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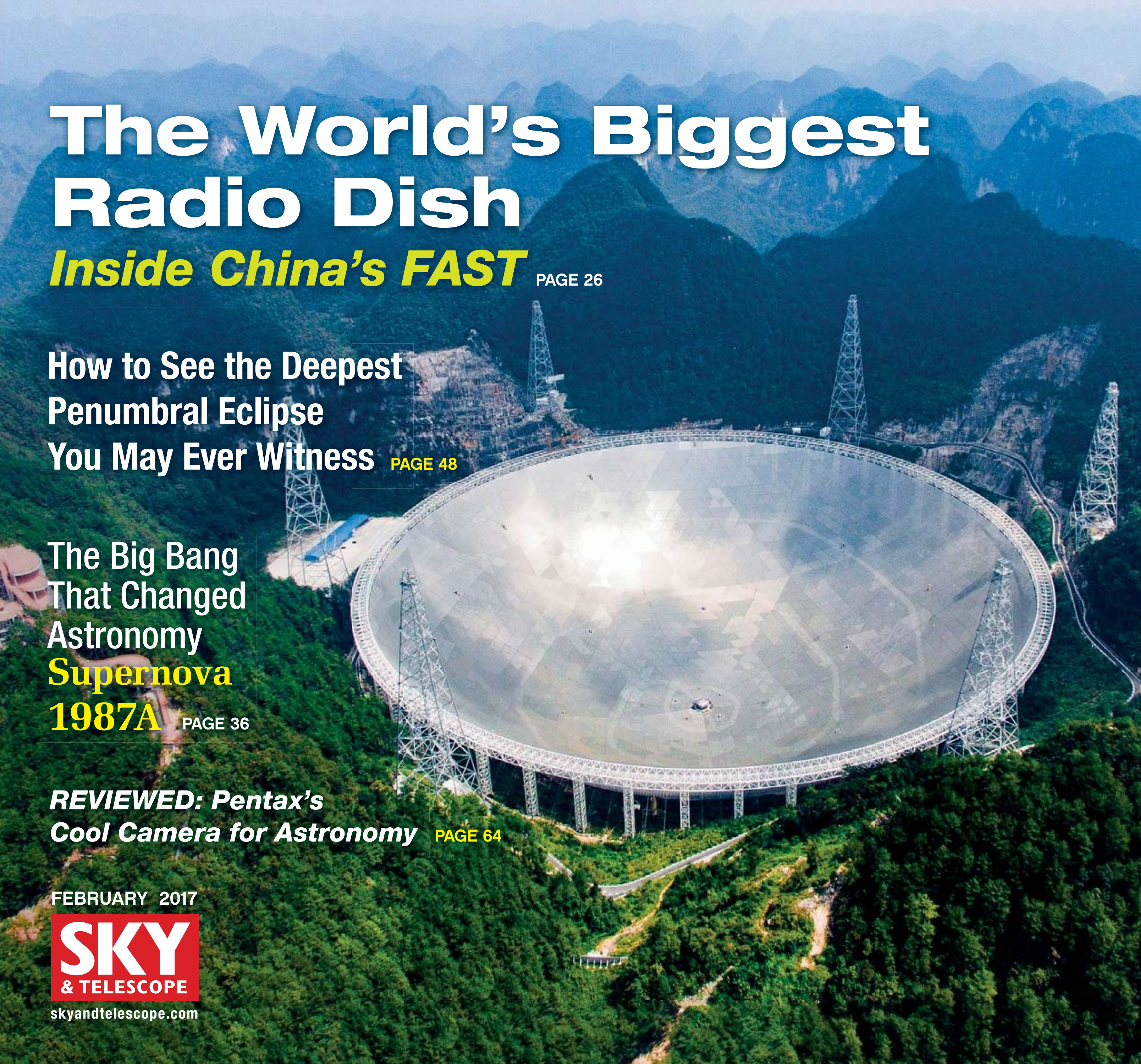
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



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FEBRUARY 2017

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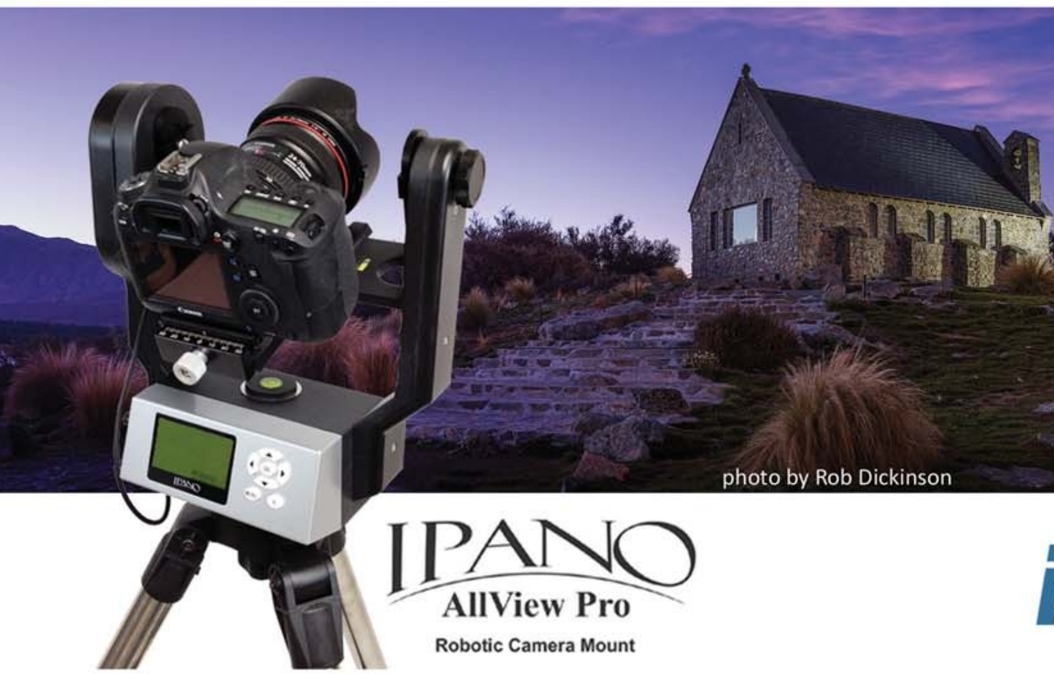

photo by Rob Dickinson

The iPano AllView Pro, a precise computerized robotic camera platform that serves to automate the tedious image capture steps needed to create gigapixel panoramic, hemispherical, and spherical images, as well as panning time lapse movies. The iPano doesn't only point the camera and trigger the shutter, it automatically calculates the number and position for every shot needed to complete the final image.

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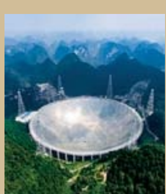

China has completed its 500-m-wide radio dish, now the largest single-dish scope of its kind.
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Witnessing a Supernova

EVERY TIME I THINK about supernovae, I feel a sense of longing: I want to get up close and watch them explode and evolve in all their stupendous glory. Why do they have to be so far away? Why does everything in the universe have to be so darn spread out? I don't mean approaching a supernova in a physical way — obviously that wouldn't be advisable — but in the way an omniscient observer could. Wouldn't it be neat if we could safely ponder these celestial blasts and their breathtaking consequences from a front-row seat, as it were?

In a way, we now can. When Supernova 1987A came alive in the Large Magellanic Cloud 30 years ago this month — see Harvard astronomer Bob Kirshner's article on page 36 — we had only a few, small space telescopes with which to study it from above the atmosphere, such as the International Ultraviolet Explorer. Today, many powerful instruments in orbit can help us track the denouements of such supergiant stars across a far wider swath of the electromagnetic spectrum. The Hubble Space Telescope allows us to observe the evolving leftovers of SN 1987A, for instance, in visible light, infrared, and ultraviolet. The Spitzer and Herschel space missions bring us the far infrared. The Chandra Observatory and NUSTAR give us X-ray views.

Artist's concept of SN 1987A's "three-ring circus" (see page 38).

L. CALÇADA / ESO

Ground-based devices supplement this input from on high, of course. Chile-based ALMA provides millimeter-wave images that rival Hubble pictures for sharpness. Three decades ago, we weren't in a position to detect gravitational waves from SN 1987A's core collapse, but Advanced LIGO should be able to pick up spacetime ripples from a future nearby supernova. And wide-field surveys like the Large Synoptic Survey Telescope will find greatly increased numbers of much more distant detonations.

Supercomputers have become more super, enabling modelers to run more refined simulations to better see exactly what happens . . . we hope. And thoughtful artists' concepts, like the one above, offer alternative ways to contemplate such wonders. This one is a visualization of SN 1987A's surrounding hourglass nebula, oriented as if we could see it from the side.

With such sophisticated capabilities, how exciting it will be when astronomers announce the first supernova to go off in our *own* galaxy during the telescopic era. It might be in decades, it might be in centuries. But as Kirshner says, "Keep looking up."

Editor in Chief

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Astrophotography challenges us to consider the universe and our place in it. It's an absolute privilege to be able to design the tools that hobbyists can use to make their own discoveries.
- Steve Chambers, CEO

Form and function should always go hand in hand. Atik products are designed not only to look good in the telescope, but also to fill the needs of the real astronomer in the real world.
- Rui Tripa, Production Manager

We're always coming up with new ideas for our software. Alongside adding new features, we also improve our testing to ensure that the latest software is not only better, but also more reliable than the previous version.
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- Vince Bygrave, Customer Support

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- DH, Atik Infinity

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- MB, Atik 460EX

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- GI, Atik One 6.0

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Photo credit: Andrei Bacila

ATIK CAMERAS

Celebrating *S&T*'s 75th Anniversary

The November issue offered a fascinating glimpse into *Sky & Telescope*'s origins — and a great overview of the past 75 years of advancements in our knowledge of the heavens. I think it's impossible to overstate the role that this magazine modestly played throughout this explosive increase in our awareness and understanding.

It's also hard to imagine what amateur astronomy would be like today had not *S&T* been around to explain and illustrate these advancements. All amateurs owe a debt to Charlie and Helen Federer, and to their selfless dedication to the dream of promoting amateur astronomy worldwide.

The universe is a vast and mysterious place. Yet thanks to them, and to *Sky & Telescope*, it doesn't feel like such a lonely place anymore.

Tom Sales
Somerset, New Jersey

When Dennis di Cicco speculated that the height of all 75 years of *Sky & Telescope* magazines "stacked one atop another" would be more than 12 feet (*S&T:* Nov. 2016, p. 22), I don't know if he expected anyone to be crazy enough to actually find the answer.

But I took this as a friendly challenge and dutifully piled up my 1941–2015 collection of bound volumes. The picture here shows the 3.12-meter-high result. Subtracting the combined 456-mm thickness of all the hard covers results in 2.66 m (8.74 feet) for just the magazines.

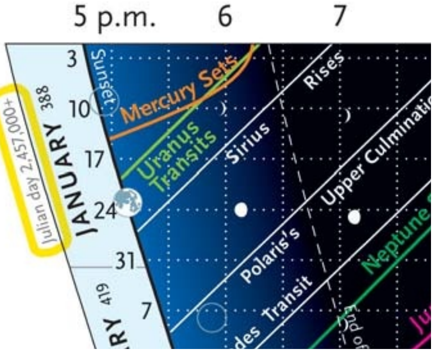
Patrick Wiggins
Salt Lake City, Utah

Dennis di Cicco replies: *You've thrown down the gauntlet, and I must defend my honor! During the winter of 2009–10, my daughter and I spent a couple of weeks in our basement sorting through several thousand* S&T *issues, assembling the set that would be scanned for the magazine's DVD collection. We packed the selected copies standing upright into large bins that extended more than 11 feet across the floor and weighed 385 pounds (175 kg). Subtracting a few inches for the thickness of the bins — but adding a few more for the six additional years since the DVD set's release — yielded the 12-foot figure I used.*

▲ Taking the true measure of all 75 years of *S&T* issues was a challenge that Patrick Wiggins couldn't pass up.

Why Julian Days?

I would like to know why Julian days are used on the Skygazer's Almanac. I'm interested in learning more about their use as an astronomical method for event logging and how this became the calendar of preference. Is it competitive with Universal Time, or is it used in conjunction with Universal Time as a logging tool?



A. H. Goodwin
Stanberry, Missouri

Kelly Beatty replies: *The use of Julian days (or dates) is tied to the Julian Period, proposed by Joseph Scaliger in 1583 as a means to tie together three different calendrical cycles. In his scheme, the starting point is January 1, 4713 BC. John Herschel popularized the counting of days using this method in 1849, and Pierre-Simon Laplace was the first to express the time of day as a decimal fraction. Note that each Julian day begins at noon (12:00) in Greenwich Mean Time, because in Herschel's era the astronomical day likewise began at noon.*

Astronomers like the Julian-day system because it simplifies the math of finding date intervals that don't depend on an Earth year, say, to clock the period of a variable star or to determine the interval between two solar eclipses.

But for a single event on a specific day, Universal Time is preferred because it allows for easy conversion to any time zone worldwide.

SKY & TELESCOPE DIAGRAM; PHOTO: BRUCE GRIM

Of Mars and Memory Lane

I enjoyed Camille Carlisle's ExoMars article so much (*S&T:* Oct. 2016, p. 22) that several days later I read it again. What caught my eye, in addition to the mission's objectives, was her wording "pretty pickle." That's an expression I heard often in my youth — but not at all in recent years. Seeing it sent me far back in time for a moment. Back then there was still a debate about canals and civilization, and galaxies were still called "extra-galactic nebulae." Memory lane is fun sometimes, especially when part of new science.

Darryl Davis
Albany, Oregon

Rafferty on Ritchey

I have never read an astronomy-related article that has had such a deep impact on me as Ted Rafferty's (*S&T:* Oct. 2016, p. 66). I had very little knowledge of George Ritchey's life story. However, I did realize how much bearing the great Ritchey-Chrétien design now has on modern astronomical optical systems. Rafferty did an amazing job conveying this, and I look forward to seeing Ritchey's 40-inch telescope later this year during our family vacation in Flagstaff, Arizona.

Tyler Welch
Beaver Dam, Wisconsin

Rükl's First Lunar Atlas

Readers might like to know that Antonin Rükl's *Atlas of the Moon* (*S&T:* Nov. 2016, p. 14) was first published in 1976 by Artia Publishing in Prague. Its English-language edition, which I bought in September 1978, is titled *A Concise Guide in Colour: Moon, Mars and Venus*. Six beautiful maps of Mars are included as a bonus — yet the book's covers do not mention the author's name! It's still available now and then; do a browser search for ISBN 0-600-36219-1.

By the way, concerning the photograph of the late Leif Robinson's office (*S&T:* Nov. 2016, p. 26), I have to ask: Was there an earthquake that day? A burglary perhaps?

Peter Gibbons
Cork, Ireland

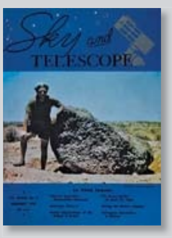
FOR THE RECORD

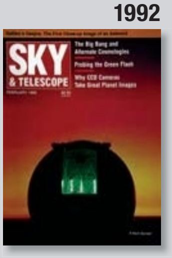
- The globular cluster pictured in Corona Australis (*S&T:* Aug. 2016, p. 76, and Nov. 2016, p. 75) is NGC 6723, not NGC 6541.
- In the illustration showing Schiaparelli's landing sequence (*S&T:* Oct. 2016, p. 23), the final two altitudes should be 2 m and 0 m.
- Isaac Roberts took his historic image of asteroid 80 Sappho (*S&T:* Oct. 2016, p. 6) on January 14, 1887.

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.

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

1942


1967


1992


February 1942

Demon Star "Jesse A. Fitzpatrick, who compiles our Observer's Page, sent us times for the minima of [the well-known variable star] Algol in January that were a continuation of those published in *The Observer's Handbook* last year. [But in] connection with his article on Algol in this issue, Dr. Zdenek Kopal gave us a schedule of February minima which agreed neither with Mr. Fitzpatrick nor with the *Handbook*. . . .

"Adding Joseph Ashbrook's 25 minutes to Dr. Kopal's 8:00 p.m. for the January 1st minimum gives 8:25 p.m., or just the time Mr. Fitzpatrick refers to in his letter to us . . . ."

Unexpected (if subtle) changes in this eclipsing binary's period had been known for a century. Joe Ashbrook, then a young grad student in astronomy, was among those who caught this latest one. He joined the Sky & Telescope *staff in 1953 and went on to become the magazine's editor in 1964.*

February 1967

Saturn's Brood "Has a tenth satellite of Saturn been discovered? A preliminary announcement of such an object has come from France . . . If the case is substantiated, this will be the first addition to that planet's retinue of moons since Phoebe in 1898 (not counting the never-confirmed finding of Themis by W. H. Pickering in 1905).

"The discovery was made photographically by Audouin Dollfus, well-known planetary and lunar specialist of Meudon Observatory . . .

"Dr. Dollfus described the new object as of magnitude 14, and as moving just outside the rings . . . with a period of 18 hours."

Dollfus's find was confirmed at other observatories and soon named Janus, but not all the images gave a unique revolution period. The confusion was not cleared up until Saturn's rings were again edgewise to our view, in 1979–80: another new moon, later named Epimetheus, and Janus travel in much the same orbit.

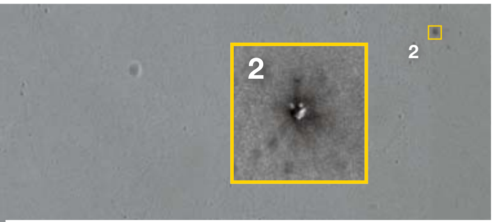
February 1992

Geminga "Powerful new observatories almost always solve long-standing astronomical mysteries. But in at least one case the Compton Gamma Ray Observatory, in orbit since last April, seems to have done the opposite.

"Several years ago, after a 20-year effort, astronomers finally thought they had linked the gamma-ray source known as Geminga to an optical and X-ray counterpart [and] inferred that the object is an isolated neutron star. . . . Yet when the Compton Observatory [examined] the oddball source, it captured gamma rays only at the very highest energies. . . . How could one source emit light, X-rays, and high-energy gamma rays but remain 'dark' in spectral windows in between?"

Geminga turned out to be an unusual pulsar (rapidly rotating neutron star). Its 0.237-second pulses are mainly seen with gamma- and X-ray satellites, but only weakly with ground-based radio telescopes. It's normally the other way around.

● To get astronomy news as it breaks, visit skypub.com/newsblog.



▲ NASA's Mars Reconnaissance Orbiter took this image (background) of Schiaparelli's disastrous landing site on October 25th. Close-ups highlight three impact locations, all within 1.5 km (0.9 mile) of one another: **(1)** the lander itself, **(2)** potential fragments of the heat shield, and **(3)** the parachute and back shell.

NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA

MISSIONS

ExoMars Lander Fails, Orbiter Succeeds

THE EXOMARS MISSION, a joint effort of the European and Russian space agencies (*S&T:* Oct. 2016, p. 22) has met with only partial success. Although the Trace Gas Orbiter reached the Red Planet as intended, the descent of the tagalong Schiaparelli lander turned into a fatal plunge on October 19th, when a glitch compromised the landing.

Designed as a technology demonstration for a planned 2020 rover, the lander was programmed to transmit data through all stages of descent. Based on those data, atmospheric braking and parachute deployment were flawless. Then, about 90 seconds prior to landing, things went awry.

First, the module jettisoned its heat shield and parachute early. Then miscommunication between the onboard navigational system and radar erroneously told Schiaparelli it was near the surface. So the braking rockets shut off after burning for only 3 seconds rather than the planned 60 seconds. At about 2 to 4 kilometers (1 to 2½ miles) above the surface, Schiaparelli went into freefall.

The lander slammed into Meridiani Planum at an estimated 300 km per hour (186 mph) and most likely exploded on impact. Orbiter images revealed an ugly new crater on Mars (#1 in the image at left), as well as two other debris impacts (#2 and #3).

European Space Agency (ESA) officials were careful to stress that Schiaparelli was only intended as a landing test. A software glitch should be a relatively easy fix, as opposed to the prospect of re-engineering a fundamental flaw in the hardware. But ESA and its partner, Roscosmos, will obviously want the upcoming ExoMars rover to reach the Martian surface intact. For now, the impact of Schiaparelli's performance on the future of the ExoMars program is unclear.

Meanwhile, the Trace Gas Orbiter (TGO) is safely looping around the Red Planet and "working perfectly," said ESA spacecraft operations manager Andrea Accomazzo. The spacecraft fired its braking rocket for 139 minutes, slowing down by more than 1.5 km/s in order to be captured by the planet's gravity.

TGO's current orbit is a highly elongated loop that ranges in altitude from 300 to 96,000 km (190 to 60,000 miles). Beginning in March, the orbiter will begin a year-long process of repeatedly dipping into the uppermost Martian atmosphere, creating a controlled drag that will gradually bleed away orbital energy and shrink the ellipse. By March 2018, the near-polar orbit should be circular, with an altitude of 400 km.

■ **DAVID DICKINSON**

MISSIONS

Juno Enters Safe Mode

ON OCTOBER 18TH, right before its second Jupiter flyby, NASA's Juno spacecraft unexpectedly stopped operations. After much angst on the part of scientists and the public, engineers restarted the craft successfully a week later and said it was apparently healthy.

Juno switched to "safe mode" after a software performance monitor rebooted the onboard computer, which it's programmed to do when "conditions are not as expected," according to a press release. It's still unclear what triggered the electronic hibernation, but one possibility is two main-engine check valves. Prior to the anomaly, engineers had decided to keep the Jupiter probe in its wide-ranging orbit for at least one more pass until they could address an issue with the valves controlling the spacecraft's fuel pressurization system. During a command sequence the team initiated, these valves should have opened in a few seconds — but instead took several minutes, explains Juno project manager Rick Nybakken (Jet Propulsion Laboratory). "We need to better understand this issue before moving forward with a burn of the main engine."

Juno did execute an orbital adjustment on October 25th using its smaller thrusters, in preparation for another Jupiter pass on December 11th.

■ **DAVID DICKINSON**

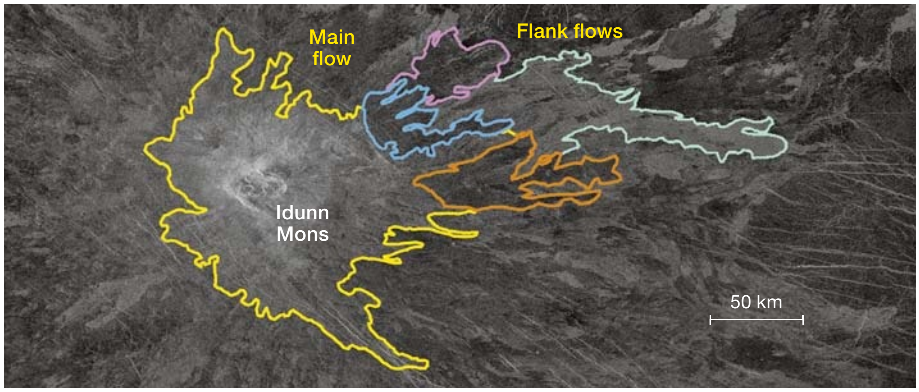
SOLAR SYSTEM

More Evidence for Volcanoes on Venus

PLANETARY SCIENTISTS haven't yet witnessed an active volcano on Venus, but they have little doubt that eruptions occur there. NASA's Magellan orbiter, which used radar to map the planet's surface in the early 1990s, found lots of fresh-looking flows. Years later, ESA's Venus Express found several hot spots that came and went. And both Venus Express and NASA's Pioneer Venus Orbiter detected surges in the atmosphere's level of sulfur dioxide (SO_2), a gas likely released during eruptions.

Now a new study pinpoints a likely set of still-warm lava flows on the slopes of Idunn Mons, a massive volcano in the planet's southern hemisphere that's about 200 km across and 2½ km tall. In 2006 and 2007, Venus Express detected excess heat coming from the mountain's eastern flank, but the atmosphere's opaque clouds blocked any direct view from orbit.

A team led by Piero D'Incecco (German Aerospace Center, Cologne) dove into the Magellan archives to identify high-resolution radar maps of Idunn Mons. The researchers identified five distinct lava flows: an extensive one that blankets the summit, and four others that trail down the mountain's eastern flank. All five look fresh. The team first modeled how much heat could be radiating from each flow, then determined that a combination of three flows on the eastern flank (outlined with purple, blue, and orange in the map above) matches the heat distribution best. These flows also appear to be superimposed on other slope features, suggesting they're the most recent additions.



▲ Radar-brightness maps from NASA's Magellan orbiter, acquired in 1990–92, reveal several fresh-looking flows on the summit and eastern flank of Venus's Idunn Mons.

D'Incecco reported these findings during October's joint meeting of the European Planetary Science Congress and the American Astronomical Society's Division for Planetary Sciences.

So what will it take to prove that volcanoes on Venus continue to spout off? More capable spacecraft — and luck. Some European scientists hope to launch an orbiter called EnVision in 2025, while a NASA-sponsored team has proposed an orbiter called Veritas that could start high-resolution radar mapping in 2021.

■ **J. KELLY BEATTY**

Artist's concept of a trans-Neptunian object.

VENUS: NASA / ESA / DLR; TRANS-NEPTUNIAN: NASA

SOLAR SYSTEM

Retrograde Rock "Stands Up" in Orbit

THE RECENTLY DISCOVERED object 471325 (formerly 2011 KT_{19}) hints that a distinct new class of high-inclination Centaurs lurks in the distant solar system. Centaurs are objects whose orbits cross those of one or more outer planets. They generally lie between Jupiter and the Kuiper Belt.

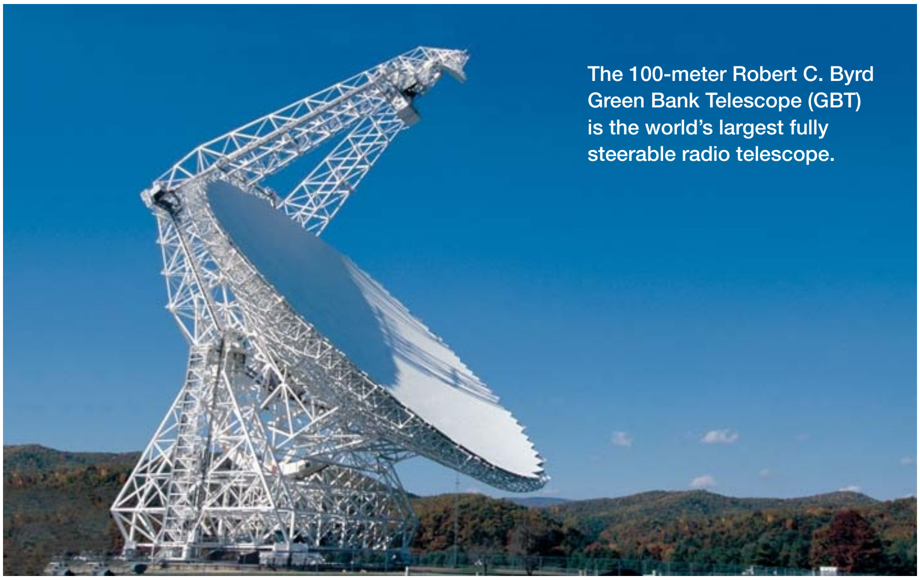
Observers with the Catalina Sky Survey first spotted 471325 in 2011. It turned up again last year in images taken in the constellation Serpens Caput with the Pan-STARRS 1 telescope in Hawai'i. Based on its 22nd-magnitude brightness, this object should be 70 to 200 km in diameter — at most one-sixth the diameter of Pluto's large moon, Charon.

But it's the orbit derived by Ying-Tung Chen (Academia Sinica, Taiwan) and others that shows what a strange little world this is. Reported in the August 20th *Astrophysical Journal Letters*, the unusual, 212-year circuit takes 471325 inside the orbit of Neptune and out to just inside the aphelion of Pluto. Furthermore, the orbit's inclination to the ecliptic is 110°, nearly perpendicular to the plane of the major planets' orbits around the Sun. The object loops around our star in a slow *retrograde* orbit — one moving "backward" with respect to the motions of the major planets.

Just one other known trans-Neptunian object has a retrograde orbit: 2008 KV_{42}, whose path is inclined 103°. These two objects — along with four other small Centaur asteroids in prograde orbits — share a common orbital plane.

Based on simulations, Chen's team calculates that the likelihood of getting all six objects in the same orbital plane is only 0.016% — and the alignment isn't stable, since orbital precession should scatter these objects in just a few million years. Dynamicists don't know what sort of mechanism is keeping these objects in the same plane.

■ **DAVID DICKINSON**



The 100-meter Robert C. Byrd Green Bank Telescope (GBT) is the world's largest fully steerable radio telescope.

OBSERVATORIES

Green Bank Goes Independent

OCTOBER 8TH marked the dawn of a new era for the radio astronomy observatory in Green Bank, West Virginia. What was once the flagship facility of the National Radio Astronomy Observatory (NRAO) is now an autonomous institution.

Green Bank's new independence makes the best of a bad situation. For the last 60 years, the National Science Foundation (NSF) has funded the observatory as part of the NRAO network, which includes other facilities in the United States and Chile. But in 2012, the NSF — trying to balance its tightening budget (*S&T:* Dec. 2012, p. 34) — decided to let Green Bank go.

This came as no small shock to the folks at Green Bank, which is home to the world's largest steerable, single-dish radio telescope (pictured above). Deprived of its primary source of funding, the observatory was scheduled to shut down on October 1, 2016.

But Green Bank staff and the NSF hammered out a plan to transform the former national observatory into an independent institution. Instead of cutting Green Bank off completely in 2016, the NSF now plans to gradually wean the observatory off federal funds. In 2017, the NSF will grant Green Bank 60% of its previous annual budget, which amounts to about $8 million. In 2018, Green Bank can count on $4 million. After that, the NSF makes no promises of financial support. "We know that they want to continue funding us at some level, but we don't know what that will be," says Michael Holstine, Green Bank Observatory's business manager.

To compensate for dwindling NSF funds, Green Bank has signed contracts with science initiatives that pay to make observations with the 100-meter-wide Green Bank Telescope (GBT). Major partners so far include the Breakthrough Listen project (*S&T:* Nov. 2015, p. 10), the North American NanoHertz Observatory for Gravitational Waves, and West Virginia University.

Under the new regime, day-to-day operations at the observatory will remain basically the same. What will change is which research projects get first dibs on observing time. Back when the NSF bankrolled the observatory, any researcher in the world could propose a project using GBT, and those with the best proposals got queued up for time on the scope. Now, the Green Bank Observatory has to prioritize its major partners. "And when you sell dedicated telescope time to individuals or specific projects, that data is theirs to do with what they would like," Holstine says.

■ **MARIA TEMMING**

IN BRIEF

Two Novae in Sagittarius

Amateur Koichi Itagaki spotted a nova above the Sagittarius Teapot on October 20th, using a 180-mm telephoto lens to take sky-patrol photos. Within two days, the explosion shot up three magnitudes to be brighter than 8.0. That put it within range of 50-mm binoculars. As of mid-November, its temporary name was TCP J18102829-2729590. Meanwhile on October 25th, the ASAS-SN automated survey and observer Yukio Sakurai turned up a second, 9.7-magnitude nova in the same region. It's designated ASASSN-16ma.

■ **BOB KING**

Read more about the novae at **https://is.gd/sagnova2016**.

Jupiter Returns with Stormy Surprise

Planetary observers were treated to an outbreak this fall in Jupiter's North Temperate Belt (NTB). Using NASA's Infrared Telescope Facility in Hawai'i, Glenn Orton first noticed the series of bright spots encircling the planet on October 19th. Visually, the outbreak appears as a series of dark spots and festoons encircling the planet. John Rogers (British Astronomical Association) notes that this type of outbreak occurs at roughly 5-year intervals, and this one seems to have come on schedule.

■ **SEAN WALKER**

Learn more at **https://is.gd/jupiteroutburst2016**.

Ewen A. Whitaker, 1922–2016

An amateur-turned-professional who became one of the world's most renowned lunar specialists has died at age 94. Whitaker was a leader of the Lunar Section of the British Astronomical Association during the 1940s. In 1949 he was hired by Greenwich Observatory, then later recruited by Yerkes director Gerard Kuiper to help create a series of lunar atlases. A skilled lunar photographer, Whitaker ultimately developed the best knowledge of lunar geography of anyone alive. He was also a humble, gentle, and practical person, with a quiet sense of humor. His book, *Mapping and Naming the Moon: A History of Lunar Cartography and Nomenclature*, remains a standard reference.

■ **CHARLES A. WOOD**

Read the full obituary at **https://is.gd/whitakerobit**.

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SOLAR SYSTEM

Subsurface Ocean on Dione?

