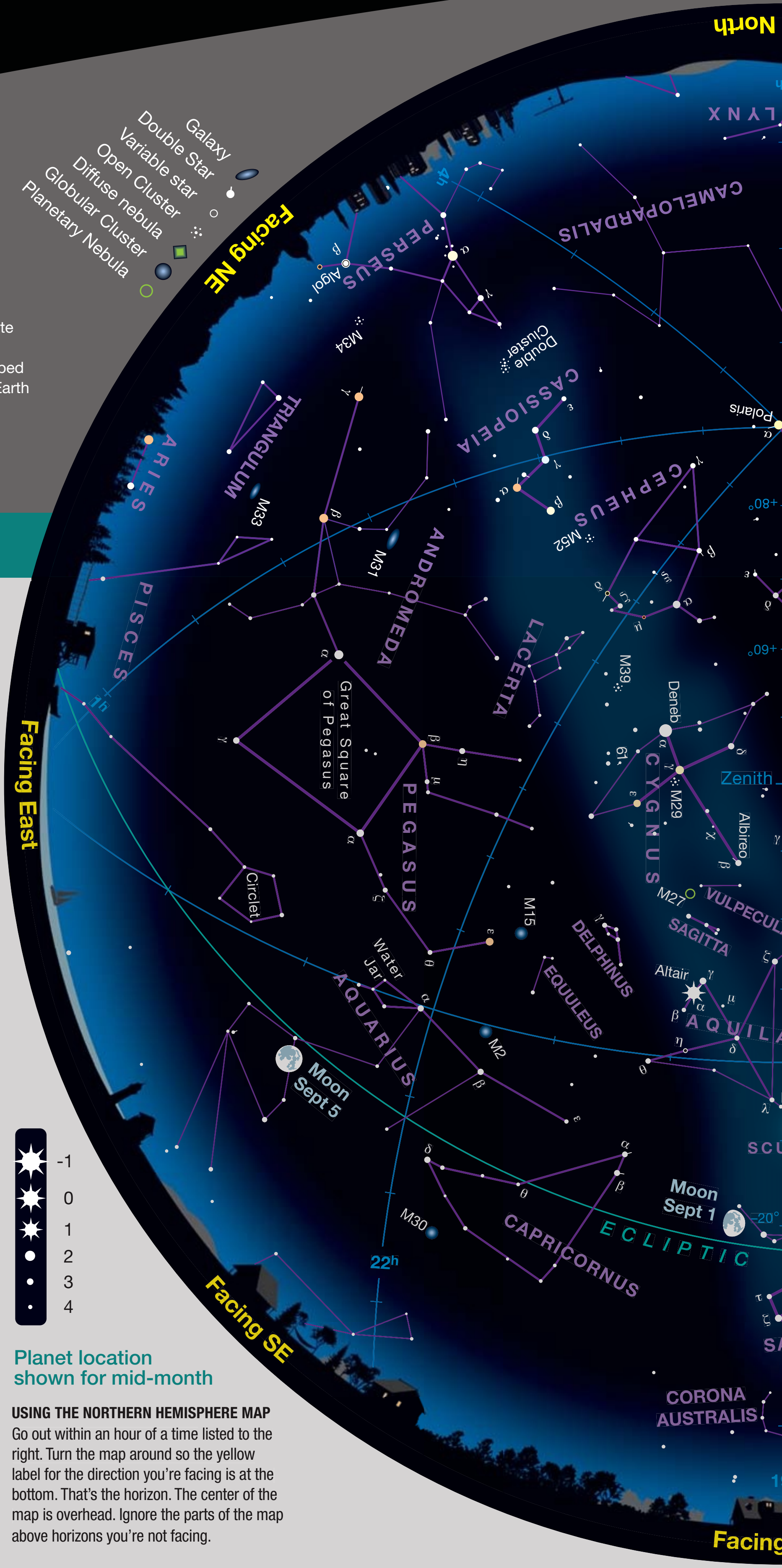
FIRST QUARTER
September 28
02:53 UT

DISTANCES

Perigee	September 13, 16^h UT
369,860 km	Diameter 32′ 19″
Apogee	September 27, 07^h UT
404,347 km	Diameter 29′ 33″

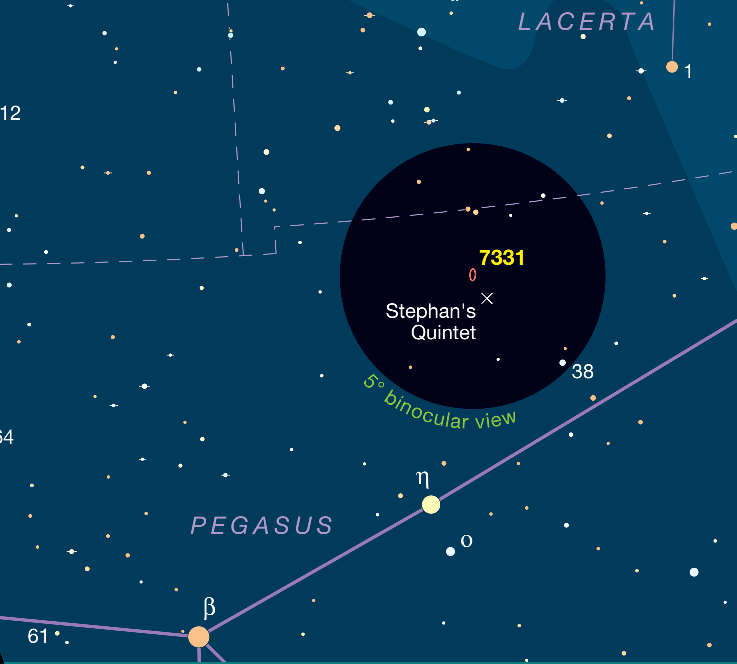
FAVORABLE LIBRATIONS

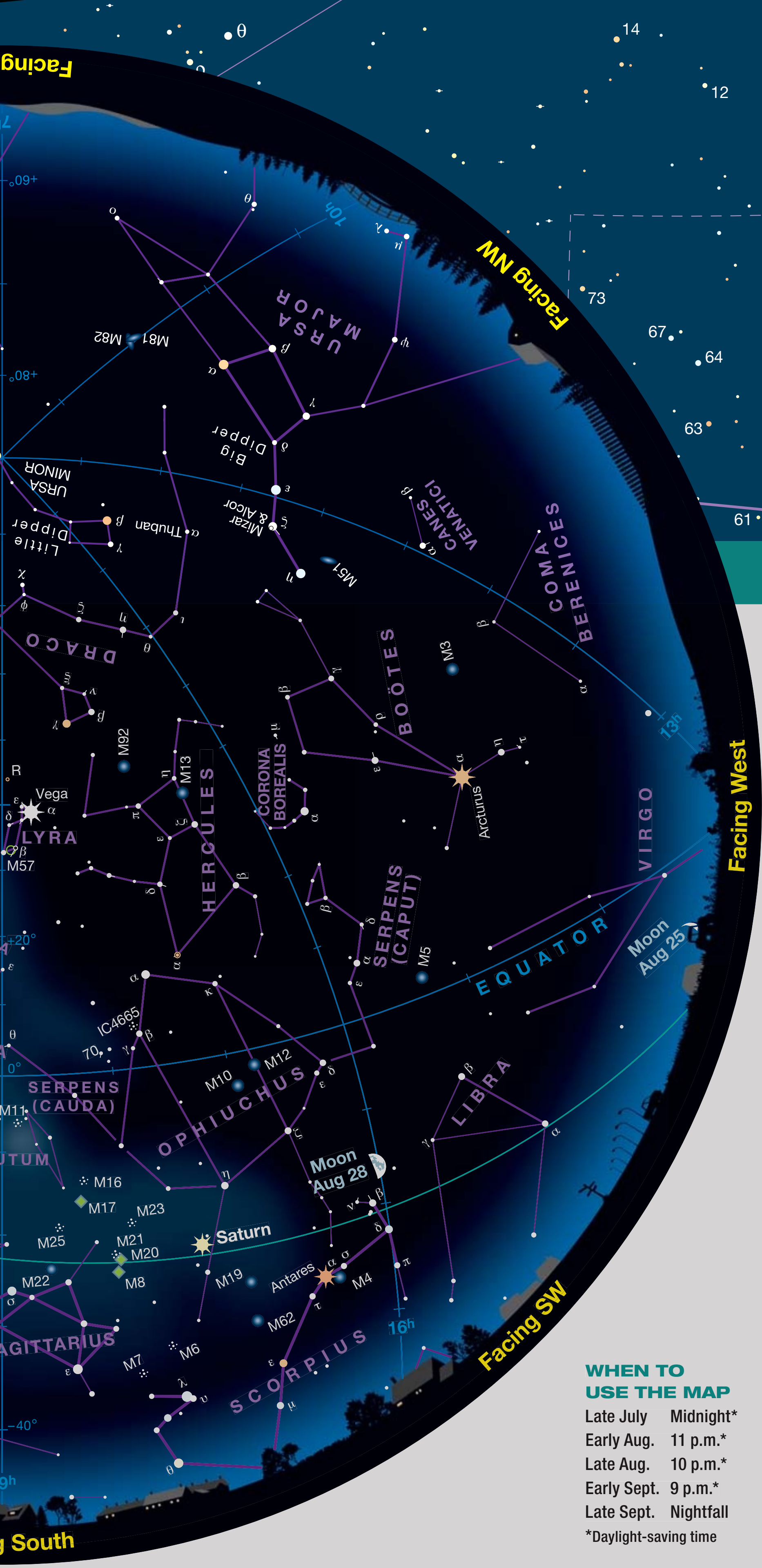
Russell Crater	September 9
Pythagoras Crater	September 11
Mare Smythii	September 23
Humboldt Crater	September 24



Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.





WHEN TO USE THE MAP

Late July	Midnight*
Early Aug.	11 p.m.*
Late Aug.	10 p.m.*
Early Sept.	9 p.m.*
Late Sept.	Nightfall

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Odd One Out

Galaxies in Pegasus, the Winged Horse, have a certain reputation: They're challenging. With famous members like Stephan's Quintet and Einstein's Cross, you could be forgiven for thinking that only observers with large scopes need apply.

There's at least one exception, however: **NGC 7331** (Caldwell 30), a big, beautiful spiral galaxy in the northern reaches of the constellation. To find NGC 7331, draw a line from Mu (μ) Pegasi to Eta (η) Pegasi and straight on for another 4½°. The galaxy also forms the northeastern corner of an imaginary right triangle with Eta Peg and Pi^2 (π^2) Peg.

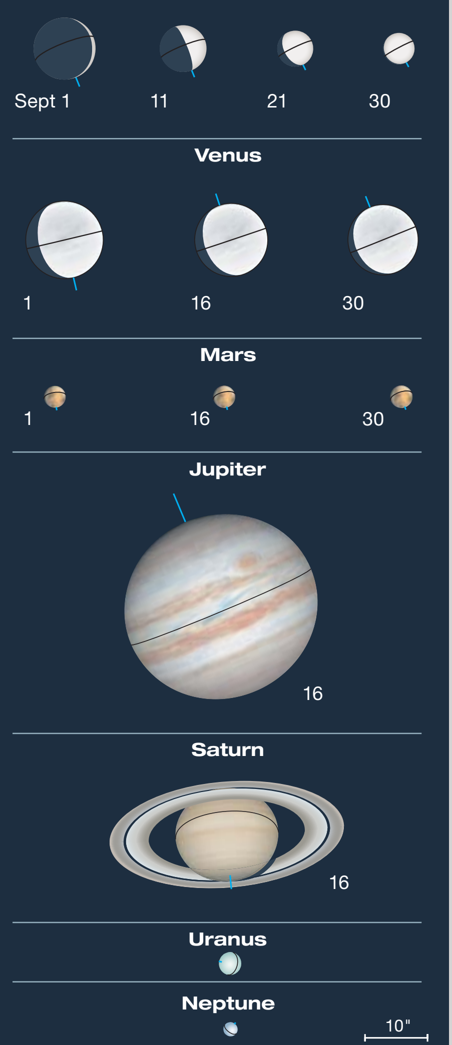
With a visual magnitude of 10.4, NGC 7331 won't necessarily be an easy catch, especially in light-polluted skies. But observers in only moderately dark skies have spotted it with 7×50 binoculars. So far I've needed at least 10×50s to pull it out, and 15×70s are better still — but when is that not true? It helps that the galaxy is big, 10′ × 4′, which is comparable to the largest Virgo galaxies. The large apparent size (as these things go) corresponds to ample proportions in real life. With a diameter of 130,000 light-years, NGC 7331 is larger than our own Milky Way.

NGC 7331 isn't just unusually bright for a Pegasus galaxy, it's also an astrophysical oddball. Several recent studies suggest that the galaxy's central bulge rotates in the opposite direction of the spiral arms.

I have one more bit of homework for you: Go online and find a high-res photo of NGC 7331. One of my favorite was taken by Vicent Peris at the Calar Alto Observatory in Spain — it looks like the cover of a sci-fi novel, but it's real. How wonderful that we can plumb the depths of intergalactic space with hand-held instruments.

■ **MATT WEDEL** likes to kick back with his binoculars on a driveway in Claremont, California.

Planetary Almanac



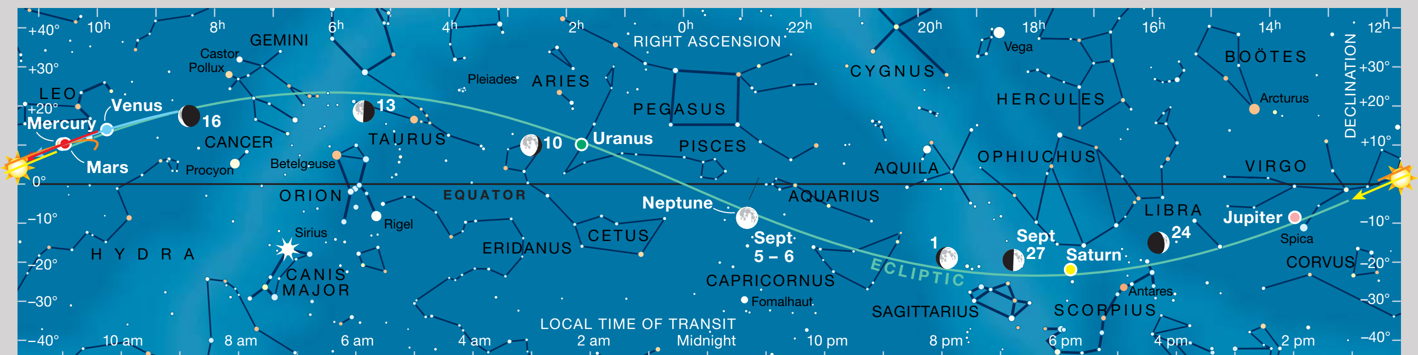
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury: Visible approximately Sept. 6 to 26, dawn, low or very low east • **Venus:** All September, dawn, east • **Mars:** All month, dawn, very low to low east • **Jupiter:** All month, dusk, low to very low WNW • **Saturn:** All month, evening, south to SW.

September Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h 40.6^m$	+8° 23′	—	–26.8	31′ 42″	—	1.009
	30	$12^h 24.9^m$	–2° 42′	—	–26.8	31′ 56″	—	1.001
Mercury	1	$10^h 02.4^m$	+8° 50′	9° Mo	+3.3	10.0″	6%	0.675
	11	$10^h 10.0^m$	+11° 22′	18° Mo	–0.2	7.5″	40%	0.897
	21	$11^h 02.2^m$	+8° 01′	14° Mo	–1.1	5.8″	81%	1.166
	30	$12^h 01.7^m$	+1° 44′	7° Mo	–1.3	5.1″	97%	1.331
Venus	1	$8^h 36.5^m$	+18° 40′	32° Mo	–3.9	12.4″	84%	1.343
	11	$9^h 25.5^m$	+15° 44′	29° Mo	–3.9	11.9″	86%	1.398
	21	$10^h 13.3^m$	+12° 03′	27° Mo	–3.9	11.5″	89%	1.449
	30	$10^h 55.3^m$	+8° 14′	25° Mo	–3.9	11.2″	91%	1.491
Mars	1	$9^h 58.3^m$	+13° 37′	12° Mo	+1.8	3.6″	100%	2.635
	16	$10^h 34.7^m$	+10° 13′	17° Mo	+1.8	3.6″	99%	2.602
	30	$11^h 07.9^m$	+6° 51′	21° Mo	+1.8	3.7″	99%	2.557
Jupiter	1	$13^h 22.1^m$	–7° 28′	43° Ev	–1.7	32.1″	100%	6.138
	30	$13^h 43.7^m$	–9° 37′	21° Ev	–1.7	31.0″	100%	6.369
Saturn	1	$17^h 21.0^m$	–21° 58′	102° Ev	+0.4	17.0″	100%	9.796
	30	$17^h 25.2^m$	–22° 07′	75° Ev	+0.5	16.2″	100%	10.272
Uranus	16	$1^h 43.2^m$	+10° 02′	146° Mo	+5.7	3.7″	100%	19.077
Neptune	16	$22^h 56.2^m$	–7° 49′	169° Ev	+7.8	2.4″	100%	28.959

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see skyandtelescope.com/almanac.



The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

Diamond of Three Rings

A total solar eclipse offers the most spectacular of jewels.

Most subscribers to *Sky & Telescope* will receive this issue in late July, well before August 21st's total eclipse of the Sun, so I want to continue the discussion of total eclipses I began last month. I'll conclude with an eclipse that brought me the most staggering moment I've ever had in a lifetime of observational astronomy.

Can you observe the F-corona? What overall shape will the corona take during the August 21st eclipse? The ultimate visible extension of the corona is not the gases of the Sun that glow on their own, but the part of the corona formed by dust particles that reflect light from the Sun out to many million miles. In fact, this "F-corona" is really the beginning of a phenomenon that stretches all the way to Earth's orbit and beyond — the zodiacal light. But we can only pick up the zodiacal light starting many degrees away from the Sun as twilight starts to fade away.

I'm familiar with only two observers who have knowingly seen the F-corona extending along the ecliptic during a total eclipse. Steve Albers did so with the naked eye. Robert Victor, columnist for *Sky & Telescope* in the 1970s and 1980s, traced the corona out to 5° with binoculars. However, both made these observations during the extremely long 1991 total eclipse of the Sun — so perhaps that gave their eyes more time to become dark-adapted.

The diamond ring of rings. The first or final piece of solar photosphere shining through the deepest valley on the Moon's edge creates, with the ring band of the inner corona, the most spectacular of all eclipse phenomena: the diamond ring. This diamond is truly brighter than all of Earth's diamonds combined. But during the eclipse of February 26, 1979, in Manitoba, I got to see a diamond wonder beyond all wonders.

The last rays of the Sun create a diamond ring as the solar corona appears during the total solar eclipse of August 1999.

BABAK TAFRESHI / GETTY IMAGES

Thin clouds had created a "cloud-corona" around the Sun before totality. The cloud-corona that most skywatchers have noticed on occasion occurs when clouds in front of the Moon produce a disk of blue or green bordered by a red ring around the Moon. The cloud-corona is an interference pattern formed by water droplets — or, rarely, ice needles — that are similar in size to the wavelengths of visible light.

Back to the 1979 eclipse: As totality began, I saw the dazzle of three Baily's beads — but no diamond ring. After 2 minutes and 50 seconds shouts of "It's coming back!" rang out.And then I heard the loudest yells and cries of all: The most briliant "star" any of us had ever seen had appeared at the edge of the Sun. The diamond brightened and hung, still starlike, second after second.

What happened next I've described best in my book *Wonders of the Sky*: "As the diamond brightened, two perfect rings of color came into view, centered upon it. It was a two-ringed cloud-corona, but never had I seen an example like this, for the smallness and incredible brightness of the diamond made the two rings also the smallest, sharpest, and most intensely deep purple-red that I have ever seen."

But most stunning of all was the positioning of the rings. "Since this phenomenon was caused by ice needles, the inner ring cut directly in front of the Moon, with the outer, exactly twice the radius of the first, encircling all. And the band of the diamond (ring), the inner corona, was still clearly visible and thus interlocked with the inner cloud-corona ring." This was the most staggering beauty I've seen in all my years of skywatching.

■ Contributing Editor FRED SCHAAF has been writing about the skies above us for more than 40 years.

Morning Marvels

Look to the pre-dawn sky for a series of close planetary pairings this month.

Jupiter and Spica drop ever deeper into the dusk during September, while Saturn still glows fairly high in the south-southwest at nightfall. But the eastern dawn sky is where exciting groupings and pairings happen this month. For a couple of mornings, no fewer than four solar-system objects form a relatively short, nearly vertical chain. Mercury, Mars, and Venus each pass Regulus, with Venus the highest and brightest. Mercury and Mars meet up twice, and Mercury presents observers at mid-northern latitudes with its best morning apparition of the year.

DUSK

At magnitude –1.7, **Jupiter** shines at its dimmest and smallest for the year and is too low for sharp telescopic views. Jupiter starts September about 10° high in the west-southwest 45 minutes after sunset for northern viewers. By the end of the month, it's only 4° high at dusk.

On September 1st, Spica gleams about 4° lower left of Jupiter. Then Jupiter slowly marches eastward past the star, passing a least distance of 3° upper right (north-northeast) of Spica on the evening of September 11th.

EVENING

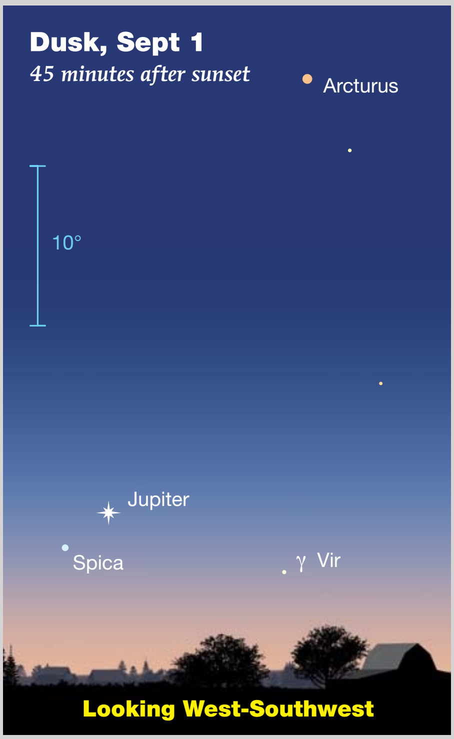
Saturn, in southeastern Ophiuchus, stands about 25° high in the south-southwest an hour after sunset this month and doesn't set until late evening. Antares twinkles some 12° to its lower right.

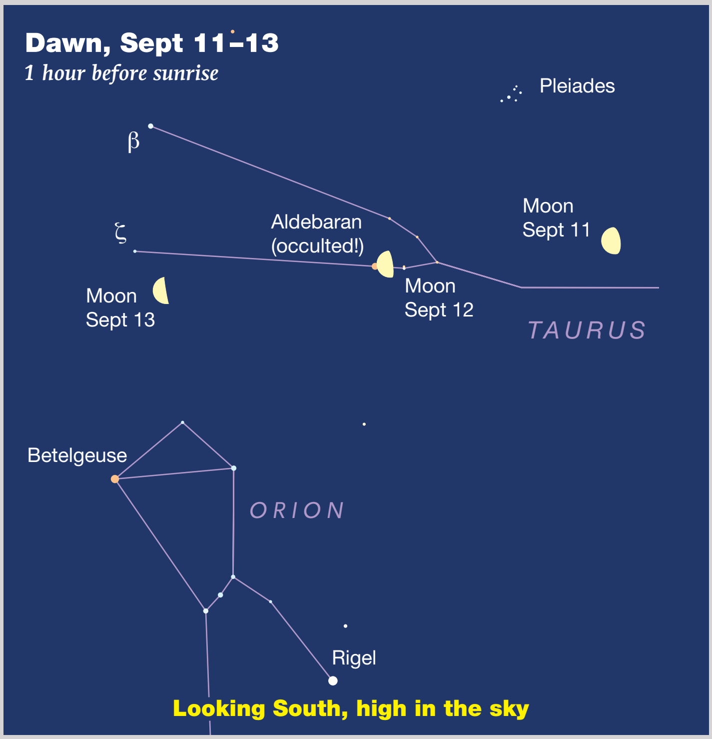
Saturn dims slightly in September, from magnitude +0.4 to +0.5, and its equatorial diameter shrinks from 17″ to 16″. But with a 27° tilt, Saturn's rings are now very close to being their most open in 15 years.

Saturn reaches eastern quadrature (90° east of the Sun) on September 14th, when its shadow falls farthest eastward onto the rings. All month the globe and rings look especially three-dimensional in the eyepiece.

NIGHT

Neptune, in Aquarius, is up at nightfall and stands highest in the south in the middle of the night. At opposition on the night of September 4–5, the distant giant remains at its brightest for





◀ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon is shown three times its actual apparent size.

● To find out what's visible in the sky from your location, go to skypub.com/almanac.

the year, magnitude 7.8, and shows its greatest apparent diameter, 2.4″.

Uranus rises in Pisces during evening twilight and culminates a few hours before morning twilight. Finder charts for Uranus and Neptune are at **skyandtelescope.com/urnep**.

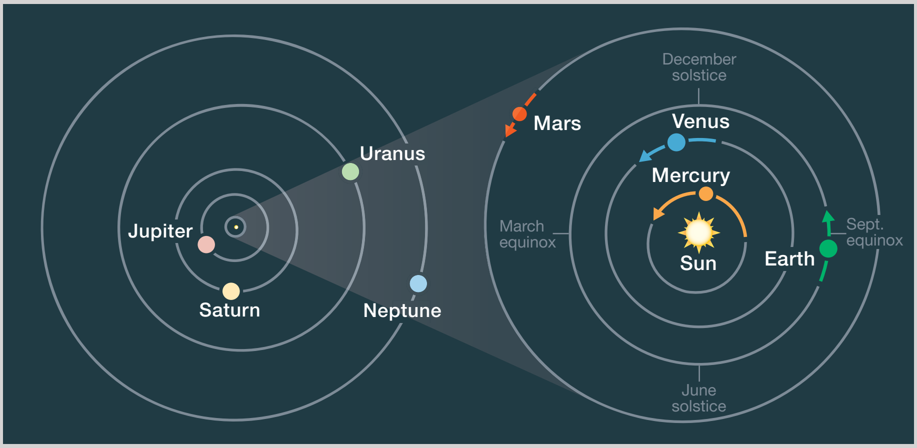
DAWN

Venus rises around 4 a.m. daylight-saving time at the start of September and 5 a.m. at month's end. It's circling away from us toward the far side of the Sun; its gibbous disk dwindles to about 11″ wide this month, while its phase increases to 90% lit.

Before first light on the morning of September 1st, use binoculars or a telescope to look for M44, the Beehive star cluster in Cancer, hanging about 1° to Venus's left.

Compare the colors of Venus and Regulus with the naked eye when the two are about 1° apart on the mornings of September 19th and 20th.

Mercury, Mars, and Regulus form a tight trio on the morning of September 5th but are too dim and low in bright twilight to see with the naked eye; binoculars may help. Look about 15° below or lower left of dazzling Venus.



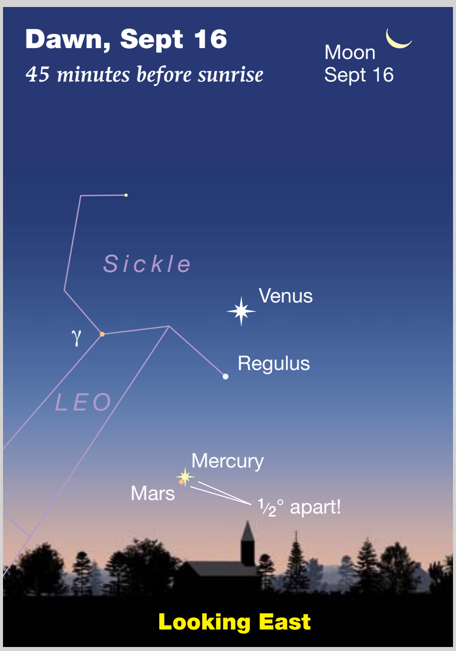
ORBITS OF THE PLANETS

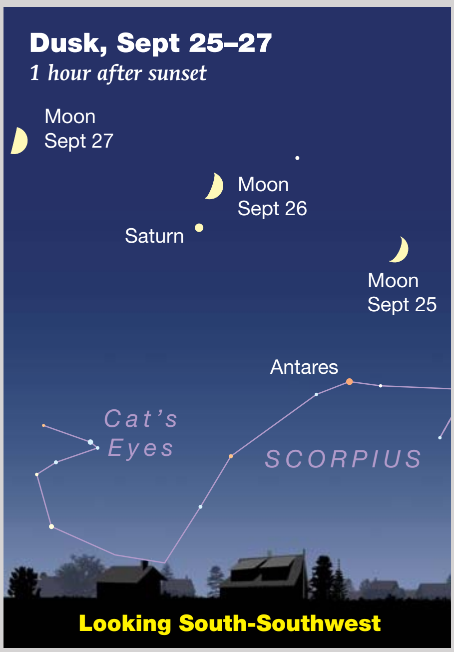
The curved arrows show each planet's movement during September. The outer planets don't change position enough in a month to notice at this scale.

At dawn on September 10th a higher Mercury, brightened to zero magnitude, shines ½° lower right of 1st-magnitude Regulus. Mars, at magnitude 1.8, is 3° below or lower left of the pair.

On September 12th Mercury is at greatest elongation, 18° west of the Sun, and at the peak of its best morning apparition of the year. On the morning of September 14th Mercury is at a minimum separation from Venus, 11° below or lower left of the bright planet.

At dawn on September 16th, Mercury is only about 0.3° from dimmer Mars. Mercury drops from view in the final days of the month, while a sinking Venus draws closer to rising Mars.





SUN AND MOON

The **Sun** reaches the equinox at 4:02 p.m. EDT on September 22nd, marking the start of autumn for the Northern Hemisphere.

The waning gibbous **Moon** occults Aldebaran for most of North America on the morning of September 12th (see page 50).

On September 16th, about 45 minutes before sunrise when the crescent Moon is far above Venus, Regulus twinkles about 4° below the brilliant planet. And 7° below Regulus shines a somewhat bright Mercury and a duller Mars separated by only ½°.

On September 17th, the Moon is almost as far above the tightening Venus-Regulus pair as the separating (but still tight) Mercury-Mars pair is below Venus. The next morning, the slim, waning lunar crescent is centered almost precisely between the close pairs.

On September 19th, just 30 minutes before sunrise, binoculars *may* reveal the *very* thin lunar crescent *very* low above the east horizon, likely unobservable. But Mercury and Mars stand above it, about 2° apart, and some 10° above them, Venus and Regulus are only 1° apart.

Back in the evening sky, the thick waxing lunar crescent is about 3° above Saturn at dusk on September 26th.

■ Contributing Editor **FRED SCHAAF** welcomes your letters and comments at **fschaaf@aol.com**.