CASSINI DATA suggest that a subsurface ocean might lie deep beneath the crust of Saturn's moon Dione.

Planetary scientists have found evidence of subsurface oceans lurking beneath the crusts of several solar system bodies. The most convincing case is Enceladus, a little icy moon of Saturn known for its salty geysers. Other contenders are Saturn's largest moon, Titan, and Jupiter's big moons Europa (see below), Ganymede, and Callisto.

At the March 2016 Lunar and Planetary Science Conference, Doug Hemingway (University of California, Berkeley) and others on the Cassini radio science team presented a preliminary analysis suggesting that Dione might have a subsurface ocean, too. They based this conclusion on the moon's overall

◀ NASA's Cassini spacecraft captured this view of Dione, with giant Saturn and its rings in the background, in August 2015.

topography and how strongly it pulls on the Cassini spacecraft, which has been touring the Saturnian system since 2004 and made three close, carefully tracked flybys of the moon between 2011 and 2015.

Using this preliminary work, Mikael Beuthe and colleagues at the Royal Observatory of Belgium did a more detailed analysis of the gravity data. The Belgian team suggests in the October 16th *Geophysical Research Letters* that the best fit to the data is a crust about 100 km thick, overlying a global ocean 35 to 95 km deep. (Dione is about 1,100 km across, or twice Enceladus's size.)

But there may be other ways of explaining the uncertain Dione data. Scientists think Enceladus has an ocean in part because it wobbles, or *librates*, significantly in its orbit around Saturn, which wouldn't happen if it were solid throughout and "all but proves the ocean is there," says William McKinnon (Washington University in St. Louis), whose team is one of several that has studied the moon. Beuthe's team predicts Dione does librate, but not enough to show up in Cassini images.

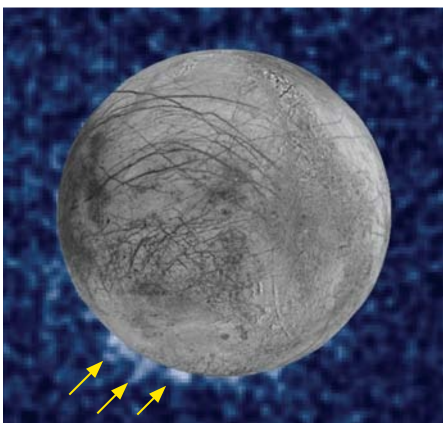
■ **CAMILLE M. CARLISLE**

Read more at **https://is.gd/dioneocean**.

SOLAR SYSTEM

Europa Geysers Point to Subsurface Ocean

FOR DECADES astrobiologists have pondered whether primitive life might exist in a global ocean presumed to lie beneath the smooth, icy crust of Jupiter's moon Europa. But this putative ocean must be at least several kilometers down — a formidable barrier to exploring it firsthand.



▲ Faint light streaks near the south pole of Europa in this composite image of Hubble (blue) and Galileo data (gray disk) might be towering geysers of water erupting from the moon.

Now it appears that sampling this briny deep might be easier than once thought. Hints that Europa sports water-powered geysers first came to light in 2012, when a team led by Lorenz Roth (Southwest Research Institute) used the Hubble Space Telescope (HST) to spectroscopically detect localized clouds of hydrogen and oxygen atoms — presumably derived from water — in Europa's vicinity.

More recently, William Sparks (Space Telescope Science Institute) and others used HST to record images of Europa as it crossed in front of Jupiter. They wanted to see if the moon has a thin atmosphere, which would show up as a dark aura around Europa when viewed in silhouette against Jupiter.

Sparks' team tracked 10 transits of Europa from December 2013 to March 2015, as well as non-transit sessions to model the appearance of Europa itself. They used a far-ultraviolet channel centered at 150 nm, because that wavelength is scattered by Jupiter's high-altitude hazes and makes the planet's disk look featureless. Hubble's resolution is also best at ultraviolet wavelengths.

Three of the resulting image sets show what could be plumes. In two cases the putative eruptions appear to come from the moon's south polar region — the same general locale implicated by Roth's team — and the third was nearer the equator. The vague puffs seem to extend at least 200 km (125 miles) above Europa's limb. Details appear September 29th in the *Astrophysical Journal*.

The researchers are hopeful but cautious about their results. In one image, for example, the base of a possible plume doesn't coincide with the limb of Europa itself, as it should. "We are really working at the limits of Hubble's unique capabilities," Sparks says.

If the geysers are real, future spacecraft might be able to assess the ocean's composition and life-hosting qualities merely by landing on the surface near an eruptive vent or flying through one of the plumes at close range.

■ **J. KELLY BEATTY**

DIONE: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE; EUROPA: NASA / ESA / W. SPARKS / USGS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Anatomy of a Black Hole

Artwork by Casey Reed

What is a black hole?

A black hole is a pit in the fabric of spacetime. Space and time, according to Einstein's theory of special relativity, are interchangeable parts of a thing called spacetime: much as width, height, and depth are dimensions of a box, so space and time are dimensions of spacetime. Although the dimensions of space and time are relative and can change, contracting or dilating depending on your frame of reference — an effect noticeable when dealing with strong gravity or relativistic speeds — units of *spacetime* are absolute.

In this wacky landscape, a black hole is a cosmic pothole. Black holes are places where the density of matter grew so high that the outward pressure of the matter's particles couldn't withstand the inward pull of gravity, and gravity, like a master poker player, gathered all the chips together and crushed them into what's called a singularity. We don't really understand what happens at the singularity; we only know that there, classical physics breaks down.

A singularity and a black hole are not the same thing. The singularity hides inside a black hole, screened from view by the black hole's event horizon. The event horizon is the so-called point of no return: the region within which nothing, not even light, can escape the black hole's gravitational pull.

However, this all becomes far more complicated if the black hole is spinning (see facing page).

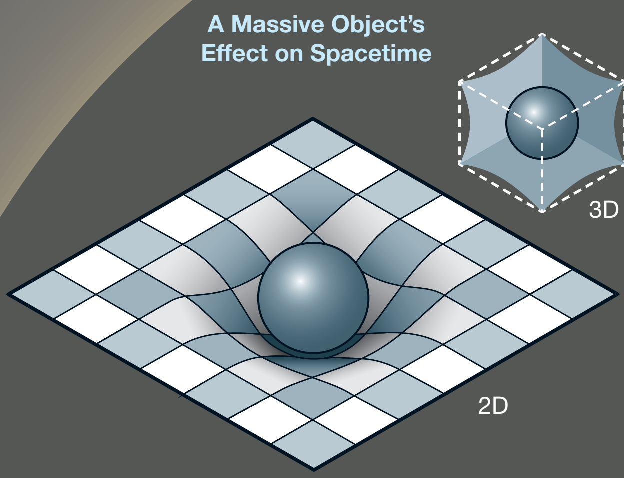
What would happen if you fell into a black hole?

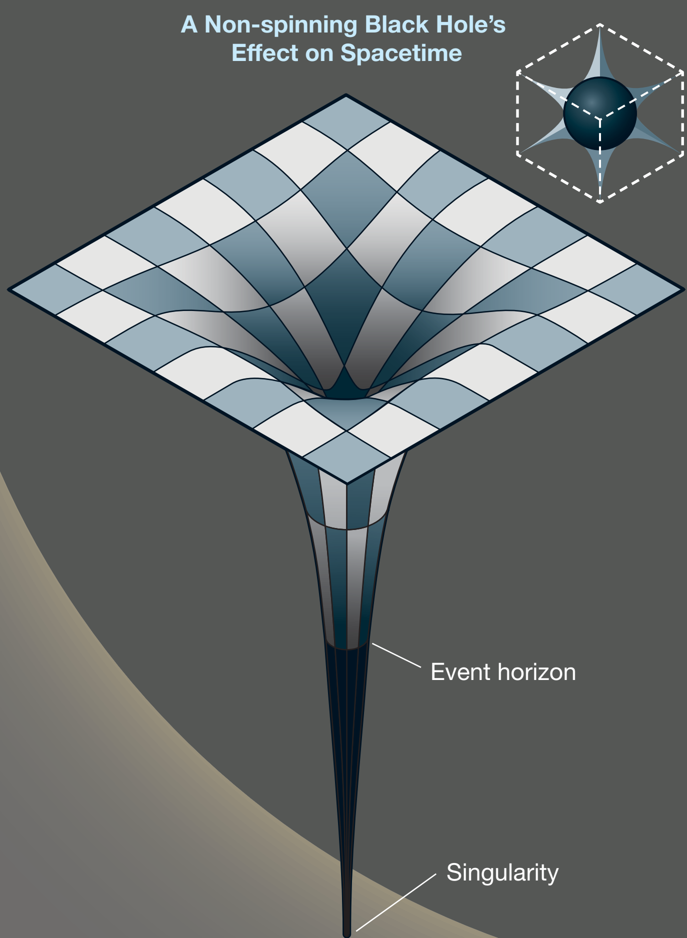
If it were a stellar-mass black hole, you'd be dead before you passed the event horizon. That's because, if you think of a black hole as a pit, a stellar-mass black hole has steeper sides than a supermassive black hole. The tidal forces become too strong too fast for you to survive to the event horizon, resulting in your spaghettification (yes, that's the technical term).

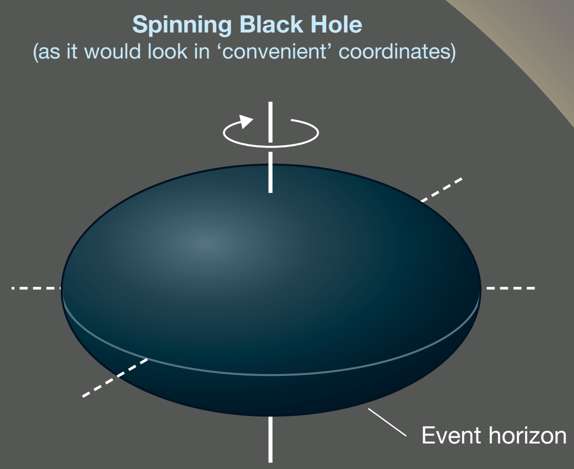
So let's travel into a supermassive black hole. Passing the event horizon, you wouldn't notice much (except some fun light effects and several extra *g*'s of gravity). But as you drew closer to the singularity, gravity would stretch and squeeze you like you were dough in a bread machine. At this point you'd die.

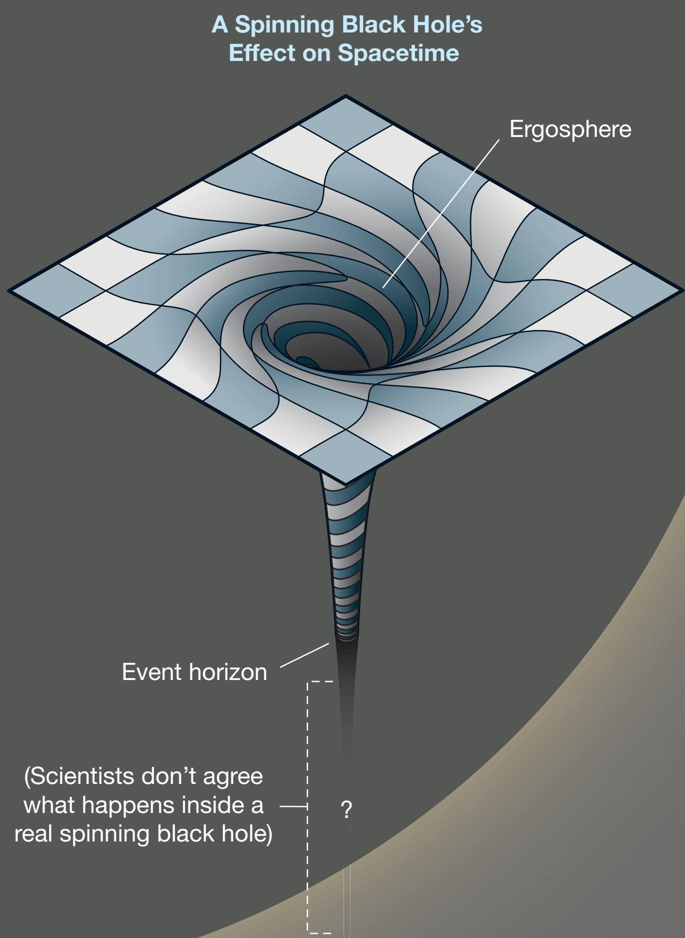
What would someone watching see as you fell in?

As you approached the event horizon, a second person far, far away would watch your image slow down and redden. Theoretically, at the event horizon your image would freeze. But in practice you would disappear: the photons lose energy as it becomes harder for them to climb out of the black hole's gravitational well, and their wavelength would increase until it grew past the observer's detection capabilities — making the image invisible. So your image would redden and dim with time, until it faded entirely.









The ergosphere

A spinning black hole is more like a whirlpool. The swirling water in this analogy is spacetime itself. It’s pulled around as the black hole rotates and falls down the maw of its drain. This region of twisted spacetime is called the ergosphere. It is impossible to stand still in this region.

A spinning black hole has kinetic energy bound up in its spin, in the same way that a spinning top is more energetic than a top lying down. That energy can be tapped into and transferred to other things in the black hole’s environment. (The term ergosphere comes from the Greek word for “work.”) Astronomers think that a black hole powers its jets with energy from its spin.

How fast does a black hole spin?

When astronomers measure a black hole’s spin, they report the value as a fraction of the maximum allowed spin (which would be 1). For example, the bigger member of the black hole binary in the quasar OJ 287 has a spin, labeled a, of 0.313, or 31.3% of its max. But what does that mean?

This number is related to the angular momentum; it’s not a fraction of the speed of light. But we can turn it into a fraction of the speed of light. *S&T* readers are often no strangers to math, so here you go: the rotational velocity at the event horizon of a black hole is given by

$$v_{rot} = \frac{ac}{1+\sqrt{1-a^2}}$$

where c is the speed of light. (The derivation is a bit messy; this equation comes thanks to Scott Hughes at MIT.) So for OJ 287 and its spin of $a = 0.313$, the black hole is spinning at $0.16c$, or 16% the speed of light.

Do black holes really exist?

We’re pretty darn sure. Stars and gas at the centers of many galaxies orbit around invisible but incredibly massive objects, and we can tell how massive the object is based on these orbits: millions to billions of Suns’ worth of mass. No observers have detected surfaces for these objects. In addition, brilliant beacons called active galactic nuclei (the galactic-center kind of black hole) and X-ray binaries (the stellar kind of black hole) put out so much radiation — notably as jets — that the only explanation we’ve found that works is that these powerhouses are fueled by black holes.

Plus, the two gravitational-wave events recently detected by LIGO (*S&T:* Oct. 2016, p. 10) came from the merger of objects that look just like the black holes predicted by Einstein’s theory of gravity. In fact, black holes are an inevitable outcome of Einstein’s theory, a fact the famed physicist wasn’t happy about and actually tried — and failed — to disprove.

Could it be that we don’t really understand gravity, and something else explains all these phenomena? Yes. But so far no other ideas have worked out. And black holes work out *really well*. As bizarre as they are, my money is on their existence.

—Camille M. Carlisle

 by Camille M. Carlisle

Of Black Holes *and* Galaxies

How much influence do supermassive black holes have on their galaxies, or vice versa?

Black holes might seem like control freaks. A gaping maw in the fabric of spacetime, devouring anything fool enough to come close, inexorable in its dominance — that's basically the dictionary entry for a tyrant.

But in fact, these objects have surprisingly tiny spheres of influence. Their gravitational reach is small, only a few light-years. Stars can even come within a few thousandths of a light-year and survive unscathed. As far as a galaxy should be concerned, its black hole could just as well not be there.

Yet that's not the case. In the 1990s and 2000s, astronomers noticed some unexpected correlations between galaxies and the supermassive beasts enthroned in their hearts. The black holes' masses increased or decreased in tandem with other galaxy properties: the more massive the black hole, the bigger and brighter the galaxy's central bulge of mature stars, and the faster those stars zipped around.

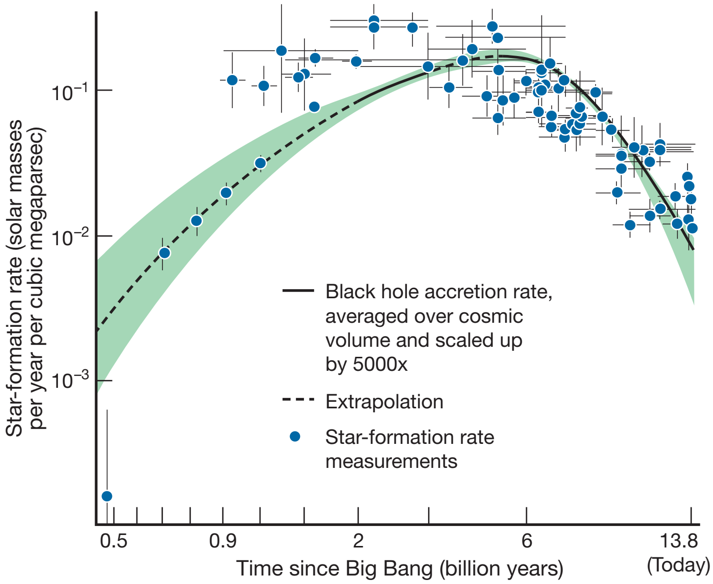
"[These connections] tell us that either the black hole cares about the galaxy that it lives in, or the galaxy cares about the black hole that's in it," says Kayhan Gültekin (University of Michigan), who has been one of many to investigate the link with star speeds, called the *M-sigma relation* (*M* for the black hole's mass, *sigma* for the range of stellar velocities).

But bulges can easily span 10,000 light-years, far beyond the black hole's presumed reach. In other words, these correlations shouldn't exist. Yet preliminary data showed relations that looked so good, they appeared to have "no scatter": all the systems tightly hugged a straight line on a graph.

"That seemed like it had to be magic," says Jenny Greene (Prince-

NASA / CXC / JPL-CALTECH / STSCI / NSF / NRAO / VLA

▶ **MONSTER WITHIN** The galaxy M106 has a pair of "anomalous arms" that intersect with its spiral disk. Astronomers suspect that the jets of the active black hole at the galaxy's heart are creating shock waves in the interstellar gas, thereby heating the gas and shoving it out of the galaxy. This outflow appears as the arms, which glow in radio, optical, and X-ray wavelengths.



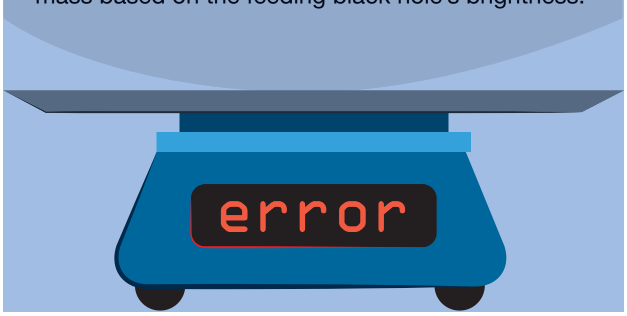
STARS AND BLACK HOLES This figure tracks the growth of black holes and of galaxies (manifested as star formation) over cosmic time. At first glance, the graph appears to show that black holes and galaxies co-evolve. But while black hole accretion and star formation rates do track each other closely in the last 10 billion years, that might arise if they're controlled by the same thing — for example, the gradual decline of fuel as the universe's cold gas supply is used up. Another explanation is that, if both black holes and galaxies grow early on thanks to galaxy mergers, then the rates might decline in recent cosmic times because galaxy mergers are increasingly rare as the universe expands.

How We "Weigh" Black Holes

Obviously astronomers can't put a black hole on a bathroom scale. (It's impolite.) So to measure the mass of one of these objects, observers clock the speed of stars or gas whirling around it in a galaxy's core. These velocities depend on the mass of the black hole that the stars or clouds are orbiting. When observers can also see how far away this stuff is from the black hole, they can then directly measure the beast's mass.

When it's impossible to see how large these orbits are directly, astronomers turn to the accreting material's glow. Active black holes are notorious for their flickering. The delay between flickers corresponds to how long light took to travel from one side to the other of the accreting gas — and since light travels at a finite speed, the travel time tells us the distance crossed. That distance, plus the gas's orbital speed, corresponds to how massive the black hole is.

When all else fails, astronomers estimate the mass based on the feeding black hole's brightness.



ton University). Astronomers immediately started speculating that galaxies and black holes grow in lockstep. "It had to be some kind of feedback loop between the black hole and the galaxy," she says, describing what scientists thought at the time.

Many suspected that the black hole dominated the relationship. If so, these little spacetime monsters controlled not just unlucky, passing stars but galaxy formation across the universe, serving as invisible masterminds in the development of cosmic structure. Black holes were suddenly the most important object in the cosmos. When I wrote my master's thesis on these objects in 2010, one astronomer told me that "understanding the whole history of the universe is locked up in understanding black holes."

But with more data, astronomers are realizing that the tale isn't so magically simple. The saga may not have the black hole as its all-powerful hero. Instead, the hole might just be along for the ride.

Messed-up M-sigma

At first, astronomers thought all galaxies obeyed M-sigma and the other correlations. But soon they realized that wasn't the case. True, the correlations did hold in typical elliptical galaxies, those big bulbous balls of old stars. But the trends show up only weakly, if at all, in disk galaxies. In such systems, none of the galaxies' properties — their total mass in stars, their bulge mass, the range of star speeds, or the mass of the dark matter clouds they sit in — closely aligns with the central black hole's mass.

If the M-sigma rule applied to every galaxy, then disk galaxies should have black holes much beefier than they do. Instead, several astronomers have seen a "lightweight" trend in recent years, including Greene's team.

"The only population left where there is a tight relationship between the black hole and the galaxy are these typical ellipticals," Greene says. Even the most massive ellipticals don't follow it well, she adds.

But spreading the message that there's no universal, tight coevolution has taken time. "We're terribly human people, and the psychology kind of took over," says John Kormendy (University of Texas at Austin), one of the first to suggest a relationship between black holes and their galaxies — and, with Luis Ho (Peking University, China), one of the first to raise the red flag against the lockstep growth many astronomers came to believe in. "Scientists get very sure of the things that they think they're very sure of. And sometimes they've been wrong — and when they are, it's a hell of a job to change the folklore."

CHART: *S&T*: LEAH TISCIONE, SOURCE J. KORMENDY AND L. HO / *ANNUAL REVIEW OF ASTRONOMY AND ASTROPHYSICS* 2013; ILLUSTRATION: *S&T* / GREGG DINDERMAN

That's not to say stellar beauties and their beasts aren't connected. Observations reveal that for at least the last 11 billion years, black hole growth and starbirth rates have risen and fallen together in a roughly constant ratio (see graph on the facing page). So there *might* be a link between them, but it could exist merely because the same factors influence the growth of both, not because they're tightly coevolving.

Thus the main question is, what is driving the apparent relationship? And that's where the real debate begins.

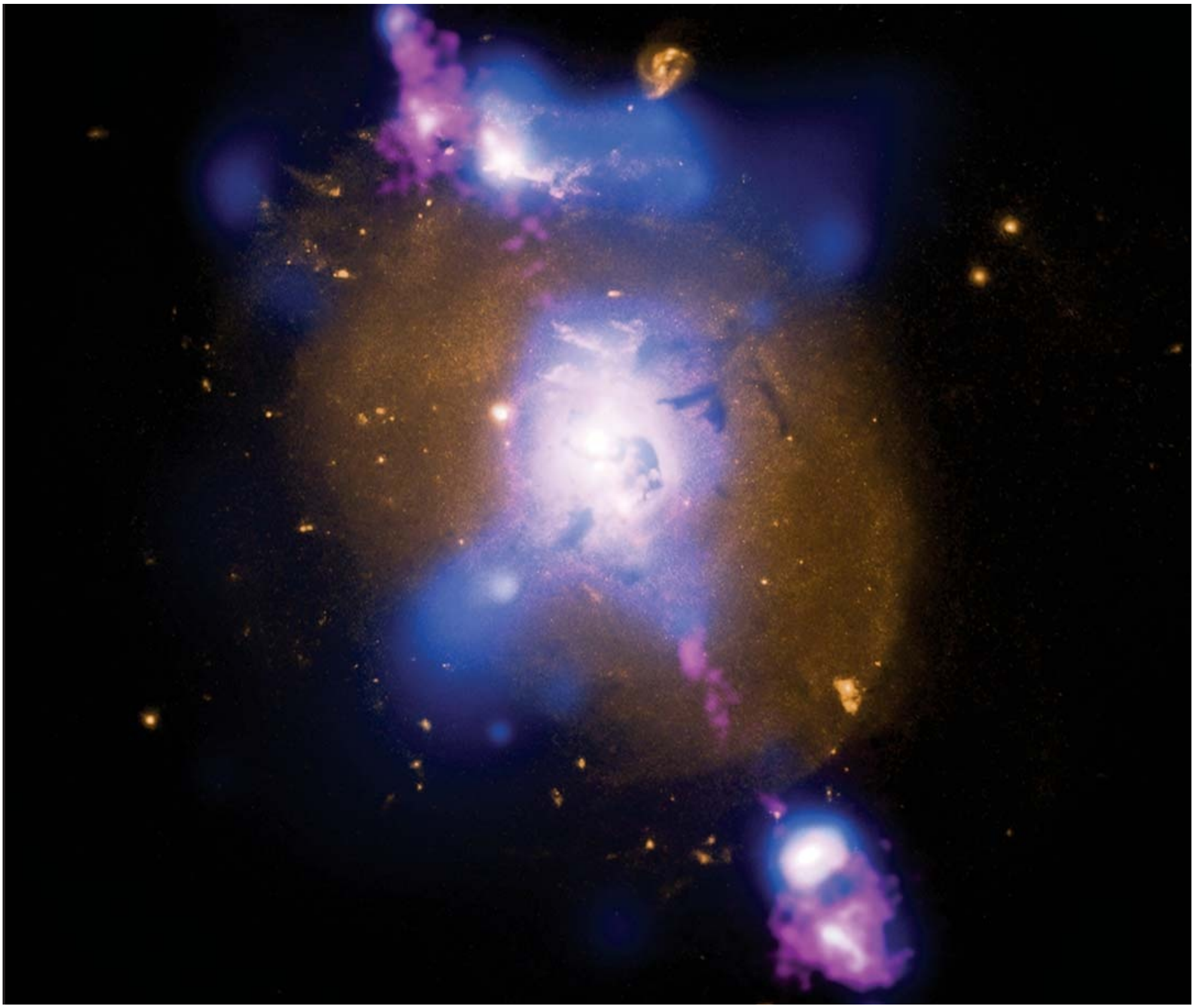
Option A: Black Hole Tyrant

Astronomers have good reason to suspect the black hole pulls the cosmic strings. The energy radiated during the hole's accretion can be 2,000 times greater than the binding energy of all the gas in the galaxy's central bulge. By the numbers, a madly gobbling black hole would be able to wreak havoc on its host. It could easily control the galaxy.

Throwing that possibility to astronomers was like throwing candy to trick-or-treaters. The major motivation for its popularity came from answering a different question: why are big ellipticals red and dead, when they're replete with gas?

Stars form from cold gas, and the gas surrounding these galaxies in big, X-ray-emitting halos is hot. But it shouldn't be: it should have enough time to cool and rain back down, fueling starbirth. Astronomers have detected a few precipi-

▼ **ON A RAMPAGE** The jets shot out by the black hole in the galaxy 4C+29.30 blaze in this composite image, which combines observations in X-ray (blue), optical (gold), and radio (pink) wavelengths. The optical light is from the galaxy's stars; the X-rays reveal million-degree gas, much of it appearing to pool around the black hole. The radio emission comes from particles accelerated by the jets. Because jets can carry so much energy into (and beyond) the surrounding galaxy, many astronomers suspect that they're the mechanism that controls star formation and black hole growth.



NASA

tating clouds (*S&T:* Nov. 2016, p. 11), but nothing like the downpour that should exist if the gas were left to cool on its own. Something is heating it.

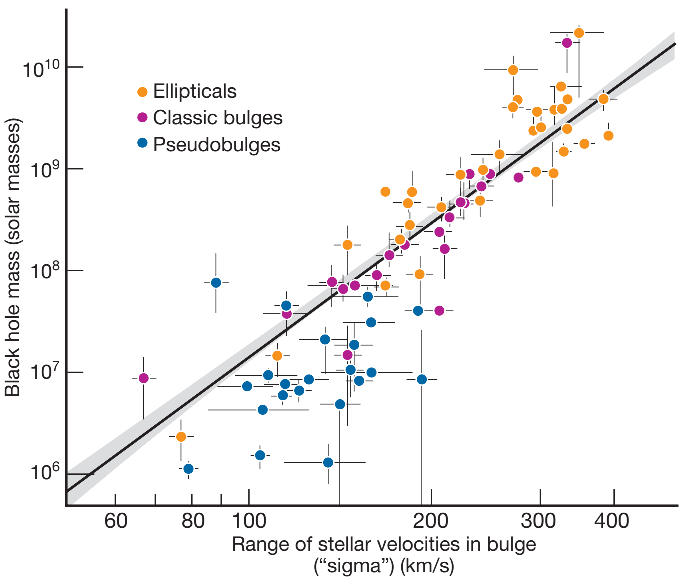
One solution is black hole feedback. Dribble some gas on the beast, and it'll rouse like an angry dragon, shooting jets and inflating gigantic bubbles as it powers an *active galactic nucleus*, or AGN. The rising bubbles drag surrounding gas with them, creating eddies and turbulence. These motions heat the gas, preventing star formation.

Observers see signs of jet activity in more than 70% of the galaxies in clusters' centers — generally the biggest, brightest galaxies with the most hot gas. Many have cavities in their X-ray-emitting gas, too. Black holes thus serve as "cosmic thermostats," as one 2014 review article put it, modulating gas temperatures and closely regulating starbirth and, therefore, galaxy growth.

"I don't think anyone disagrees with that," Kormendy says. "I would be very surprised if we were barking up the wrong tree."

Spurred on by its utility in heating gas, feedback became *the* thing in astronomy. Many suspected that the hole forced its host to adhere to its own growth rate as the beast haphazardly chomped on gas, explaining the trends. "At some black hole conferences you'll still see people show the M-sigma correlation and say, 'This is evidence for AGN feedback,'" says Chien Peng (Giant Magellan Telescope Organization) told me in 2012. "People often say that black holes have to grow by accretion and that feedback must happen. To that I usually respond by saying, 'All those things could happen but still have no bearing on a correlation.'"

▲ **BULGES** M87 *(above left)* is the classic example of a massive elliptical galaxy. Distinguishing between classical bulges like the one in M81 *(center)* and pseudobulges like that of M77 *(right)* is tougher — knowing the stars' orbital paths helps, because those in classical bulges are less orderly.



▲ **M-SIGMA** As astronomers gathered more observations, it became clear that the masses of all galaxies' black holes do not tightly trend with the galaxies' other properties. In their 2013 review John Kormendy and Luis Ho divvied up galaxies based on their shapes and concluded that, although elliptical galaxies and those with classical bulges still follow the trend (black line), galaxies with pseudobulges do not. Not all astronomers are convinced by this distinction, but this result helped astronomers recognize that all black holes and galaxies don't grow in lockstep. This figure only includes black holes for which astronomers have direct mass measurements, not indirect ones (see sidebar, p. 20).

That's because, although the black hole is no doubt partly responsible for heating galaxies' halos of gas, the thermostat effect would preserve a correlation that was already there — it wouldn't necessarily create it. And AGN feedback is too weak to control growth in most galaxies. There are plenty of active galaxies that don't follow the trends, Kormendy says, including the two spirals NGC 1068 and NGC 4151, whose black holes astronomers have studied for decades.

"It's still thought that the black hole has an influence on the galaxy, but it may not be as dominant as was thought," Gültekin sums up. Nowadays the question is what *kind* of feedback is important — maybe jets, or winds driven out by the accreting black hole's glow (called *quasar feedback*). Generally jets get the attention, says Gültekin.

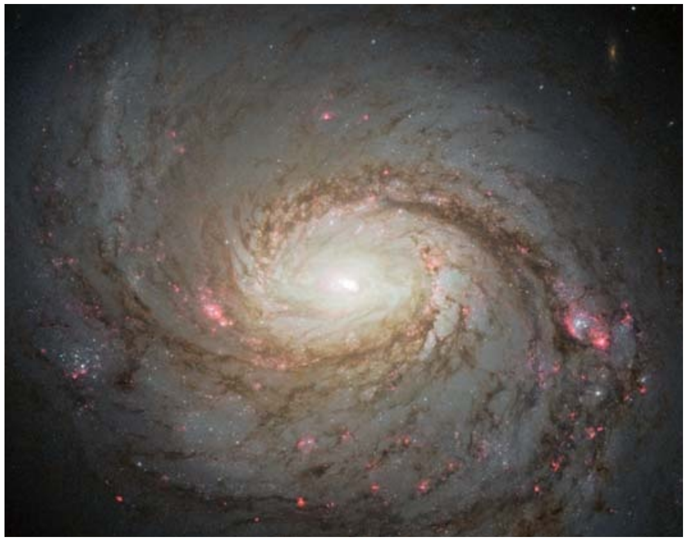
"I'm actually probably in the minority now in thinking that quasar feedback is still an important component," he says. "But there's been no vote on this, this is just my informally taking the temperature of the community."