Help Verify a Giant Ringed Exoplanet

For about 25 days in September, its ring system should cross an easily watched star.

UNIVERSITY OF WARWICK

Astronomers think a small object with enormous rings orbits the young star PDS 110 in Orion, which is still accreting gas and dust from its surroundings. In this artist's concept (not to scale), the ring material has been cleared of gas, and its jostling particles have had time to settle into a thin plane like the rings of Saturn. The infrared-glowing material around the star actually extends 100 times farther out than the ringed companion.

Remember Epsilon Aurigae? Every 27 years, this naked-eye supergiant star gets eclipsed for months by an enormous, dark *something* that was a mystery for generations. Modern techniques confirm that the object is an opaque disk around a smaller hot star that orbits the supergiant. A few other eclipsing-disk star systems are also now known.

In September, amateurs with telescopes equipped for photometry can help to confirm and study a new, miniature case on a perhaps even more interesting scale. In this instance the dark disk surrounds not a star, but a brown dwarf or a giant planet. Visual observers with small scopes may also be able to detect its expected eclipse event.

PDS 110 is a young star west of Orion's Belt, 7 to 10 million years old and still accreting gas and dust. The Wide Angle Search for Planets (WASP) and Kilodegree Extremely Little Telescope (KELT) sky surveys caught it dimming from magnitude 10.4 to 10.75 — a nearly 1/3 loss of brightness — for about 25 days in November 2008 and again in January 2011. Hugh P. Osborn (University of Warwick) and colleagues interpret these events as eclipses by a very large, dark object that's in an 808-day orbit around the star. "Shearing over a single orbit rules out diffuse dust clumps as the cause," they write in a paper to appear in the *Monthly Notices of the Royal Astronomical Society*. "The characteristics of the eclipses are consistent with transits by an unseen low-mass planet or brown dwarf" with a mass of 1.8 to 70 Jupiters. This object would be circling the star at a distance of about 2 a.u. Its disk would be an enormous 0.3 a.u. wide.

Whatever the eclipsing body is, its next pass across the star should last for much of September.

PDS 110 (also known as HD 290380) is about 1,100 light-years distant, located in the Orion OB1a Association of young stars. It's estimated to have 1.6 solar masses. About a quarter of its light is absorbed by nearby dust, which re-emits it as infrared radiation.

Osborn and his team spotted the star dimming in data from automated surveys, including WASP and KELT. The depth of the dimmings made them particularly interesting. Moreover, they appeared somewhat ragged and irregular, indicating that the putative eclipsing object has complex structure.

"What's exciting is that during both eclipses, we [saw] the light from the star change rapidly, and that suggests that there are rings in the eclipsing object," says coauthor Matthew Kenworthy (Leiden University).

Five years ago, Kenworthy was a member of the team led by Eric Mamajek (University of Rochester) that discovered similar behavior in the young star J1407 (officially, 1SWASP J140747.93-394542.6) in Centaurus. But that system has only shown one eclipse so far. The intricate light curve of that event suggested more than 30 separate ring structures in a disk 1.2 a.u. wide around an exoplanet. As in the much smaller rings of Saturn, the gaps may indicate embedded moons (*S&T:* June 2015, p. 12). The PDS 110 companion's ring system could be showing similar signs of exomoons.

Observations Wanted

The next eclipse is predicted to run from about September 9th to 30th, plus or minus 10 days. The two past eclipses showed gradual fading and rebrightening. If the next happens on schedule, astronomers hope to assemble a fuller picture of the ring system and what it may tell us about any exomoons.

This will require getting as complete and continuous a light curve as possible. Orion will be observable for only the two or three hours before dawn from any one site; it will be rising from low in the east-southeast to high in the southeast. Photometric observers are wanted all around the globe to hand off the job ever westward as dawn intrudes. Dawn begins about 1½ hours before your local sunrise.

Doing this for a month will require lots of observers with lots of clear nights! Coverage is especially needed in sparsely populated longitudes. Hawai'i and Tahiti, are you listening?

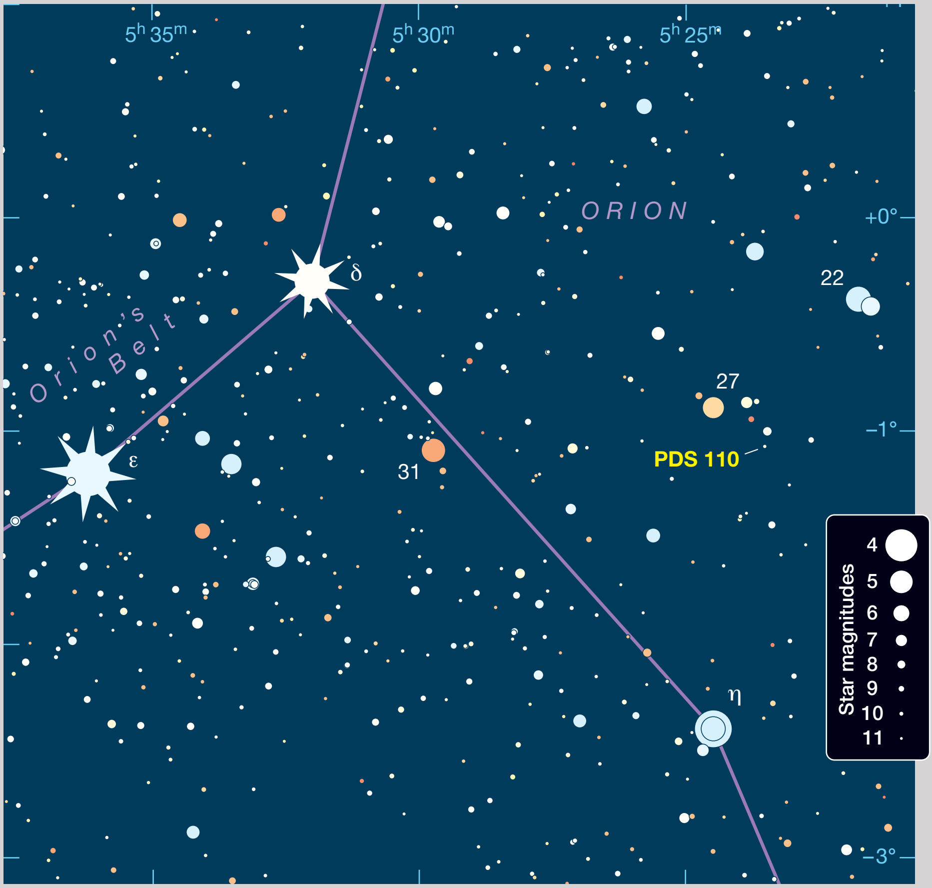
CCD photometry will be necessary to record any evidence of ring gaps. But careful visual observers with 4- or 6-inch scopes should be able to at least verify an eclipse happening.

The discovery team is running this campaign through the American Association of Variable Star Observers. For updates, comparison-star charts, and to subscribe to the discussion, go to **aavso.org/aavso-alert-notice-584**.

As for when to start watching, the sooner the better. Significant changes in the star have been seen at odd times.

If the eclipsing disk dims the star on schedule, the planet (or brown dwarf) will become the only *confirmed* low-mass ringed object orbiting a star outside our solar system.

This system is becoming a hot item. Spectroscopy will eventually determine the companion's mass. Millimeter-wave observations by ALMA in Chile may reveal additional material or companions in more distant orbits. If you contribute observations now, you can say you were there when it was all getting started.



▶ Easily found west of Orion's Belt is little PDS 110, usually but not always magnitude 10.4. From bright Delta Orionis, an arc of three 5th-magnitude stars (31, 27, and 22 Orionis) makes this an easy star-hop. The fainter asterism around 27 provides a distinctive pointer for the last step. To print a comparison-star chart with standard magnitudes for all observers to use, see aavso.org/aavso-alert-notice-584.

Moon Occults Aldebaran

ON TUESDAY MORNING September 12th for North America, the Moon once again occults the brightest star it ever can. The event happens in daylight for the eastern and central parts of the continent, and before or during dawn for the West. Aldebaran will vanish on the bright limb of the waning gibbous Moon and will reappear up to an hour or more later from behind the Moon's dark limb.

For the disappearance you'll need a telescope no matter where you are, and you'll also need one for any chance at seeing the reappearance unless you're near the West Coast. Hawai'i sees both events in darkness.

Here are some times:

Los Angeles, *disappearance* 4:34 a.m. PDT, *reappearance* 5:49 a.m. PDT; **Seattle,** *d.* 4:43; a.m., *r.* 5:54 a.m. PDT; **Phoenix,** *d.* 4:48, *r.* 6:00 a.m. MST, **Denver,** *d.* 6:05 a.m., *r.* 7:24 a.m. MDT; **Chicago,** *d.* 7:37, *r.* 8:51 a.m. CDT; **Austin,** *d.* 7:39, *r.* 8:16 a.m. CDT; **Toronto,** *d.* 8:49, *r.* 10:00 a.m. EDT; **Atlanta,** *d.* 8:56, *r.* 9:52 a.m. EDT; **Pittsburgh,** *d.* 8:51, *r.* 10:01 a.m. EDT; **Washington, DC,** *d.* 8:58, *r.* 10:05 a.m. EDT; **New York,** *d.* 8:59, *r.* 10:07 a.m. EDT; **Boston,** *d.* 9:01, *r.* 10:08 a.m. EDT.

Predictions for hundreds of locations, including the altitudes of the Sun and Moon, are at **lunar-occultations.com/iota/bstar/bstar.htm**. (The page for each star displays three long tables with less-than-obvious divides: for the disappearance, the reappearance, and the locations of cities.)

In the hours leading up, the Moon will also mow down several stars along the southern branch of the Hyades. The brightest of these, magnitudes 3.4 to 3.8, are Gamma Tauri and the Theta^1 and Theta^2 Tauri pair. Timetables for each are at the link above, but you'll need a pretty dark sky with the Sun at least 12° or so below the horizon ("Sun Alt –12").

Minding Mercury

MERCURY OFFERS its best morning apparition of the year for northern observers this month. This fast-moving world is only observable low to the horizon, where the seeing is seldom good, but morning views are often better than evening ones. The angle of the ecliptic affects visibility, and this is the time of year when the ecliptic tilts most sharply up from the dawn horizon. So this is when our littlest planet reaches almost its highest dawn elevation.

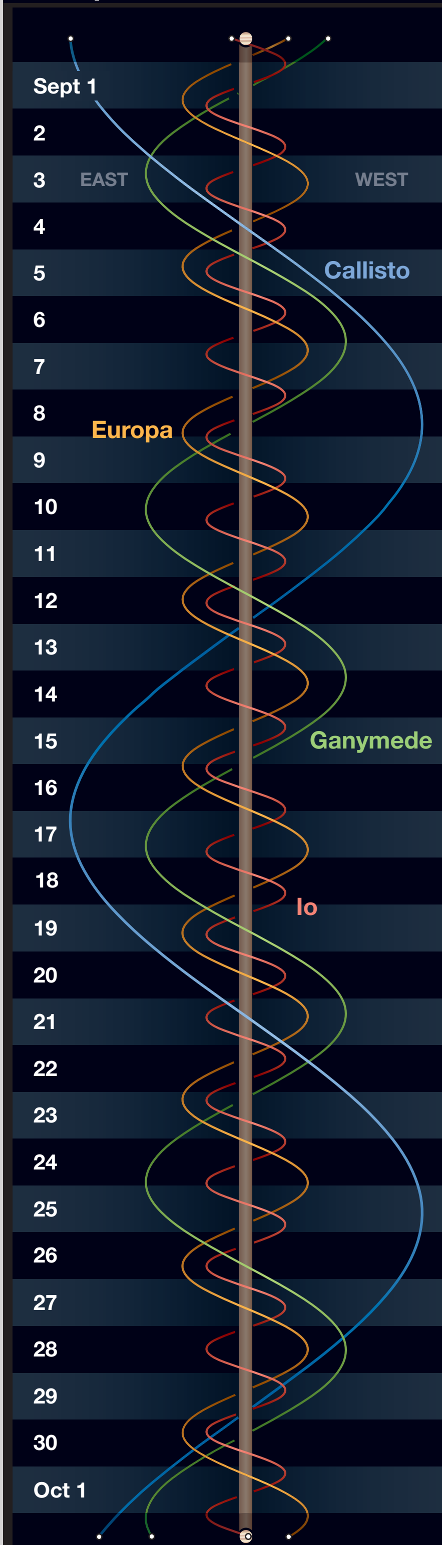
Watch for Mercury coming into view as early as September 5th, when it glimmers at magnitude 1.4. It reaches greatest elongation, 18° west of the Sun, on September 12th. That morning it's a resplendent –0.3 magnitude. It continues to brighten for the next two weeks, reaching –1.3 as it becomes unobservably low around the 26th or 27th.

Minima of Algol

Sept.	UT	Oct.	UT
3	5:15	1	21:22
6	2:04	4	18:10
8	22:53	7	14:59
11	19:41	10	11:48
14	16:30	13	8:36
17	13:18	16	5:25
20	10:07	19	2:14
23	6:56	21	23:03
26	3:44	24	19:52
29	0:33	27	16:40
		30	13:29

These geocentric predictions are from the heliocentric elements Min. = JD 2452500.179 + 2.867335*E*, where *E* is any integer. For a naked-eye comparison-star chart and more information about Algol and its history, see **skyandtelescope.com/algol.**

Jupiter's Moons



The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites' positions east or west of Jupiter.

The Enduring Mystery of Luna 2

Amateur observers claimed to see its impact — but no trace of the crash site has ever been found.

Fifty-eight years ago this month, the first spacecraft reached the Moon. On September 12, 1959, the Soviet Union launched Luna 2 on a collision course with the Moon. Weighing 170 kilograms (375 pounds), the probe consisted of an 81-cm (32-inch) spherical pod festooned with protruding antennas. Crammed aboard were a magnetometer, radiation counters, micrometeorite detectors, and many stainless steel pennants bearing the nation's hammer-and-sickle coat of arms that were to be scattered around the impact site.

Soviet authorities announced that Luna 2 would crash into the lunar surface at a velocity of 3.3 kilometers per second at 21:01 Universal Time on September 13th, about 38½ hours after launch. The announced target was **Mare Imbrium**, though there was considerable uncertainty in that. An error of only 1 meter per second in the rocket's final velocity would displace the point of impact on the Moon by a whopping 250 km, while a deviation of just 1 arcminute in its trajectory would introduce a further offset of 200 km.

On September 13, 1959, observers scrutinized a waxing gibbous Moon just like this one to try to spot the crash landing of Luna 2. Yellow dots show the locations of "confirmations" discussed in the text.

The uppermost stage of the rocket, which carried the probe toward the Moon, broadcast a series of pulses so that the vehicle's trajectory could be monitored. The world's most powerful radio telescope at the time, the 250-foot-diameter steerable dish at Jodrell Bank in England, tracked Luna 2 throughout its mission. Frequent updates on the spacecraft's progress dominated news reports — reaching the Moon was a feat of considerable technological prowess in 1959.

As the hour of predicted impact drew near, hundreds of observers trained their telescopes on the Moon in the hope that some trace of the event might be visible. The Moon was at a waxing gibbous phase, less than four days from full, so any effect would have to be glimpsed against a brilliant sunlit surface.