Option B: Mergers

Peng was among the first to say that the apparent connection between galaxies and their black holes could simply be a matter of math. Take any two galaxies and merge them, then do it again and again and again, and the correlations will arise naturally, no feedback needed. It's an inevitable outcome of adding big numbers together.

But when Peng first suggested the idea, feedback was "a super-hot topic," he says. "You can imagine the excitement, and fear, I had to potentially start a controversy," he says,

M87: CHRIS MIHOS (CASE WESTERN RESERVE UNIV.), ESO; *S&T:* LEAH TISCIONE / SOURCE: J. KORMENDY AND L. HO / *ANNUAL REVIEW OF ASTROPHYSICS* 2013



M81: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA); M77: NASA / ESA / A. VAN DER HOEVEN

recalling when the scenario first popped into his head. “The merger idea was so exciting to me that I almost missed my flight to Germany that morning in 2007 from a lack of sleep.”

Kormendy also thinks mergers are the answer, but in a different way. He explains that the correlations don’t just appear in ellipticals: they’re also in spiral galaxies with *classical bulges*, which are essentially little ellipticals skirted by a big disk. Mergers with other galaxies made both these systems.

But the trends show up only weakly — if at all — in disk galaxies that have *pseudobulges*. Pseudobulges look similar to classical bulges but probably didn’t grown via galactic crashes. (The Milky Way has a pseudobulge.) Instead, astronomers think that these central spheroids arise thanks to internal dynamics that reorganize stuff in the galaxy. Pseudobulge stars tend to follow more orderly, disk-like orbits, ostensibly because they’ve developed slowly over several billion years as gas trickled to the galaxy’s core and fed star formation. In contrast, classical bulges would have grown suddenly, when a merger dumped a bunch of gas into the galaxy’s center and triggered a starburst, Kormendy says.

Given that the correlations are tighter in galaxies with violent histories, the mergers must somehow be connected, he argues.

“If you’re not making classical bulges, you’re not making the correlations,” he sums up. “You may be growing black holes, but you’re not making the correlations.”

Mergers in of themselves aren’t enough in this picture, though; the intermingling galaxies also have to be full of cold gas. Cold gas makes stars and feeds black holes, and without it, mergers can only preserve a galaxy–black hole trend that’s already there, not create one, he says. That could only happen in the early universe, 10 to 12 billion years ago. Back then galaxies were half gas, whereas nowadays a typical big galaxy has only 5 to 15% of its mass in cold gas, he explains. Observations confirm that mergers in today’s universe aren’t producing the correlations. “The magic that happened in the early universe that allowed this coevolution can’t now be recreated,” he says.

Despite Kormendy’s confidence, other astronomers doubt that a galaxy’s merger history explains everything. “Unfortunately in elliptical galaxies, *everything* is tightly correlated — the sizes, the masses, and the black hole,” Greene says. “But once you open up to the entire galaxy population — which we have very painstakingly done over the last decade — it gets much messier.”

At lower masses, the galactic population is dominated by spirals. These galaxies mostly have pseudobulges, not merger-made classical bulges, she explains. Although there are a few ellipticals at lower masses, she doesn’t think there are *enough* merger-created structures at all scales to prove that the trends’ driver is galactic history.

Option C: The Galaxy Reigns

If a galaxy were the size of Earth, its central black hole would be the size of a penny. Our planet certainly doesn’t notice its pennies. So perhaps galaxies don’t notice their black holes, either; the beasts just grow when their hosts deign to feed them.

Although cold gas feeds both starbirth and black holes, astronomers have found that, when a burst of star formation begins — say, due to a collision with another galaxy — AGN activity doesn’t blaze up for another 250 million years. That suggests the black hole has to wait for gas to make its way to the center.

Perhaps the delay is one the galaxy itself imposes. This time frame matches a stellar switch point, specifically the stage at which the most massive stars in the galaxy’s center have all died in supernovae. The remaining suns would be much smaller and evolve more slowly, with no violent outflows to stem the gas raining down into the core and onto the black hole. Thus, it could be that stellar feedback prevents the black hole from accreting, forcing the beast to grow when the galaxy does and thereby creating the M-sigma trend.

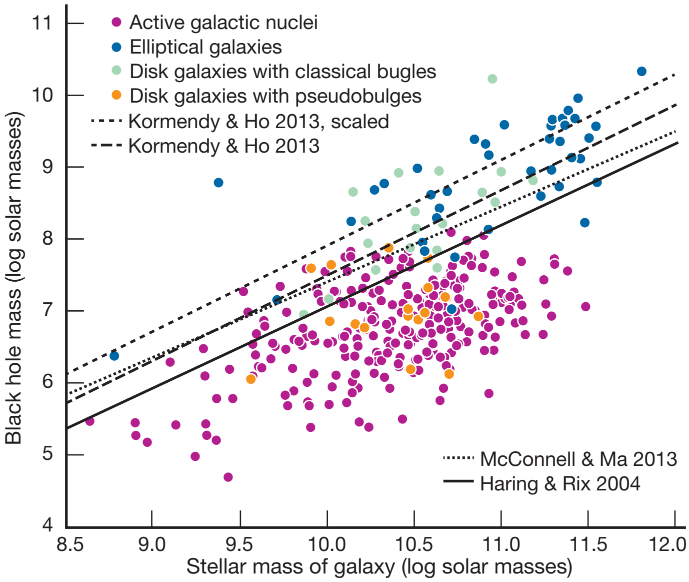
The details of this scenario are still unclear, and the stellar switch is just one option. But in big-picture terms, the black hole depending on the pleasure of the galaxy makes sense: the galaxy is *much* bigger than the black hole, and it serves as the fuel reservoir for both star and black hole growth.

That might explain why astronomers sometimes find weak echoes of a trend across other segments of the galactic population. Marta Volonteri (Paris Institute of Astrophysics) and Amy Reines (NOAO) recently looked at 341 nearby galaxies, 262 of which contained an actively accreting black hole. The

> “Even if there’s no real coevolution going on, it would be a little surprising if there wasn’t a crummy correlation.”

duo found that the black hole’s mass did increase with the galaxy’s total stellar mass. But for a given galactic weight, the accreting beasts were roughly one-tenth as massive as those that weren’t feasting on gas.

Volonteri and Reines couldn’t see the shape of the galaxies they studied, because the accreting black hole acts as a floodlight, blinding telescopes to the stellar metropolis that contains it. But today’s active galaxies are usually spirals, with small bulges and smaller black holes than ellipticals have. If these AGN are spirals, then the result hints that there is some sort of trend governing black hole masses in these galaxies.



▲ **GALAXIES AND THEIR BLACK HOLES** This graph shows the relationship between galaxies’ masses in stars and the masses of their central black holes. The straight lines are possible relations between black hole mass and the mass of the galaxy’s *bulge* (ellipticals are essentially all bulge). The active galactic nuclei (AGN) shown have had their masses measured in a more indirect way (so they’re more uncertain) and include many dwarf galaxies. For many AGN shown here, it’s unclear what shape the host galaxies have. But today’s AGN usually appear in spiral galaxies, so *if* most of these galaxies are spirals, then this graph confirms that spirals generally have less massive black holes than ellipticals do.

That makes sense, Kormendy says. “Even if there’s no real coevolution going on, it would be a little surprising if there wasn’t a crummy correlation between the gas reservoir and how much you could feed a black hole,” he says. “It would be completely unnatural if there weren’t.”

Perhaps all the correlations are crummy. All of the astronomers interviewed for this article noted that, because feedback and lockstep evolution were such popular ideas, they’re now entrenched far more deeply than the data justify. “I tend to be a little more cynical,” Greene says. “I was a kid when the M-sigma relation got everyone excited,” so she doesn’t have a lifetime of work riding on its defense.

Volonteri also doesn’t believe in lockstep growth. “I strongly believe that there is a coevolution, but the way I mean coevolution is very different,” she says. “To me, coevolution means simply big black holes, big galaxies; small black holes, small galaxies.”

Both galaxy and black hole depend on something much bigger, though: the cosmic gas supply. Recent simulations by Tiziana Di Matteo (Carnegie Mellon University) and others follow the growth of galaxies and their black holes across the early eons of cosmic time. The researchers found that the biggest black holes tend to grow in spheroidal galaxies, not those dominated by disks — which matches what astronomers see observationally. But, Di Matteo’s team explains, this is because such galaxies form at the nodes of several filaments in the cosmic web, where cold gas pours straight in instead of coming in at an angle, as it does for disk galaxies. That could explain why a galaxy’s shape is connected to its black hole’s mass. The simulations also suggest that whether a galaxy is a ball or a disk depends on where it’s born and how the cosmic web feeds it, not on whether it merges with something else.

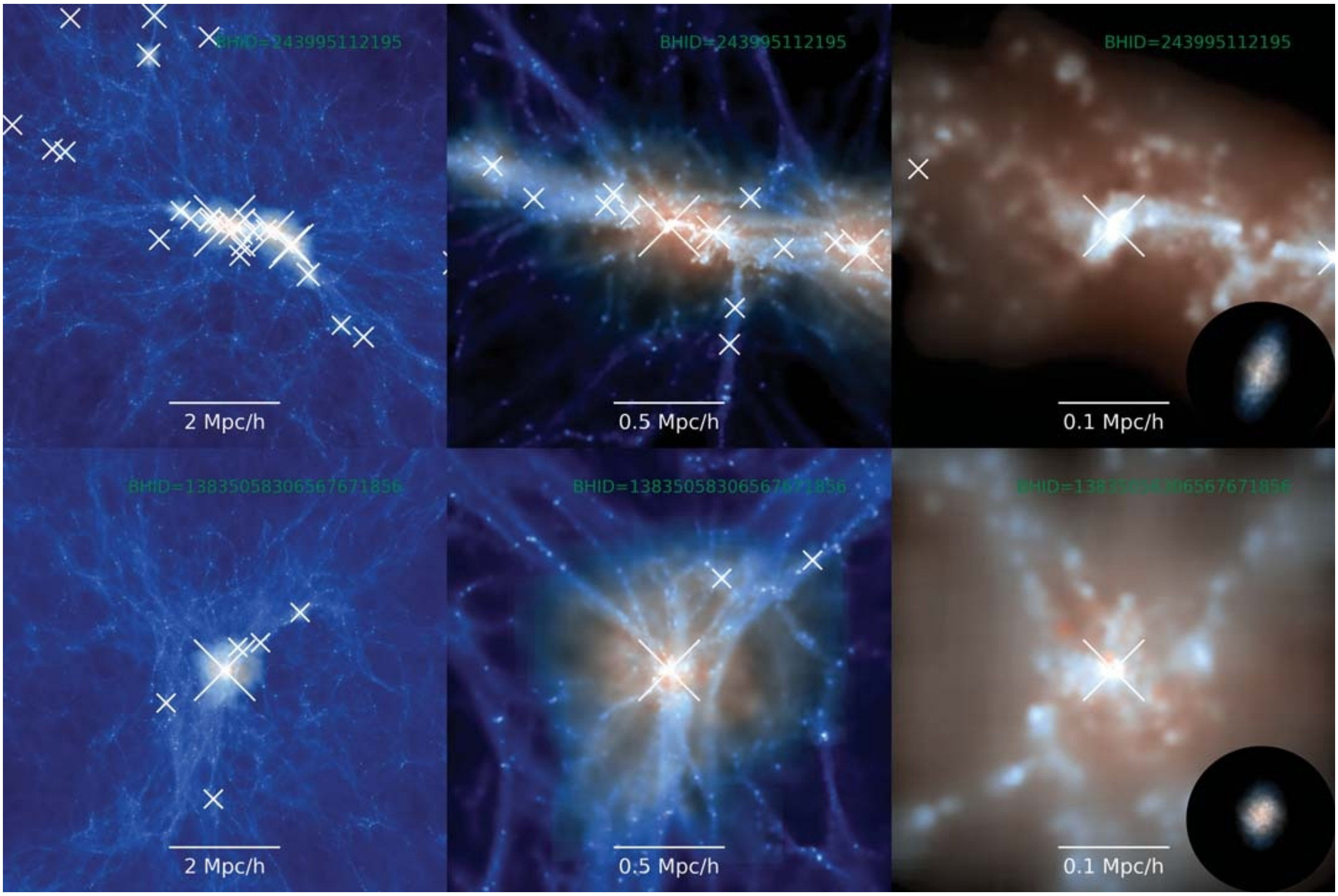
Finding the Culprit

Astronomers do not agree on which of these scenarios is true. They might all be, to some extent. Part of the problem is that we don’t know when the correlations arose or what they looked like early on. Studying galaxies from the universe’s first couple billion years requires valiant struggle. The systems are far away, so they’re small and faint, plus cosmic expansion shifts their light to longer wavelengths, making them harder to study. Not to mention the universe was smaller and more crowded, and things were rowdy; a big galaxy back then was much smaller — or in pieces — compared with now, with gas pouring in from the cosmic web to boot. “Life back then was really seriously messy,” Kormendy says.

Astronomers see hints that the M-sigma relation is looser in the early universe, with bigger black holes for a given range of star speeds. But they’re wary of trusting that impression. The AGN detectable in that cosmic era are the brightest ones, and they might be the basketball players of the population, far larger than the norm, Volonteri cautions.

Kormendy agrees. “I wouldn’t want to stick my neck out terribly far on our understanding” of what was happening 11 or 12 billion years ago, he admits.

S&T: LEAH TISCIONE, CHART SOURCE: A. REINES & M. VOLONTERI / *ASTROPHYSICAL JOURNAL* 2015 (813:2:82)



▲ **COSMIC WEB** These snapshots from the BlueTides simulation show the gas environments of the most massive disk galaxy that formed in the simulation (top row) compared with the most massive black hole and host galaxy. These stills are from about 650 million years after the Big Bang; the rightmost, circular inset in each row is a zoom in on the host galaxy. Hotter gas appears redder. Large crosses mark the positions of black holes, and their sizes are proportional to each hole's mass. Although massive disk galaxies did grow big black holes in the simulation, they generally didn't contain the most massive ones. The simulation also confirms that spheroidal (elliptical) galaxies grow at the crossroads of many filaments in the cosmic web, whereas disk galaxies form along more isolated filaments. The results suggest that a galaxy's shape depends on where it forms in the cosmic web, not on whether it merges with another galaxy.

Dwarf galaxies may help. Greene and others have been tracking down the black holes at the centers of these galactic runts because dwarfs are the primordial crumbs of galaxy formation, left more or less unscathed since they first formed. "There's something interesting to learn by looking specifically at galaxies that don't really have mergers and didn't really undergo that kind of growth," she says. If they and their black holes follow any trends today, it will be because they were born with them.

Gültekin agrees that galaxies shirking M-sigma, whether barely or flagrantly, are an important place to look. "Things that don't follow the relation are important clues for telling us what's not important for driving the relationship," he says.

His team is investigating gas outflows from a range of galaxies. If researchers can pin down how fast this material moves, then they can determine how much energy must be launching the flows and whether the black hole is to blame.

What astronomers really need is a census, Greene says. What is the full distribution of black hole masses across the entire galaxy population? ALMA and the next-gen superscopes should enable observers to peer out to 60 or 70 million light-years, detecting all types of galaxies and measuring black holes down to a million solar masses, the same size as the Milky Way's (relatively puny) supermassive beast, she predicts.

"Then we'll be able to see the full range of black hole masses," she says. "We'll be able to slice and dice the sample into things that are round and things that are flatter and things that evolved slowly and things that are more like bulges and ask whether they're different."

At that point, astronomers will finally discover just what the connection between black holes and galaxies is. Maybe they'll exonerate the poor little beasts of cosmic guilt. Or maybe the objects will prove just as ruthless as the sci-fi stories claim.

■ Every time she writes a story about these spacetime potholes, Science Editor **CAMILLE M. CARLISLE** resists the urge to cry out, "BWAHAHAHA BLACK HOLES!"

FAST RADIO TELESCOPE by Renjiang Xie

Mega-Eye on the Sky

CHINESE ACADEMY OF SCIENCES

Completed last September, China's FAST has eclipsed Arecibo as the largest single-dish radio telescope in the world.

In 1986 Chinese archaeologists unearthed remnants of Sanxingdui, a mysterious and ancient city of the Shu kingdom located 1,700 kilometers southwest of Beijing. Among the Bronze Age relics was a bronze mask with protruding, cylinder-shaped eyes and ears spread like wings. It's believed to be a likeness of Cancong, the legendary first king of Shu, who possessed uncanny sight and hearing.

Three decades later, in September 2016, the descendants of this ancient Chinese culture achieved those superpowered senses — thanks to an amazing, gigantic machine nestled in a basin about 800 km southeast of the Sanxingdui site. There, amid a dramatic, rugged landscape, engineers and scientists have built the Five-hundred-meter Aperture Spherical Radio Telescope, FAST for short, which now ranks as the world's largest single-dish radio telescope.

It took 5½ years, beginning in March 2011, to construct this behemoth, but its origins date back to 1993. That's when astronomers attending the General Assembly of the International Union of Radio Science proposed a next-generation radio telescope with unprecedented collecting area. Originally called the Large Telescope, the concept morphed into the Square Kilometer Array (SKA).

Over time, the SKA concept transitioned away from a few, very large dishes to thousands of smaller antennas to be built in Australia and South Africa instead. But by then astronomers led by Rendong Nan had already extensively surveyed the Chinese countryside in search of an ideal site for a large, spherical dish — much like the one near Arecibo, Puerto Rico, but much bigger.

Nan and his team had sifted through some 400 candidate sites, most of them in deep depressions amid the limestone hills of remote Guizhou and Yunnan provinces in southern China. There, the terrain (called karst topography by geologists) includes many large, bowl-shaped sinkholes — a natural foundation for building

◄ **ALIEN PRESENCE** Completed last September after 5½ years of construction, the immense FAST radio telescope — 500 m (1,640 feet) across — is nestled amid the verdant, rugged hills and depressions of Guizhou Province in southern China.

► **"FATHER OF FAST"** Part engineer and part astronomer, Rendong Nan led the project's development from its inception.

FAST PROJECT

a large, single radio antenna at a comparative low construction cost. In addition, the surrounding peaks and sparse local population would minimize electromagnetic interference.

With dreams of hosting the SKA dashed, Nan championed the idea of going forward with an enormous dish anyway. The site would be a nearly perfect depression about 170 km southeast of Guiyang, the provincial capital of Guizhou, and known locally as Dawodang (meaning "grand puddle").

Meanwhile, engineers carried out studies on the critical technologies that would be needed, including a deformable reflecting surface, systems for precisely measuring and controlling its shape, a lightweight housing and cable-driven transport system for the instrument's receivers (to be suspended over the dish), and the receivers themselves.

Thanks in part to China's booming economy, government officials finally gave the green light to the FAST project in July 2007, providing 1.2 billion renminbi (about $180 million) for the giant receiver's construction.

Building FAST

Dawodang wasn't completely uninhabited, and in October 2009 the 65 villagers living there were moved into new apartments in the nearby town of Kedu. Then, to create a radio-quiet zone, an additional 9,110 residents living within 5 km of the telescope site were resettled to two contiguous towns.

China Railway Construction Corporations Limited coordinated the construction effort, a mammoth task made more difficult because the primitive roads near the site were too narrow for large equipment and vehicles. So the first task was building a 7-km-long access road. Then the Dawodang

▲ **JIGSAW PUZZLE** On July 3, 2016, workers installed the last of 4,450 triangular panels that form the telescope's reflective surface.

▲ **REMOTE AND QUIET** FAST was built in a sparsely inhabited section of south-central China — a location with little radio interference from terrestrial sources.

sinkhole had to be reshaped to provide a solid base, and this meant digging out more than 900,000 cubic meters of dirt and stone. Also, to protect the antenna from flooding, crews carved out a 1.1-km-long drainage tunnel.

The real construction started in November 2012. A ring of 50 support columns appeared first, and then those were topped by an annulus of steel girders. Next came the installation of 8,895 thick steel cables, suspended over the giant, circular hole to form a sphere-shaped "net"; adding thousands of tie-down cables anchored into the ground; and, finally, attaching the telescope's shiny "skin."

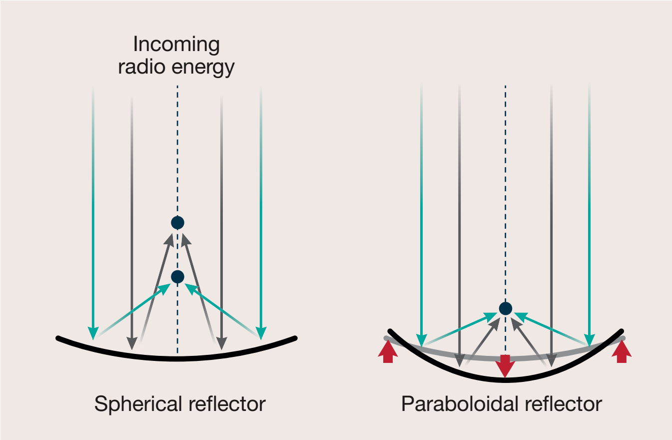
FAST's big dish consists of 4,450 triangular panels, each 11 m on a side. It has a total mass of more than 2,000 tons and a combined reflecting area roughly equal to 30 soccer fields! The deep, spherical bowl has a 300-m radius of curvature.

A unique — and unprecedented — aspect of the FAST design is that a portion of its surface can be reshaped in real time into a paraboloid, which concentrates all the incoming radio energy from that area at a single focus. As the diagram at upper right shows, a spherical surface can't do that. At Arecibo, which has a spherical reflecting surface, the focus is strung out along a line.

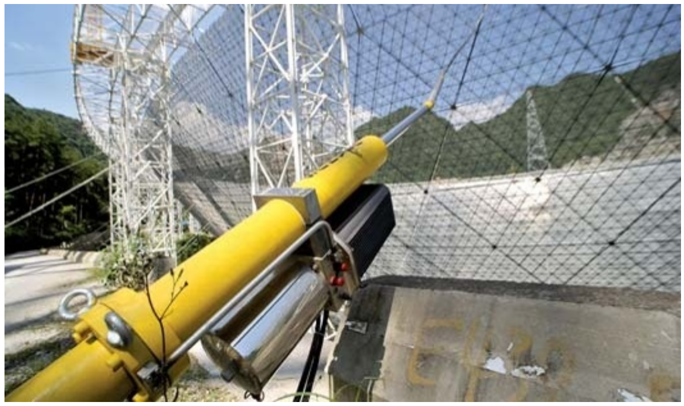
Computers will change FAST's shape using 2,226 mechanical actuators. Anchored to the ground at one end, each actuator is connected by a cable to a node where the corners of six panels meet. These devices can shorten their respective cables by about 47 cm (18½ inches) and can be manipulated independently. Working together, they can alter any portion of the surface to form a real-time paraboloidal reflector with an effective diameter of 300 m. Di Li, one of FAST's project scientists, refers to this arrangement as "a bowl within a wok."

In order to concentrate a signal reflecting from such a large area into a table-sized focal plane, all the panels had to be manufactured very precisely. Also, the shape of the

BOTTOM: CHINESE ACADEMY OF SCIENCES / CHAO ZHANG; MAP: *SKY & TELESCOPE* / LEAH TISCIONE



▲ **SHAPE SHIFTING** A spherical reflecting surface, like that used at Arecibo Observatory, can't bring all incoming radio energy to a single focus. However, a portion of FAST's spherical surface can be deformed (red arrows), effectively making a paraboloidal sub-reflector that's 300 m (1,000 feet) across.



▶ **PULLING TOGETHER** The shape of FAST's reflective surface can be modified by more than 2,200 mechanical actuators that are anchored to the ground and connected by cables to the dish.

overall surface must be controlled to within 3 mm. In fact, each panel has a curved surface that conforms closely to the paraboloid's shape. This actuator-controlled design allows the surface to be reshaped continuously, so it can track specific celestial targets for several hours as they cross the sky or shift from one aim point to another.

However, such a shape-changing operation creates up to 500 megapascals of stress in the underlying network of steel cables, and the plan is to do so often during observations. So the engineering team had to install specially built cables, developed in China, that can survive this much stress for 2 million fatigue cycles — ensuring reliability of the reflecting surface for the facility's planned 30-year lifetime.

The Receiving End

All of the radio energy collected during an observation is directed to a feed cabin that is 13 m long and weighs only 30 tons. (By contrast, Arecibo's very large receiver platform has a total mass of 900 tons.)

Designing an overhead feed cabin that can be supported and positioned precisely via cables became a real challenge. The team built quite a few scale models and carried out many simulations to verify the feasibility of the concept.

The chosen cabin-suspension system connects three opposed pairs of cables to six towers around the circumference that average more than 100 m tall. Instead of moving the receivers along a fixed track on the central platform, the cable lengths are adjusted at the towers to position the entire feed cabin to within 100 mm in a 206-m-wide "focal plane." The cables also adjust the cabin's tilt so that it closely parallels the curved reflector surface below.

After this rough positioning, robotic motors within the

▼ **MAJOR UNDERTAKING** The FAST effort transformed a large, natural depression known locally as Dawodang ("grand puddle") from a tiny hamlet with 65 villagers to the world's largest single-dish radio telescope. Before construction could really begin, crews first removed nearly a cubic kilometer of rock.

BOTTOM: FAST PROJECT; CHINESE ACADEMY OF SCIENCES / LING XIN; TOP RIGHT: CHINESE ACADEMY OF SCIENCES / LING XIN & CHAO ZHANG; DIAGRAM: *SKY & TELESCOPE* / LEAH TISCIONE

▲ **HIGH-WIRE ACT** This enclosure, suspended 138 m (453 feet) above the dish, contains an assortment of receivers. The attached cables can position it in the telescope's focal plane to within 100 mm (4 inches).

feed cabin point and orient the receivers with six degrees of freedom. The power and signal cables that are attached to the cabin hang in loops from the main suspension cables like a movable curtain. These were designed to survive 100,000 curving fatigue cycles — 100 times the Chinese military's endurance standard for cables.

Feed-cabin positioning depends on rapid, highly accurate measurement and control of the cabin's position and orientation. To accomplish this, engineers built 25 benchmark piers inside the main reflector, and the tops of 2,226 prisms poke up from the panels' nodes. Additional prisms are arrayed on the feed cabin. Lasers shoot beams of light to both sets of prisms, which provides a feedback loop for positioning the feed cabin and adjusting the reflecting surface's deformation. Thanks to this complex control system, a particular receiver can be positioned to an accuracy of a few millimeters. Moreover, observers will spend less than 10 minutes changing from one observing target to another.

The feed cabin itself houses seven low-noise receivers that cover frequencies from 70 megahertz (MHz) to 1.8 gigahertz (GHz), corresponding to wavelengths from 4.3 m to 17 cm. Chinese scientists developed five of these, and teams from the National Astronomical Observatories of China and Caltech together built a broad-spectrum L-band receiver. But the core instrument will be a narrowband receiver designed and built by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). It can accept beams of radio energy from 19 individual targets over a frequency range of 1.23 to 1.53 GHz.

Given FAST's extremely high sensitivity, project managers have gone to great lengths to minimize any electromagnetic interference. Naturally, this compatibility applies to all of the facility's electronics, though the greatest source of radio noise seems to come from the actuator motors. Also, the FAST team has convinced the local authorities to enact a law establishing an electromagnetic "quiet zone" in the surrounding area. This has prevented potential radio noise from a planned local airport and a motorway.

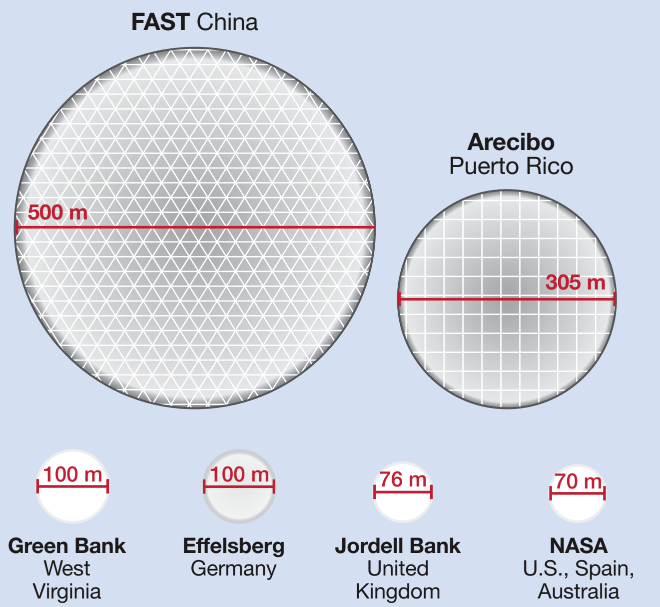
In order to prop up the local economy in return, you can now visit an international radio-science "theme park" near the telescope, which has already attracted a flood of tourists from around the country. (Of course, electronic devices are prohibited, and the park limits the number of visitors.)

What Will FAST Do?

The project's scientists started early tests with their gigantic new receiver in January 2016, though its "first light" occurred last September 16th when they observed the quasar 3C 409.

Mega-Matchup: FAST vs. Arecibo

	FAST	Arecibo
Completion	2016	1963 (1974*, 1997*)
Full aperture	500 m	305 m
Surface area	203,000 m^2	73,000 m^2
Effective aperture	300 m	225 m
Sky coverage	Zenith ± 40°	Zenith ± 20°
Tracking (hours)	4 – 6	2.6
Frequency range	70 MHz – 1.8 GHz	327 MHz – 8.5 GHz
Radar system	—	1 megawatt



BRAGGING RIGHTS FAST has more than 2½ times the surface area of Arecibo's 305-m (1,000-foot) dish, and its effective aperture is nearly twice as great. These cyclopean structures dwarf the largest fully steerable radio dishes. (*Major upgrade to Arecibo completed.)

BOTTOM: *SKY & TELESCOPE* / LEAH TISCIONE; TOP: HONG SU

Other Projects in China's Future

China's professional astronomical community is growing rapidly, and its researchers are planning several major new facilities both on the ground and in space.

Hard X-ray Modulation Telescope (HXMT) will be China's first orbiting X-ray observatory. Proposed by Li Tipei and Wu Mei of the Chinese Academy of Sciences' Institute of High Energy Physics in 1993 and officially approved in 2011, HXMT will: (1) scan the galactic plane to find new transient sources and to monitor known ones, and (2) observe X-ray binaries to study the dynamics and emission mechanisms in strong gravitational or magnetic fields. HXMT carries low-, medium-, and high-energy X-ray telescopes that cover energies from 1 to 250 keV. The spacecraft is complete and ready for launch.

Large Optical-infrared Telescope (LOT), with an aperture of 12 m, would serve as a general-purpose telescope most likely located at a high-altitude site in Tibet's Ali Prefecture. The government has given this project preliminary approval, and construction could begin as soon as 2019. In that case LOT would briefly rank (until the era of 30-m facilities begins) as the world's largest optical telescope.

Thirty Meter Telescope (TMT), an ambitious, international joint project involving six countries and institutions, will become the most advanced and powerful optical telescope on Earth. The National Astronomical Observatories of China (NAOC) is funding 10% of the project, including "in-kind" contributions. For example, NAOC has participated in designing TMT's primary (M1) and tertiary (M3) mirrors, laser guide-star facility, and first-generation scientific instruments.

110-m Qitai Radio Telescope will have a fully steerable receiver located near Qitai in the Xinjiang Uyghur Autonomous Region (200 km northeast of Urumqi). Developed by the Chinese Academy of Sciences' Xinjiang Astronomical Observatory, this dish will have a deformable surface and cover the frequency range from 150 MHz to 115 GHz. Construction has not yet begun; however, once finished, it will be the largest fully steerable radio telescope in the world.

A day later they targeted a pulsar near zenith, J1921+2153, and it took just 1 minute to achieve a signal-to-noise ratio of more than 5,000!

For now, observers using FAST will have to settle for such short integration times, because two significant actuator problems have prevented any real-time tracking. First, the optical fibers that interconnect the actuators are behaving unpredictably, raising the possibility that errant commands received while adjusting the dish's surface might actually lead to damage. Second, the actuators themselves are wearing out much faster than expected, and they will likely all be replaced.

Until these problems are fixed, FAST's observations will be restricted and no real-time tracking will be attempted. Instead, plans call for deforming the dish so that it points toward one spot for an entire day, allowing radio sources to glide across the 2-arcminute-wide field of view. Then the declination will be adjusted slightly to sweep through a new strip of sky.