While most saw nothing, seven observers reported seemingly credible sightings. Hugh Percy Wilkins, a leading British lunar observer who'd recently published a 300-inch-wide map of the Moon, reported to the prestigious journal *Nature* that he had swept Mare Tranquilitatis, Mare Serenitatis, and Mare Vaporum using his 15-inch reflector at a power of 300×:

> *The stated time for the impact arrived and nothing was seen. I decided to continue for a short while and 1½ minutes after the stated time at 21h02m23s I was looking at the Mare Vaporum, the nearest part to the center [of the lunar disk]. At this point, north of the Hyginus Cleft and close to Schneckenberg, I observed a pinpoint of light and a kind of dark ring, just as though dust had been disturbed and heated. This lasted a few seconds.*

DMITRY MAKOLKIN; BANNER IMAGE: NASA

Fifty miles from Wilkins' observatory in Kent, his close collaborator Patrick Moore, host of the BBC's popular television program *The Sky at Night*, kept a vigil with a 12½-inch reflector. In a seemingly striking corroboration of Wilkins' observation, Moore reported seeing a "minute pinpoint of light" at 21:02:23 UT. "It appeared suddenly and faded out within half a second . . . in the Hyginus area, close to **Schneckenberg**." Moore cautioned that "the phenomenon was so uncertain and so close to the limit of visibility that it seemed unwise to trust it."

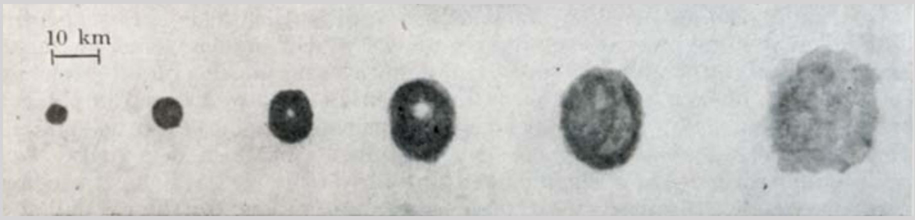
Meanwhile, at Konkoly Observatory in Budapest, a young assistant observer named Miklós Lovas turned a 7-inch refractor on the Moon. Recounting the events of that night a half century later, he recalled:

> *The Soviets had only provided the time, so I had to fit an eyepiece that allowed one to see the whole face of the Moon. I think they didn't even know where it would hit . . . All of a sudden, a dark speck appeared. The phenomenon lasted twenty minutes. It expanded and faded slowly. At first it was quite dark, but it turned to gray and was much fainter toward the end . . . The first detection of the speck (21h 02m 30s) agreed well with the termination of the radio signal of the probe (21h 02m 24s).*

Lovas' slowly fading dusky cloud was located in **Palus Putredinus**, on the southeastern edge of the Mare Imbrium, not far from the outer ramparts of the crater Archimedes but hundreds of kilometers from the bright flashes reported by Wilkins and Moore.

Damningly, a series of photographs taken that night through the 24-inch refractor at Pic du Midi Observatory in France failed to record anything out of the ordinary. In time, Patrick Moore would recant:

> *Eleven months later, when I was in Moscow, I discussed the optical observations with authorities at the U.S.S.R. Academy of Sciences and studied the other reports. They were, to put it mildly, in violent disagreement with my observation and with each other; there were flashes, luminous glows, and dark expanding spots dotted over a huge area of the Moon! This confirmed a view that none of us had in fact seen the true impact. When straining to catch a glimpse of an excessively faint phenomenon, without even knowing its position in advance, it is only too easy to be deceived.*



According to Hungarian observer Miklós Lovas, Luna 2's impact created a dark cloud of debris that enlarged and dimmed for about 20 minutes. Modern impact simulations suggest such an obvious splash would not have occurred.

Modern-day consensus, based on the observations of the impacts of other spacecraft on the Moon, holds that the crash of Luna 2 would not have been visible against a sunlit background. The sightings of Moore and his contemporaries are classic cases of the phenomenon that psychologists call *expectation bias*, the proclivity of observers or experimenters to allow their expectations to affect the outcome — and the tendency to distort recalled events to make them fit expectations.

It's worth noting that the impact sites reported by Wilkins, Moore, and Lovas are all consistent with the rocket's initial ballistic trajectory, Jodrell Bank's determination of its acceleration, and radio interferometry measurements of its course by Soviet tracking stations. Although impact specialists have grave doubts about Lovas' observation, Palus Putredinis is nonetheless listed as the impact site of Luna 2 in most databases.

Painstaking examination of Lunar Reconnaissance Orbiter images has turned up traces of 32 spacecraft or components that have crashed into or landed on the Moon — but the tiny crater and ejecta blanket created by the impact of Luna 2 remain an elusive needle in a vast haystack.

More recently, telescopic observers have indeed witnessed chunks of interplanetary debris crashing into the Moon. But those impacts are much faster, and the observed strikes have all occurred at locations darkened by lunar night.

In three months you'll have a golden opportunity to watch for impacts on the unilluminated portion of the crescent Moon. In the predawn hours of December 14th, Earth and Moon will sweep through the stream of particles shed by the near-Earth asteroid 3200 Phaethon during the annual Geminid meteor shower. Cosmic shrapnel will strike the lunar surface at roughly 36 km (22 miles) per second, an order of magnitude faster than Luna 2 did. At such speeds, a meteoroid with a mass of only 5 kg can excavate a crater more than 9 meters across and hurl 75 metric tons of lunar soil and rock on ballistic trajectories above the lunar surface.

The Moon will be a narrow waning crescent only 14% illuminated. Keep a vigil on the dim, earthlit portion of the lunar disk, where Geminid impacts will appear as flashes of light as bright as 6th to 9th magnitude.

The Meteoroid Environment Office at NASA's Marshall Space Flight Center monitors meteoroid impacts on the Moon in collaboration with the Association of Lunar and Planetary Observers. Their websites are noted below.

■ Contributing Editor **TOM DOBBINS** has observed most reported phenomena on the planets, both real and illusory.

• Learn more at **https://is.gd/NASA_lunar_impacts** & **https://is.gd/ALPO_lunar_impacts**.

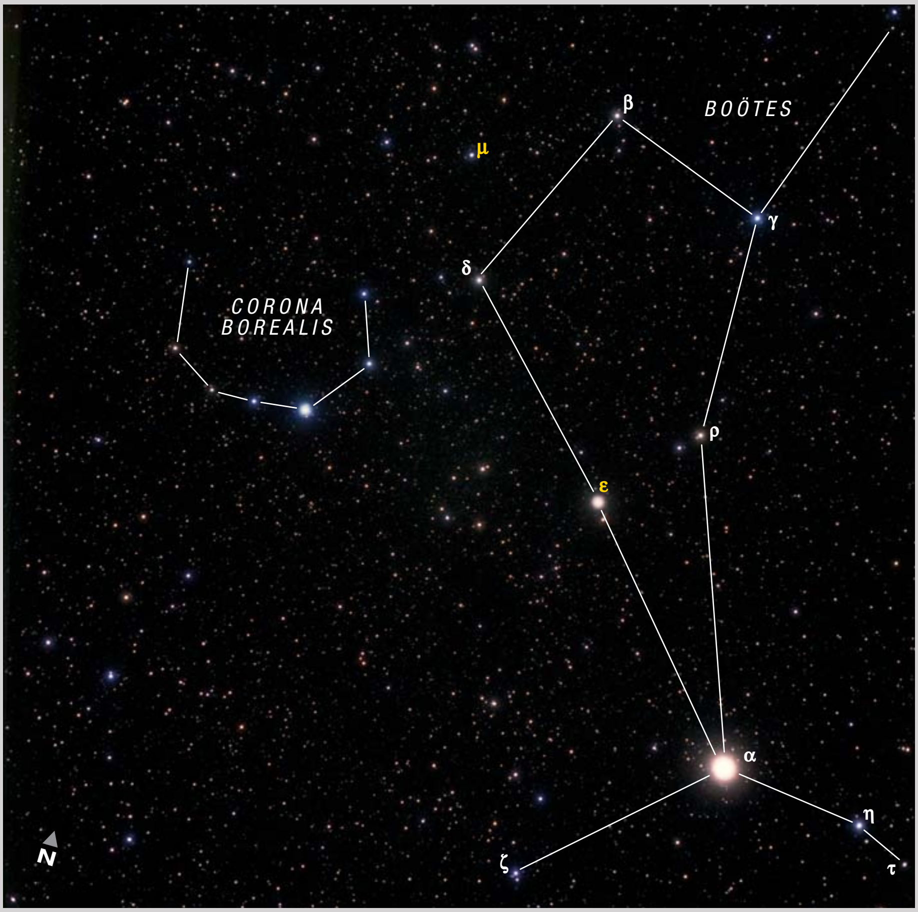
Showpiece Doubles

Point your telescope toward these gems of the late-summer sky.

▲ **Left:** Fourth-magnitude Mu¹ Boötis is sometimes called Alkalurops, a mellifluous name that derives from the Arabic adaptation of the Greek *kalaurops*, meaning "a shepherd's crook" or "staff." The above sketch shows Mu¹ and the Mu² pair as viewed at 240× through a 6-inch Newtonian.

Observing multiple stars is a joy. They come in varied combinations of brightness and color, they often have tantalizing qualities to spark the imagination, and you don't need dark skies or a big telescope to admire them. Let's immerse ourselves in the wonders some of the best and brightest offer, each labeled on the all-sky chart at the center of this magazine. They're also among what I affectionately call Kaler's stars, stars with fascinating bios on Jim Kaler's Stars website (**https://is.gd/kalerstars**), which I'm pleased to credit for many of the details here.

We'll begin with the highly praised double Epsilon (ε) Boötis, commonly known as **Izar** (EYE-zar). The name means "girdle" or "loin cloth" and refers to the star's position within its constellation figure. William Herschel discovered Izar's dual nature in 1779, describing it as "very beautiful." In his 1867 double-star catalog, the Reverend William Rutter Dawes called Izar "one of the most beautiful stars in the heavens," but his contemporary Friedrich Georg Wilhelm von Struve is generally credited with bestowing the name Pulcherrima (most beautiful) on this pair.



▲ The name Boötes, meaning "Herdsman" or "Plowman" in archaic Greek, can be traced as far back as Homer, whose hero Odysseus used the constellation to guide his night journey away from Ogygia, the island of Calypso. Izar, the common name for Epsilon Boötis, translates to "girdle" or "loin cloth" and marks the waistline of the celestial keeper of cattle.

Izar is nicely split through my 105-mm refractor at 122×. The brilliant, golden primary watches over a snowy white companion to the north-northwest that shines 2.2 magnitudes dimmer. Many observers see the companion as blue or green, a common color-contrast illusion that can sometimes be dispelled by using enough magnification to widely separate the stars.

Izar's primary is a *K0* giant that has exhausted the hydrogen fuel in its core. Its outer layers have expanded, turning the star into an immense, amber light bulb 33 times as big across and 400 times as bright as our Sun. The white star is an *A2* dwarf — a main-sequence star that's still burning hydrogen in its core. It's about twice as big across and 27 times as bright as our Sun. According to Kaler, the pair's orbital period must be well over a thousand years.

Farther north in Boötes we find Mu¹ (μ^1) and Mu² (μ^2) Boötis. Mu¹ also bears the name **Alkalurops** (uhl-kuh-LOO-rops), which in the course of a

AKIRA FUJII; SKETCH: JEREMY PEREZ

torturous history evolved from a word meaning "club" into a corrupted form of another word that's supposed to signify a "shepherd's staff."

Through my 105-mm scope at 28×, white Mu^1 is widely separated from yellow Mu^2, which stands a roomy 109″ to the south. At 127× Mu^2 splits into a close pair of yellow stars, one shining at magnitude 7.1 and the other a half magnitude fainter. The Mu^2 pair is a visual binary with a period of only 265 years. This is a good time to observe the pair since its stars are currently 2.2″ apart, close to their greatest separation, with the brighter one south of its attendant. While Mu^1 is also a binary, the components always appear too close together to discern.

Are the two pairs physically related? A Bayesian probability analysis by Ed J. Shaya and Rob P. Olling (*Astrophysical Journal Supplement*, 2011) places the likelihood at nearly 100%. However, a 2014 study by Olga Kiyaeva and colleagues (*Astronomy Reports*) indicates that differences in the heavy-element abundances between the two systems favors a scenario in which they have different origins and are simply undergoing a close encounter.

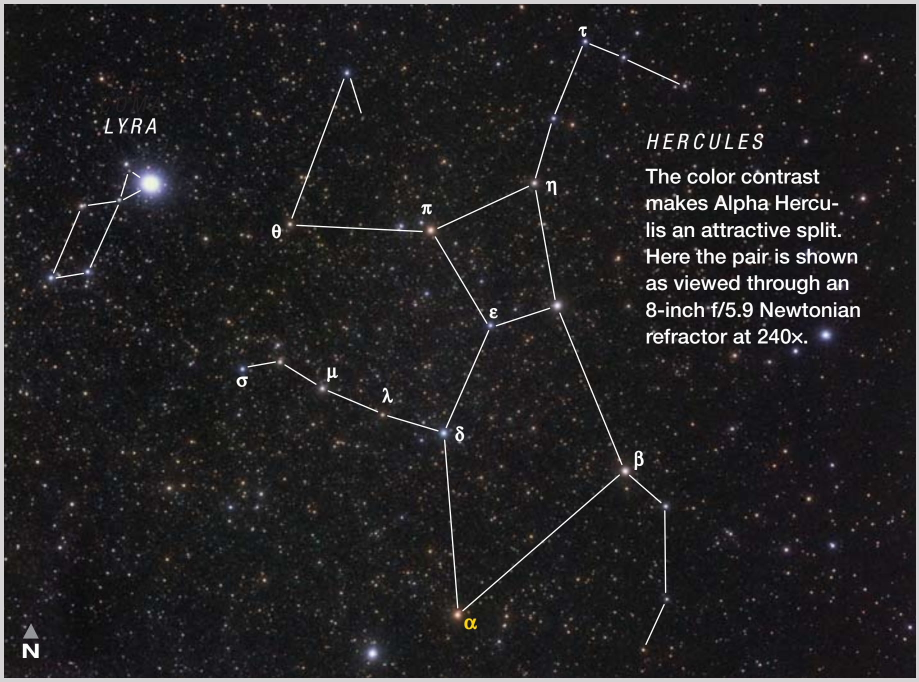
Now we'll head over to Hercules where we'll meet the spectacular double Alpha (α) Herculis, **Rasalgethi** (rahs-uhl-JAY-thē). Rasalgethi means "the Kneeler's Head," as we see Hercules upside-down in the sky. In the 105-mm scope at 76×, this remarkable pair boasts a splendid, orange primary guarding a yellow companion 4.6″ to the east-southeast. A magnification of 122× makes distinguishing the colors easier. The stars orbit each other in a stately march of roughly 3,600 years. The direction of the companion with respect to its primary shifts slowly, but the apparent separation barely changes throughout the orbit.

There's more to the Rasalgethi system than meets the eye! The companion is actually a spectroscopic binary composed of a G5 giant star and an F2 dwarf separated by only two-fifths the distance between the Earth and Sun. They complete an orbit in a mere 52 days. The primary giant is a semi-regular variable with a magnitude range of about 2.7 to 3.6 and a mean period of roughly 126 days. The primary also appears to be binary, resolved three times at separations 0.16″ to 0.19″.

One of my favorite doubles is Beta (β) Cygni, **Albireo** (al-BIH-ree-oh). Strangely, the common name is meaningless. The story begins with Ptolemy's name for Cygnus, *ornis* (bird), which was transliterated into Arabic. The Arabic name was then transliterated into Latin during the Middle Ages, and one

AKIRA FUJII; SKETCH: JEREMY PEREZ

▲The multiple-star system Alpha Herculis, popularly known as Rasalgethi, marks the head of Hercules, who kneels upside down in our night sky.