It will take roughly seven months of this shift-and-stare mode for the CSIRO multi-beam receiver to cover all of the sky that FAST can observe — everything that passes within 40° of zenith. But the effort should yield as many as 1,000 new pulsar discoveries, all detected at the atomic-hydrogen emission at 1.4 GHz (21 cm in wavelength).

Once all the equipment tune-ups and fixes are finished, FAST should start producing amazing results. It has nearly twice the collecting area of Arecibo's dish — which, although 305 m (1,000 feet) across, has an effective aperture of only 225 m for astronomical observations. FAST's areal advantage, combined with its paraboloidal focus, should permit the new telescope to probe the radio universe three times deeper, complete surveys 10 times faster, and cover four times more sky than Arecibo can.

(It must be noted that, although Arecibo now ranks second in aperture, it can conduct radar observations of solar-system targets — a capability that FAST will never have.)

Chinese astronomers expect to use FAST to discover thousands of new pulsars within our galaxy and to search for the first extragalactic pulsars beyond the Magellanic Clouds. They'll also map the interstellar medium's abundances of hydrogen and carbon monoxide (CO) at high resolution, hunt for previously unseen clouds of neutral hydrogen, and detect hydrogen's 21-cm emission from hundreds of thousands of galaxies up to 6 billion light-years away.

Also on FAST's "to do" list is searching for radio emissions from exoplanets and whatever alien civilizations might be broadcasting from them. It will participate in international very-long-baseline interferometry (VLBI) experiments and might someday assist in tracking ambitious deep-space explorations by future Chinese spacecraft.

Here in China people refer to FAST as Tianyan, meaning "heaven's eye." It is still too early to estimate how this giant new facility will influence radio astronomy. But as scientists gradually become more familiar with FAST's capabilities, important new discoveries will undoubtedly follow.

RENJIANG XIE is a science writer focusing on developments in Chinese astronomy. He's president of Dalian Boötes Astronomical Society and runs China's largest astronomy website. Reach him at **facebook.com/renjiangxie**.

 by Richard S. Wright, Jr.

Imaging Adventure: Dry Tortugas

Shoot from the darkest skies in the southeast.

▲ **SHOOTING FROM THE GULF** The Dry Tortugas is a small group of islands in the Gulf of Mexico dominated by the large brick structure of Fort Jefferson on Garden Key. Up to 10 people can camp on the island for three days, providing a great opportunity for some serious imaging and observing. All photos were provided by the author.

Many of my peers have remote observatories and boast about imaging from the comfort of their couch using a laptop to control their equipment in another state. Not me — I'm strictly a hands-on imager. Perhaps it's my childhood love of the outdoors, but when I image, I want to go someplace and *earn* the data. I must go there to hunt my prey!

So it was on a trip to the Winter Star Party in the Florida Keys that I learned about Dry Tortugas National Park, which is about as far from civilization as you can get in the southeastern United States. A Google search turned up a handful of nightscape images taken from the islands' dark skies, which made me determined to try my hand at imaging from this remote destination.

Located 70 miles west of Key West, the Dry Tortugas are accessible only by seaplane or boat (**drytortugasinfo.com**), though overnight visitors are restricted to traveling via the ferry from Key West. Here you'll find a lighthouse and Fort Jefferson, which was built in the mid-1800s to guard the trade route in and out of the Gulf of Mexico. For a time the fort was used as a prison, and even held several convicts from the conspiracy to assassinate President Abraham Lincoln. Today it's a haven for birds and sea turtles and is surrounded by some of the best-preserved coral reefs in the gulf. There is a small campground where you can spend up to three nights.

What you won't find here is electricity, cell phone service, or freshwater, much less a Starbucks. Wonderfully absent as well is any kind of skyglow. These are, quite simply, the darkest skies I've ever seen, anywhere.

If 70 miles from Key West doesn't sound that far offshore, consider that the park is nearly 200 miles from the light pollution of Miami, and that Key West isn't exactly a huge metropolis. These are primordial dark skies. Imagers hoping to shoot overnight from the island need to make camping reservations months in advance and travel on the Yankee Freedom ferry from Key West (**drytortugas.com**).

When camping at Dry Tortugas, you must bring everything you need with you, including food and water. There's a weight limit of 60 to 70 pounds of gear per person, though your food and water are exempted. The weight limit and lack of power make sophisticated deep-sky astrophotography impractical — or so I thought.

▲ **REMOTE LOCATION** Dry Tortugas is a small group of islands in the Gulf of Mexico located about 70 miles west of Key West. The site is far from any significant sources of light pollution.

Testing the Waters

My first trip to Dry Tortugas was a two-night family camping excursion with mostly cloudy weather. I had brought along two DSLRs, a few lenses, and a Sky-Watcher Star Adventurer tracking mount. The first night was overcast, but on the second day the skies cleared and I had about an hour and a half of darkness after sunset before the clouds returned.

I cannot overstate how dark the skies are here. When clouds pass through, they appear as inky black silhouettes against the starlit sky. There are some nuisance lights, such as the occasional fishing boats, as well as the lighthouse. This means if you're observing, you'll have to be careful in order to preserve your dark adaptation. The net effect of these few lights on the night sky, however, is nil.

As darkness fell, I began to set up in a picnic area away from the campsites. My family joined me for some stargazing and laid themselves out on the picnic tables to watch the stars come out. According to my daughter, this trip was "legit." Score one for being a cool dad.

Soon after dark some clouds began rolling in, but I made the most of every minute. I did some Milky Way shots and also tried some panoramic nightscape images that included Fort Jefferson, the dominant structure on Garden Key.

I came away from that first trip with one nightscape and a couple of Milky Way images featuring family members — not a bad haul for less than two hours of darkness. The next day, while waiting for the ferry to depart, I spoke with the park rangers. "January is pretty much cloud-free," one of them told me, "albeit a bit windy." At that very moment I was sold on a full-blown astrophotography excursion.

Challenge Accepted

On January 2nd, 2015, we were in Key West bright and early for a 6:30 a.m. loading of the ferry. This time we booked

LIMITED ACCESS Campers and most day-trippers take the Yankee Freedom ferry from Key West to the island.

MAP: *S&T* / LEAH TISCIONE

three nights of camping. Every detail of the trip had to be planned carefully. Besides the food, water, and camping gear, we had to be creative with how we packed for my three nights of imaging. Seventy pounds doesn't sound like much weight, and throw in a lot of photography equipment and it can add up quickly!

For this second trip, my youngest son came along, so together we were permitted a generous 280 pounds of gear between the four of us. We also were allowed carry-on items that aren't included in the limit, so we loaded up on whatever we could carry, just like most people do when flying. I strapped my big Canon 5D Mark III DSLR and lens around my neck, loaded the telescope in a hand carrier, and even put a 10-pound counterweight in my backpack.

My primary goal this time was deep-sky astrophotography with a small telescope under these remote dark skies. I brought along my Software Bisque Paramount MyT robotic mount, a Sky-Watcher Esprit 80-mm ED refractor, and a Starlight Xpress Trius SX694C cooled CCD camera. Getting this to, and using it from, what was essentially a desert island was quite a trick. The mount itself weighs 35 pounds, and the tripod is another 20. Throw in two lithium batteries, counterweights, and a telescope, and I'd already soared way past my 70-pound limit. Success depended on asking my family to sacrifice some of their weight allotment.

I opted for the small 80-mm refractor because it would present less of a problem under the predicted windy conditions and would be lightweight and easier to hand-carry. Its short 400-mm focal length is quite forgiving of bad seeing as well. The one-shot color camera I settled on was chosen specifically to eliminate the extra weight and power draw of a color filter wheel. Combined with its low-noise Sony detector, modest power requirements, and the scope's reasonably fast f/5 focal ratio, I figured this "bare-bones" setup should do well for me if I took relatively short exposures under exceptionally dark skies.

To power the mount, I brought an EGO 56-volt 7.5-amp-hour battery that ideally would last two full nights. I also had a custom battery box with a LiFePO4 25-amp-hour lithium battery I'd made that would power the CCD camera for two nights. This battery technology is expensive but extremely lightweight. I also knew that if it was going to be windy, dew was not going to be an issue, so I could forgo any dew heaters.

Surprisingly, the largest power drain for most portable imaging setups used to be the laptop computer needed to control the mount and camera. These days, there are computers the size of a deck of cards that can run Windows or some variant of Linux, which draw very little power. While most people overestimate how much computer horsepower they need for imaging in the field, these tiny computers are more than up to the task.

I chose the Raspberry Pi2 kit for this purpose and installed Software Bisque's *TheSkyX* imaging suite on the Raspberry Pi2 myself. All that is required to run it is a remote desktop server on the device and a corresponding remote desktop client on my tablet computer. I simply had to connect to the system over its built-in Wi-Fi and use it just like a laptop, except I could then disconnect the tablet and put it to sleep after starting my imaging run, and the system would keep on chugging along taking pictures.

◀◀ **SIMPLE SETUP** On his first trip to the island, the author used a Sky-Watcher Star Adventurer tracking mount and Canon EOS 5D Mark III DSLR with a wide-angle lens to record constellations and a few nightscapes over Fort Jefferson.

◀ **DEEP, DARK SKY** The island's small stand of mangrove trees doesn't interfere with the views of the Milky Way. This image featuring the author's children was captured with the setup seen at left using a 50-mm lens and a 60-second exposure at ISO 800.

◀ **SUCCESSFUL SHOOTING** The exceedingly dark skies in the Gulf of Mexico, combined with fast optics and a sensitive camera, permitted deep images like this shot of NGC 2264, the Cone Nebula, with relatively short exposures totalling one hour.

▲ **READY FOR ACTION** The author's astrophotography setup for his second Dry Tortugas excursion — including a Software Bisque MyT German Equatorial mount, Sky-Watcher Esprit 80 ED refractor, and a Starlight Xpress Trius SX694C cooled CCD camera — stands near the fort. Note the two power supplies at the base of the tripod.

Hunting Prey

The camping area on the island is south of the fort and surrounded by trees, so it isn't an ideal location for astrophotography. I chose to set up on one of the sites along the east edge of this small grove of trees, providing a large swath of sky near the campsite. The adjacent overflow camping area is treeless and located right in front of the fort — another ideal location to shoot for the night.

Thanks to El Niño, a stream of moisture stretching from the Pacific Ocean all the way across the Gulf of Mexico and Florida fell right across us. The first night we had a vicious storm with heavy rain and high winds. Glad we packed with rain in mind! The second night was much better and provided a few hours of imaging between scattered clouds.

Hunting is an apt metaphor for my imaging routine at Dry Tortugas, as slow-moving clouds came through regularly. I quickly settled into a pattern of shooting one target for half an hour or so, and then switching to another part of the sky as the clouds threatened to block my prey. Between these there was some haze, so some of my images have a characteristic halo around the brighter stars. Despite the conditions, I still came away with quite a few images.

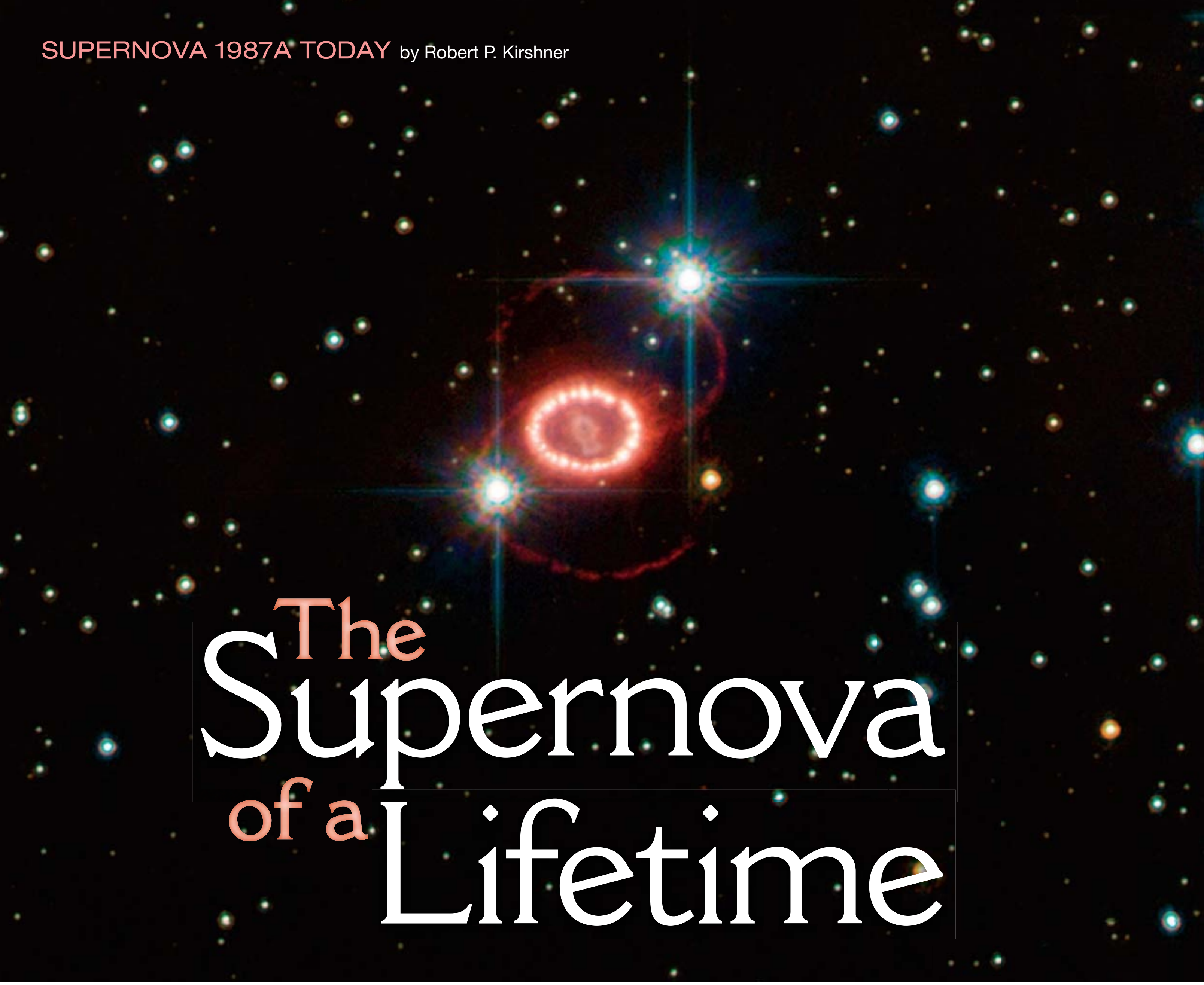
A trip to the Dry Tortugas is truly an astrophotography adventure that has plenty to offer for non-astronomers as well. Your family can snorkel, kayak (bring your own), or explore a historic fort, and the islands are a birding paradise. At night there are abundant opportunities for creative nightscape compositions. And with careful planning, deep-sky imaging is also possible.

Given this, will I return? You'd better believe it!

■ **RICHARD S. WRIGHT, JR.** dedicates this article to the memory of his youngest son, Alex, who died shortly after their trip to Dry Tortugas National Park.

 by Robert P. Kirshner

The Supernova of a Lifetime



Thirty years later, Supernova 1987A continues to develop and surprise.

▲ **THREE-RING CIRCUS** This Hubble image of the Supernova 1987A remnant and rings, taken in October 2011, is one of the best made. The central ring has been entirely lit up by the impact of the fastest-expanding debris. The bulk of the debris, expanding more slowly, forms the misshapen nebula inside the ring. The bright inner ring is 1.6 arcseconds in diameter, or 1.3 light-years at the supernova's distance.

ESA-HUBBLE / NASA

On the morning of February 23, 1987, the phone on my desk at the Harvard-Smithsonian Center for Astrophysics started ringing. Word was filtering in of the brightest supernova since Kepler's in 1604. I thought it might be a practical joke; my friends had fooled me before. In that pre-internet era the teletype was the gold standard of instant communication, so I hustled down the hall to the quaintly named Central Bureau for Astronomical Telegrams in Brian Marsden's office.

Brian was on his phone, and the teletype next to his desk was clunking away with reports from Chile, New Zealand, and around the world. A bright new star had erupted in the Large Magellanic Cloud, the largest satellite galaxy of the Milky Way, 165,000 light-years distant. Three months later I saw the supernova in person as it peaked at magnitude 2.9. It was the most distant naked-eye star in recorded history.

Technology has changed our lives since 1987, but it has changed astronomy more. The instruments we used in those first heady days were primitive compared to the ones we use now. And a good thing, too: today SN 1987A is ten million times fainter than at its peak, but better tools let us study it across the electromagnetic spectrum. For example, in 1987 the space telescope available to our team was the International Ultraviolet Explorer, with an aperture of 45 centimeters (18 inches). I had been using IUE to study extragalactic supernovae and had mentioned in passing that we would also like to observe any supernova that might appear in the Local Group of galaxies. The Large Magellanic Cloud certainly qualified, and in a phone call that morning, Yoji Kondo at the IUE proudly told me that observations had already begun.

Since the Hubble Space Telescope was launched, we've been able to use its 2.4-meter aperture with a succession of ever more powerful visible-light, infrared, and ultraviolet instruments installed by Space Shuttle astronauts. At radio wavelengths, the Australian Compact Telescope Array (ACTA) has tracked the rising radio emission from SN 1987A. The new ALMA observatory is creating millimeter-wave images of it that are as sharp as our HST images, to tease apart the ongoing chemistry and physics of the explosion. Far-infrared observations from the Spitzer and Herschel missions have probed the cold dust that formed from the expanding debris. X-ray observatories, such as the durable Chandra and the recent NUSTAR, measure emission from million-degree gas where the debris is currently colliding with surrounding clouds. These tools give us a rich view, as the supernova of 30 years ago morphs into the supernova remnant of the future.

The Cry of a Collapsing Star

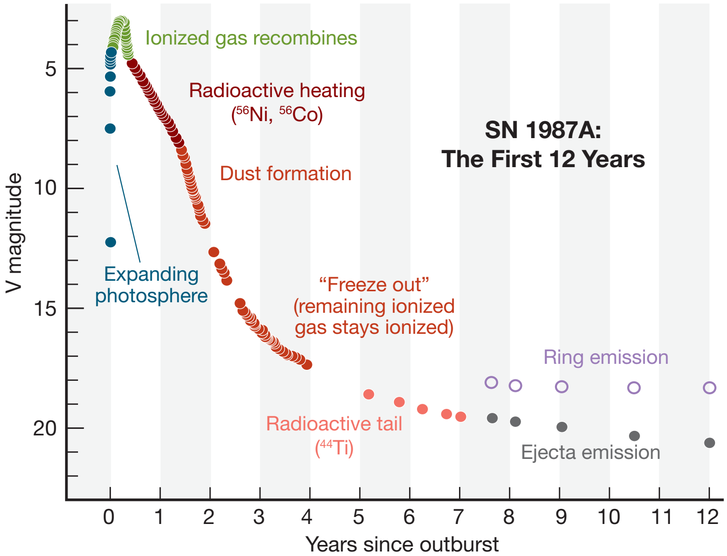
There were some real surprises in 1987. To start with, the star that exploded turned out to be number 202 in the –69° band of Nick Sanduleak's catalog of bright stars in the Large Magellanic Cloud. It had been a 12th-magnitude blue supergiant, spectral type *B*3Ia. Oops. In giving astronomy exams at Harvard, the answer that I marked correct was that core-collapse supernovae happen only in *red* supergiants at a different stage of development. Nature hadn't read the textbook.

Stars in the Large Magellanic Cloud have less than half the heavy-element abundance of in stars in the Milky Way's disk, and people calculated the effect that this chemical difference would have on the life of a massive star. If it began with 18 times the mass of the Sun, a likely estimate, it would shed about 4 solar masses as its core stepped through the

▲ **BEFORE AND AFTER** Ten days in, the exploded blue supergiant star Sanduleak –69° 202 was shining in naked-eye view and still brightening as it expanded.

▼ **HANGING IN SPACE** The three-ring ornament and the supernova remnant inside it are seen against the fringe of the Tarantula Nebula in the Large Magellanic Cloud. The two bright stars that appear on the rings are unrelated chance alignments. This view was assembled in 1998 from Hubble images of the region, by the Supernova Intensive Study group at the Harvard-Smithsonian Center for Astrophysics.

TOP: DAVID MALIN / AUSTRALIAN ASTRONOMICAL OBSERVATORY; BOTTOM: NASA / STSCI / HARVARD SINS



▲ **SLOW FADE** After the supernova exploded, it brightened rapidly for many days as its opaque photosphere expanded like that of a gigantic star. Then as it cooled and thinned, new energy sources took over. Peak brightness came three months after the explosion, from the energy released by electrons and ionized atoms recombining in the debris. Radioactive heating later kept the remnant glowing as it dimmed, though new-formed dust suddenly began hiding some of the light. By 7 years out, the surrounding hydrogen ring was brighter than the expanding ejecta.

final, unstable stages of nuclear burning — fusing helium to carbon and oxygen, then step by step up to silicon, ending with a hot and brief episode of fusing silicon into iron. Iron is nearly the minimum-energy atomic nucleus: it's unburnable, the "ash" at the end of the line for releasing energy by fusion. As the core of Sanduleak –69° 202 accumulated iron and could produce no further heat to hold it up, it shrank, teetered on the edge of gravitational collapse, and finally fell over the brink.

Computer models had shown that the headlong collapse of a star's core would stop only when the inner few solar masses became as dense as an atomic nucleus — forming an incredibly dense neutron star about the size of a city on Earth. In those last seconds, as the neutron star forms, the material crashing down heats to about 100 billion kelvin. It should be hot and dense enough to produce an immense pulse of neutrinos, amounting to about 10% of the star's rest mass. Most of the neutrinos fly clean out of the star, carrying off the vast majority of the energy released in the entire disaster.

One of the great physics events of 1987 was the first detection, in two giant underground neutrino detectors, of this surge of ghostly neutrinos. It began with a burst and trailed out in the next 13 seconds.

The visible brightening got under way in the subsequent hours, as the shock wave from the core hit the star's surface, abruptly heating it to ultraviolet temperatures and blasting it outward to enormous size.

The neutrino event is widely regarded as the yelp of a newborn neutron star, not a black hole. But our careful scrutiny of the wreckage of SN 1987A using the Hubble Space Telescope has failed to show any sign of a point source in the center, even with the view clearing during the last 30 years. Is the neutron star shrouded by dust? Or did infalling debris shove it over the *next* gravitational-collapse brink, to become a black hole? The case is open, and we will keep looking with ever more sensitive techniques for the presumed hot corpse, as the remaining light from the explosion continues to fade away.

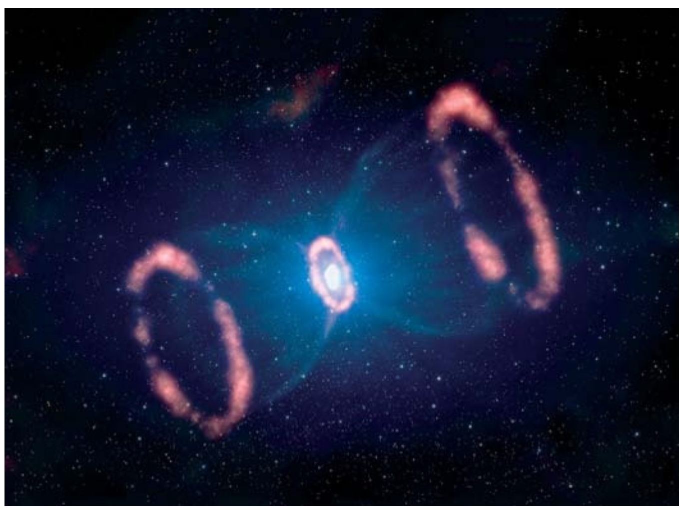
Struck By the Light . . .

Other surprises have played out over the past three decades. Our IUE measurements showed a prompt flare of ultraviolet light, denoting the shock wave bursting through the star's surface. In the next 1.1 years, that flare of ultraviolet brilliance travelled 1.1 light-years outward and reached something that was already loitering in the neighborhood: slow-moving, dense gas. We saw new emission as the ultraviolet flash excited it to glow. This was, plausibly, gas that the star had shed tens of thousands of years earlier, toward the unstable end of its fuel-burning life.

Then in 1990 Hubble was launched. Even with its compromised resolution due to the notorious error in its primary mirror, we were surprised and delighted to see that this newly illuminated material was not a spherical shell as we expected, but a beautiful, thin ring. Something had previously sculpted the star's ejecta into this shape. Here was a lesson: nature doesn't always produce the simplest thing we think of.

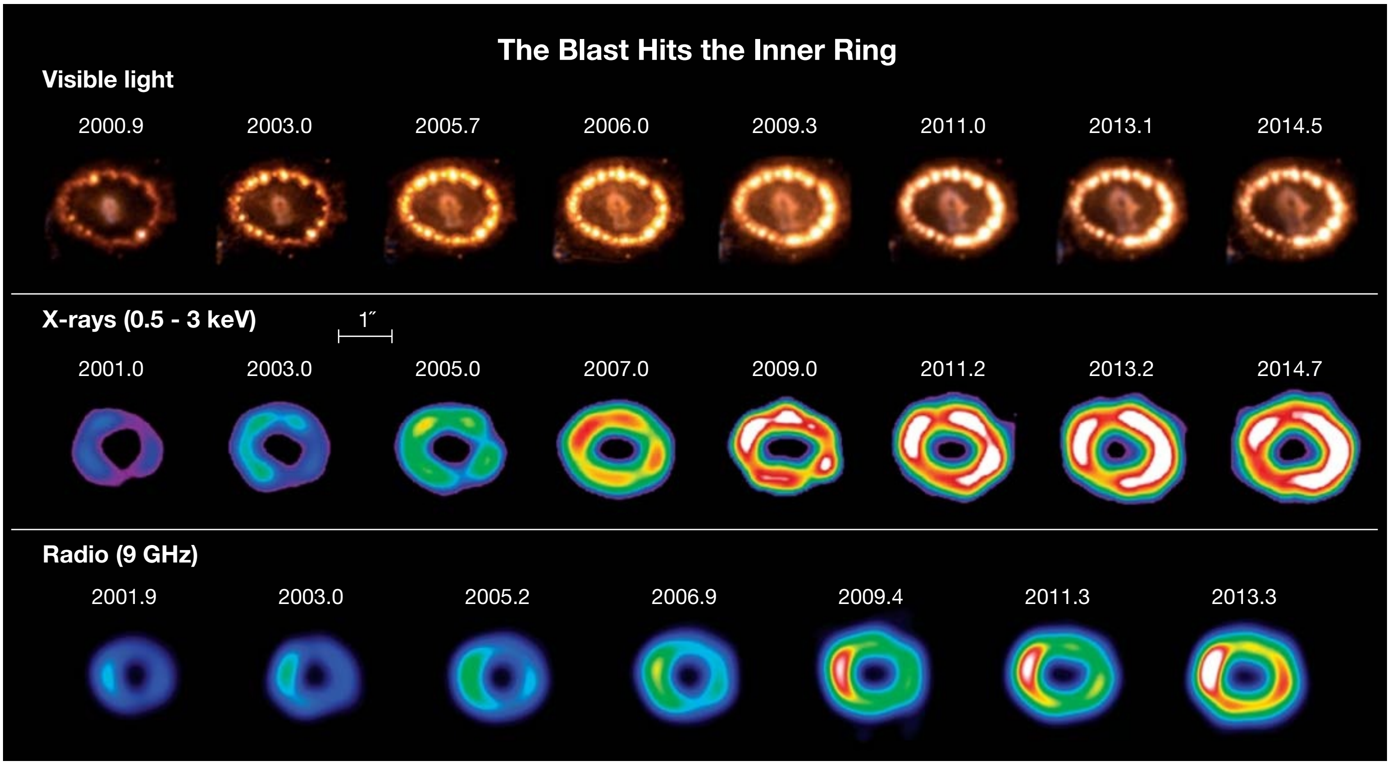
That lesson was repeated when we obtained the first images of SN 1987A after astronauts installed corrective optics into Hubble in 1993. We saw not just one ring but three, aligned in remarkable symmetry.

The two larger, fainter, outer rings seem to indicate a tilted hourglass-shaped structure around the exploded star, with the inner ring as its neck — like the hourglass shapes often seen among planetary nebulae, where a star with lower mass blows off material near the end of its life. An artist's concept



▲ **SIDE VIEW** This artist's concept from a different perspective illustrates the hourglass-shaped cavity that the three visible rings highlight.

BOTTOM: ESO / L. CALÇADA. TOP: S&T / LEAH TISCIONE, DATA FROM C. FRANSSON / P. LUNDQVIST / R. A. CHEVALIER



▲ **THE NECKLACE LIGHTS UP** As the leading edge of the supernova debris reached the inner ring, astronomers tracked developments at many wavelengths. In the visible-light images at top, from the Hubble Space Telescope, the brightness of the ring has been reduced by a factor of 20 to make it possible to see the faint emission from the bulk of the debris: the expanding, oddly shaped nebula inside.

DICK MCCRAY AND CLAES FRANSSON (VISIBLE: C. FRANSSON *ET AL.* / *ASTROPHYSICAL JOURNAL LETTERS* 2015, X-RAY: K. FRANK *ET AL.* / *ASTROPHYSICAL JOURNAL* 2016, RADIO: C.-T. NG *ET AL.* / *ASTROPHYSICAL JOURNAL* 2013)

of the side view is at lower left. More recently, astronomers have found other superluminous blue-giant stars with similar three-ring structures. One is pictured on the next page. Are these, too, about to become core-collapse supernovae?

. . . and Then By the Blast

Meanwhile, the shredded remains of the star itself were hurtling outward behind the ultraviolet pulse at up to about 10% the speed of light. It did not take a supercomputer to calculate that a ring about 1 light-year from the explosion would get whacked in about 10 years. Sure enough, in 1995 Hubble began to see this collision.

But, just as the material around the star was not a shell but a three-ring extravaganza, the collision was more intricate than we expected. Instead of lighting up all at once as the first debris hit, the ring lit up in about 30 "hot spots," spaced around its circumference like a string of pearls.

The necklace of spots was presumably the sign of dense fingers of gas in the surrounding ring pointing toward the star, a little like stalagmites from the floor of a cave. As the shock wave expanded, it hit the tips of the fingers first. Now this preliminary encounter is coming to an end: some of the hot spots are fading and merging, and the destruction of the entire ring by the oncoming blast is under way.

Radioactive Time Release

The interaction of the expanding shock with the ring was not just a spectacle — it represented a fundamental change in the energy source for the light and other emissions we see.

In the initial supernova explosion itself, the nuclear alchemy that changes one element into another produces an array of isotopes. Some of these are stable nuclei of iron and other elements near iron in the periodic table. The iron in your blood came from star-core destruction of this sort, which seeded iron into interstellar clouds before our solar system formed from them. But not all the nuclei produced are long-lived. Some are radioactive, having decay times from moments to years.

The exploding debris was initially heated by the shock wave that blew the star apart. As it expanded and cooled, the recombination of ionized atoms with their lost electrons provided most of the light around the time of peak brightness a few months along. But after that, the debris was kept hot and glowing by the decay of radioactive nuclei.

In the case of SN 1987A, we infer that the heat and pressure of the core collapse created 0.07 solar mass (2,300 Earth masses) of nickel-56: the isotope of nickel with 28 protons and 28 neutrons. It decays with a half-life of 6 days to cobalt-56, which then decays with a half-life of 111 days to iron-56. That was the main energy source lighting the debris for about the first 500 days of its long, slow fade. Along the way an abrupt episode of dust formation partially veiled the view, further dimming the visible light. But when you added up the light, the infrared radiation re-emitted by the warm dust, and the gamma-ray photons coming directly from the decaying nuclei, the total continued to track the decay of the nickel-56 and its cobalt-56 daughter.

In time, as the cobalt decayed away, a slower time-release of stored energy became dominant: the decay of titanium-44, half-life 1,200 days. This was the main power source for the remnant's dimming emission until about 5,000 days (14 years) after the explosion.

That was more or less what astrophysicists had inferred from the fading light curve. They were able to test these ideas directly for the first time by measuring the energies of gamma-ray photons arriving from the debris. These matched the laboratory energies from decaying ^{56}Ni and ^{44}Ti. It's an iron-clad case that these iron-peak elements powered the remnant's long-lasting glow.

A New Process Takes Over

But now, the energy source for the supernova remnant has shifted again. Radioactivity accounted neatly for the decline, but since about 2001, careful measurement of Hubble images shows that the expanding debris remnant inside the inner ring — the keyhole-shaped nebula seen in the top row on the previous page — is *rebrightening.* Radioactivity cannot do that. But the violent collision of the blast's outer wave with the ring converts some of the blast's kinetic energy into heat. The gas at the collision sites becomes so hot that it shines in X-rays, which we can see with the Chandra satellite. Chandra has sharp enough vision to show that the X-ray emission is indeed coming from near the ring. The surprising thing is that these X-rays are shining back on the slower debris that has yet to reach the ring, reheating it from the outside.