The color contrast makes Alpha Hercu-lis an attractive split. Here the pair is shown as viewed through an 8-inch f/5.9 Newtonian refractor at 240×.

Double-Star Showpieces

Object	On Chart	~Dist. (l-y)	Mag(v)	Size/Sep	RA	Dec.
Izar	ε Boötis	200	2.6, 4.8	2.9″	14^h 45.0^m	+27° 04′
Alkalurops AB	μ Boötis	120	4.3, 7.1	109″	15^h 24.5^m	+37° 23′
Alkalurops BaBb	μ Boötis	120	7.1, 7.6	2.2″	15^h 24.5^m	+37° 21′
Rasalgethi	α Herculis	350	2.7–3.6, 5.4	4.6″	17^h 14.6^m	+14° 23′
Albireo AB	β Cygni	400	3.2, 4.7	34.3″	19^h 30.7^m	+27° 58′
Albireo AaAc	β Cygni	400	3.4, 5.2	0.4″	19^h 30.7^m	+27° 58′
Delta Cyg AB	δ Cygni	170	2.9, 6.3	2.8″	19^h 45.0^m	+45°08′
Delta Cyg AC	δ Cygni	170	2.9, 12.0	62.6″	19^h 45.0^m	+45°08′

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

▲ **Left:** Though Albireo A and B combine to form a beautiful double-star scene, their visual proximity may be happenstance, as astronomers aren't certain the two stars are related physically. **Right:** This sketch shows Albireo as viewed through an 80-mm refractor at 112×.

commentator wrote that the resulting moniker might be derived *ab ireo* (from ireus), the name of an aromatic plant. A Latin version of Ptolemy's Almagest showed the words *ab ireo* on the line just before the constellation's first star, and it seems to have been mistaken for the name of that star. Finally, *ab ireo* was made to look Arabic again, morphing into Albireo. If you'd like to know more about the often amazing origins of star names, pick up a copy of the authoritative book *A Dictionary of Modern Star Names* by Paul Kunitzsch and Tim Smart.

Albireo is a must-show at public star parties as a wonderful study in color, temperature, and stellar evolution. The colors show surprisingly well even in 15×45 binoculars, where I see them as gold and blue, yet the secondary looks blue-white when I use a telescope. Sissy Haas, author of the gem-packed book *Double Stars for Small Telescopes*, is much more creative with color names than I am and surely must have had the 64-color pack of Crayola crayons as a child. She describes Albireo as "a stunning pair of deeply colored stars, brilliant citrus orange and vivid royal blue." With its golden or citrus hue, Albireo A must be much cooler than bluish Albireo B, so why does it look brighter? The answer, of course, is that the A component is an aged giant, and thus a much bigger light source than the blue-white dwarf.

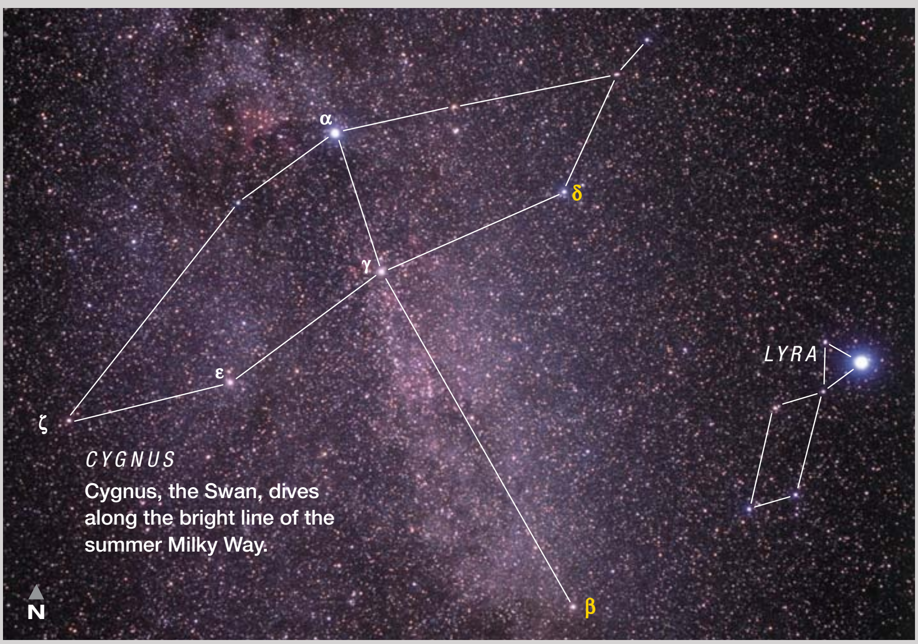
According to the Washington Double Star Catalog (**http://ad.usno.navy.mil/wds/**), the primary star has two very close companions. One (Ac) is a hot, blue dwarf with an orbital period of 214 years. The separation is currently 0.40″, increasing to a maximum of 0.66″ near the end of this century. The other (Ab) is a much closer companion about which little is known. Albireo B was once considered double as well, but there was only one detection, now believed to be a mistakenly assigned measure of the primary and one of its close companions.

Are Albireo A and B physically related? It's not certain. They have statistically the same parallax distance and may be moving through space together, but their distance from us and their apparent separation implies an unusually long orbit, on the order of 100,000 years.

Our final target also lies in Cygnus, at the bend of the Swan's northern wing. Despite being the 4th-brightest star in the constellation, **Delta (δ) Cygni** bears no common name. Delta is a triple star made up of a tight pair accompanied by a faint companion at a spacious remove, an arrangement that helps stabilize a triplet.

Through the 105-mm refractor at 122×, the close pair is well split, showing a resplendent white primary with a 6th-magnitude, yellow-white companion 2.8″ southwest. At any magnification high enough to split this pair, the much dimmer, 12th-magnitude companion shyly standing off 63″ to the east-northeast hardly looks like a true companion.

The close pair is a visual binary with a period of 918 years. Its apparent separation will increase for nearly four centuries to a maximum of 4.8″. From a hypothetical planet circling the yellow-white dwarf star, the subgiant primary would shine with the light of several thousand full Moons, effectively banishing the night with its presence. What a sight!



Cygnus, the Swan, dives along the bright line of the summer Milky Way.

■ Contributing Editor **SUE FRENCH** welcomes your comments at **scfrench@nycap.rr.com**.

CYGNUS: AKIRA FUJII; ALBIREO PHOTO: BOB FRANKE; ALBIREO SKETCH: MICHAEL VLASOV

M17: The Nebula With Too Many Names

Follow this observer's guide to find one of the best H II regions in the night sky.

Messier 17 has at least five proper names — Omega Nebula, Horseshoe Nebula, Checkmark Nebula, Swan Nebula, and the Lobster Nebula. Why so many?

Sir John Herschel started off the story by comparing M17 to the capital Greek letter Omega. His 1833 sketch shows something like an Ω with a long tail, and given his immense intellect, I can see why he chose the name. But he used the names Omega and Horseshoe interchangeably, and his sketches from the first half of the 19th century accentuate the horseshoe part of the nebula. Although the shape of M17 doesn't conjure up an Omega or a horseshoe for most 21st-century observers, both names are still widely used.

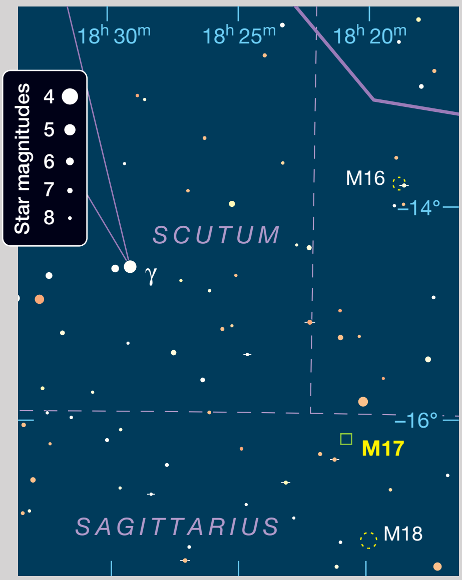
On the other hand, I totally get the Checkmark name — that's what M17 looks like in my 8-inch scope from home. And I could see it as the Swan with my old 12½-inch Dobsonian.

Now, flip the page and turn this magazine upside down to see why observers in the Southern Hemisphere call it the Lobster Nebula. Pareidolia — the phenomenon of seeing a familiar pattern where there is none — really depends on your orientation.

Cool, right? So even though M17 has too many names, at least they're a good selection from which to choose.

▲This image of the star-forming region of M17 was captured by the Wide Field Imager on the MPG/ESO 2.2-meter telescope at the ESO's La Silla Observatory in Chile. The pink-to-red color comes from hydrogen gas clouds that are being excited by extremely hot newborn stars. North is down, west is to the left.

M17 IMAGE: ESO



What Is It?

M17 is a bright H II region in the Milky Way with a colossal but hidden star cluster cataloged as **NGC 6618**. It's also the brightest portion of a giant molecular cloud (GMC) located approximately 6,000 light-years away in the Sagittarius spiral arm. That makes the optically visible portion of M17 roughly 15 light-years in length.

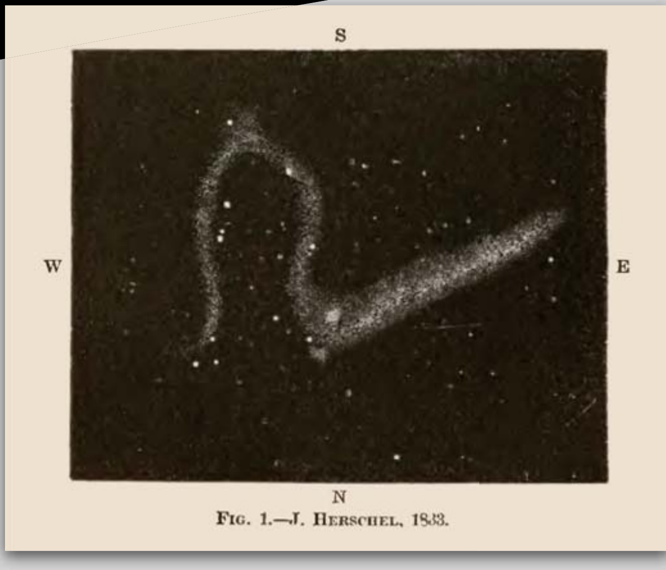
M17 has nourished three waves of star formation. The first formed roughly 2,000 stars between 2 and 5 million years ago, followed by the rapid compression of gas and dust. That increase in density, nearly 2 million years ago, kick-started the formation of approximately 12,000 more stars and continues today, making up the huge NGC 6618 star cluster. Unfortunately, these stars lie mostly hidden within the H II gas of M17 and are best seen in infrared.

A third phase of star formation is ongoing in the outer regions of M17's GMC, involving about 1,000 stars.

The massive O-class stars in NGC 6618 blast out intense ultraviolet radiation that excites the hydrogen gas in the M17 molecular cloud to emit visible light, creating the emission nebula/H II region we're so fond of naming.

The Swan's Neck & Head

All but one of M17's names implies a loop somewhere in the nebula, which represents the head and neck of my favorite shape, the Swan.



▶ John Herschel, who sketched this representation of the nebula in 1833, alternated between the names Omega and Horseshoe. What do you see? North is down, west is to the left.

FURTHER READING: To learn more about Messier 17 and view the author's earliest sketch of the region, see https://is.gd/BanichM17.

Although visually smaller and fainter than the body, what we see as the gracefully curved head and neck of the swan is actually the most massive part of the nebula. The brightest portions look like a vaporous number 2 to me, and yet this is the area that inspired the Omega and Horseshoe names.

The most dramatic part is actually the black area inside the curve of the 2 — on the best nights it looks almost impossibly black. This dense portion of M17's molecular cloud creates a memorably high contrast region with the bright head and neck curving around it.

On close inspection I was able to see two faint stars in the foreground of the darkness — close to its south and northwest edges. I also noticed a rather sharp corner on the inside edge near the top of the 2.

Farther down the neck, and almost on the border with the black molecular cloud, shine three rather prominent stars, which are opposite a star of comparable brightness right near the southern end, or top, of the 2. These are some of the visible stars of the NGC 6618 cluster. Just east of the center of the three stars is a small, bright knot of nebulosity that I see only on the most transparent nights.

Continuing the curve past the top of the 2 are two subtle, not quite parallel streaks that flow into a faint haze that circles back to the base of the 2. This faint nebulosity completely encloses the dark area inside the curve of the 2 and reinforces its utter blackness. Also note the two, equally faint, feathery streaks pointing south from the head.

Above the 2 is a small puff of nebulosity with a fairly prominent star that crowns the head of the swan. There are other puffs of fainter nebulosity surrounding the head, but this is the most obvious and picturesque.

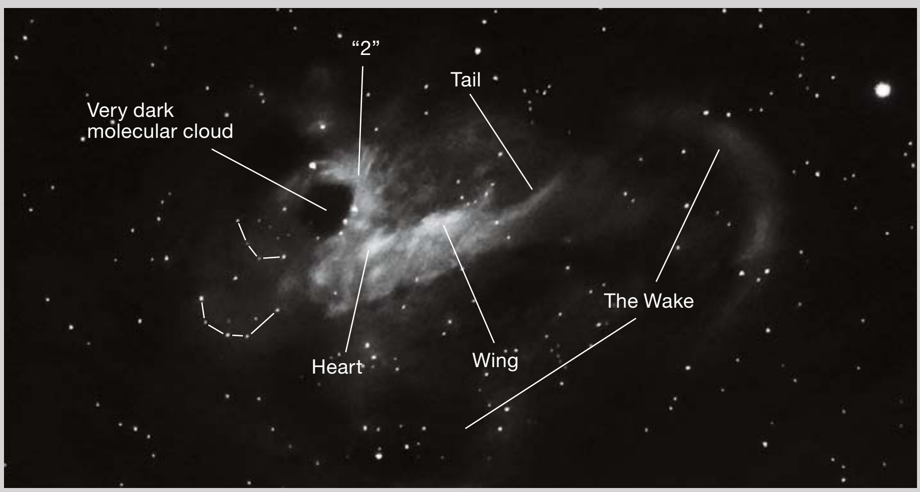
The Swan's Heart, Wing & Tail

Extending mostly east-west, the swan's body is the brightest and most detailed portion of M17. It's also the most fun area to observe at various magnifications, especially around the two brightest areas along the southern edge of the body. The one closest to the swan's neck and head is shaped much like an elongated heart.

The next brightest area lies closer to the tail end of the body and, with pareidolia now in full force, I can even conjure up a wing. Boosting magnification brings out its undulations and ragged outline, and a thin extension — the wing tip — curving toward the southeast. Its shape is reinforced by an arc of stars along its southern border.

There's a longer, beautifully curved extension off the eastern end that gracefully arcs toward the southeast that makes an excellent tail. It shows up best with averted vision.

Although we can't see much of the NGC 6618 cluster, its main concentration of stars is located in the crook between the swan's neck and body. If human vision was sensitive to near-infrared wavelengths, this might be the most spectacular part of M17.



▲ In this sketch by the author, the components of M17 have been labeled to match the descriptions in the text. Note how dark the molecular cloud inside the curve of the head and neck appears, as well as the sharp corner it makes. Can you spot the two arcs of relatively faint stars highlighted by the dashed lines? These stars reinforce the appearance of the faint haze in this area, looking as if they've collected the last bit of nebulosity that drained from the darkness inside the 2. North is down, west is to the left.

SKETCH: HOWARD BANICH; HERSCHEL SKETCH: POPULAR SCIENCE MONTHLY / WIKIMEDIA COMMONS / PUBLIC DOMAIN

▲ This infrared image shows the massive NGC 6618 star cluster that's still forming deep inside the gas clouds of M17. Notice how the head of the Swan disappears at near-infrared wavelengths. North is down, west is to the left.