The collision with the ring is also accelerating electrons there to relativistic energies. When the electrons interact with the magnetic fields in the neighborhood, they emit at radio wavelengths (synchrotron radiation). We've seen increasing radio emission over the past decade, again mostly coming from near the ring.

Nobody alive today will live long enough to see the complete transition of *Supernova* 1987A into the supernova *remnant* SNR 1987A. But the balance has tipped in the 30 years we've watched. The physical processes that make the star-debris shine have shifted from the explosion itself, to radioactive decay of what the explosion created, to its kinetic crash into the surrounding interstellar gas.

When we look at remnants of historical supernovae, such as Kepler's of 1604 or Tycho's of 1572 or somewhat older ones in the Milky Way, we see their completed transitions. Their conspicuous features now are radio emission from particles that the shock wave accelerates to nearly the speed of light, and X-ray emission from gas heated to millions of degrees. For SN 1987A, we have a much richer and more complete story that tells us what type of star exploded, what elements the explosion initially produced, and the detailed sequence of events that then unfolded. We can watch as the explosion destroys the evidence of the star's pre-explosion behavior, as

▲ **NOT UNIQUE** Other blue supergiants — that haven't blown up yet — show similar three-ring hourglass ejecta as they near the ends of their lives. This is a Hubble image of SBW 2007 (also known as SBW1), 20,000 light-years distant.

ESA HUBBLE / NASA / NICK ROSE & STEVE BYRNE

embodied in the three-ring circus of surrounding hydrogen. Nature made SN 1987A in a more intricate and interesting way than we imagined. It will be good to remember that lesson of humility.

The Fire Next Time

Tycho had his supernova, Kepler had his. Perhaps there's an astronomer on Earth today whose name will go on the next one in the Milky Way itself. More likely, the first galactic supernova of the telescopic era will be caught by some large cooperative effort. Perhaps it will be an array of survey telescopes staring unblinkingly at the whole sky. Perhaps it will be specks of light produced by neutrinos as they slash through Antarctic ice, or a flare of ultraviolet light detected by a satellite, or the jiggle of the gravitational waves that a messy core collapse should produce. The next Milky Way supernova could outshine every star in the sky, or it might remain hidden from view behind thick interstellar dust. But the statistics are pretty clear: the Milky Way has a supernova about once a century on average. The next could happen at any time. Keep looking up.

■ Harvard professor **ROBERT P. KIRSHNER** specializes in supernovae. He won the 2015 Wolf Prize in Physics, and the U.S. National Academy's Watson medal, for his work using supernovae to measure cosmic expansion. He is the chief program officer for science for the Gordon and Betty Moore Foundation and author of the popular-level book *The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos.*

OBSERVING
February 2017

1 MORNING: Jupiter and Spica open the month separated by 3.6°, highest in the south about 2½ hours before sunrise. They remain about this close all month.

2 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:54 p.m. EST; see page 50.

5 EVENING: The waxing gibbous Moon beams left of Aldebaran as twilight deepens for North America. The Moon occults Aldebaran for southern Europe and northern Africa.

10 EVENING: A very deep penumbral eclipse of the Moon is visible around sunset or early evening for most of the Americas; see page 48.

10–11 ALL NIGHT: Regulus travels with the full Moon. Watch through the night as they edge closer to each other.

15 MORNING: The waning gibbous Moon, Jupiter, and Spica form a shallow arc 6°–8° long.

19 NIGHT: Algol shines at minimum brightness for roughly two hours centered at 9:50 p.m. PST.

20 MORNING: The waning crescent Moon rises about two hours past midnight. Saturn, fairly bright at magnitude +0.5, follows about an hour behind. By dawn they're shining in the south-southeast.

22 NIGHT: Algol shines at minimum brightness for roughly two hours centered at 9:39 p.m. EST.

26 DAYTIME: An annular solar eclipse is visible in the morning along a line stretching from Chile and Argentina across the Atlantic Ocean through Angola. A partial solar eclipse occurs for viewers in much of South America and Africa; see page 49.

This composite image, which combines X-ray (pink) and optical data, shows the superheated gas surrounding the stellar core of the planetary nebula NGC 2392.
◖ See more on page 58.
X-RAY: NASA / CXC / IAA-CSIC / N.RUIZ ET AL.; OPTICAL: NASA / STSCI

FEBRUARY 2017 OBSERVING

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				

FIRST QUARTER
February 4
04:19 UT

FULL MOON
February 11
00:33 UT

LAST QUARTER
February 18
19:33 UT

NEW MOON
February 26
14:58 UT

DISTANCES

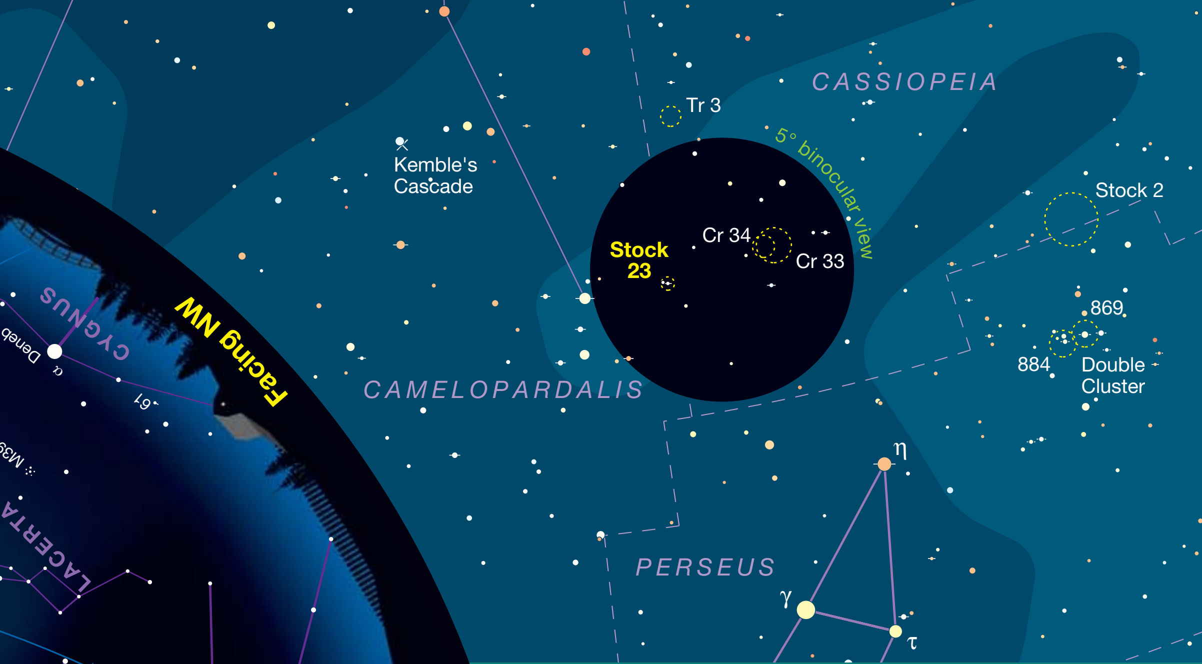
Perigee	February 6, 14^{h} UT
368,816 km	diam. 32′ 24″
Apogee	February 18, 21^{h} UT
404,376 km	diam. 29′ 33″

FAVORABLE LIBRATIONS

• Florey (crater)	February 6
• Goddard (crater)	February 11
• Le Gentil (crater)	February 20
• Baade (crater)	February 23

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.



Binocular Highlight by Mathew Wedel

Often Overlooked

Quiz time! I'm thinking of a celestial object. It lies just over 10° from Alpha (α) Persei, with a visual magnitude of 6.5, but it isn't a Messier or Caldwell object, isn't included in the NGC or IC, wasn't discovered until the mid-1950s, and wasn't brought to the attention of amateur astronomers until 1977. Despite that long record of being ignored, it looks great in a telescope, shows some detail in even modest binoculars, and might even be naked-eye visible under optimum conditions. What is it?

It seems like an impossible set of provisions, but one object fits the bill: **Stock 23**, also known as Pazmino's Cluster, in Camelopardalis, the Giraffe. Its two names pay homage to the observers that originally logged this starry wonder. Professional astronomer Jürgen Stock seems to have been the first to spot it around 1957, but amateur observers didn't take notice until 1977, when John Pazmino stumbled across it while scanning for the nearby Double Cluster with a rich-field telescope. Pazmino's Cluster has been getting more attention ever since.

I first observed Stock 23 by accident myself, trying to star-hop from the Double Cluster to Kemble's Cascade. The cluster lies approximately halfway between these two popular targets. You can also get there from the wide pair CS and CE Camelopardalis — Stock 23 is 1.5° straight west. In town, 50-mm binos will show at least the four brightest stars, and under dark skies you may pick up half a dozen or so fainter ones. It's not clear if Stock 23 is actually a true open cluster. Its stars seem to lie at different distances, so it may just be a chance alignment. Whatever it is, it's bright, easy to find, and rewarding to observe, so go check it out.

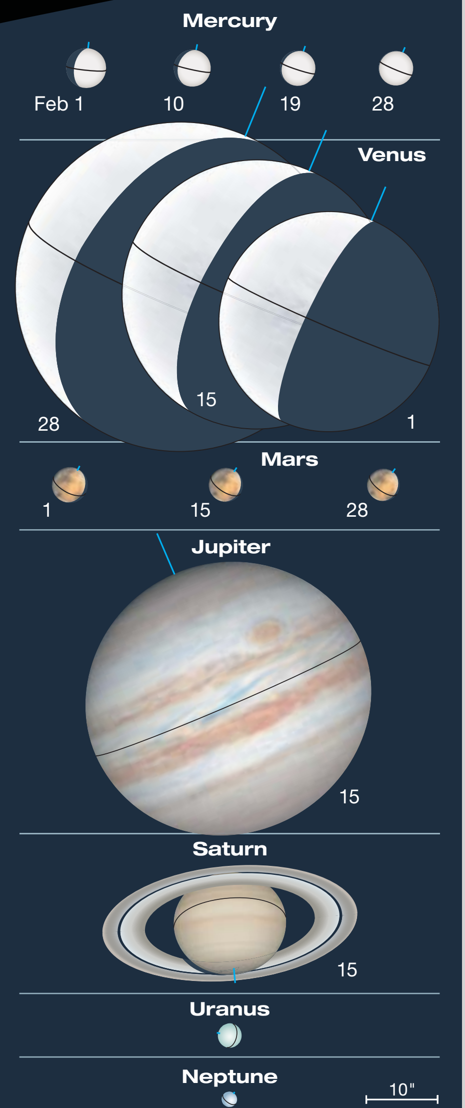
■ **MATT WEDEL** likes to kick back with his binoculars on a driveway in Claremont, California.

WHEN TO USE THE MAP

Late Dec	11 p.m.
Early Jan	10 p.m.
Late Jan	9 p.m.
Early Feb	8 p.m.
Late Feb	Dusk

These are standard times.

PLANET VISIBILITY: **Mercury:** Dawn, Feb. 1 – 24, very low southeast • **Venus:** Evening, all month, west • **Mars:** Evening, all month, west • **Jupiter:** Very late evening to dawn, all month, east-southeast to southwest • **Saturn:** Dawn, all month, south-southeast.

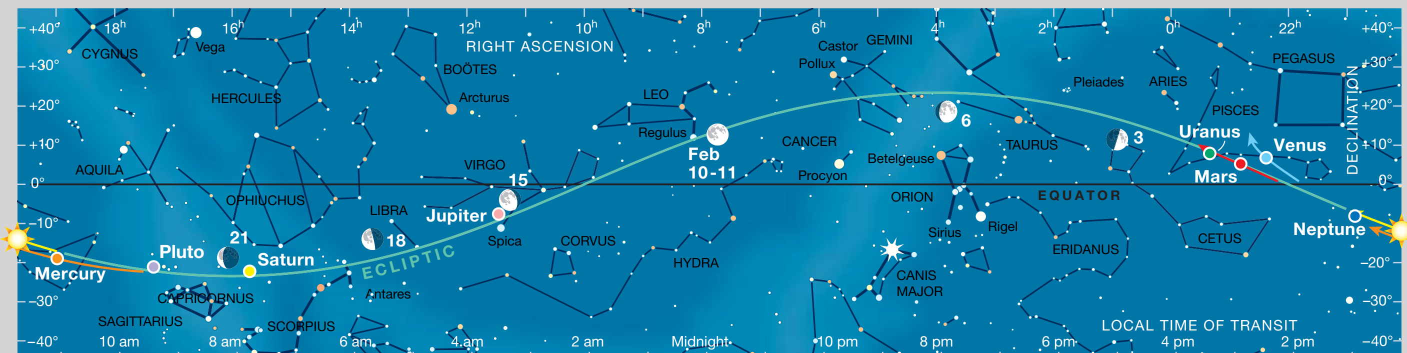


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h 58.2^m$	–17° 10′	—	–26.8	32′ 28″	—	0.985
	28	$22^h 43.7^m$	–8° 04′	—	–26.8	32′ 18″	—	0.991
Mercury	1	$19^h 29.5^m$	–22° 21′	21° Mo	–0.2	5.6″	81%	1.203
	10	$20^h 25.4^m$	–20° 45′	18° Mo	–0.3	5.2″	88%	1.299
	19	$21^h 24.0^m$	–17° 24′	13° Mo	–0.6	4.9″	94%	1.359
	28	$22^h 24.3^m$	–12° 12′	6° Mo	–1.2	4.9″	98%	1.381
Venus	1	$23^h 48.4^m$	+0° 40′	46° Ev	–4.7	30.8″	40%	0.541
	10	$0^h 11.3^m$	+4° 38′	43° Ev	–4.8	35.0″	33%	0.477
	19	$0^h 28.0^m$	+8° 04′	40° Ev	–4.8	40.1″	26%	0.416
	28	$0^h 36.3^m$	+10° 40′	34° Ev	–4.8	46.2″	18%	0.361
Mars	1	$0^h 10.0^m$	+0° 41′	51° Ev	+1.1	5.1″	92%	1.849
	15	$0^h 47.9^m$	+4° 58′	47° Ev	+1.2	4.8″	93%	1.943
	28	$1^h 23.2^m$	+8° 46′	43° Ev	+1.3	4.6″	94%	2.029
Jupiter	1	$13^h 26.7^m$	–7° 35′	109° Mo	–2.1	39.0″	99%	5.052
	28	$13^h 24.2^m$	–7° 14′	137° Mo	–2.3	42.0″	100%	4.688
Saturn	1	$17^h 35.7^m$	–22° 02′	48° Mo	+0.5	15.6″	100%	10.687
	28	$17^h 44.6^m$	–22° 05′	73° Mo	+0.5	16.1″	100%	10.298
Uranus	15	$1^h 19.5^m$	+7° 46′	55° Ev	+5.9	3.4″	100%	20.486
Neptune	15	$22^h 50.8^m$	–8° 16′	15° Ev	+8.0	2.2″	100%	30.905

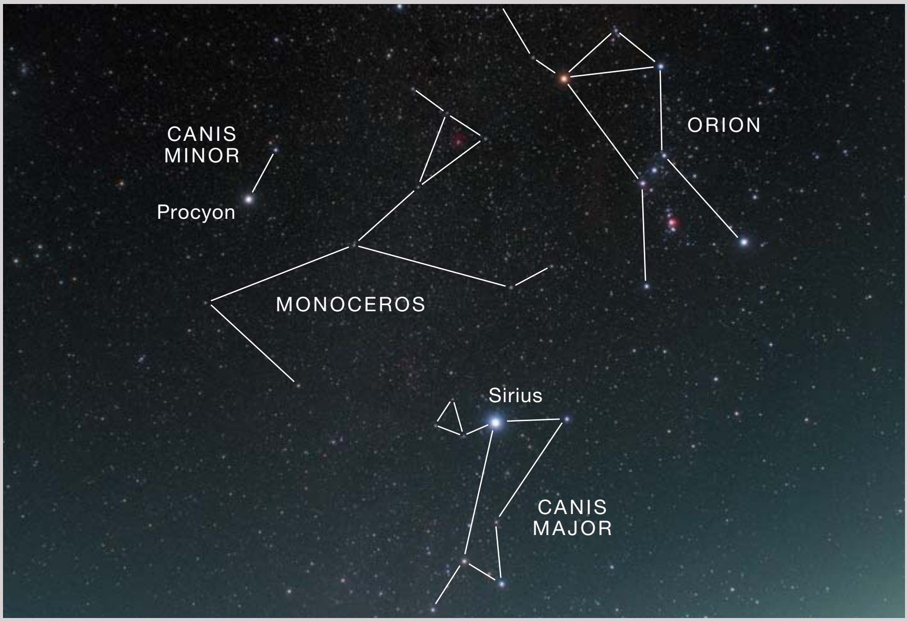
The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial 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-February; 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.

Between the Dogs

Canis Major and Canis Minor frame a dim but intriguing patch of sky.



Last winter, I was driving home late on some December evenings, then early on some January evenings. On these occasions, when skies were clear, I noticed a wonderful thing: to either side of the dark country highway there shined, low over the treeline, two brilliant stars. To the left was Procyon, brightest light of Canis Minor, the Little Dog. To the right was Sirius, chief luminary of Canis Major, the Big Dog. I was driving to a home between the Dogs.

Now that February has arrived, Sirius and Procyon have moved to the southeast and south by mid-evening. They're high, making this a good time to observe the stars and clusters in the sky that lies "between the Dogs."

The Milky Way and Messier. Monoceros, the Unicorn, is the only constellation traversed by the line that connects Sirius to Procyon. This line passes through the band of the winter Milky Way that divides those two Dog Stars from each other. Under moderately dark skies when the Milky Way reaches the meridian, its long dim band can be detected running from upper right to lower left between the dogs and onward south and east. A moonless February evening under dark skies is also a prime time to look for the tilted pyramid of gentle glow called the zodiacal light. Can you trace it from low in the west to as far upper left as the Pleiades, or even farther?

In contrast to these somewhat elusive and extended glows, there's a rich open cluster of Monoceros about one-third of the way along the line from Sirius to Procyon. This is Messier 50, whose magnitude-5.9 fuzzy spot can be glimpsed with the naked eye in very dark skies. Roughly 100 stars sparkle within about 16 arcminutes, with one ruddy star prominent among them. More than one deep-sky writer has noted that the cluster as a whole is heart-shaped.

Winter Triangling the Unicorn. Let's seek even more sights by extending our "between the Dogs" criterion to include not just the sky between Sirius and Procyon, but also the expanse between each pair of stars that forms the Winter Triangle, the corners of which are pinned down by Sirius, Procyon, and Betelgeuse.

I've noted that M50 lies about one-third of the way between Sirius and Procyon. The splendid triple star Beta (β) Monocerotis shines a little more than one-third of the way between Sirius and Betelgeuse. English-German astronomer William Herschel discovered the triplicity of this 3.7-magnitude brightest star of the dim Unicorn in 1781, the same year he discovered the planet Uranus.

The third side of the Winter Triangle also has a key object one-third of the way between Betelgeuse and Procyon, just about 1° north of the connecting line. 13 Monocerotis is the middle star of what I like to consider the horn of the Unicorn. The celestial wonders in and near this horn are so complex and marvelous that we'll focus on them in next month's column.

One dog from another. It's interesting to be between the two dog stars in the sky but there's little point in being between them in space. What, however, do they look like as seen from each other? Sirius and Procyon would each appear about a magnitude brighter than they do in our own sky. Each star's white dwarf companion would burn much brighter in the star's own sky than our Full Moon does for us. But perhaps most interesting is how bright Procyon would look from Luyten's Star, the red dwarf star of extremely low luminosity just 1.2 light-years from Procyon. From Luyten's, Procyon would blaze at an amazing magnitude –7.

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

AKIRA FUJII

Brilliant Venus Owns the Evening Sky

Mars accompanies the bright planet early; Jupiter shows up a bit later.

This is an eclipse month. On the night of February 10–11, a deep penumbral eclipse of the Moon occurs for viewers in the Americas, Europe, Africa, and Asia. On February 26th, an annular eclipse of the Sun is visible in a narrow band across parts of southern Chile and Argentina and the South Atlantic to Angola and Zambia.

Venus blazes in the west for a few hours after sunset, at its greatest brilliance of the year. Modestly bright Mars follows Venus fairly closely down to the horizon. By late February Jupiter, accompanied by Spica, rises before Mars sets and shines prominently the rest of the night. Saturn comes up well before dawn, while Mercury rises lower and lower in the morning twilight until it's lost late in the month.

DUSK TO MID-EVENING

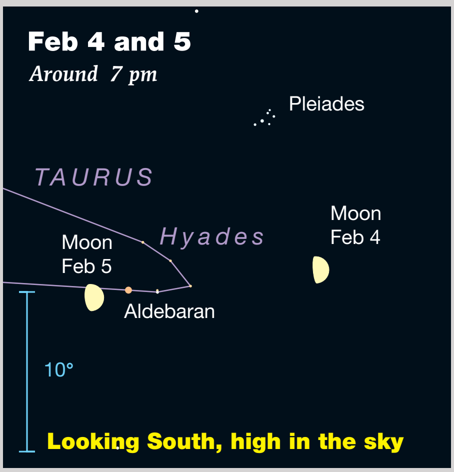
Venus dominates the sky in the west-southwest to west, blazing at a stunning magnitude –4.8 all month. This is a prime time to try to see Venus with the naked eye in daylight; it's highest due south in mid-afternoon. At night, at really dark observing locations, look for shadows cast by the radiant planet, especially on snow or a white wall. Be sure your eyes are well dark-adapted.

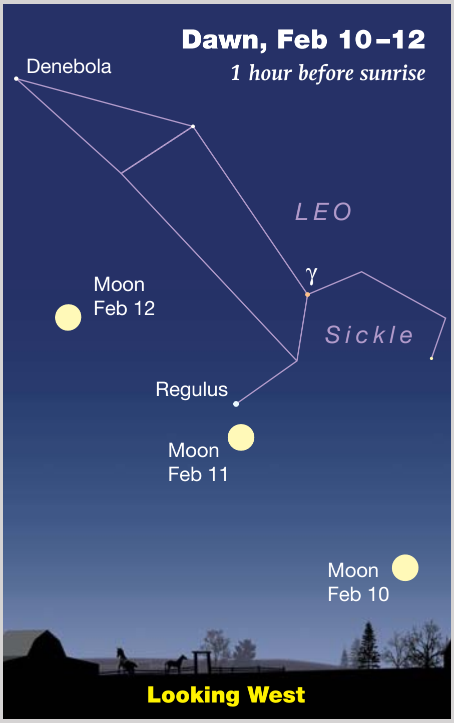
Venus reaches a peak sunset altitude of 40° on February 3rd as seen from latitude 40° north. Although Venus only declines to about 32° high at sunset by the end of the month, the interval between sunset and Venus-set shrinks from about 3¾ to 2¾ hours.

Telescopes show Earth's sister planet swelling from 31″ to 46″ in diameter (wider than Jupiter), while its phase thins dramatically from 40% to 18% lit. Venus displays its greatest illuminated extent (maximum illuminated area in square arcseconds) on February 16th.

Mars, easy to find to the upper left of beacon-like Venus, fades from magnitude +1.1 to +1.3 in February, while its disk dwindles from 5.1″ to 4.6″ (one-tenth the diameter of Venus at month's end). Venus reaches a minimum separation of 5.4° west of Mars on February 1st, and then, slowing its eastward motion, loses ground on (also eastbound) Mars. Thus they barely miss having a quasi-conjunction, defined as two planets coming within 5° of each other without passing. They're about 12° apart by month's end.

Mars opens February setting only 20 minutes after Venus but ends the month setting about 50 minutes after Venus (as viewed from mid-northern latitudes). The two move eastward



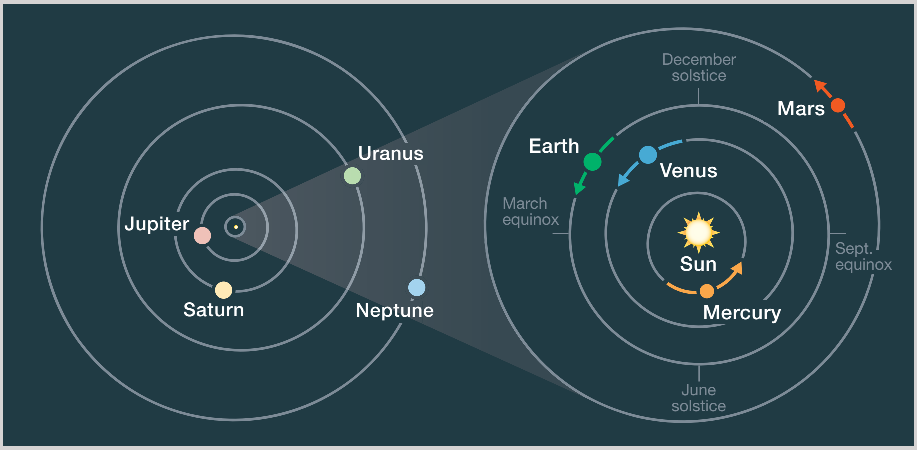


• To find out what's visible in the sky from your location, go to skypub.com/almanac.

across dim Pisces in February, heading toward the east side of the Great Square of Pegasus.

On February 26th, Mars passes just 0.6° north-northwest of 6th-magnitude **Uranus**. No star that close to Mars is that bright. At 3.4″ wide, Uranus appears even smaller than Mars in a telescope.

Neptune is hidden in the Sun's afterglow this month.



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

MID-EVENING TO DAWN

Jupiter rises in the east about 11 p.m. as February opens but two hours earlier as the month ends. Venus has already left the sky before Jupiter comes up, but the giant world briefly shares the evening scene with Mars.

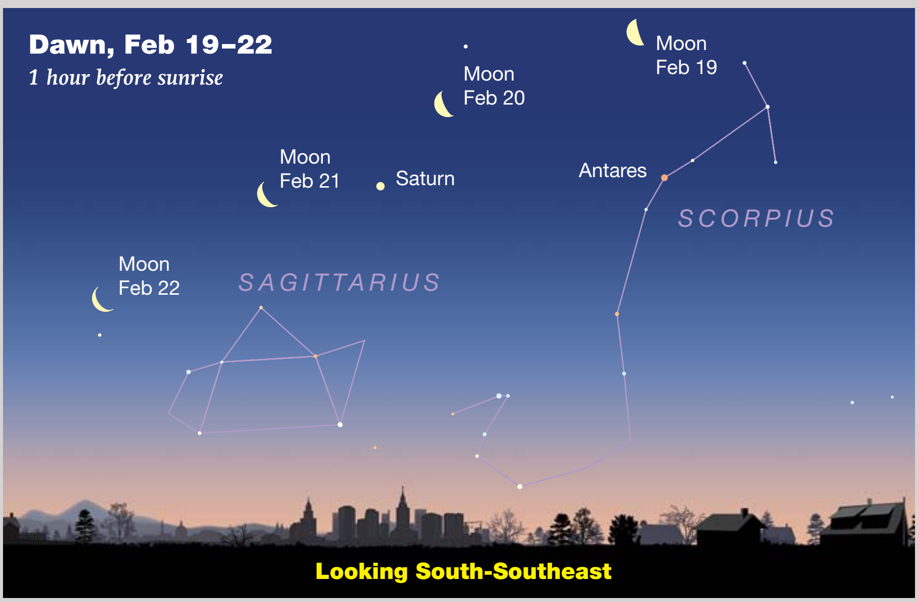
Jupiter brightens from magnitude −2.1 to −2.3 this month as its disk grows from 39″ to 42″ wide. Jupiter crosses the meridian around 4 or 5 a.m. as February opens and around 2 or 3 a.m. as the month closes, depending on how far east or west you live in your time zone. While you observe the banded orb of Jupiter with your telescope this month, ponder the fact that on February 17th the planet reaches aphelion — its farthest from the Sun in space — for the first time in 12 years.

Naked-eye observers will enjoy watching Jupiter tarry near Spica in the early months of 2017. On February 6th, the planet halts its direct (eastward) motion in Virgo and begins retrograde (westward) motion, bringing Jupiter to 4° due north of Spica on February 23rd.

DAWN

Saturn rises not long before Jupiter reaches the meridian. As dawn begins to brighten, the ringed world hangs in the south-southeast at the same altitude as, but nearly 20° left of, Antares. The planet shines at magnitude +0.5 all month, noticeably brighter than the 1.1-magnitude star, and its rings remain near their maximum tilt all year. Saturn crosses the border from Ophiuchus into Sagittarius in late February.

Mercury brightens from magnitude −0.2 to −1.2 low in the dawn, but it appears later and later in the east-southeast each morning. It should last be visible around February 24th.



SUN AND MOON

The **Sun** undergoes an annular eclipse and the **Moon** a deep penumbral eclipse this month. See page 48.

The waxing crescent Moon poses well to the upper left of Venus and Mars at dusk on February 1st, after hanging right in their midst on January 31st. The waxing gibbous Moon just misses occulting Aldebaran around nightfall February 5th for observers in eastern North America. The full Moon hangs below Regulus before sunrise on February 11th, then farther lower left of the star that evening.

The waning gibbous Moon forms a beautiful short arc with Jupiter and Spica at dawn on February 15th. The waning crescent is upper right of Saturn on the morning of February 20th and left of Saturn on the 21st. At nightfall on February 28th, the waxing lunar crescent lingers some 10° to the lower left of Venus.

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

A Deep Penumbral Lunar Eclipse

Watch the Moon flirt with Earth's shadow on the evening of February 10th.

A penumbral eclipse is a tease, but it illustrates principles of light and shade you may not have thought about. Watch them play out on a grand scale.

▲ A penumbral eclipse not quite as deep as the one we're about to get occurred over the Far East on November 28, 2012.

HONG KONG SPACE MUSEUM

No shadow that you normally see has a sharp edge. A shadow is always surrounded by a hazy penumbra, unless the light casting it comes from a point source. Neither a light bulb nor the Sun qualify.

The penumbra is where, if you were in it, you would see the shadow-casting object cover part of the light source but not all of it. So a penumbra's width, as seen from the shadow-casting object, always equals the angular width of the light source. Which is why, in the diagram for the upcoming penumbral lunar eclipse at the top of the facing page, the penumbra of Earth's shadow is almost exactly as wide as the Moon. As seen from Earth, both the Sun and Moon appear very nearly the same width: about ½° across.

A penumbral eclipse is a tease. None of the Moon enters Earth's interestingly dark-red umbra, as happens during a partial or total lunar eclipse. But on Friday evening February 10th (for North America), we'll see just about the best penumbral eclipse possible. The Moon's northern limb will miss the Earth's umbra by only about 100 miles (160 km), or 5% of the Moon's diameter. Although none of the Moon will go dark, the penumbral shading will be very plain to see.

When and Where

Eastern North America, and all of Central and South America, will have a fine view of these shadowy happenings. In these locations twilight will be deepening or entirely over, and the full Moon will be shining well up in the eastern sky, by the time of maximum shading. Northeasterners can watch the whole progression from start to finish. Seen from the central part of North America, the eclipse will already be at maximum around or soon after moonrise and sunset, with the Moon still low in a bright eastern sky. For the West, the Moon rises and the Sun sets after the eclipse has passed its peak. But even here you may be able to witness the subtle anomaly on the Moon fading away.

Europe, Africa, and western Asia have a trouble-free view, with the Moon high in a dark sky during the early morning hours of February 11th.

The outer part of Earth's penumbra, like the outer part of any penumbra, is so pale that you can't detect it. You won't see anything happening until the Moon's edge is at least halfway across the penumbra. For this event, that means about 90 minutes before mid-eclipse (which will come at 0:44 February 11th UT). The Moon's celestial northeastern side, where the shading will begin, is its left side as seen in early evening from mid-northern latitudes.

In North America, only the northeastern U.S. and eastern Canada will have the Moon well up in time to watch for this beginning. A lot will depend on how uniform any thin cloudiness may be, and on how much time and care you take to judge the reality of subtle impressions.

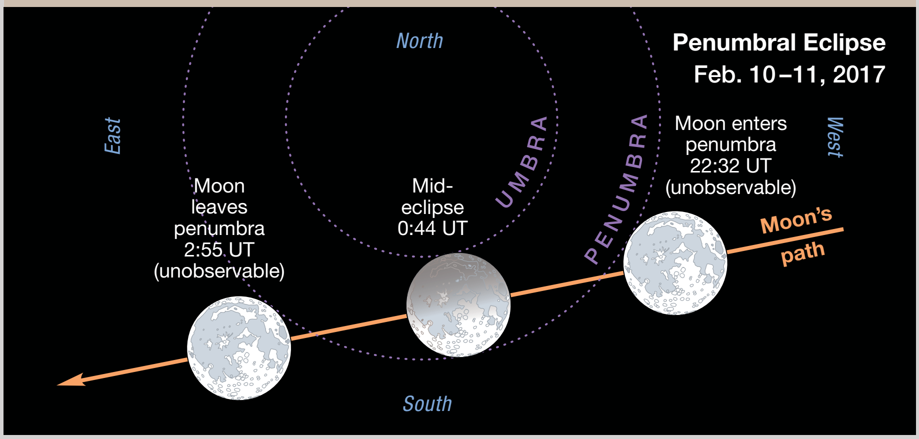
The passing minutes will gradually confirm your first correct judgments. By the time mid-eclipse approaches, the lopsidedness of the Moon's illumination will be totally obvious. The shading will appear to become ever more sharply concentrated toward the northern limb, because an umbra drops off in brightness most sharply near its inner edge.

And then, as the Moon rises higher and any last twilight fades down, the process reverses. This is the part of the eclipse most Americans will be able to see best. How long can you hold a trace of shading with your eyes, and with a telescope? Will 90 minutes after mid-eclipse really be the last time anything is visible?

For a world map of visibility and more information about this event, see **https://is.gd/penumbraleclipse2017**.

Penumbral Eclipse of the Moon, February 10, 2017

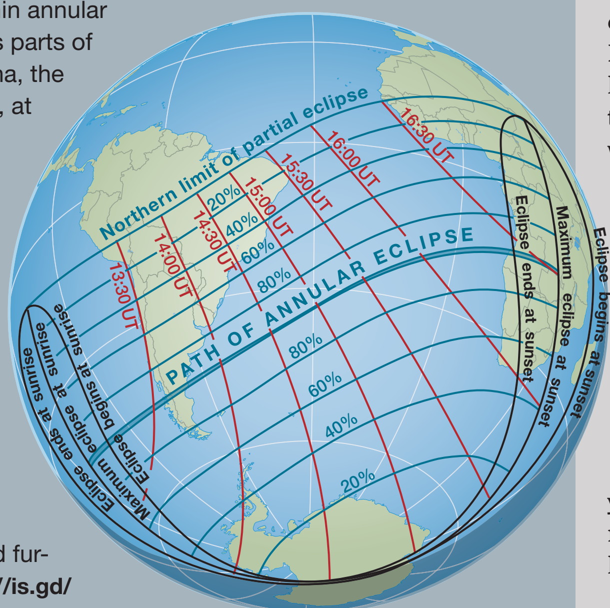
Eclipse event	EST	CST	MST	PST
Penumbra first visible?	6:14 p.m.	5:14 p.m.	—	—
Mid-eclipse	7:44 p.m.	6:44 p.m.	5:44 p.m.	—
Penumbra last visible?	9:14 p.m.	8:14 p.m.	7:14 p.m.	6:14 p.m.



A Far-Southern Annular Eclipse

On February 26th, a very thin annular eclipse of the Sun will cross parts of southern Chile and Argentina, the South Atlantic, Angola, and, at sunset, the Zambia-Congo border. A partial eclipse will grace much larger sections of South America, Africa, and Antarctica.

At any location, interpolate between the red lines to find the Universal Time of greatest eclipse. Interpolate between the blue lines to see what percent of the Sun's diameter the Moon will cover at that time. For detailed maps and further information, see **https://is.gd/annulareclipse2017**.



S&T: LEAH TISCIONE (2)

Jupiter High at Dawn

THE MOST INTERESTING PLANET for amateur scopes continues to show itself well only in the early-morning hours, especially in the hour or two before dawn. But it's getting nearer and bigger, enlarging from 39″ to 42″ in equatorial diameter during February.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually show at least two or three. Identify them at any date and time using the diagram at far right.

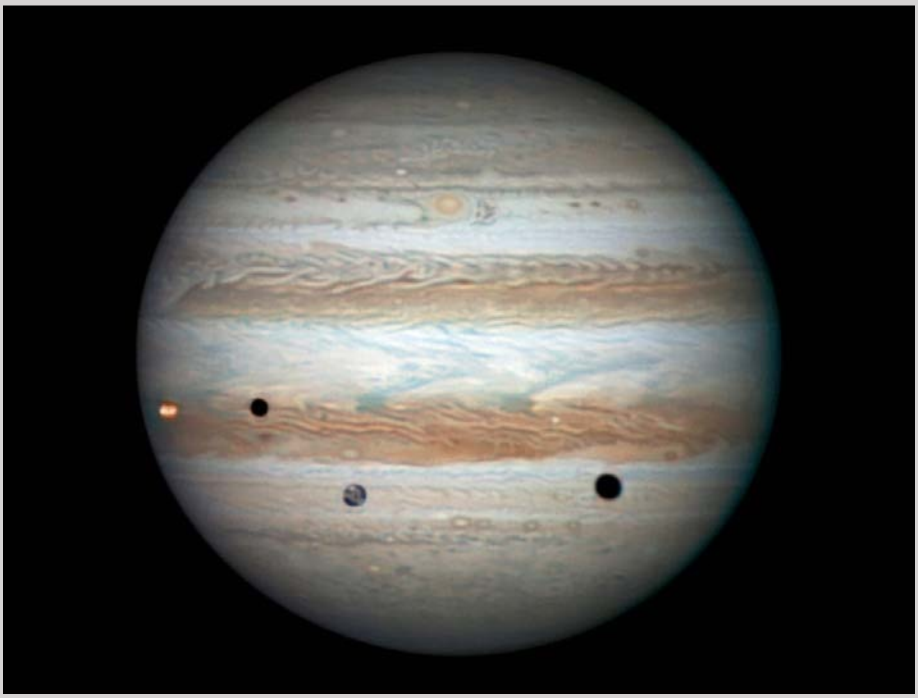
All the interactions in February between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter will be in good view for you.

And here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

January 1, 7:42, 17:37; **2,** 3:33, 13:29, 23:25; **3,** 9:20, 19:16; **4,** 5:12, 15:07; **5,** 1:03, 10:59, 20:54; **6,** 6:50, 16:46; **7,** 2:41, 12:37, 22:33; **8,** 8:28, 18:24; **9,** 4:20, 14:15; **10,** 0:11, 10:07, 20:03; **11,** 5:58, 15:54; **12,** 1:50, 11:45, 21:41; **13,** 7:37, 17:32; **14,** 3:28, 13:24, 3:19; **15,** 9:15, 19:11; **16,** 5:06, 15:02; **17,** 0:58, 10:53, 20:49; **18,** 6:45, 16:40; **19,** 2:36, 12:32, 22:27; **20,** 8:23, 18:18; **21,** 4:14, 14:10; **22,** 0:05, 10:01, 19:57; **23,** 5:52, 15:48; **24,** 1:44, 11:39, 21:35; **25,** 7:31, 17:26; **26,** 3:22, 13:18, 23:13; **27,** 9:09, 19:05; **28,** 5:00, 14:56; **29,** 0:52, 10:47, 20:43; **30,** 6:38, 16:34; **31,** 2:30, 12:25, 22:21.

February 1, 8:17, 18:12; **2,** 4:08, 14:03, 23:59; **3,** 9:55, 19:50; **4,** 5:46, 15:42; **5,** 1:37, 11:33, 21:29; **6,** 7:24, 17:20; **7,** 3:15, 13:11, 23:07; **8,** 9:02, 18:58; **9,** 4:54, 14:49; **10,** 0:45, 10:40, 20:36; **11,** 6:32, 16:27; **12,** 2:23, 12:18, 22:14; **13,** 8:10, 18:05; **14,** 4:01, 13:57, 23:52; **15,** 9:48, 19:43; **16,** 5:39, 15:35; **17,** 1:30, 11:26, 21:21; **18,** 7:17, 17:13; **19,** 3:08, 13:04, 22:59; **20,** 8:55, 18:51; **21,** 4:46, 14:42; **22,** 0:37, 10:33, 20:29; **23,** 6:24, 16:20; **24,** 2:15, 12:11, 22:07; **25,** 8:02, 17:58; **26,** 3:53, 13:49, 23:45; **27,** 9:40, 19:36; **28,** 5:31, 15:27.

These times assume that the spot will be centered at System II longitude 254°. If the Red Spot has moved elsewhere — it has been drifting toward increasing longitudes for many years now — it



▲ In this very sharp stacked-video image, Damian Peach caught orange Io and darker, gray Ganymede casting their shadows onto Jupiter at 0:31 UT March 24, 2016. Color contrasts are somewhat exaggerated. South is up.

Minima of Algol

Jan.	UT	Feb.	UT
2	11:52	3	0:54
5	8:41	5	21:43
8	5:30	8	18:32
11	2:19	11	15:22
13	23:09	14	12:11
16	19:58	17	9:00
19	16:47	20	5:50
22	13:37	23	2:39
25	10:26	25	23:28
28	7:15	28	20:18
31	4:04		

Algol remains near minimum brightness for about two hours. It takes several additional hours to fade and to rebrighten. These geocentric predictions are from the heliocentric elements Min. = JD 2445641.554+ 2.867324*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol**.

will transit 1⅔ minutes earlier for each degree less than 254°, and 1⅔ minutes later for each degree more than 254°.

The best magnification for Jupiter with your scope depends on the seeing. I always start at low or moderate powers, which make the planet small, sharp, and bright, and when I think I've exhausted what I can see, I move a step up. There comes a point where higher power just makes things worse. The better the seeing, the higher you can go.

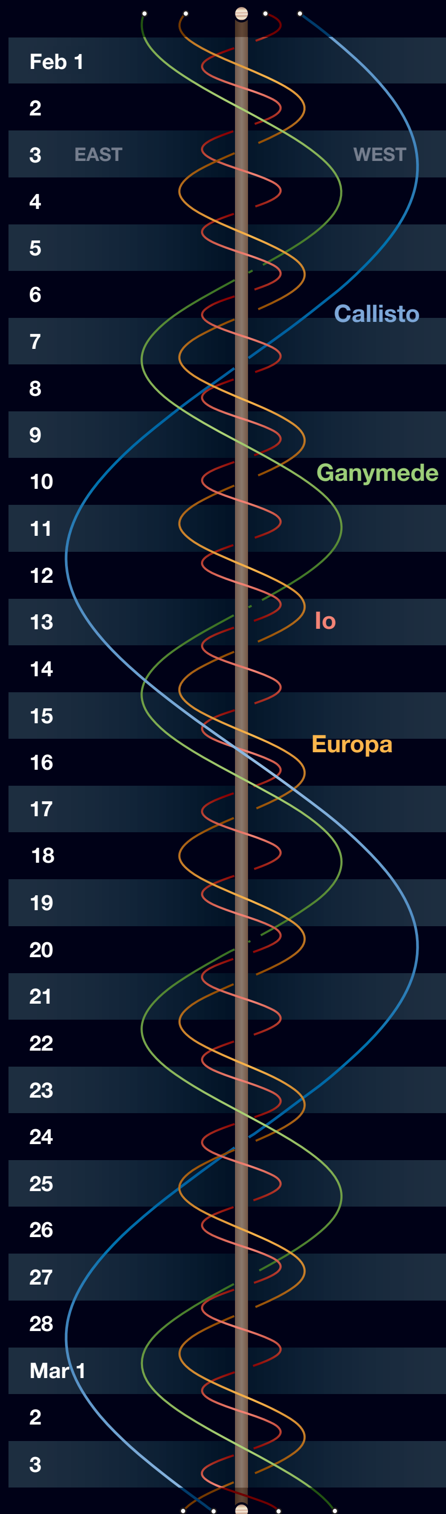
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases the contrast of Jupiter's reddish or brownish markings.

Phenomena of Jupiter's Moons, February 2017

Date	Time	Event
Feb. 1	2:07	I.Ec.D
	5:28	I.Oc.R
	11:20	II.Sh.I
	13:42	II.Tr.I
	13:50	II.Sh.E
	16:03	II.Tr.E
	23:29	I.Sh.I
Feb. 2	0:38	I.Tr.I
	1:40	I.Sh.E
	2:47	I.Tr.E
	6:51	III.Sh.I
	9:25	III.Sh.E
	11:43	III.Tr.I
	13:47	III.Tr.E
	20:35	I.Ec.D
	23:56	I.Oc.R
Feb. 3	6:28	II.Ec.D
	11:12	II.Oc.R
	17:57	I.Sh.I
	19:05	I.Tr.I
	20:09	I.Sh.E
	21:15	I.Tr.E
Feb. 4	15:03	I.Ec.D
	18:23	I.Oc.R
Feb. 5	0:37	II.Sh.I
	2:56	II.Tr.I
	3:07	II.Sh.E
	5:17	II.Tr.E
	12:25	I.Sh.I
	13:33	I.Tr.I
	14:37	I.Sh.E
	15:42	I.Tr.E
	20:53	III.Ec.D
	23:29	III.Ec.R
Feb. 6	1:41	III.Oc.D
	3:46	III.Oc.R
	9:32	I.Ec.D
	12:50	I.Oc.R
	19:45	II.Ec.D
Feb. 7	0:25	II.Oc.R
	6:53	I.Sh.I
	8:00	I.Tr.I
	9:05	I.Sh.E
	10:10	I.Tr.E
Feb. 8	4:00	I.Ec.D
	7:18	I.Oc.R
	13:54	II.Sh.I
	16:09	II.Tr.I
	16:24	II.Sh.E
	18:30	II.Tr.E
Feb. 9	1:22	I.Sh.I
	2:27	I.Tr.I
	3:33	I.Sh.E
	4:37	I.Tr.E
	10:49	III.Sh.I
	13:22	III.Sh.E
	15:27	III.Tr.I
	17:28	III.Tr.E
	22:28	I.Ec.D
Feb. 10	1:45	I.Oc.R
	9:02	II.Ec.D
	13:38	II.Oc.R
	19:50	I.Sh.I
	20:54	I.Tr.I
	22:02	I.Sh.E
	23:04	I.Tr.E
Feb. 11	16:56	I.Ec.D
	20:12	I.Oc.R
Feb. 12	3:11	II.Sh.I
	5:22	II.Tr.I
	5:41	II.Sh.E
	7:43	II.Tr.E
	14:18	I.Sh.I
	15:21	I.Tr.I
	16:30	I.Sh.E
	17:31	I.Tr.E
Feb. 13	0:51	III.Ec.D
	3:26	III.Ec.R
	5:22	III.Oc.D
	7:24	III.Oc.R
	11:25	I.Ec.D
	14:39	I.Oc.R
	22:19	II.Ec.D
Feb. 14	2:50	II.Oc.R
	8:47	I.Sh.I
	9:49	I.Tr.I
	10:58	I.Sh.E
	11:58	I.Tr.E
Feb. 15	5:53	I.Ec.D
	9:06	I.Oc.R
	16:28	II.Sh.I
	18:35	II.Tr.I
	18:58	II.Sh.E
	20:55	II.Tr.E
Feb. 16	3:15	I.Sh.I
	4:16	I.Tr.I
	5:27	I.Sh.E
	6:25	I.Tr.E
	14:46	III.Sh.I
	17:19	III.Sh.E
	19:05	III.Tr.I
	21:04	III.Tr.E
Feb. 17	0:21	I.Ec.D
	3:33	I.Oc.R
	11:37	II.Ec.D
	16:02	II.Oc.R
	21:43	I.Sh.I
	22:43	I.Tr.I
	23:55	I.Sh.E
Feb. 18	0:52	I.Tr.E
	18:50	I.Ec.D
	22:00	I.Oc.R
Feb. 19	5:45	II.Sh.I
	7:46	II.Tr.I
	8:15	II.Sh.E
	10:06	II.Tr.E
	16:11	I.Sh.I
	17:09	I.Tr.I
	18:23	I.Sh.E
	19:19	I.Tr.E
Feb. 20	4:49	III.Ec.D
	7:23	III.Ec.R
	8:59	III.Oc.D
	10:58	III.Oc.R
	13:18	I.Ec.D
	16:27	I.Oc.R
Feb. 21	0:54	II.Ec.D
	5:13	II.Oc.R
	10:40	I.Sh.I
	11:36	I.Tr.I
	12:51	I.Sh.E
	13:46	I.Tr.E
Feb. 22	7:46	I.Ec.D
	10:54	I.Oc.R
	19:03	II.Sh.I
	20:58	II.Tr.I
	21:32	II.Sh.E
	23:18	II.Tr.E
Feb. 23	5:08	I.Sh.I
	6:03	I.Tr.I
	7:20	I.Sh.E
	8:13	I.Tr.E
	18:43	III.Sh.I
	21:15	III.Sh.E
	22:38	III.Tr.I
Feb. 24	0:35	III.Tr.E
	2:15	I.Ec.D
	5:20	I.Oc.R
	14:11	II.Ec.D
	18:23	II.Oc.R
	23:36	I.Sh.I
Feb. 25	0:30	I.Tr.I
	1:48	I.Sh.E
	2:39	I.Tr.E
	20:43	I.Ec.D
	23:47	I.Oc.R
Feb. 26	8:20	II.Sh.I
	10:08	II.Tr.I
	10:49	II.Sh.E
	12:28	II.Tr.E
	18:05	I.Sh.I
	18:56	I.Tr.I
	20:16	I.Sh.E
	21:06	I.Tr.E
Feb. 27	8:47	III.Ec.D
	11:20	III.Ec.R
	12:30	III.Oc.D
	14:28	III.Oc.R
	15:11	I.Ec.D
	18:14	I.Oc.R
Feb. 28	3:28	II.Ec.D
	7:33	II.Oc.R
	12:33	I.Sh.I
	13:23	I.Tr.I
	14:45	I.Sh.E
	15:32	I.Tr.E
	20:59	II.Oc.D
	23:55	II.Ec.R
	14:42	III.Ec.R
	20:42	I.Oc.D

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

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.

How Are Crater Rims Made?

The circular rim crests that surround big lunar impacts tell interesting stories.

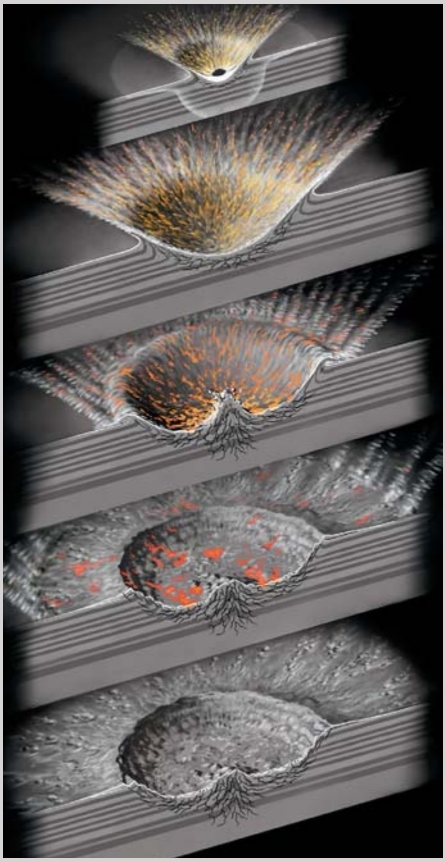
Without rims, craters would just be holes in the ground. Rims provide visual drama. As the first rays of sunlight hit a majestic crater such as Copernicus, its elevated circumference brightly reflects the morning light — while the interior floor remains in inky blackness. A little later, as the Sun rises higher, we delight in long shadows dramatically cast across the floor by individual peaks along the enclosing rim.

Craters form when mountain-size fragments of cosmic debris slam into the Moon's surface. Their high velocity and great mass excavate huge volumes of crustal rock. This material is forcefully ejected, spreading debris near and far. In fact, fragments of lunar rock from the Copernicus impact probably lie buried in billion-year-old sediments here on Earth.

Some ejecta, shot out of the forming crater nearly vertically, land in and around the excavated hole. This fallback builds up at least part of a crater's rim. Another component is the uplift of the preexisting rock layers. The impact's powerful shock wave compresses the surrounding rock, pushing it sideways and upward out of the crater. This uplift tilts the target rock to a higher elevation than it had originally.

For a simple lunar crater, typically less than 10 to 15 kilometers across, the preexisting rock layers are strong enough to resist collapsing into the relatively small excavated hole. At impact sites that puncture mare plains, these craters display upwarped exposures of the previously flat-lying lava flows on their inner walls, capped by fallback ejecta. Most of these are too small to clearly see their interiors telescopically, but try examining **Chladni** (13 km) and **Pickering** (15 km).

Early studies showed that, for simple, bowl-shaped craters, structural uplift and the overlying blanket of fallback debris each account for about 50% of the rim height. But recent investigations by Tim Krüger and Thomas Kenkmann (Albert-Ludwigs-University, Frieburg, Germany) show that this is not the case for larger, complex excavations.



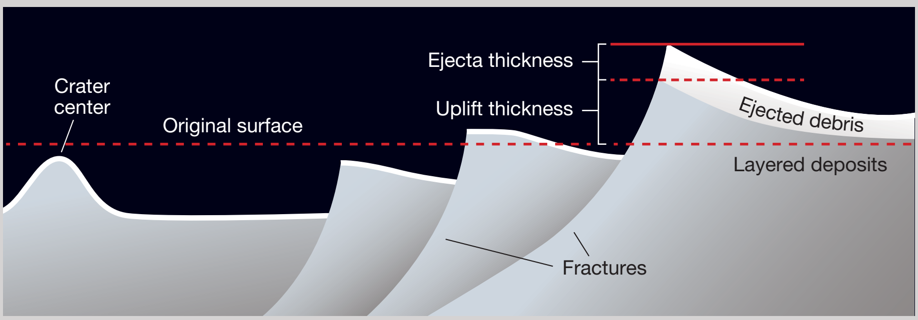
◀ Big craters are more complex than their simple, bowl-shaped siblings. The initial (*transient*) cavity slumps inward, forming terraces and enlarging the crater's width. This inward slumping and upward rebound of deeper rocks form central peaks in craters larger than 15 km.

▼ A recent analysis shows that the rims of big, complex craters mostly involve uplift of the original surface, with ejected debris adding only about 30% to the total height.

Slope-Shifting in Big Craters

During especially powerful impacts, the outward-spreading shock wave excavates a large *transient cavity* with steep slopes and a high rim. But near the cavity's edge, the preexisting rock layers are strongly shaken and fractured, and they collapse into the hole along a series of concentric faults, creating ring-shaped terraces. You can easily see this geologic staircasing in large, fresh craters such as **Copernicus** and **Tycho**.

The terraces don't result from a



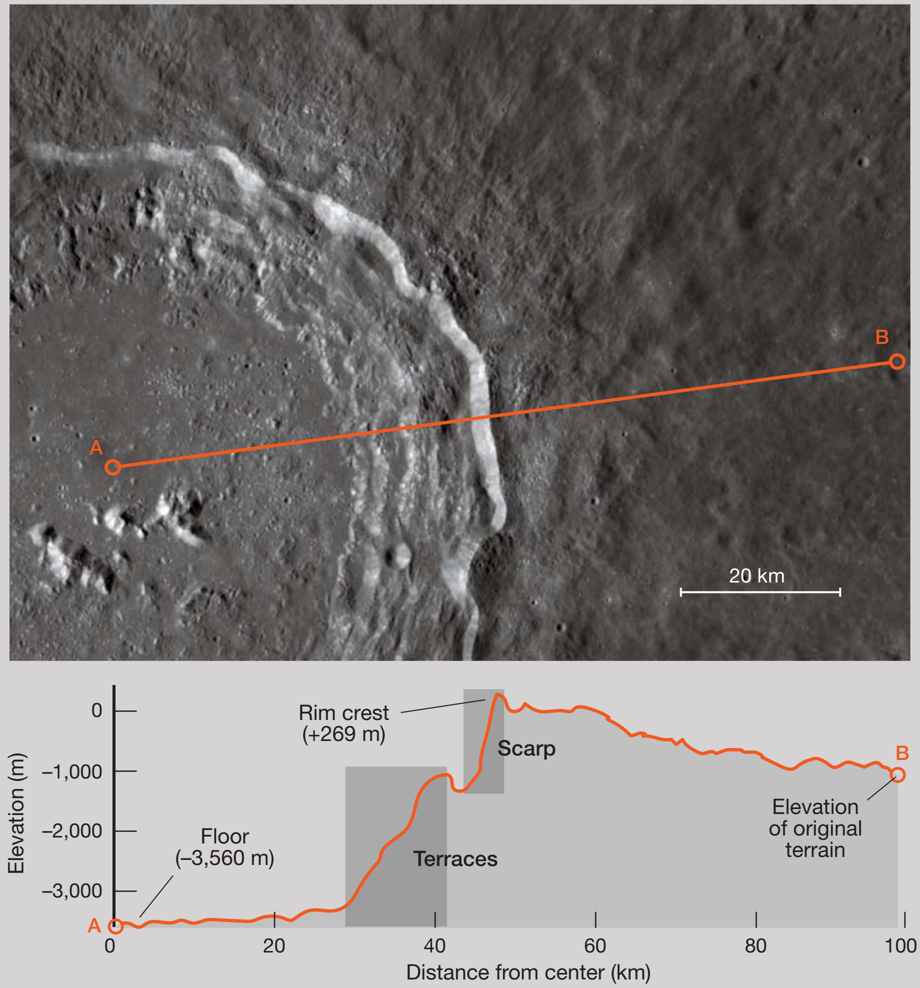
IMPACT SEQUENCE: DON DAVIS; CRATER PROFILE: *S&T*: LEAH TISCIONE, SOURCE: TIM KRÜGER & THOMAS KENKMANN strictly vertical drop; instead, structural failure occurs along curved faults that slide previously flat-lying rocks downward into the hole. In the process, the slabs rotate so that their surfaces end up tilting downward away from the crater's center and toward its rim. These outward-facing tilts are easy to recognize in high-resolution Lunar Reconnaissance Orbiter (LRO) images, which show where impact-produced molten rock fell as a liquid onto a terrace, flowed downhill, and collected in ponds against the walls of adjacent terraces.

The inward slumping of terraces makes the final diameters of big craters 30% to 40% larger than their transient cavities were initially. And because the thickness of ejected debris tapers outward from its maximum at the transient cavity's rim, it's not as thick at the final, terraced-enlarged rim crest. This means that the contribution of fallback ejecta to the rim's height should be less than 50% for large craters.

To test this assumption, Krüger and Kenkmann used high-resolution images from LRO and the Japanese Kaguya lunar orbiter to look in detail in crater walls. They calculated the amount of structural uplift of preexisting rocks and measured the thickness of ejecta at the rim for 11 craters, ranging in size from Bessel (16 km) to Pythagoras (130 km).

As an example, they found that the final rim of 41-km-wide Bürg shows about 850 meters of structural uplift and 300 m of overlying ejecta. This ratio fit the pattern seen in all of the craters studied: ejecta constitutes about 30% of a rim's height, and uplift makes up the other 70%.

So now that you know how crater rims are made, can you observe any of these details? Start by looking at Copernicus under a high Sun, when just a narrow line of shadow hugs the rim. Just below the rim crest is a steep, bright scarp, 1½ km high, and below it are the terraces that widened the original diameter of the crater. This scarp includes both uplifted preexisting surface and the ejecta that rained down on top of it. Interestingly, the bottom of the scarp is the same elevation as the surrounding, pre-impact terrain well beyond the rim.



▲ This topographic cross-section shows that Copernicus is nearly 4 km deep from its floor to the crest of its rim. The dramatic scarp just inside its rim crest (bright in the image) is 1½ km high.

NASA / ARIZONA STATE UNIV.

For a real challenge, observe **Bürg**. It's on the lava-covered floor of **Lacus Mortis** and less than half the diameter of 93-km-wide Copernicus. With high power you just might notice that the uppermost part of Bürg's rim scarp looks brighter than the bottom two-thirds. The bright material is ejecta, and below it is the structural uplift of the mare lavas. These brightness differences make sense, because lavas are dark, but pulverized ejecta (which makes rays) is highly reflective. High-quality amateur images show the same brightening atop the north rim scarp of Plato — though I have never observed it visually.

To see these rims more in profile, observe large, fresh craters near the limb. You can gaze across the near rims and floors of the limb-hugging craters **Moretus**, **Pythagoras**, **Langrenus**, and **Zucchius** to the bright rim-crest scarps and the jumble of terraces below on their far walls. Compare the narrow extent of the scarps — typically they're 1 to 1½ km high — and the greater heights of the terraces. This shows how much farther craters excavate below the original terrain than they pile up ejecta on their rims. And it reminds us of the powerful forces that shaped the Moon's heavily battered face.

■ **CHUCK WOOD** would prefer to study the rim scarps of lunar craters by repelling down one.
For more information: www2.lpod.org.

It's All About the Ears

A few short hops lead from a carbon star to a planetary nebula and a pair of interacting galaxies.

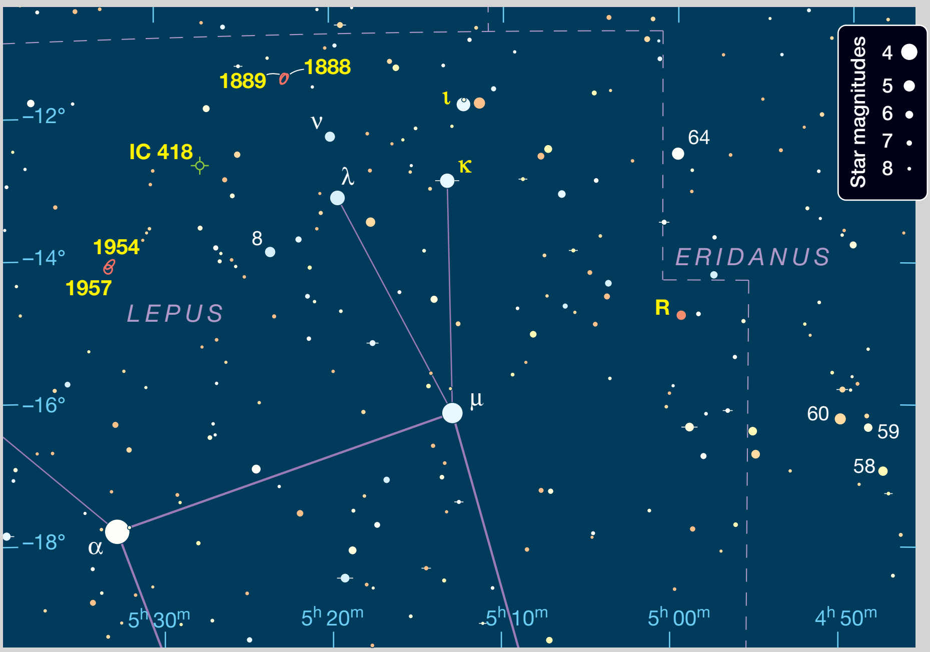
▲ Johann Bayer's 1603 celestial atlas *Uranometria* contains 51 star charts engraved by Alexander Mair, a German artist who, like Bayer, lived in Augsburg. Mair based his charts on woodcuts carved by Jacob de Gheyn for Hugo Grotius's edition of *Aratus*, published in Leiden in 1600.

LEPUS DRAWING: ETH-BIBLIOTHEK ZüRICH / ALTE UND SELTENE DRUCKE

On a cold winter's evening rich with brilliant stars, dim Lepus, the Hare, shyly crouches beneath Orion, hoping to be overlooked by the mighty hunter. Among the stars used to place the Hare's image in the sky, four of the faintest mark his ears as seen on our image of Lepus from Johann Bayer's unprecedented 1603 atlas, *Uranometria*. They are ι, κ, λ, and ν, and around them lie the deep-sky wonders for this month's sky tour. As lagomorph lovers are fond of saying, it's all about the ears.

The jumping-off point for our foray is **Kappa (κ) Leporis**, which itself is worth a look along the way. Kappa is a double system composed of two white stars. Their magnitude difference and close quarters beg high magnification for a good look, somewhere around 200×, depending largely on your viewing conditions. The fainter star sits atop (north of) its primary.

About three-fifths of the way from Kappa Leporis to 60 Eridani we encounter **R Leporis**, also known as Hind's Crimson Star. Its striking color was first noted by John Russell Hind, who came across it while comet-sweeping in October 1845. He wrote, "At that time it was of the most intense crimson, resembling a blood-drop on the black ground of the sky." In a letter he penned to William Henry Smyth in 1850, Hind avers, "This is by far the most deeply-coloured of any that I have yet seen, and in striking contrast with a beautifully white star preceding it one minute."