The Wake

North and east of the body ranges a complex of much fainter loops and patches of nebulae. There's a lot of subtle detail here, especially under ideal skies. Look for small, subtle dark patches as well as bright ones. The most prominent are off the northern edge of the swan's body — use higher powers to see them best. A nebula filter will give the fainter wisps and dark areas greater contrast and will, for that matter, boost the contrast of the entire nebula.

East of the tail is a large, faint loop that arcs south to north at about 90 degrees to the body of the swan. It can be surprisingly prominent on a good night but doesn't quite connect to the tail. The northern end of the arc leads to the patches of nebulae just north of the swan's body, which in turn connects to the base of the neck — and suggests a wake through water, completing the illusion of a swimming swan.

However you see M17, it's a marvelous H II region with exceptionally contrasting dark nebulae. Even the Orion Nebula doesn't have an area with such contrast. Unfortunately, M17 and M42 are never visible at the same time for a direct comparison, so take good notes, make a sketch or two, and see for yourself. It's possible M17 will become your second favorite H II region of the Milky Way, regardless of what it looks like.

▲ This sketch of M17 was done by the author over 4½ hours of drawing at the eyepiece over three nights at the 2017 Oregon Star Party. Although the article discusses observations made with the author's 28-inch telescope, most of what he sketched can be seen in considerably smaller scopes under a dark sky. He mostly used 253×, but didn't use nebula filters. The entire "body" of the nebula can appear twisted like a barber pole because the orientations of the brighter areas are similar. North is down, west is to the left.

SKETCH: HOWARD BANICH; COLOR IMAGE: 2MASS / UMASS / IPAC / CALTECH / NASA / NSF

■ Contributing Editor **HOWARD BANICH** loves a good H II region whether it looks like something else or not. He can be reached at **howard.banich@nike.com**.

Get Up and Go with AZ Mount Pro

iOptron's full-featured alt-azimuth Go To mount provides convenience and performance.

iOptron AZ Mount Pro Altazimuth Mount with 2-inch Tripod

U.S. Price: $1,299
iOptron.com

▲ The compact AZ Mount Pro can handle a payload of up to 33 pounds and includes the Go2Nova hand controller, a universal saddle plate that accepts both Vixen- and Losmandy-style dovetail mounts, and an internal rechargeable battery good for up to 10 hours of observing. Also pictured is the optional 2-inch steel tripod and 10-pound counterweight.

ALL PHOTOS BY SEAN WALKER / SKY & TELESCOPE

What We Like:

Automatic alignment routine works well

Accurate pointing & tracking across the entire sky

Intuitive, user-friendly hand controller

What We Don't Like:

User manual

Serial-to-USB interface cable not included

Charger cable too short

THE MERRIAM-WEBSTER dictionary defines *convenient* as "suited to personal comfort or to easy performance." Personal comfort isn't necessarily something we associate with amateur astronomy — in decades past it took considerable knowledge and effort to aim a telescope at anything you couldn't see with the unaided eye.

Enter today's computerized Go To telescopes and mounts. Once initialized, they make easy work of observing one faint target after another. Some of the latest models have made setup as effortless as flipping a switch. Today, backyard astronomy can be very convenient indeed!

After appearing on the scene about 10 years ago, iOptron has become a respected supplier of Go To mounts and related gear. Among its newest offerings is the AZ Mount Pro, an altitude-azimuth Go To mount that, at first glance, could be mistaken for the company's older Mini-Tower Pro (*S&T:* December 2008, p. 48). The newer mount incorporates more sophisticated electronics, as suggested by the words "easy 'level and go' intuitive setup" in iOptron's ads.

In addition to easy setup, the new mount's key features include a saddle that can accept either Losmandy- or narrower Vixen-style dovetail bars, an internal rechargeable lithium-ion battery, and the ability to attach two telescopes at once by swapping the counterweight for an optional secondary saddle ($79) — one that accepts only a Vixen-style dovetail bar. To see whether the AZ Mount Pro lives up to its marketing claims, we borrowed a production unit from iOptron and took it for a test drive.

Thinking Inside the Box

The mount is available in several configurations. The kit that iOptron

▲ iOptron includes a rugged case with a custom foam insert to hold the mount head, Go To controller, and several small accessories.

supplied to us sells with product code 8900, which ships in two boxes. One box includes the mount head, hand controller, battery charger, cables, leveling screws, and tripod-locking knob, all neatly tucked into a foam-fitted carrying case. The other contains a heavy-duty tripod with 2-inch-diameter legs, a 10 lb. (4.5 kg) counterweight, and a triangular spreader to stabilize the tripod and lock its legs in position.

Upon opening the case, I found a quick-start guide but not a more detailed manual. The guide lists some online resources available on the company's website — including a PDF version of the user's manual, which I downloaded. Call me old-fashioned, but I think a product in this price range should include the printed manual. (As I'll explain later, there were two other items absent that I think should have been in the box too.) I went to the Support section of **iOptron.com**, scrolled through the list of available instruction manuals, and downloaded the PDF for the AZ Mount Pro.

Step 1 in the quick-start guide says to charge the mount using the included AC charger, which has an LED that turns from red to green when the battery is fully charged. The charger's cord is not quite 4 feet (1.2 meters) long; with the mount sitting on my desk, I had to use a household extension cord to reach the nearest power outlet. It took less than an hour to top off the battery's charge. (Subsequent charges, done after draining the battery in the field, took only a few hours.)

Assembly and Setup

The quick-start guide says to install the three level-adjustment screws into the tripod head and then place the mount atop them. However, the tripod pictured in the quick-start guide — and in the full user's manual — didn't match my tripod, which had two sets of holes for the adjustment screws. I figured out which set to use by looking at the holes in the bottom of the mount. iOptron should incorporate new photos into future versions of these documents.

For the AZ Mount Pro to operate properly, it needs to be level. Leveling the tripod itself isn't critical; you just level it by eye using the adjustable legs. You then level the mount on the tripod by twisting the leveling screws as needed to center the built-in bubble level on the base.

The AZ Mount Pro is rated for a primary payload of 33 pounds (15 kg). I tested it with my Explore Scientific 80-mm f/6 refractor, which tips the scales at about 10 pounds including its 8×50 finder, star diagonal, and a 2-inch eyepiece. With such a light telescope, iOptron says the mount's counterweight isn't necessary, but I used it anyway, for a total payload of 20 pounds.

For proper alignment of the AZ Mount Pro, you need to make sure the telescope aperture points in the same direction as a small white triangle on the dovetail saddle. This little indicator isn't very prominent, and it gets covered by the dovetail bar. It would be helpful to have additional white triangles on the saddle's sides, so that you can double-check after attaching the telescope. I also balanced the telescope in the saddle as indicated in the quick-start guide to avoid straining the mount's altitude motor.

The first time I put everything together, I did it indoors and then carried it outdoors. Too heavy! Subsequently, I took the gear outside in pieces and assembled it at my observing site.

On the Sky

The AZ Mount Pro's claim to fame is its self-calibration routine. I wasn't entirely sure what would happen when I first powered up the mount, because I found

◀ Orientation of the saddle plate is important for the mount's level-and-go setup. Your telescope's aperture must point in the direction of the small white triangle on the plate. **Above:** Attaching the AZ Mount Pro to the 2-inch tripod requires first installing three leveling knobs within the inner set of threaded holes.

▲ There are three input ports on the base of the mount. The HBX port accepts the Go2Nova hand controller, while the RS232 serial port is used to connect to a computer, though you'll need to provide your own serial-to-USB adapter if your computer lacks a serial port. The port at right is for the AC charger.

conflicting instructions in the quick-start guide. Step 10 says to flip the power switch to ON and wait for the mount to perform its self-calibration. But Step 13 says that when you power up the mount, a message on the hand controller will ask if you want to run the "assist alignment wizard" — if you do, you're supposed to press the ENTER key, and if you don't (that is, if you'd prefer to manually perform a one-, two-, or three-star alignment), you're supposed to press BACK instead.

It turns out both are true. The hand controller does indeed ask for the user's input but doesn't wait very long for it. If you don't respond within a few seconds, it assumes you want it to self-calibrate and proceeds accordingly. The mount makes a complete turn in azimuth and swings the telescope between horizontal and vertical; concurrently, it establishes a GPS satellite link to determine your geographic location and local time. After a brief pause in the so-called zero position (facing south with the telescope at the zenith) it determines a suitable naked-eye alignment star, identifies it on the hand controller, and slews toward it.

Once the mount stops moving, the instructions on the hand controller say to center the target star using the left- and right-arrow keys, then press ENTER. Pressing the up- and down-arrow keys has no effect. This seems to imply that the star will already be centered vertically, but it turns out that you'll adjust the up-down pointing in the next step.

On this first attempt to have the mount align itself to the sky automatically, my telescope ended up pointed several degrees from the target star in both azimuth and altitude, placing it outside the finderscope field. I used the hand controller to get closer in azimuth, then loosened the altitude-lock knob and manually adjusted the aim closer in altitude too (I didn't yet know that the up- and down-arrow keys would be activated in the next step). With the star now in the finder field, I centered it on the crosshair and confirmed that it was in the eyepiece, then pressed ENTER. The hand controller then reported a successful alignment.

Before describing what happened next, I need to offer two observations. First, neither the quick-start guide nor the user's manual say anything about using a low-power eyepiece or finderscope when aligning the mount — they assume you already know to do this. Second, the hand controller identifies alignment stars by name. I think it's fair to expect amateur astronomers to know the names of bright 1st- and 2nd-magnitude stars, but the AZ Mount Pro's internal catalog of alignment stars (listed in an appendix to the user's manual) numbers more than 250, and some are 4th magnitude. Most of us need to consult a star chart to identify such faint stars. Accordingly, I think iOptron should include in its user's manual a rudimentary all-sky chart that labels all the alignment stars for quick reference in the field.

With the mount successfully aligned/calibrated, I commanded it to point to a selection of stars and deep-sky objects scattered all over the sky. Initially I fitted my refractor with an eyepiece providing a generous 3° field of view. Not surprisingly, every slew put the target in the field, usually near the center. Next I switched to an eyepiece giving a 1° field. Each new target still landed in the eyepiece, though not as consistently near the center.

As for the stability of the mount, I found the AZ Mount Pro on its beefy tripod to be rock-steady. My telescope settled down within 2 to 3 seconds after a light tap on the eyepiece. And it tracked its targets tenaciously. I could leave the scope unattended for an hour or so, and when I'd come back, the last object I'd been looking at was still visible in the eyepiece.

The more I used the mount, the more comfortable I became with the hand controller, which is really quite intuitive in its operation. It takes no more than

▲ A retractable counterweight shaft is secured using a collet-style twist-lock system. It's most useful when using scopes weighing more than 12 pounds.

▲ iOptron's Go2Nova 8407 controller includes a database of more than 212,000 objects, including the Messier, NGC, and IC catalogs, as well as many solar system objects (though excluding Pluto). A bracket is included on the mount to conveniently hang the hand paddle when not in use.

two or three button-pushes to navigate to different celestial catalogs and choose objects to view. If I picked something that wasn't up yet, the controller helpfully said as much. And if you do a little exploring and sweep up a star or "faint fuzzy" whose identity you're not sure of, the controller will identify it for you if it's in one of its catalogs — which is likely, as the database includes more than 200,000 objects.

Additional Features

The mount normally tracks at the sidereal rate, but it can also track at solar or lunar rates, though you'll need to switch to these speeds manually. I was disappointed that Pluto is missing from the solar system menu. Pluto may no longer be an official planet, but it hasn't been kicked out of the solar system!

Another nice feature of the AZ Mount Pro is built-in Wi-Fi connectivity. When you turn on the Wi-Fi system with the hand controller and connect to its network with your smartphone or tablet, you can remotely control the mount with a compatible planetarium program. I used *SkySafari Pro* on my iPad, and it worked like a charm: Touch an object on the screen's sky chart, press the program's Go To button, and the AZ Mount Pro slews to the target without hesitation.

Once aligned to the sky, the mount had no trouble putting objects in the eyepiece, no matter how long the slew. But I kept having trouble with the initial self-calibration, rarely getting the auto-alignment star in the eyepiece, let alone the finder. It occurred to me that perhaps this could be fixed with a software update. The only item I hadn't yet removed from the aluminum case was the supplied RS232-RJ9 serial cable, which is included for this purpose. But my laptop PC doesn't have a 9-pin serial port, and I suspect yours doesn't either; much like parallel ports for connecting printers, serial ports have been replaced by USB ports on modern computers. I needed a serial-to-USB adapter, and iOptron sells one for $25. Fortunately, I already owned one, but this accessory should be included with the mount.

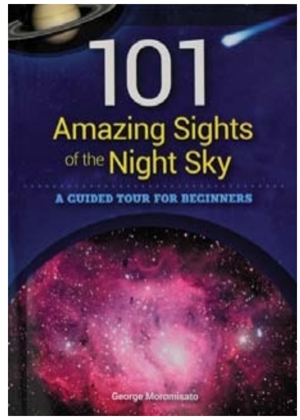
I went to the Support section of iOptron's website and saw that not only was there new firmware for the AZ Mount Pro, but that it purportedly improved initial calibration accuracy. Following the step-by-step instructions in the user's manual, I updated both the hand controller and the mount's main electronics board, and after that the initial alignment routine went much better.

Final Thoughts

So, who is the AZ Mount Pro for? I don't think it'd be a good first mount for a newcomer to amateur astronomy, because its operation requires at least a modicum of knowledge and experience in the hobby. But for anyone looking to match a small- to medium-size optical telescope assembly with a sturdy, full-featured alt-az mount for visual observing, the AZ Mount Pro would be a terrific choice. With its automated alignment routine and superb pointing and tracking, it takes backyard astronomy to a whole new level of convenience.

■ **RICK FIENBERG** served in a variety of roles at *Sky & Telescope* from 1986 to 2008, including eight years as Editor in Chief. He is now the American Astronomical Society's press officer.

▲ An optional Vixen-style saddle ($79) is available that replaces the counterweight, permitting users to mount a second telescope.



BEGINNER ASTRONOMY ▶

Looking for light reading to help introduce newcomers to the wonders of the universe? *101 Amazing Sights of the Night Sky* by George Moromisato might be your answer. This guide acquaints the reader with near-sky treats such as aurorae as well as distant targets such as M31, the Andromeda Galaxy, and beyond. Moromisato leads you through his list of sights ranked by beauty, accessibility, and historical importance with the aid of color photographs and simple finder charts. Many of his chosen targets require no additional optics. A short primer on telescopes, optics, and magnification is included in the appendices, along with several astrophotography tips to help you take your own photographs of the night sky. Paperback, 260 pages, ISBN 978-1-59193-557-5

Adventure Publications
adventurepublications.net

ROBOTIC MOUNT ▶

PlaneWave Instruments introduces the L-500 Direct Drive Mount ($18,000). This single-arm fork mount can operate in equatorial or alt-azimuth configurations, and is rated to support up to 200 pounds of equipment (including its own CDK17 and CDK20 telescopes). The mount incorporates axial-flux direct drive motors, providing no backlash or periodic error, and can slew to objects at speeds of up to 50° per second. Both axes include high-resolution encoders for precise pointing accuracy when operated with the included *PlaneWave Interface* (*PWI4*) control software. Additional features include through-the-mount cabling, and a dual mounting bracket, allowing users to mount a second telescope outside of the fork arm.