R Leporis is a carbon star, or more specifically, a cool red giant with carbon molecules in its atmosphere. This carbon soot scatters what little blue light the star's photosphere emits, so only ruddy hues make their way to the observer's eye. Most carbon stars are variable, and R Lep pulsates with a period of about 445 days and an overall magnitude range of 5.5 to 11.7. It reached minimum light last October, and maximum is expected in late May or early June. This gives us a good observing window with R Lep likely to be between magnitude 8 and 9 during February, if the last cycle is any indication. The star should be bright enough to find without difficulty, yet dim enough to show off its fiery hue. A carbon star looks less red to your eye when it's bright. While visiting Hind's Crimson Star, compare it with Hind's "beautifully white star," 14.6′ (one minute of right ascension) west.

Now we'll move on to the planetary nebula **IC 418**, which sits at the sharp end of a 1.9° long, eastward-pointing isosceles triangle that it forms with two of Lepus' ear stars — Lambda (λ) and Nu (ν). Florida amateur Vic Menard nicknamed IC 418 the Raspberry, which refers to the unusual color some observers see in this nebula. Through my 130-mm refractor at 23×, I see the bright central star wearing a thin, pinkish-red fringe. At 63× there is less color, but the nebula is more obvious. My 10-inch reflector at 70× displays a hue that I'd call dusty rose. At 118× IC 418 is small, oval, and annular. It's still garbed in some indistinct shade of red, but when I use higher powers the color starts to look bluish grey or is lost altogether. The oval annulus is better seen at 220× and rakishly leans north-northwest. Averted vision (the practice of directing your gaze a bit to one side of a dim object so that its light will fall on a more sensitive area of your eye's retina) makes the nebula seem considerably brighter.

Professional astronomers dubbed IC 418 the Spirograph Nebula, because the interwoven filaments seen on its Hubble Space Telescope image resemble patterns that can be drawn with a child's toy marketed as Spirograph. You can play with a similar pattern-generator online at **http://nathanfriend.io/inspirograph/**. Strictly speaking, the Hubble image doesn't show true colors, but rather maps light emitted by different elements. Red represents singly ionized nitrogen (N II), which dominates the relatively cool outer region of the nebula, and blue shows doubly ionized oxygen (O III), which reigns in the hot interior of the nebula. Hydrogen-alpha (Hα) emission is mapped as green, and it modifies the hues seen where red gives way to blue. In reality, both the nitrogen and hydrogen lines singled out by their filters are nearly identical shades of red, while the chosen oxygen line glows green.

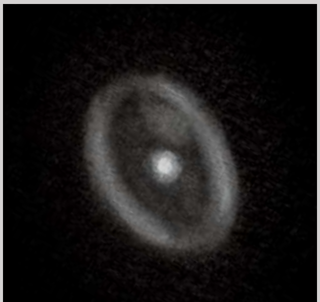
Many galaxies inhabit Lepus, and an interacting pair made up of **NGC 1888** and **NGC 1889** resides 1° northeast of Nu Leporis. I can just spot the brighter galaxy, NGC 1888, in my 130-mm scope at 48×. At 102×, the galaxy appears slender and about 1½′ long north-northwest to south-southeast. It grows slightly brighter toward the center. The 10-inch scope shows this strip of light surrounded by a faint, thin halo. Little NGC 1889 finally makes its appearance through the 10-inch at 220×. Its faint roundish spot harbors a starlike nucleus and nuzzles the larger galaxy's east-northeastern flank near its core. This close-knit pair lie about 110 million light-years away from us.

Sweeping southeast from Lambda, you'll come to a 5th-magnitude star that slightly outshines Nu, yet was never granted a Greek-letter Bayer designation. Instead it's known as 8 Leporis, according to its Flamsteed number. As popular as Flamsteed numbers are, they weren't actually used in Flamsteed's catalog or atlas, which were published after his death. To see where they came from, let's wind back the clock. As president of the Royal Society, Isaac Newton felt that the Astronomer Royal, Flamsteed, was needlessly slow when it came to the publication of his star catalog. Having a manuscript of the work, Newton encouraged Edmond Halley to edit it, and this unapproved edition

Rabbit Ears

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Kappa (κ) Lep	Double star	4.4, 6.8	2.2″	5^h 13.2^m	–12° 56′
R Lep	Variable star	5.5–11.7	—	4^h 59.6^m	–14° 48′
IC 418	Planetary Nebula	9.3	14″ × 12″	5^h 27.5^m	–12° 42′
NGC 1888	Interacting galaxy	11.9	3.0′ × 0.8′	5^h 22.6^m	–11° 30′
NGC 1889	Interacting galaxy	13.1	0.7′ × 0.5′	5^h 22.6^m	–11° 30′
NGC 1954	Galaxy	11.8	4.2′ × 2.2′	5^h 32.8^m	–14° 04′
NGC 1957	Galaxy	13.9	1.2′ × 1.2′	5^h 32.9^m	–14° 08′
Iota (ι) Lep	Double star	4.5, 9.9	12.0″	5^h 12.3^m	–11° 52′

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.



▲ In most backyard scopes, teasing out the oval shape or a hint of color can be considered an observing victory with IC 418. It takes aperture and patience to reveal the annularity: when viewed through a 20-inch f/4.5 Newtonian reflector, the ring of nebulosity surrounding IC 418's central star is more apparent.

▼ This Hubble Space Telescope image of IC 418, captured with the Wide Field Planetary Camera 2, shows emission from ionized nitrogen (mapped to red), hydrogen (green), and ionized oxygen (blue).

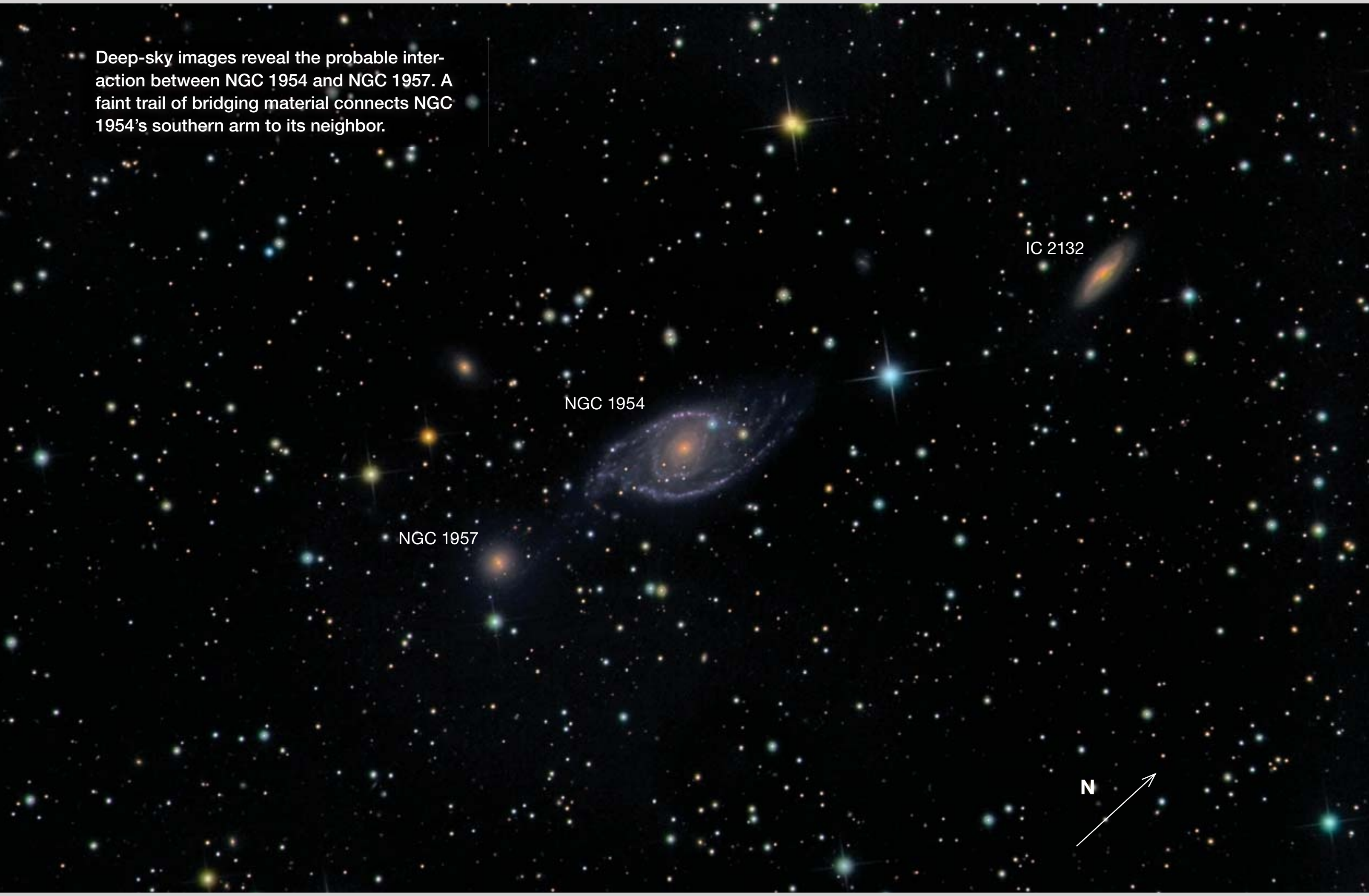
SKETCH: UWE GLAHN; SPIROGRAPH NEBULA: NASA / HUBBLE HERITAGE TEAM (STSCI / AURA) was published in 1712. Flamsteed was incensed, and he managed to procure and burn most of the copies — but those that survived include a column where Flamsteed's stars are numbered. How strange that numbers known worldwide today spring from the spurious edition that Flamsteed reviled!

With that historical detour behind us, let's use 8 Leporis to help us find our next galaxy, **NGC 1954**, which lies 2.3° east of the star. A roughly staple-shaped group of twenty 7th- to 9th-magnitude stars fills much of the space between 8 Lac and NGC 1954, and you can follow them most of the way to the galaxy by climbing up the staple's back and down its eastern leg. Through the 130-mm refractor at 48×, NGC 1954 shares the field of view with the orange star at the point of the staple's leg. At that magnification, the galaxy is a very faint, oval glow with a 10th-magnitude star off its northwestern tip. At 117× a faint star adorns the galaxy's edge, north-northwest of center. The 10-inch reflector at 220× draws out a second star, west-northwest of the first and beyond the pallid face of the galaxy. Within the galaxy a small, brighter core hosts a starlike nucleus. The field of view also acquires a bonus galaxy, **NGC 1957**. Its little round form sits off the opposite end of NGC 1954 as the 10th-magnitude star and at the same separation from it. Boosting the power to 308×, I see NGC 1957's tiny brighter heart. These two galaxies also seem to be related to each other and dwell about 140 million light-years away from us.

Let's finish with the only ear star we've not yet employed, **Iota (ι) Leporis**, a double whose components you can split through any telescope at low to medium magnifications. The brighter star sparkles diamond white, but its companion to north-northwest is much dimmer, making its yellow hue a challenge to detect. Can you?

Although our sky tour has been all about the ears, it can't truly be appreciated until the eyes have it.

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



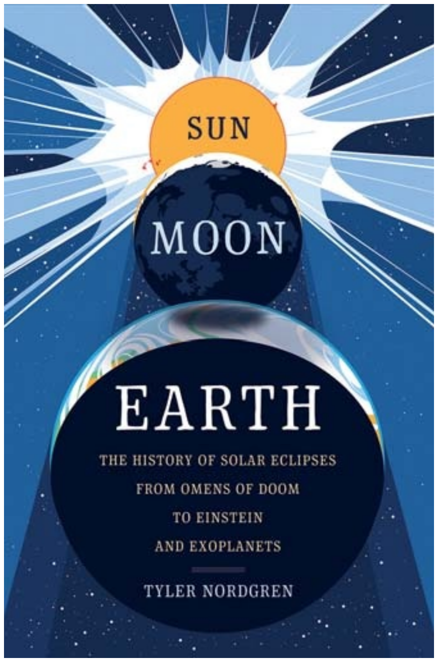
Deep-sky images reveal the probable interaction between NGC 1954 and NGC 1957. A faint trail of bridging material connects NGC 1954's southern arm to its neighbor.

KENT BIGGS

Totality Changes Everything

SUN MOON EARTH: The History of Solar Eclipses from Omens of Doom to Einstein and Exoplanets

Tyler Nordgren
Basic Books, 2016
264 pages, ISBN 978-0-465-06092-4
$26.99, hardcover.



ASTRONOMER TYLER NORDGREN (University of Redlands) has a knack for connecting people with the sky. Since 2005, he's been a member of the National Park Service (NPS) Night-Sky Team, working with NPS Rangers to develop educational programs on dark-sky preservation and astronomy for park visitors. His first book, *Stars Above, Earth Below: A Guide to Astronomy in the National Parks*, showed readers how to explore astronomy and planetary science via familiar and much-loved landscapes. And, thanks to his whimsical line of "astronomy travel" posters (**tylernordgren.com**), inspired by the aesthetics of New Deal WPA National Park travel posters, the skies above look both welcoming and exotic to new astronomers — a manageable space, but still one worth visiting. His work combines to turn our fear of darkness into a heady anticipation of night-time wonders.

Nordgren's astronomy outreach has always stressed friendliness and accessibility, so it comes as no surprise that his new book, *SUN MOON EARTH: The History of Solar Eclipses from Omens of Doom to Einstein and Exoplanets* is as entertaining as it is educational. On August 21, 2017, millions of Americans (and thousands of international visitors) will have the chance to see their first total solar eclipse. The path of totality stretches across the United States, from Oregon to South Carolina, making this the most easily viewable total solar eclipse in most of our lifetimes. Nordgren uses August's event as a touchstone in this broad-reaching history of astronomy, meandering across centuries and cultures, but always coming back to the upcoming eclipse. Total solar eclipses are magnificent spectacles, but as Nordgren demonstrates, they're much more than that: throughout human history, we've used them to evaluate and redefine our place in the universe. Will 2017's be any different?

There's plenty of science in *SUN MOON EARTH*. Nordgren shows how the Greeks used eclipses to measure the size of the cosmos, how 19th-century scientists worked out the Sun's composition thanks in part to observations made during total solar eclipses, and how 20th-century astronomers used a total eclipse to test Einstein's theory of relativity — all important topics that reveal how studying the Sun-Moon-Earth relationship continues to change our view of the world. But the real strength of the book is Nordgren's wedding of eclipse science to the emotional side of totality. Many of us are self-proclaimed "corona-philes," or eclipse chasers, watching the calendar and waiting for our next chance to see a total solar eclipse. Arguably, it's the feelings of wonder and awe at totality that keep us in the hunt, not the science of Relativity. Yet affect and the cultural practices arising from it are often dismissed by astronomers, derided as mere superstition. Nordgren embraces the emotions unleashed by totality — uneasiness, euphoria, happiness, fear — and shows how they push against the boundaries of knowledge.

SUN MOON EARTH consists of eight chapters and an introduction. Each chapter discusses a different historical problem, but the book as a whole follows a long narrative arc, from Nordgren's first (missed) attempt at total eclipse viewing in 1979, to his next try in August 2017, and on into a far distant future. Nordgren clearly explains eclipse mechanics, providing a good introduction (or refresher course) for anyone a little hazy on the relationship between the Sun and Moon shadows. He also provides a short guide — including safety tips — to viewing the upcoming total eclipse. If you've been trying to get your friends and family excited about this year's event, give them this book. They'll come away from reading it with a good understanding of the science of eclipses while undoubtedly being infected by Nordgren's enthusiasm. And don't be surprised if they turn into eclipse chasers, too. As Nordgren points out, totality changes everything.

■ Observing Editor **S. N. JOHNSON-ROEHR** will be watching the August 2017 total solar eclipse from a front yard in central Oregon.

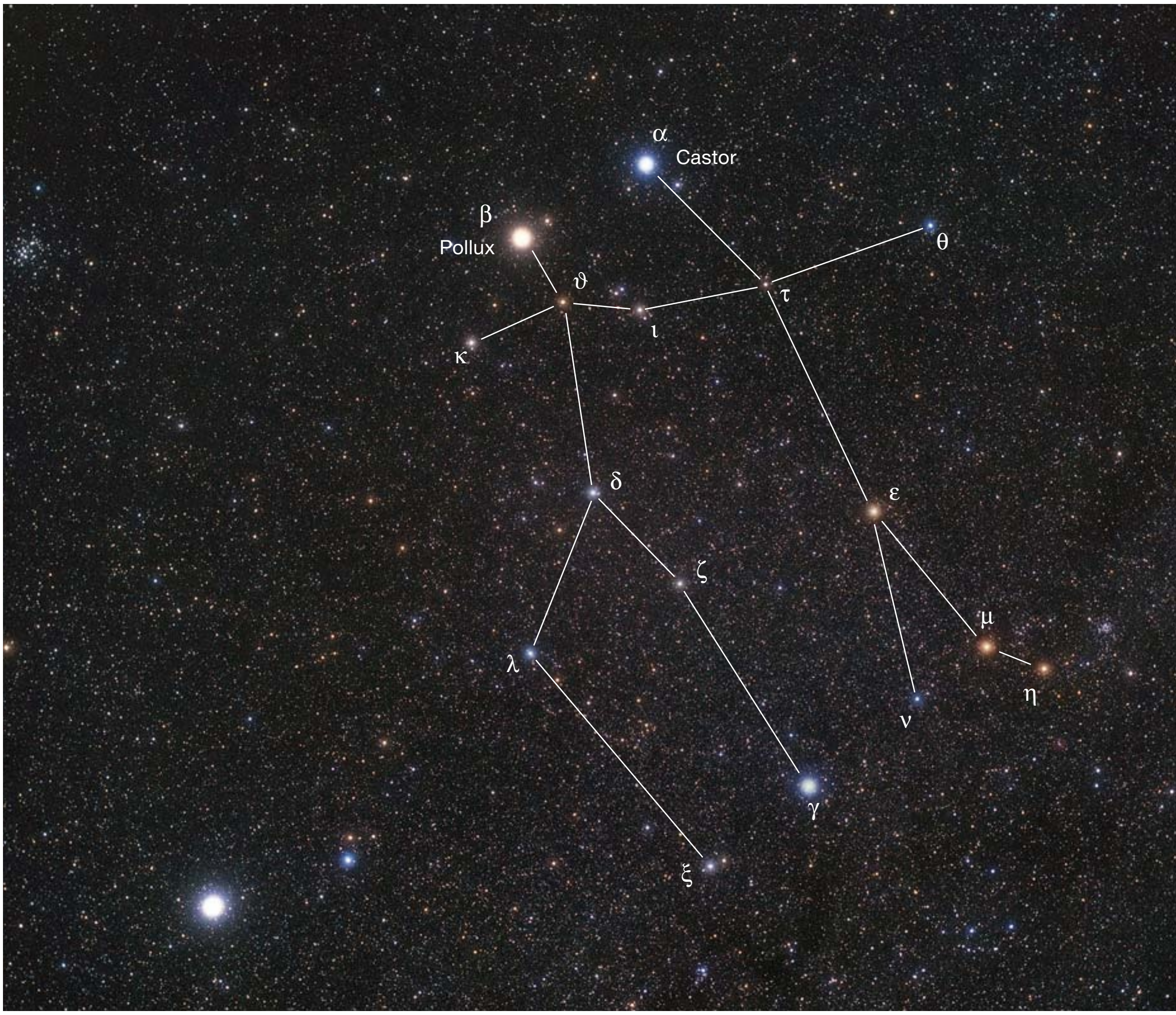
Gemini City Sights

The deep-sky treasures scattered across the Twins look great in backyard scopes.

Move over Orion!

Gemini, the Twins, is an alluring constellation, too. Join me in my suburban yard on a clear winter's night as I examine these celestial siblings from head to toe, first with the naked eye, then with a small telescope and binoculars.

BABAK TAFRESHI



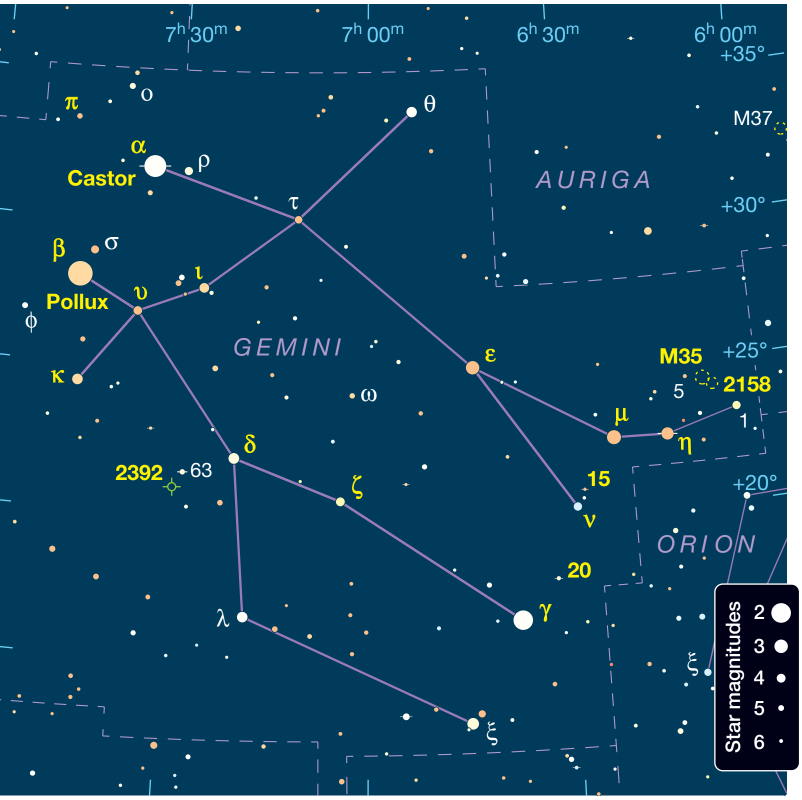
Taking the Twins' Measure

Ranked 30th in size among the 88 official constellations, Gemini covers a middle-of-the-pack 514 square degrees of sky. Within that area are two dozen stars better than magnitude 5.0, 16 of which connect to make side-by-side stick-figures of the twin boys. If we connect only the eight best dots, though, we get something simpler: a 20°-long, rough-hewn rectangle slanted northeast-southwest.

Atop the rectangle are the bright stars symbolizing the boy's heads: 1.9-magnitude **Alpha (α) Geminorum**, known as Castor; and 1.2-magnitude **Beta (β)**, or Pollux. (Gemini is one of several constellations in which Alpha is dimmer than Beta.) Partway down the rectangle's left side are 3.5-magnitude **Delta (δ)**, or Wasat, and 4th-magnitude **Zeta (ζ)**, or

▲ **THE LUMINARIES** Alpha (α) Geminorum (Castor) and Beta (β) Geminorum (Pollux) mark the heads of Gemini's Twins. Despite their apparent proximity, the stars have no physical relationship: Castor is 52 light-years away while Pollux lies just 34 light-years distant.

RIGHT: GETTY IMAGES; TOP: AKIRA FUJII



Mekbuda. The bottom-left corner is held by 2nd-magnitude **Gamma (γ)**, also called Alhena. Along the rectangle's lower-right side are 3rd-magnitude **Epsilon (ε)**, **Mu (μ)**, and **Eta (η)** — respectively: Mebsuta, Tejat, and Propus. These eight Gemini markers all merit closer inspection.

Propus, for example, is a long-period variable star that fluctuates between 3rd and 4th magnitude in a semi-regular fashion over about eight months. You won't notice any change in Propus from one night to the next, but give it a glance once a month. When Propus reaches maximum, it's almost as prominent as Mu to the east. At minimum, it's nearly as faint as 4.2-magnitude 1 Geminorum to the west. And keep your eye on Mekbuda. A classic Cepheid variable star, Mekbuda cycles between magnitudes 3.6 and 4.2 every ten days. At its height, Mekbuda rivals Wasat; at bottom, it's no brighter than 1 Gem.

Do you have binoculars? My 7×50s reveal a wonderful range in color among the Gemini Eight. Castor, 52 light-years away, gleams white tinged with blue. Pollux, at 34 light-years the closest star of the set, exudes a golden radiance. Wasat (60 light-years) is cream-colored, while Mekbuda (1,200 light-years) is straw-yellow. Alhena (110 light-years) is as white as snow. Mebsuta (800 light-years), Tejat (230), and Propus (400) are all orange.

But there are more stellar splendors here. Northeast of Castor, 5th-magnitude **Pi (π)** is dimly reddish. South and west of Pollux are 3.6-magnitude **Kappa (κ)**, sunny yellow; 4.0-magnitude **Upsilon (υ)**, ruddy-orange; and 3.8-magnitude **Iota (ι)**, deep yellow. Finally, two-thirds of the way from Alhena to Tejat, 4.1-magnitude **Nu (ν)** seems vaguely bluish. My 4¼-inch f/6 Newtonian reflecting telescope confirms the blue tint; indeed, it intensifies all these colors.

Seeing Double in the Twins

A telescope will also confirm that Gemini has double stars aplenty. Most show in my scope at just 27×. Nu is one — it comes with a wide 8.0-magnitude companion star 112″ (arcseconds) approximately northward. In the same low-power field, northwest of Nu, 6.7-magnitude **15 Geminorum** holds an 8.2-magnitude secondary 25″ to its south. (Don't be misled by the 6th-magnitude star lying halfway between 15 Gem and Nu.) And near Alhena (Gamma), **20 Geminorum** is a pretty pair boasting 6.3- and 6.9-magnitude components 20″ apart.

Still at 27×, the scope shows the wide companions of three more bright stars. Mekbuda oversees a 7.6-magnitude companion 101″ north. Mebsuta has a 9.6-magnitude outlier 111″ eastward, and Castor sports a 9th-magnitude red dwarf, called Castor C, 71″ southward. This wee star is an easy catch, but I must increase the power to perceive its fiery hue. In truth, Castor C is a pair of red dwarfs that look single no matter how high the magnification. Fortunately, the extra power produces a much more impressive prize — Castor itself.

Castor is a marquee binary star. Its 1.9- and 3.0-magnitude components, 4.8″ apart, divide beautifully in my trusty star-splitter at 93×. (Like Castor C, both Castor A and Castor B are indivisible pairs. In all, Castor is a six-sun system!) After ogling Castor, I drop southward to 3.5-magnitude Wasat, which guards an 8.2-magnitude companion only 5.5″ to the southwest. Wasat is one tough twosome, but I can resolve it at 186×. Splitting this tight, strongly unequal binary is always satisfying.

▲ **FUZZ AND FLUFF** The visual appearance of the planetary nebula NGC 2392 depends somewhat on aperture and filters. In a 4-inch scope at moderate power, you'll see a bright blob that's slightly too thick to be a star. Upping the magnification and adding an O III filter to the eyepiece will give you a better chance at distinguishing the shell of nebulosity from the planetary's central star.

JIM RADA AND STUDENTS / ADAM BLOCK / NOAO / AURA / NSF

Famous Disappearing Act

Wasat is my star-hop gateway to something much deeper. To locate it, I return to 27× and shift less than 2° east-southeast to the 5th-magnitude star 63 Geminorum, then veer south-eastward a further ⅔° to what seems like a faint, delicate double star. The 8th- and 9th-magnitude points of light, 99″ apart, lie north-south. Oddly, the dim southern "star" looks out of focus. I bump up to 50×, but every time I concentrate on that fuzzy southern component, it disappears!

The finicky fuzz is a planetary nebula labelled **NGC 2392**. The term "planetary nebula" is a centuries-old misnomer that endures because in telescopes most of these nebulae appear vaguely planet-like. In reality, a planetary nebula is the ejected atmosphere of a dying star. Our specimen in Gemini is a whopping 4,100 light-years from Earth yet highly photogenic. In certain images NGC 2392 resembles a human face inside the fur-lined hood of a winter parka, an allusion that years ago led to an evocative but archaic name: the Eskimo Nebula. I prefer another popular moniker — the Clown Face Nebula. One observer I know dubs it the Bozo Smudge!

NGC 2392 glows at magnitude 9.2, a full magnitude less than the 8.2-magnitude star guarding it. Officially, it has dimensions of 47″ × 43″, but in the scope at 50× it's essentially a spherical blob punctuated by a 10th-magnitude central star (the "nose" in the face). At 97×, the surrounding nebulosity becomes a more obvious disc, provided I keep looking with averted vision. As mentioned earlier, the fuzz totally disappears when I stare at the central star. Upping the power to 194× (and maintaining averted vision) greatly intensifies both nebula and star. By the way, with each change of eyepiece, I refocus on that convenient 8th-magnitude guardian star.

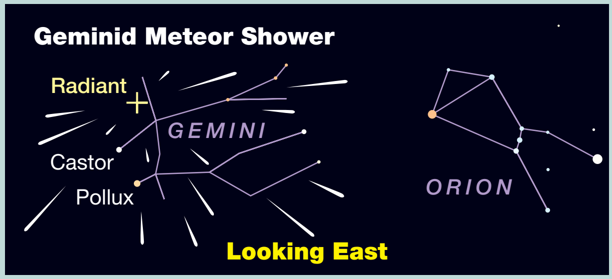
Observing NGC 2392 can be aided by a general light-pollution filter. Better yet are the popular Ultra-High Contrast (UHC) and doubly-ionized oxygen (O III) filters. When the eyepiece in my little Newtonian is O III-equipped, the central star and nearby guardian star are noticeably attenuated, and the background sky is dark. What remains is a high-contrast nebula that actually outshines the guardian star. Even so, a strongly filtered view at high magnification can be difficult to appreciate if, like me, you're observing amid illuminated city surroundings. All you can do is cover your head, cup your hands around the eyepiece, and stare (patiently) with averted vision. Hey, it works!

Best Foot Forward

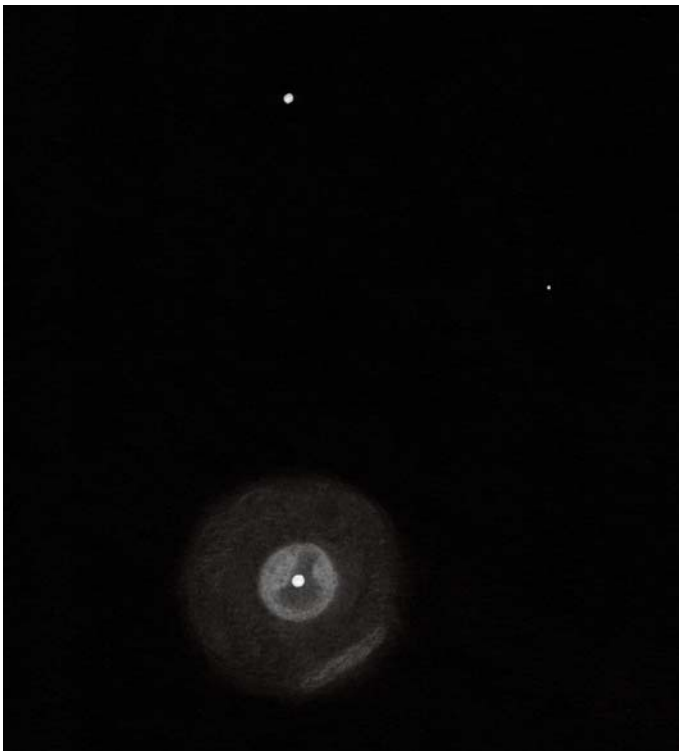
Back to the binoculars. From Wasat I sweep to the southwest, encountering myriad stars as I go. That's because Gemini is crossed by the Milky Way; its center line — the galactic equator — runs beneath the Twins' feet. I stop at Propus ("forward foot") in the richest portion of the Gemini Milky Way. In addition to Propus, the field includes Tejat and 1 Geminorum, plus Gemini's brightest deep-sky object: the open cluster **Messier 35**. About 2,800 light-years away, M35 is populated with a few hundred young, blue-white suns that my binocu-

Gemini Spawns Geminids

Gemini hosts one of the best annual meteor showers, albeit at a wintry time of the year — the night of December 12–13. The prospects for the 2017 Geminid shower are almost ideal, as there will be virtually no interference from moonlight. If you can travel away from city lights, you might spot several dozen "shooting stars" per hour streaking away from the Geminid radiant near Castor. On December 12th, find a dark area and watch for Twins throwing darts!