PlaneWave Instruments
1819 Kona Dr., Rancho Dominguez, CA 90220
310-639-1662; planewave.com

BIG ASTROGRAPH ▶

German manufacturer Knaeble Optical Systems announces the RCM 360 FC/Ti (starting at $25,000). This 14.2-inch f/7.5 Ritchey-Chrétien reflector is constructed primarily of carbon fiber to virtually eliminate thermal expansion. The telescope's rear cell includes active cooling fans and accepts up to 3½-inch focusers, producing a 60-mm non-vignetted field. Its hybrid aluminum/carbon fiber dovetail mounting system promises to reduce deformation by a factor of 40 as compared to aluminum plates. The entire telescope weighs 66 pounds (30 kg). Additional options include titanium/carbon back plate and titanium truss joints, and a choice of Sitall, Pyrex, or Zerodur optics.

Knaeble Optical Systems
Brandenburgische Str. 28 10707; Berlin, Germany
+49-30-30839066; knaeble-eng.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.com. Not all announcements can be listed.*

Ethics in Astrophotography

Seeing isn't always believing in the digital age.

Is it real, or is it Photoshopped?

That's often the first thing we ask ourselves when looking at a photograph today, meaning: Is it real, or is it fake?

Photoshop, the trademarked name of Adobe's image-processing program, originally was a noun. But today it's listed in the Merriam-Webster Dictionary as a verb, that means: "to alter (a digital image) with *Photoshop* software or other image-editing software especially in a way that distorts reality (as for deliberately deceptive purposes)."

Fake images have become so sophisticated that most casual observers often can't tell the difference between a fabricated and a real photograph. And, like fake news stories, fake images have become ubiquitous online — there's even an @FakeAstropics handle on Twitter.

Experienced astrophotographers are justifiably upset when fabricated images garner attention, because they know firsthand how much effort and skill it takes to shoot the night sky "for real." But, more importantly, when a fraud is exposed, it erodes the general public's confidence in what's seen in astronomical images. Fraudulent imagery desensitizes viewers to fakes as well as to the truth. It also fosters cynicism about photography and science in general. This is probably the most damaging aspect of faked astrophotos that are presented as real — the erosion of trust.

Counterfeit and More

There are two main types of deception associated with problem astrophotos. The most common is *misrepresentation* of the picture and how it was recorded.

An image published January 22, 2016, on the Astronomy Picture of the Day website (**apod.nasa.gov**) purported to depict the International Space Station (ISS) transiting Saturn as captured by Julian Wessel. The photo displayed both the ISS and Saturn perfectly exposed, with the space station perfectly placed exactly in the center of — as well as exactly the same size as — the disk of the planet. The problem wasn't

JERRY LODRIGUSS

◀ **FULL DISCLOSURE** The Moon was added to this image of the Philadelphia skyline by the author for planning purposes to determine its position and size. It was never published until now.

▲ **PROPER EXECUTION** The real photo of the Moon setting over Philadelphia, shot on the evening of April 1, 2016. The author waited three years for the combination of Moon phase, location, time, and weather to cooperate. The Moon's brightness was diminished by high clouds.

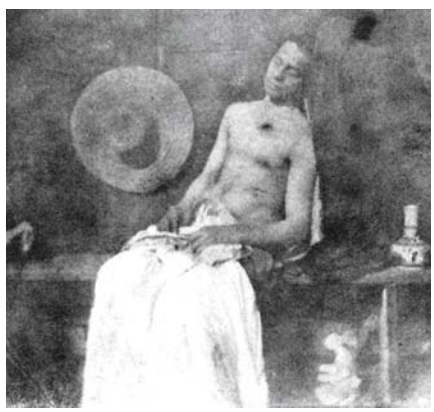
that this was a multiple-exposure composite. It was that it was misrepresented as being a real image from that event when, in fact, it was faked. Wessel recorded the images of the ISS and Saturn on different days, and the Sun-Saturn-ISS geometry was all wrong. Wessel initially claimed the scene was real but later recanted when confronted with the facts.

The other basic deception is *plagiarism*, when an individual takes another's work and claims it as his or her own. On January 12, 2017, APOD published an image of NGC 891 with a copyright by Alessandro Falesiedi. But actually it had been taken from an original photo by Adam Block. The editors of APOD removed his image and replaced it with Block's when the similarities between the two images were pointed out.

Both of these images — Wessel's and Falesiedi's — now reside in shame, with others, on the APOD retractions page on Facebook at **bit.ly/2szepXi**.

Some leading astrophotographers, quite upset about the ISS and Saturn fabrication, objected strongly on the APOD forums. Planetary imaging expert Damian Peach wrote, "It is a total slap in the face to every imager that had dedicated in some cases thousands of hours of time to getting the best real images they can. Incidents like this also serve to undermine the pro/am relationship that exists in the planetary imaging community."

APOD now includes a brief ethics statement on the submissions page that states, "APOD accepts composited or digitally manipulated images, but requires them to be identi-



◀ **THE FIRST FAKE** This photograph by Hippolyte Bayard, taken in 1840, is considered to be the first staged photograph. Entitled *Self Portrait as a Drowned Man*, it depicts the photographer pretending to have committed suicide in response to the French government acknowledging Louis Daguerre as the inventor of photography.

SKYLINE: JERRY LODRIGUSS; FIRST FAKE: HIPPOLYTE BAYARD

▲ **CONVINCING FAIRIES** The Cottingley Fairies are a famous example of an early photographic deception. Acquired by Sir Arthur Conan Doyle in 1920 to illustrate an article on fairies in *The Strand Magazine*, the photos were presented as genuine, though decades later the two cousins who took them admitted they were faked using cutouts from a popular children's book.

fied as such and to have the techniques used described in a straightforward, honest and complete way."

Phony images that undermine our belief in science are a real concern. Photographs are incredibly powerful to us, because our visual system is so connected to our survival. It is the primary way we interact with the world — we think, literally, that "seeing is believing."

Photography is also important to science because it extends human vision to reveal things that are invisible to the eye, even when looking through giant telescopes (including wavelengths beyond those visible to our eyes, such as ultraviolet, infrared, and radio wavelengths). This comes from its ability to integrate exposures and keep collecting photons for much longer time periods than the eye is capable of, revealing a previously hidden world of faint astronomical objects. Most of the major discoveries in astronomy over the past 100 years involved astrophotography, including Edwin Hubble's discovery of the expansion of the universe.

Blurred Lines

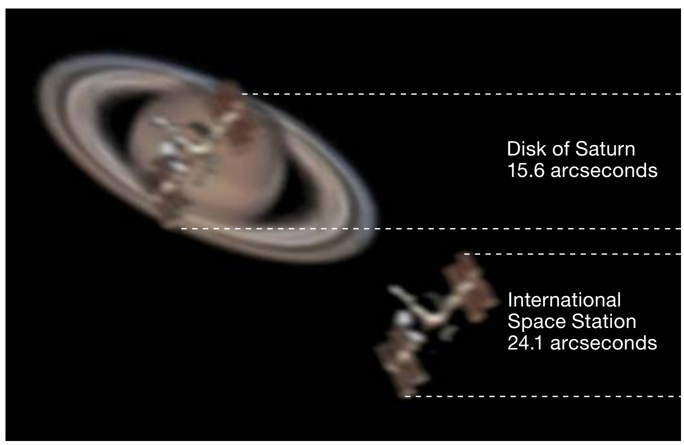
Fakes have existed in photography since the invention of the medium, but in its early days forgeries were more shocking when exposed because of that "reality" element of photography. Even Sir Arthur Conan Doyle believed in the truthfulness of the faked Cottingley Fairies photos.

Today we don't have any problem accepting fiction as entertainment. Think of all the computer-generated special effects used in movies. We don't think Gollum is real in *Lord of the Rings*. We don't feel a sense of betrayal by them because we know up front that they are fiction. Historians consider Ansel Adams a "realist" nature photographer, yet one of his most famous images — *Moonrise, Hernandez, New Mexico* — is extremely unrealistic. The photograph depicts the rising gibbous Moon in a pitch-black daytime sky taken when the Sun was still above the horizon (*S&T:* Nov. 1991, p. 480). Viewers in this case willingly accept the emotional impact of the art of the image without worrying about it being exactly as Adams' camera recorded the scene.

Astronomical images can also present some interesting ethical considerations when it comes to image manipulation, especially in this age of digital photography and *Photoshop.*

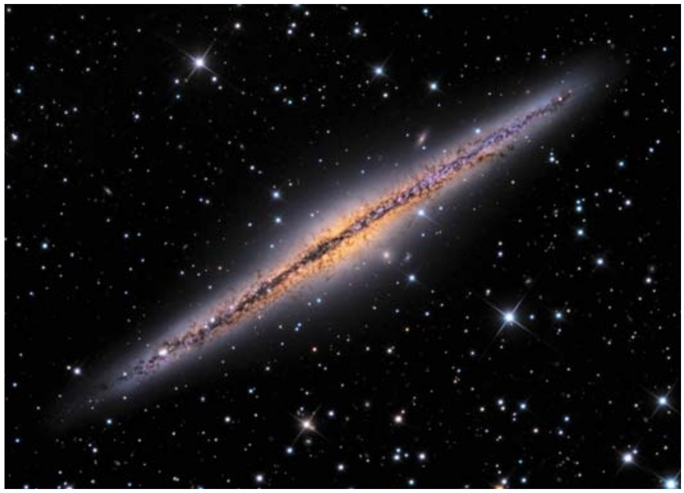
Some imagers believe astrophotos should reflect what objects should look like if they could be seen visually. But if this argument was enforced, almost all long-exposure, deep-sky images would be merely shades of gray, because the eye just doesn't see colors under faint illumination.

Others, especially those in journalism, feel an image should strictly be presented as it came out of the camera, in a single frame, without any changes. But this is unrealistic and



◀ **DECEPTIVE COMPOSITE** This image purported to capture the International Space Station as it passed in front of Saturn on January 15, 2016. **Above:** Skeptical visitors to the APOD website noticed several inconsistencies with Wessel's image. One major discrepancy was the apparent size of the space station compared to the disk of the planet as seen from the photographer's location near Dülmen, Germany.

FAIRIES: ELSIE WRIGHT; SATURN & ISS (2): JULIAN WESSEL

▲ **PLAGIARISM** Another APOD post, on January 12, 2017, shows the edge-on spiral galaxy NGC 891 (left). Although credited to Alessandro Falesiedi, it shared many similarities with an image taken by well-known astrophotographer Adam Block. The unique light scattering around the bright stars is one of several characteristics that helped conclusively identify the deception. Block's original is seen at right.

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA (2)

uninformed. All images from a digital camera are manipulated to some degree, including by the camera itself. The raw data are linear. Yet human vision is nonlinear, so special adjustments are applied to the image before it's displayed.

To make faint details visible, most deep-sky astrophotos require contrast enhancement far beyond what we would do to a normal daytime image. Color is produced from monochrome sensors by the clever use of red, green, and blue filters over alternating pixels. At its most fundamental level, a digital photograph is just a series of colored blocks!

Many other examples demonstrate how lines are blurred when manipulating an image. Some are considered acceptable almost without question, such as white balancing to produce natural colors. Others are more complex, such as high-dynamic-range processing, which has the potential to be more "truthful" to a scene in nature, and to what the eye actually saw, than what a single frame can record, because the eye has a much greater dynamic range than a camera does. For instance, the wide range of brightness within the solar corona visible during a total eclipse of the Sun is impossible to capture in a single exposure.

Ethics Defined

Once we get past the fact that all images are "manipulated" in some way, we get to the heart of the matter: the ethics involved. Ethics define a set of moral values of acceptable conduct. So what kinds of image manipulation are acceptable?

Personally, I believe that almost anything goes when it comes to image manipulation — *if* the photographer is honest about what he or she has done. Then the viewers can judge the image and place a value on its truth and aesthetics for themselves. Is it something they can trust to be a faithful representation of reality, or is it merely eye candy?

What is important from an ethical standpoint is transparency and intent. Did the photographer lie about how an image was created with the intent to deceive, or was another person's image intentionally stolen? Almost everyone would agree that those behaviors cross the ethical line.

It's really pretty simple. It comprises two of the first things we learn in life: Don't steal, and don't lie.

So Is It Real?

Photography can be an honest and believable representation of reality. It can also be fantasy and fabrication. The crucial thing is to be honest about how you create an image and then its viewers can make their own judgments.

We trust our eyes and, by extension, we trust images. But in reality, we're placing our trust in the photographer. It is only when fake images are deliberately presented as the truth that potential problems arise. These forgeries, whether in news stories or as astronomical images, erode the public's ability to distinguish between fiction and reality, desensitizing us to differences between the two.

What the unscrupulous fail to realize is that with the scrutiny that many amateurs invest in examining astrophotos, it is extremely difficult to fool us. The perpetrators' reputations are seriously compromised after being revealed. After they're exposed as frauds, every other image they've produced suddenly becomes suspect.

When viewing an image in today's post-factual world we should remain skeptical, because it is a useful survival trait. Remember this unattributed skeptic's maxim: "Do not be so open-minded that your brains fall out."

Accept that if it's someone's intention to deceive, some people are going to be deceived. But the perpetrators are almost certainly going to be exposed eventually. And you shouldn't let these deceptive images harden your heart to the sense of natural wonder and joy that a real astronomical or nature photograph can bring.

■ Contributing Editor **JERRY LODRIGUSS** shoots real astrophotos from suburban New Jersey.

A Simple Observing Stool, Plus

Build the Swiss Army Knife of observing stools.

EVERY AMATEUR ASTRONOMER needs something to sit on. Those of us who do star parties often need something for kids to stand on. We also need something to carry our gear in. And it's nice to have a visual guide to help locate our scopes in the dark.

Australian ATM Tony Morris has answered all these needs with a single project: a multi-purpose seat/stand/storage compartment/marker light.

Tony says, "I find that far more than half of my viewing time is spent poring over my star atlas, checking my viewing plans and making notes. I need to be sitting down. As the design of my stool took shape in my head, I could see that the seat could also serve as a storage container and homing beacon to guide me between my truck and telescope."

Practicality, utility, durability, and functionality were uppermost in his mind. He also wanted it to be light, strong, and stable. That led him to a three-legged design to ensure stability on uneven surfaces. This in turn steered him toward a triangular seat that required less complicated cutting of materials than if he had decided on a hexagonal shape.

Tony Morris with his multi-purpose seat/stand/storage compartment/homing beacon.

TONY MORRIS

He started by cutting the sides of the box, using half-inch-thick particle board, and gussets for the corners (both top and bottom) out of 1.4-inch particle board. He screwed and glued those pieces together, then added the feet, which are made of 1-by-2-inch hollow steel tubing that he splayed outward slightly to improve stability. He didn't have to bend the tubing; he simply mounted the legs at an angle when he drilled the holes to bolt them in place. He usually observes on hard ground, so he hasn't had to plug the feet yet, but he plans to do that with angle iron when necessary.

The floor of the box is Masonite, and the lid is ¾-inch particle board edged with angle aluminum. The edging extends below the outer sides of the box and keeps the lid from slipping sideways.

The triangular box gives the stool strength and rigidity. It easily supports Tony's weight with no wobble. The stool weighs 15 lbs. when empty, light enough to carry easily but heavy enough to not tip over when you bump against it.

Tony painted it glossy white inside and out to increase visibility of the accessories he stores in it and to keep from tripping over it in the dark, but his observing site is dark enough that that wasn't quite enough. That led him to the idea of lighting it from within and drilling holes in the sides and top so the light could shine outward.

The light is simply a jumbo red (10 mm) LED mounted through a hole in a small piece of Perspex acrylic sheet taped to a 9-volt battery. A little experimentation led him to use a 420-Ohm resistor in series to drive the LED with the optimal light output. Tony reports that "under very dark conditions when my pupils have dilated sufficiently, I can

▲▲ Corner gussets and slightly angled legs provide stability. Angle aluminum edging keeps the lid from sliding off.

▲ At night the interior LED provides a soft glow visible from a fair distance, yet is not too bright when the box is opened.

TONY MORRIS (2)

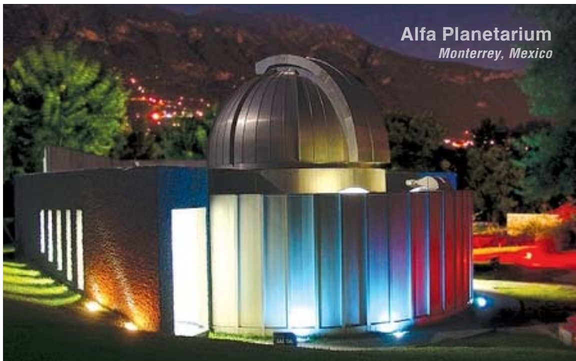
see the seat from quite a distance. But the light level is so low that no other astronomer has ever complained when I have lifted the lid to find some item."

The holes in the lid serve a second, valuable function: They provide markers for where to put your feet when standing on the stool. This is especially useful at star parties when children need to stand tall to reach the eyepiece. The holes are drilled near the outer edge to serve as a warning of where the footing ends. Tony says, "My stool is far more stable than a step ladder, and the dim red light shining through the holes in the lid lets a child know exactly where his/her feet are."

Overall, Tony is very happy with his combination project. He reports just one glitch: "If I were to build another astronomy stool I would definitely build it to the same basic design, but I would make the box's sides 2 inches longer so my star atlas would fit inside it!"

For more information, contact Tony at **pandt@vic.chariot.net.au**.

■ Contributing Editor **JERRY OLTION** is a fan of not tripping over equipment in the dark. Reach him at j.oltion@gmail.com.



GAUZY GLITTER

Guillaume Richard

September brings the return of the Pleiades (Messier 45) to late-evening skies. The delicate nebulosity is unrelated to the cluster but instead lies along our line of sight. North is to the left.

DETAILS: *Celestron C11 EdgeHD Schmidt-Cassegrain telescope with HyperStar and Sony Alpha a7S camera at ISO 3200. Total exposure: 23 minutes.*

◁ ANCIENT SUNS

Ron Brecher

The globular star cluster Messier 10 is easy to spot in central Ophiuchus. Its densely concentrated stars are more than 11 billion years old.

DETAILS: *Astrosysteme Austria ASA Astrograph 10N with SBIG STL-11000M CCD camera. Total exposure: nearly 5 hours through LRGB filters.*

▽ GLOWING "PHANTOM"

Eric Africa

Cassiopeia's Sh 2-173, a cloud of glowing hydrogen listed in Stewart Sharpless' catalog, has been nicknamed Phantom of the Opera Nebula.

DETAILS: *Takahashi FSQ-106N astrograph with SBIG STL-11000M CCD camera. Total exposure: 14½ hours through Hα and RGB filters.*

Visit **skyandtelescope.com/gallery** for more of our readers' astrophotos.

Gallery showcases the finest astronomical images submitted to us by our readers. Send your best shots to gallery@skyandtelescope.com.
See **skyandtelescope.com/aboutsky/guidelines**.

△△SATELLITE GALAXY

Chris Schur

Although overwhelmed by the enormous Andromeda Galaxy (see facing page), M110 is a dwarf elliptical galaxy that Charles Messier faithfully sketched but did not include in his iconic list of deep-sky objects.
DETAILS: *Orion 10-inch Newtonian astrograph with SBIG ST-10XME CCD camera and LRGB filters. Total exposure: 1½ hours.*

△ CELESTIAL ROSEBUD

Peter Jenkins

NGC 7822, a young star-forming complex in Cepheus, encompasses the emission region Sharpless 171 and a cluster of young stars known as Berkeley 59.
DETAILS: *Officina Stellare 115-mm Hiper Apo with Atik 383L+ CCD camera. Total exposure: 11.3 hours through Astrodon narrowband filters.*

PARALLEL UNIVERSE

Chuck Manges

Although often called the Milky Way's twin, the Andromeda Galaxy (M31) is larger than our home galaxy and contains far more stars.

DETAILS: *Celestron C11 EdgeHD at f/2 and Astro-Tech AT65EDQ astrograph used with QHY23M and QHY10 CCD cameras, respectively. Mosaic of 12 images. Total exposure: 11.7 hours.*

DELICATE AURORA

Jamie Cooper

Lots of aurora photos show riots of color, but this view from near Tromvik in northern Norway captures delicate braiding.

DETAILS: *Canon EOS 5D Mark III DSLR camera with 24-mm lens. Total exposure: 2½ seconds at ISO 5000.*

SKY & TELESCOPE

Market Place

Your essential source for astronomical products

ACCESSORIES

ACCESSORIES (continued)

CAMERAS (continued)

BINOCULARS

CAMERAS

EYEPIECES

BOOKS

MISCELLANEOUS

OBSERVATORIES/DOMES

OPTICS

ORGANIZATIONS

SOFTWARE

TELESCOPES

TELESCOPES

TRAVEL

CLASSIFIEDS

QUESTAR 7 TITANIUM: Pristine condition. Fully accessorized with original Questar equipment, including its pier. Offered at $17,000 or best offer. Inquire at LEBJLAW@yahoo.com or 717-464-0846.

DRY CAMPING AVAILABLE: View eclipse in the path of totality! Three-day minimum 8/18 through 8/22, one day free on either end. Rural Douglas, WY. Call 307-358-4751 or e-mail: dwn2erth@hughes.net for details.

WATCH ECLIPSE IN IDAHO: Near Grand Tetons and Yellowstone. Beautiful, grassy, safe, and self-contained RV spaces available for phenomenal eclipse viewing. $125/night, 4-night minimum; Email eclipsewatchidaho@gmail.com; visit EclipseVictorCampingRV.com, or Facebook: Solar Eclipse RV Camping 2017, Victor ID.

WANTED: All types of good antique telescopes and accessories, especially Alvan Clark and James Short. Also, astronomical prints, early colored atlases, Burritt's, Muggletonian's, plus very early books. Top dollar paid. donyeier@frontier.com 607-280-0007

FOR RENT: 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500

NEW SOLAR HOME: on 20 acres, 4 miles from Portal, Arizona. Quality PV system. 16" wide masonry construction. 1,134-sq-ft home plus 350-sq-ft guest house. 360 degree views. Dark skies. Privacy. $236,000. Phone: 505-470-3014; E-mail slushymeadows@gmail.com.

DARK SKY LAND FOR SALE: Adjoins Arizona Sky Village in Portal, Arizona. 5 acres $15,000; 8 acres $8,000; soldiercreekranch1990@gmail.com 530-279-2757

Classified ads are for the sale of noncommercial merchandise or for job offerings. The rate is $1.75 per word; minimum charge of $28.00; payment must accompany order. Closing date is 10th of third month before publication date. Send ads to: Ad Dept., Sky & Telescope, 90 Sherman Street, Cambridge, MA 02140.

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Product Locator

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Meade.com
800-919-4047 | 949-451-1450

CAMERAS

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FLIcamera.com
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Tele Vue Optics, Inc. (Cover 2)
TeleVue.com
845-469-4551

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Astro-Physics.com
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Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events.

August 17–22
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 19–26
MERRITT STAR QUEST
Loon Lake, BC
merrittastronomical.com

August 21
TOTAL/PARTIAL SOLAR ECLIPSE
Events across the U.S.
eclipse.aas.org/event-map

August 23–28
SASKATCHEWAN SUMMER STAR PARTY
Maple Creek, SK
sssp.saskatoon.rasc.ca

August 25–27
NORTHWOODS STARFEST
Fall Creek, WI
cvastro.org/northwoods-starfest

September 15–17
IDAHO STAR PARTY
Bruneau Dunes State Park, ID
isp.boiseastro.org

September 15–17
ALBERTA STAR PARTY
Caroline, AB
calgary.rasc.ca/asp2017.htm

September 15–17
THE CONJUNCTION
Northfield, MA
philharrington.net/astroconjunction

September 16–24
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

September 21–23
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org/2017-idssp

September 21–24
HIDDEN HOLLOW STAR PARTY
Mansfield, OH
wro.org/hidden-hollow-star-party

September 22–24
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

September 22–24
CONNECTICUT STAR PARTY
Goshen, CT
asnh.org/slideshow/CSPpicIndex.php

September 29–30
ASTRONOMY AT THE BEACH
Island Lake State Recreation Area, MI
glaac.org/astronomy-at-the-beach

September 30
ASTRONOMY DAY
Events everywhere!
astroleague.org/al/astroday/astroday.html

For a more complete listing, visit https://is.gd/star_parties.

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The Crisis in Astronomy

One NASA flagship mission at a time hurts astrophysics and planetary science. Here's a solution.

DAVIDE BONAZZI / SALZMANART

NEXT YEAR NASA will launch the biggest, most expensive space observatory it has ever built. The James Webb Space Telescope will be a wonder of its age, promising to reveal secrets of exoplanets, the deep universe, and much more.

But Webb's launch will also mark the end of an era. For three decades, astronomers have had deep access to the entire spectrum: from X-rays and gamma rays through the ultraviolet, optical, and infrared bands. But Webb, an infrared telescope, is so big a step that no instrument in other bands of the spectrum can match it.

Surely we should be patient and wait a few years while NASA builds amazing telescopes for other wavelengths? Not this time. Webb cost NASA almost $8 billion. That's a lot. The agency's Astrophysics Division has about half a billion dollars a year for new, big space observatories. So at Webb's cost, we will have matching X-ray, ultraviolet, and far-infrared observatories in 50 years!

This is a crisis. Why? Because, as the band Nada Surf's 2012 album has it, "the stars are indifferent to astronomy." Stars don't care about the limits of our telescope technologies. They shine as they will, and we must capture their messages, whatever the wavelength. That makes 21st-century astronomy a team sport: All of our observatories must play together, passing the ball rapidly to the best-positioned player.

> Big missions do fantastic science.
> But are we getting the most science for the buck?

Today, if you make an ultraviolet-band discovery with Hubble, within a year you can check it out in X-rays with Chandra and in the infrared with Spitzer. That's why they are called the Great Observatories — they are a great team. In the Webb era, we must wait a decade or more to do that. That won't be a fun game to watch. Our long golden age of astronomy will be over.

What can we do? Asking to double our budget would be as unsuccessful as Oliver Twist asking for "some more." The only way out is to make observatories cheaper. New rockets, from newcomer SpaceX and traditional players, are slashing costs to orbit by two-thirds or more. That lets us consider how we can build spacecraft and telescopes cheaper, too.

But to take advantage of the savings we must choose wisely. Every ten years astronomers from the National Academies perform a "decadal review." Their task is to make a wish list of large- and medium-size missions, in priority order. So far, so good. But once a list reaches the decision makers, it becomes a way of selling "astronomers' #1 priority" — and only that. After all, who wants second best?

So we go heavily for "one big mission." Of course, these big missions do fantastic science. But are we getting the most science for the buck? Could two or three less expensive missions do more in aggregate?

To find out, we must pit one choice against another. And there are many great ideas for breakthrough missions costing far less than Webb. So I suggest that NASA ask the next decadal review not for a wish list but for a complete program of spectrum-spanning missions, at the same total cost. Then our golden age will thrive for another generation.

■ **MARTIN ELVIS** is a senior astrophysicist at the Harvard-Smithsonian Center for Astrophysics. He has worked on quasars and now on near-Earth asteroids. All opinions expressed here are his own and not those of the Smithsonian.

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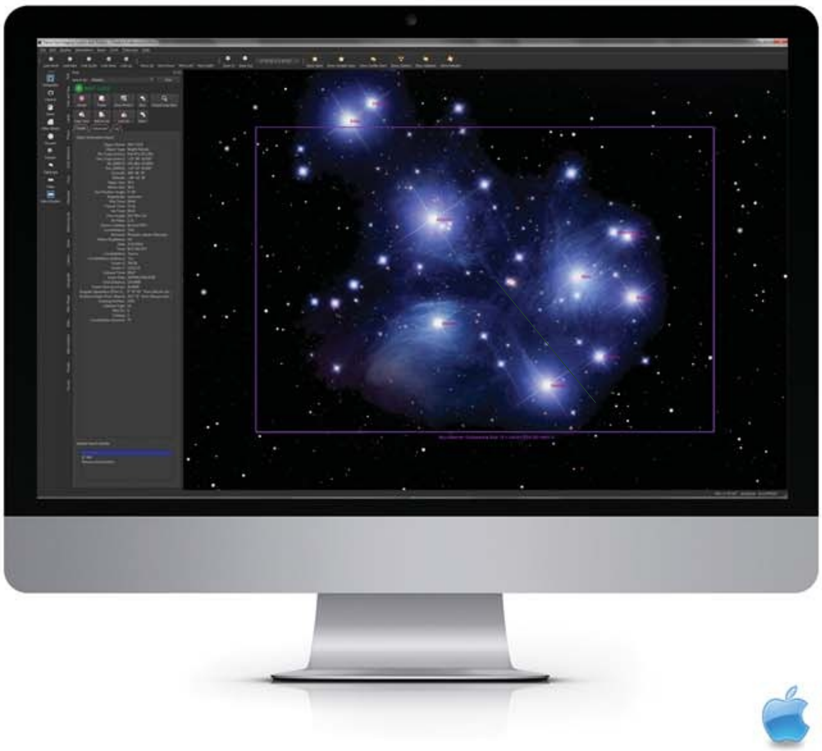

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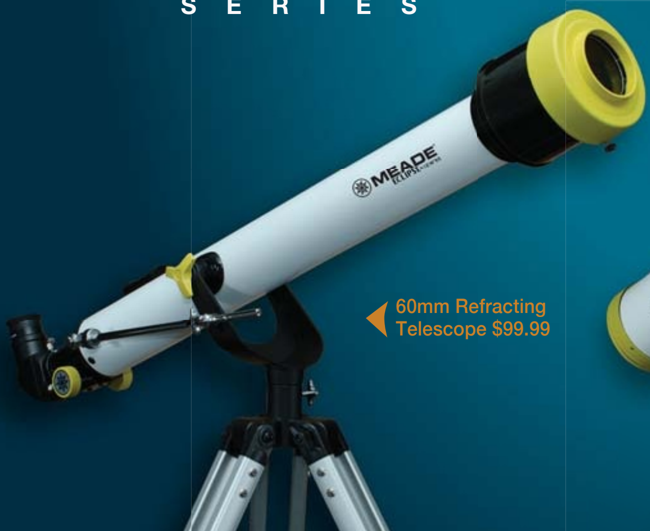

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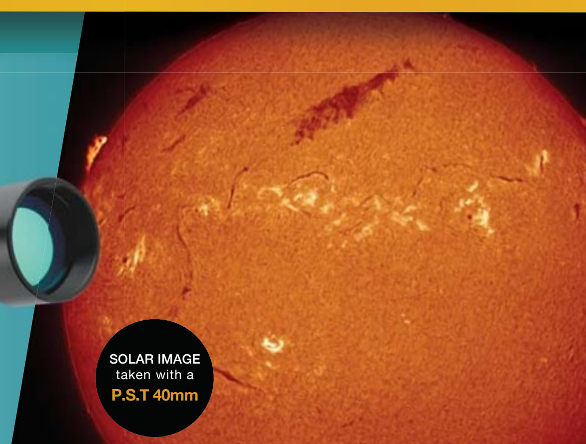

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