S&T ILLUSTRATION



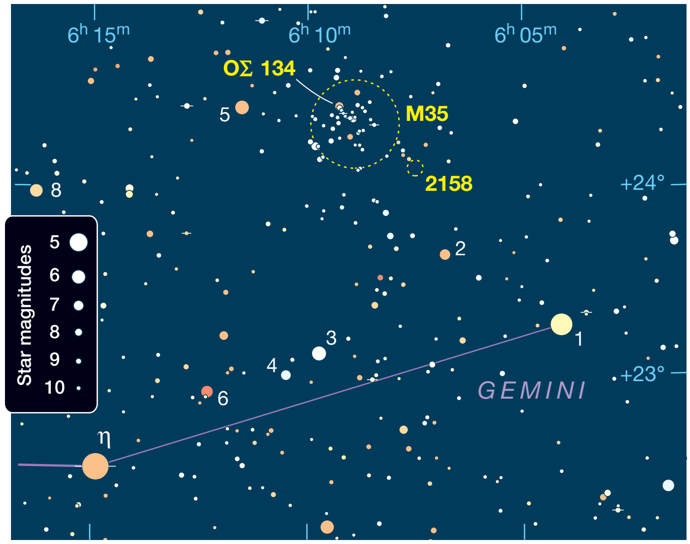
MARTIN SCHOENBALL

▲ **STELLAR CYCLOPS** Backyard astronomers frequently compare NGC 2392 to the head of a clown or lion, but the illusion falls apart in larger scopes. The view through a 10-inch f/5 reflector reveals a bright central star surrounded by attenuating rings of nebulosity.

lars reveal as a tiny, 5.1-magnitude "cloud" 2¼° northwest of Propus and 1½° northeast of 1 Gem.

For a steadier view, I mount the 7×50s on a camera tripod. That permits my averted vision to register M35 as a small but enticing patch of distinctly grainy glitter. A 7.5-magnitude star attends the southeast edge while a dimmer star flickers in the patch's southern half. In the northern half, stars of magnitude 7.4 and 8.2 stare back at me like uneven eyes. The surrounding scene is sprinkled with Milky Way stardust. From Propus I can follow a chain of successively fainter stars curving gently toward the cluster. Another ragged star-chain runs back from M35 until it peters out between Propus and Tejat. Spectacular!

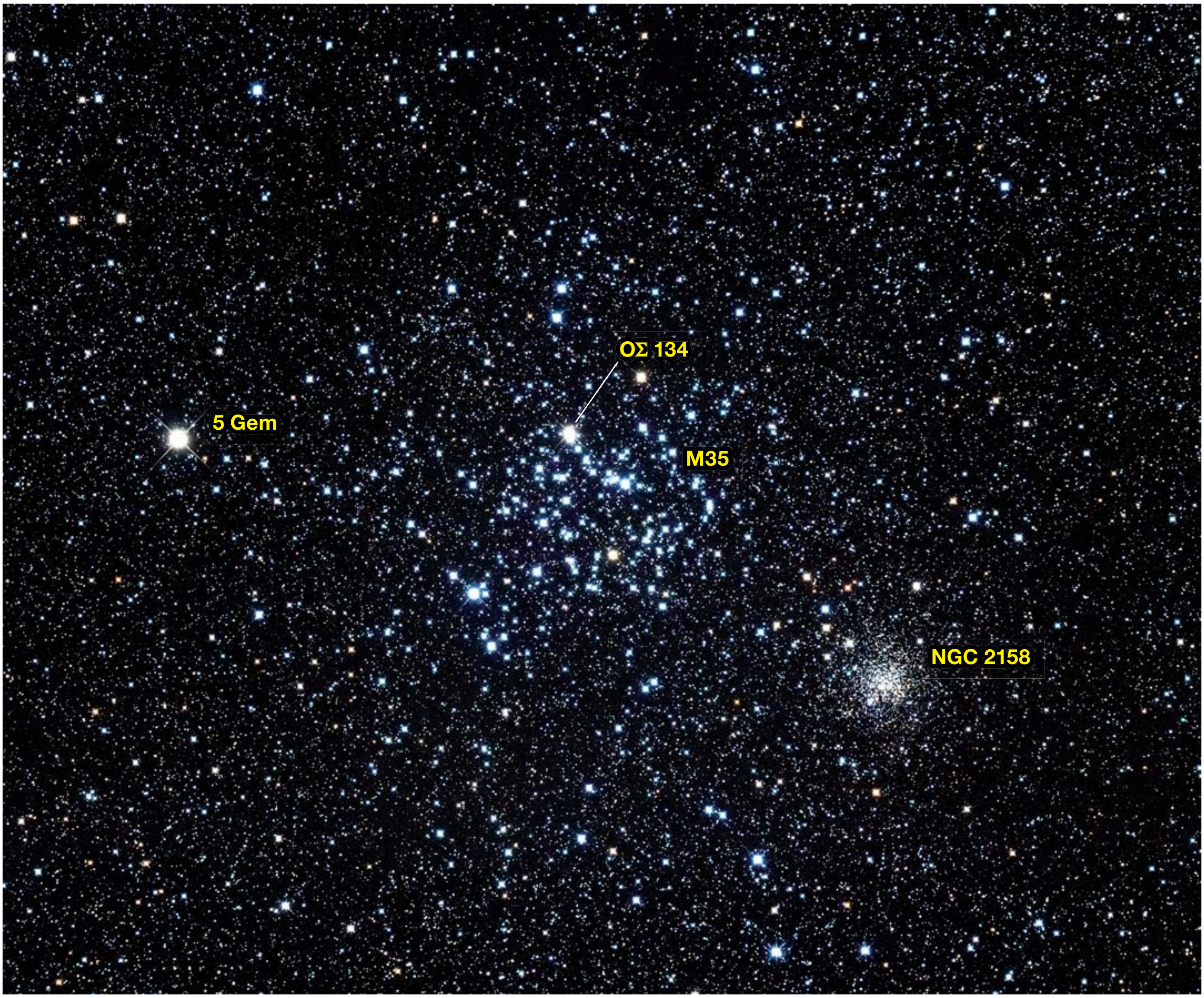
In the telescope, 22× resolves M35 into a compact spangle of stars with one curious highlight: a blurry "arc" stretching across the cluster's northeast quadrant. At 27×, the seemingly solid arc becomes beads on a curved string. Doubling



Gemini Sights

Object	Type	Mag(v)	Size/Sep	RA	Dec.	Distance (l-y)
Alpha (α)	*A1, A5*	1.9, 3.0	4.8″	07^h 34.6^m	+31° 53′	52
Beta (β)	*K0*	1.2	—	07^h 45.3^m	+28° 02′	34
Delta (δ)	*F0, K6*	3.5, 8.2	5.5″	07^h 20.1^m	+21° 59′	60
Zeta (ζ)	*F7–G3, F4*	3.6–4.2, 7.6	101″	07^h 04.0^m	+20° 34′	1,200
Gamma (γ)	*A1*	1.9	—	06^h 37.7^m	+16° 24′	110
Epsilon (ε)	*G8, K–*	3.1, 9.6	111″	06^h 43.9^m	+25° 08′	800
Mu (μ)	*M3*	2.8–3.0	—	06^h 22.9^m	+22° 31′	230
Eta (η)	*M2*	3.2–3.9	—	06^h 14.9^m	+22° 30′	400
Pi (π)	*M0*	5.1	—	07^h 47.5^m	+33° 35′	560
Kappa (κ)	*G8, G4*	3.6, 8.2	7.2″	07^h 44.5^m	+24° 24′	140
Upsilon (υ)	*M0*	4.0	—	07^h 35.9^m	+26° 54′	270
Iota (ι)	*G9*	3.8	—	07^h 25.7^m	+27° 48′	126
Nu (ν)	*B6*	4.1	—	06^h 28.9^m	+20° 13′	500
15 Gem	*K2*	6.7, 8.2	25″	06^h 27.8^m	+20° 47′	575
20 Gem	*F7*	6.3, 6.9	20″	06^h 32.3^m	+17° 47′	364
NGC 2392	Planetary nebula	9.2	47″ × 43″	07^h 29.2^m	+20° 55′	4,100
M35	Open cluster	5.1	28′	06^h 08.9^m	+24° 20′	2,800
ΟΣ 134	*G0*	7.4, 9.1	30″	06^h 09.3^m	+24° 26′	—
NGC 2158	Open cluster	8.6	5′	06^h 07.5^m	+24° 06′	12,000

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.



FRED ESPENAK

▲ **IN GOOD COMPANY** Star clusters — open and globular — make ideal targets for suburban viewers. Small binoculars reveal M35 as a patch of grainy glitter. Turn your 10×50s on this fine open cluster and individual stars will really start to pop into view.

to 54× resolves the beady blur into nine closely spaced stars, the piercing pinpoints at each end being the "eyes" I saw in the steady binocular view. The "eye" at the arc's eastern end is a yellowy 7.4-magnitude star with a 9.1-magnitude bluish companion 30 arcseconds south. This delightful duo is called **Otto Struve 134** (ΟΣ 134).

Increasing to 100×, I see M35 not as a smooth powder of stars but as curls and clumps of twinkling lights separated by irregular voids. In all, I count perhaps four dozen cluster members down to 10th magnitude. Not bad for a suburban site.

The Twins Rule, by Jiminy!

Medium to high magnification also pulls in the miniscule open cluster **NGC 2158**, buried in the Milky Way southwest of M35's outskirts. Although packed with stars, NGC 2158 is nearly five times more distant, glows wanly at magnitude 8.6, and is a pint-size five arcminutes in diameter. In my humble optics, NGC 2158 is a pale mist — like a nebula or comet — that's almost overwhelmed by the starry aggregate next door. I consider M35's ghostly sidekick the toughest test on this small-scope tour. Wait for a moonless night and go for it.

Considering its variety of telescopic targets on offer to city stargazers, Gemini compares favorably to its brilliant, winter-sky neighbors. Even the celestial poster boy, Orion, might agree. March on, you heavenly Twins. I'll catch up to you soon.

■ Contributing Editor KEN HEWITT-WHITE, a stargazer all his life, studies celestial objects with telescopes small and large. A resident of Chilliwack, British Columbia, he observes from his home during the winter and at dark, high-elevation sites during the summer.

Pentax's "Astro" DSLR

The K-3 II DSLR promises to simplify astrophotography by tracking the sky and stacking images, all from within the camera.

▲ The Pentax K-3 II from Ricoh Imaging is a cropped-frame digital single lens reflex camera with a 24-megapixel sensor. It is competitive with other APS-format DSLRs currently offered by Canon and Nikon.

Pentax K-3 II

U.S. Price: $849.95 for camera body, $649.95 for lens

ricoh-usa.com

What We Like:

Very good noise performance
Built-in intervalometer
In-camera star-trail stacking
In-camera average-stacking

What We Don't Like:

Astrotracer only partially accurate
Dark frame did not equal light frames
Dim "Live View" image
Short battery life

ASTROPHOTOGRAPHY is a niche market, and yet we have seen major camera manufacturers introduce DSLRs aimed at amateur astronomers. Its latest offering comes from Ricoh Imaging. Their new Pentax K-3 II contains innovative features of interest primarily to astrophotographers and unique to Pentax.

We tested a unit on loan from Ricoh, along with a 14-mm f/2.8 SMC Pentax-DA lens, a popular focal length for nightscape and Milky Way photography.

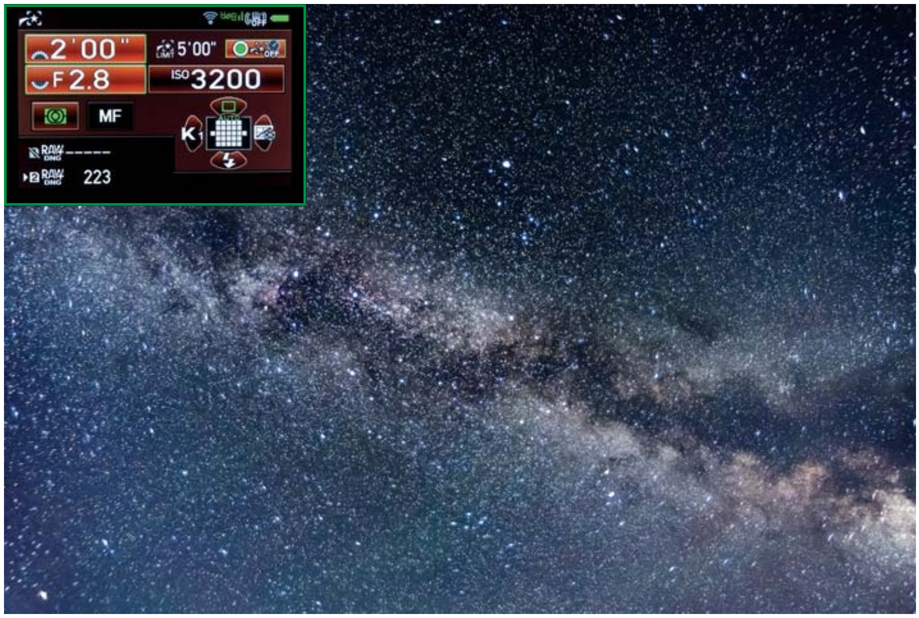
The K-3 II's Unique Features

Unlike the recent "A" model DSLRs from Canon and Nikon aimed at astrophotographers, the Pentax K-3 II does not incorporate a modified infrared-blocking filter that improves the red light response of the camera, important for recording colorful reddish nebulae. The K-3 II is a stock camera suitable for all kinds of photography.

The unique feature it does have that is most widely promoted for astronomers is called Astrotracer. Even with the camera on a fixed tripod, turning on Astrotracer allows the camera to track the sky by slowly shifting its sensor using the motor mechanism normally used for image stabilization.

Less well publicized is the K-3 II's built-in intervalometer, which offers the option of shooting multiple images and then stack them automatically within the camera. This can be used to create either an image with reduced noise by averaging multiple tracked photos, or a star-trail photo by stacking exposures so they accumulate. No need to stack files later in processing — the Pentax K-3 II takes care of it for you.

These features all promise to make it easy for beginners to produce exciting images of the night sky. But did they work? The answer is both yes and no.



▲ With the Astrotracer on, the Bulb mode switches to offer an extended range of exposures, in 10-second increments from 10 seconds up to 5 minutes. No external timer is needed, a very nice feature. This 2-minute exposure at ISO 3200 was taken without any separate tracking mount, just the K-3 II on a tripod with its Astrotracer mode turned on. Stars exhibit trailing only in the lower left and upper right corners. Distorted stars at the corners are from lens aberrations in the 14-mm lens when used wide open at f/2.8.

Astrotracer

The Astrotracer is a unique feature that has been offered on earlier Pentax camera models, but required the additional purchase of an O-GPS1 module. The K-3 II comes with GPS built in. Ricoh's 36-megapixel, full-frame Pentax K-1 also includes GPS and Astrotracer, selling for about twice the price of the K-3 II and targets the serious enthusiast. At just under $1,000, the APS-format K-3 II is more appealing to beginners.

Astrotracer exploits the camera's ability to shift the sensor in tiny increments, and is also used to provide the Pixel Shift function described later. Combined with the camera's knowledge of where it is on Earth (via the GPS) and where it is aimed in the sky (derived from its internal compass and tilt meter), the camera sensor can, in theory, follow the stars no matter where it is aimed — at least for short exposures.

I took pictures on several nights, shooting in all directions, both toward the horizon and up to the zenith, using the 14-mm f/2.8 lens.

The results were mixed. In some directions — and it was not consistent — star trailing was minimal, except often at the frame corners. But in other directions trailing was obvious, and not in the direction of the sky's motion, but usually perpendicular to the east-west motion of the stars. The trailing was never consistent across the frame, indicating the sensor was not turning around the correct rotation point.

▲ When aimed south with Astrotracer on, the Pentax showed considerable trailing, mostly in a north-south direction but inconsistently across the frame. This is a single 2-minute exposure, with the ground blurred due to the camera tracking the sky.

I found that if exposures were kept under two minutes the results could be acceptable, and they were certainly much less trailed than you'd get with a fixed camera. But they never compared well to the pinpoint stars across the entire frame that's possible using a polar-aligned tracking mount.

The Astrotracer will be most useful in nightscape photography for achieving deeper one- to two-minute exposures of the Milky Way without the significant trailing of fixed-camera shots. But for those seeking the sharpest images of rich star fields, the Astrotracer is no substitute for a tracking mount.

Star-Trail Stacking

Another favorite type of nightscape image comes from creating star trails on purpose. The usual technique in the digital age is to shoot many short exposures and then stack them later in post-processing using software. But that takes more work at the computer.

By contrast, the Pentax K-3 II can do it "in camera." It has a special "Interval Composite: Bright" mode that uses its built-in intervalometer to record up to

▲ The K-3 II's Interval Composite: Bright mode created this star trail automatically by shooting and stacking fifty 30-second exposures in the camera, producing a single RAW file as a result.

2,000 frames at shutter speeds up to 30 seconds. At that exposure, setting the interval to 33 seconds fired the shutter as quickly as possible, minimizing gaps in the trails. The Pentax stacks the images on the fly as it shoots.

While this "star-trail" mode worked very well, it produces an image with trails of uniform brightness. Specialized stacking programs and *Photoshop* actions can produce striking "comet trail" effects, with trails that taper in brightness from beginning to end by stacking images at decreasing opacities.

In-Camera Compositing

The Interval Composite stacking mode also has an "Average" option, to mathematically average the images as they stack internally. It's the same technique astrophotographers use to reduce noise. In this case, it's done in the camera.

This function allows shooting and stacking several images to smooth noise in untracked nightscapes, perhaps for an image that contributes the ground in a final composite. In that case, the sky would need to come from a separate single image, possibly taken using Astrotracer. However, Astrotracer cannot be used in conjunction with the Interval Composite mode to internally stack "astrotraced" tracked images.

Images stacked with the Average mode did indeed exhibit much less noise than did single images, identical to what's possible by stacking images later in processing.

While Average mode stacking can't be used with Astrotracer, you can stack multi-minute exposures taken with the camera riding on a conventional tracker. In that case exposures must be timed by an external intervalometer set to take the same number of images as you've told the camera to stack.

With both stacking modes, the result is a single 14-bit RAW file, in either Pentax's proprietary PEF format or in Adobe's more universal DNG format. Pentax is unique in offering DNG as a file format choice.

These in-camera compositing modes worked great. Only Olympus and Sony (the latter through its camera apps) have anything similar; Canon and Nikon do not. However, these functions are buried deep in the K-3 II's menus, and their scant descriptions in the instruction manual make their benefits for night-sky shooting less than obvious. I suspect most beginners would never discover them.

Pixel Shifting

A more publicized feature is what Pentax calls "Pixel Shift," a feature unique to Pentax. It's similar to what astrophotographers do when drizzle-stacking images, only the camera is doing it automatically and precisely. No need to align exposures yourself.

With Pixel Shift turned on the camera uses its electronic, not mechanical, shutter to take four exposures, shifting the sensor by one pixel in each of the four directions. This allows a pixel of each color in the sensor's Bayer filter array to sample every point in the

▲ Using the Interval Composite: Average mode (left) to internally stack eight 30-second ISO 3200 exposures produces a much smoother image than the single 30-second exposure at right.

▲ A rule of thumb is that a camera's realistic upper limit is two ISO settings below the maximum the camera can provide. The Pentax can shoot at ISO 25600 (far left), but in practice ISO 6400 is its top end, producing good image quality in nightscapes where high ISOs are often required.

image. This provides increased resolution, because luminance information is now sampled at each pixel position and not synthesized from a blend of adjacent pixels as usually happens when "de-Bayering" RAW data from the sensor. Noise also goes down, because four images are being merged to create a single image.

In test shots of night scenes, I did find lower noise in pixel-shifted exposures versus single shots, and slightly better resolution. The drawback to using Pixel Shift is that most RAW developing software (such as *Adobe Camera Raw* or *Lightroom*) will produce odd checkerboard artifacts on any parts of the image that moved during the four-shot acquisition. RAW files are also four times the size, up to 130 megabytes each.

For deep-sky photographers, this in-camera drizzle-stacking sounds attractive, but unfortunately it only works on exposures up to the camera's internal maximum of 30 seconds. It doesn't work with Astrotracer shots or on long exposures taken using the Bulb setting. At best, Pixel Shift is useful for nightscapes, for increasing resolution and decreasing noise in the foreground, but only if nothing is moving. It's not for moonlit shots of waterfalls!

Noise Performance

The K-3 II has tiny 3.9-micron pixels, which are great for high resolution but risk high noise. However, I was pleasantly surprised to find that the K-3 II exhibited no worse noise than the 18-megapixel Canon 60Da with its larger 4.4-micron pixels, providing very good results at ISO 3200 and acceptably low noise even at ISO 6400.

However, the Pentax, like Canon DSLRs (but unlike Nikons and Sonys), does not have what is called an "ISO-invariant" sensor. Images have to be properly exposed for the best signal-to-noise performance.

Even so, while noise in the Pentax was higher than in full-frame cameras with larger pixels, the cropped-frame Pentax still performed very well at high ISOs and in long multi-minute exposures.

One oddity was that the Pentax's Slow Shutter Speed Noise Reduction option took internal dark frames that were consistently only 75% of the duration of the light frames, compromising their ability to accurately reduce thermal noise.

Nevertheless, the in-camera darks did help eliminate hot pixels. But shooting a dark frame separately that was the same length as the light frame, then subtracting it later in processing, did a better job of cleaning up most thermal artifacts.

I also found that the Live View function so critical to focusing astronomical images presented quite a dark image. There seemed to be no "Exposure Simulation" function as other cameras have that brightens the view in dim scenes. Pentax's Live View requires a very bright star or planet to focus on.

Perhaps the sensor-shifting functions were responsible, but on my test nights I found I could get only about 90 to 120 minutes of continuous shooting out of a battery, compared to 3 to 4 hours with other cameras.

Despite its drawbacks, the Pentax K-3 II offers an attractive array of unique features useful for astrophotography. If the Astrotracer function had worked more accurately, the camera might be attractive enough even for non-Pentax owners, especially for shooting nightscapes. As it is, I would consider this a camera of interest first and foremost to Pentax fans wanting to try their hand at astrophotography.

▲The K-3 II's Pixel Shift mode moves the sensor by one pixel over four exposures to improve resolution and reduce noise in exposures 30 seconds and shorter. However, moving targets such as stars can exhibit pixelated artifacts in RAW files, either when developed in *Adobe Camera Raw* (left), and to lesser extent even in Ricoh's own RAW developing software Digital Camera Utility that comes with the camera (middle).

■ A member of The World at Night (TWAN), Contributing Editor **ALAN DYER** is author of the ebook *How to Photograph & Process Nightscapes and Time-Lapses*, available on his website at **amazingsky.com/nightscapesbook.html**.

ZHUMELL UPGRADE KIT ▶

Farpoint Astronomical Research introduces upgrade kits for Zhumell 10- and 12-inch Dobsonian telescopes ($119.99). The kit includes a snap-on light shield that prevents stray light from entering the front of the telescope, while 3 machined primary-mirror-cell collimation knobs with tension springs eliminate the need for tools in the field. A magnetic bag weight allows you to effortlessly re-balance the telescope when switching eyepieces. And two lifting straps make placing your OTA on its rocker base easier to lift.

Farpoint Astronomical Research
11358 Amalgam Way, Suite A1
Gold River, CA 95670
877-623-4021; farpointastro.com

DEEP-SKY GOGGLES ▶

Here's a novel observing aid for deep-sky aficionados: the Flip-Filter Goggles from Apache-Sitgreaves Research Center ($42). These goggles feature 2-inch threaded ports that accept a pair of filters, allowing users to see the expansive nebulae that permeate the Milky Way with no magnification. The filter rack flips up and out of the way while still blocking extraneous light, enabling you to better enjoy the view through telescopes and binoculars. The goggles accept any standard 2-inch threaded filters (not included), including the company's UHC filters ($95 each) and O-III filters ($105).

Apache-Sitgreaves Research Center
apache-sitgreaves.org

MID-SIZED CCD CAMERA ▶

QHYCCD introduces the latest model in its "all-in-one" product series, the QHY16200A ($3,999) CCD camera. Its 4,540 $\times$ 3,630 (16-megapixel) array APS-H format detector measures 27 $\times$ 21.6 mm with 6-micron-square pixels, providing high resolution in a compact area. The cameras dual-stage thermoelectric cooling is capable of stable temperatures of 40° below ambient. The QHY16200A includes a removable off-axis guider and an internal 5-position filter wheel that accepts 2-inch filters, as well as a USB slave port with a locking clip to power an autoguiding camera. Each purchase comes with a 1-meter 12V threaded power cord, a 1.8-m USB 2.0 cable, and a 2-inch nosepiece. See the manufacturer's website for additional details.

QHYCCD
qhyccd.com

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The Craig Daniels Dogson Telescope

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WHAT WOULD YOU GET if you took practically every convention in telescope making and stood it on its ear? Something that looks and functions remarkably like the "Dogson" created by Oregon ATM Craig Daniels.

Craig didn't set out to make the anti-Dob. His goal was to produce a simple-to-build, easy-to-use, modest-aperture scope that would break neither the bank nor the back of the person carrying it out the door for an evening's observing.

He started with a 6-inch f/8.3 mirror. Why f/8? Because at long focal lengths a 6" mirror can remain spherical and still be well within ¼-wave accuracy. Spherical mirrors are way easier to produce than parabolic mirrors, so that gives a first-timer a leg up right away.

The "tube" is a wooden box. Boxes are easier to build than tubes or trusses. In order to keep the secondary mirror small and keep the upper end of the scope simple, Craig eliminated the traditional focuser. Instead, he focuses by moving the primary mirror up and down the "tube" on a sled. (Sound familiar? Schmidt-Cassegrains and Maksutovs do this.)

Since Craig lives near the coast, he doesn't leave his primary mirror exposed to the salt-laden air. It's easily removed through a trap door in the side of the scope for storage in a sealed, desiccated plastic container.

All this would simply make an odd-looking Dobsonian if it were mounted on a traditional alt-azimuth rocker and ground board, but Craig opted for simple and direct here, too. Inspired by the stability of classic mounts like Hadley's, Herschel's, and Lord Rosse's telescopes, and especially F. J. Sellers's 1920s design, Craig decided to set the back end of his scope on the ground and prop the front end on a stick. An early articulated "dog-leg" prop lent the Dogson its name.

◖ Learn more about the Dogson on Craig's website at http://tinyurl.com/gmsm87k

▲ The inside of the Dogson, showing the primary mirror sled.

▲ *Above:* Craig Daniels with his Dogson telescope. *Right:* The top end of the Dogson holds the eyepiece, setting circles, split-pupil finder, and swing-out camera mount.

CRAIG DANIELS (3)

To use the scope, Craig simply sets the back end on the ground, aims the front end at his target, and adjusts slow-motion altitude via coarse threads at the top of the foreleg. Gentle sideways tugs adjust for azimuth.

Says Craig, "The Dogsonian design eliminates bearings, counterweights, and weight. It's also easier for an amateur astronomer to build, since weight distribution and eyepiece hole location aren't critical. Adding accessory items to flat surfaces is fairly easy. For considerations of operation, transport, and storage, this is a one-piece, one-handle design."

For aiming, Craig uses several options, starting with open sights near the top of the scope, which he says "eliminates that time-honored tradition of groveling on the ground to sight up the OTA." From there he uses a split-pupil finder. Indeed, Craig's split-pupil finder was the inspiration for mine, featured in this space (*S&T:* June 2013, p. 66). Craig is kind of a gadget guy, though, so he also built in setting circles. Since his scope moves in altitude and azimuth rather than equatorially, the setting circles are calibrated in altitude and azimuth, too. Altitude was easy: a spirit level and a protractor. Azimuth is read with a magnetic compass, with attention to local magnetic declination and care in not locating ferrous fasteners near the compass.

Craig admits that "The Dogson is not a scope for swinging about and earning your Messier certificate. It's for picking and finding a target/object, studying it, and maybe shooting an afocal snapshot if the object is bright enough."

One of the Dogson's big advantages is stability. Craig says, "With the foreleg, the scope itself becomes two legs of a tripod. The Dogson has good resistance to vibration and breezes. A tired astronomer can even rest an arm on the OTA."

Viewing near the horizon would put the eyepiece uncomfortably low. Higher up, though, where the viewing is better anyway, the scope truly comes into its own. Craig reports that "At 30 degrees and above, an observer moves from a kneeling pad to chair or stool, and then to standing, depending on one's height. The design is intended for 6 inches of aperture and can go to f/9 without need for a step stool."

All in all, Craig is very happy with his Dogson. In summary, he says, "Without knowing how it would end up, this telescope has gone through numerous design changes over the past 60 years — ever since I was 14 years old. I think it's finally matured into a satisfactory 'scope."

Contributing Editor **JERRY OLTION** admires dogged persistence in telescope building.

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△ BLAST FROM THE PAST

Harel Boren

Sprawling across the northwestern corner of Vela, the Sails, are the delicate remnants of a supernova some 800 light-years away whose light reached Earth about 11,000 years ago. What a stunning sight that must have been! This view is roughly 6° wide, with east up. **DETAILS:** *Officina Stellare Veloce RH 200 astrograph and SBIG STL-11000M CCD camera with six wide- and narrowband filters. Total exposure: 11.7 hours.*

◁ SEAGULL'S HEAD

John Vermette

Located 8° northeast of Sirius, van den Bergh 93 is known as the Parrot Nebula — but, confusingly, it also serves as the head of the much larger Seagull Nebula (IC 1277 or Gum 1). **DETAILS:** *Hyperion 12.5-inch astrograph and SBIG STL-11000M CCD camera with Hα and RGB filters. Total exposure: 17.7 hours.*

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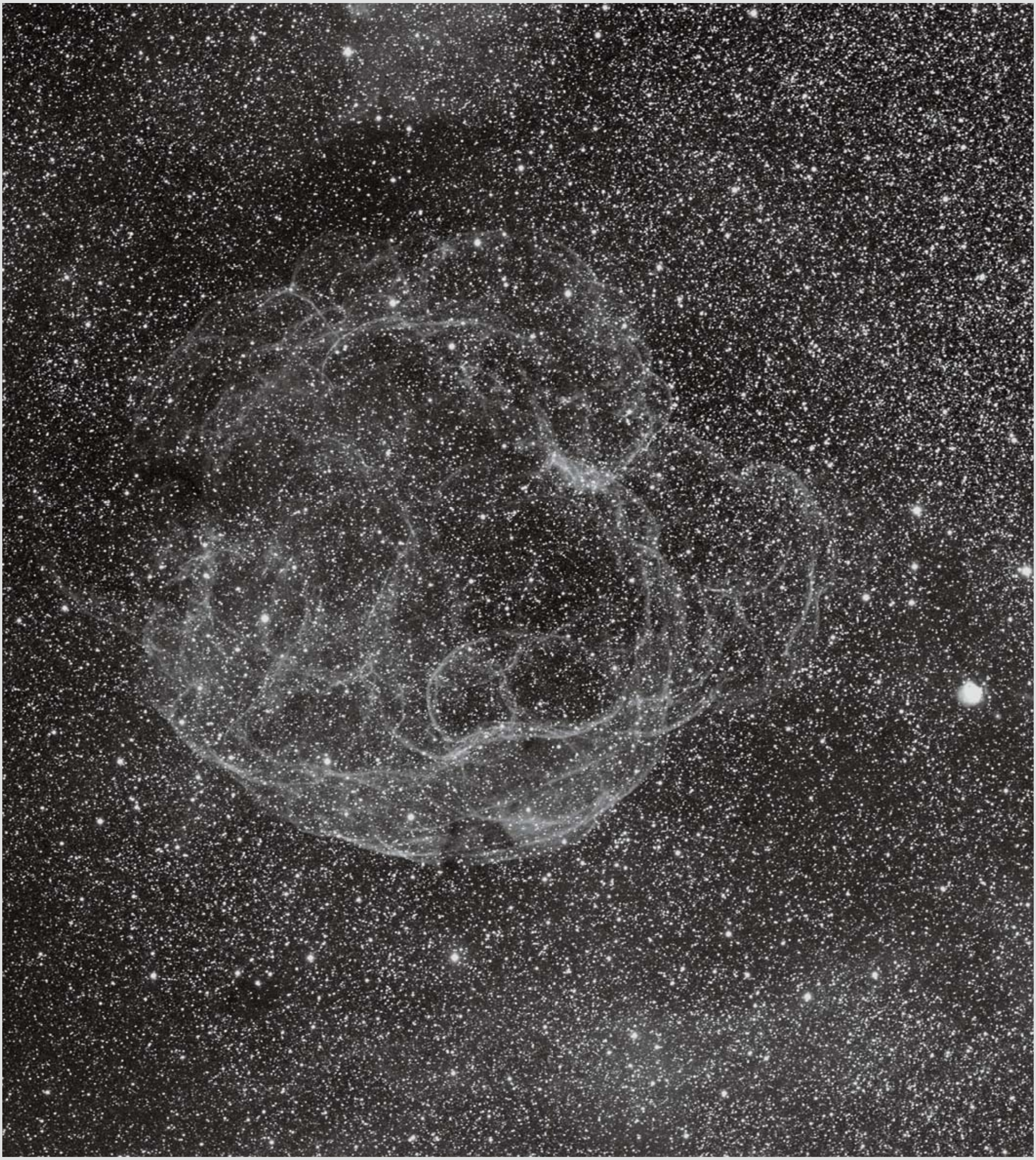

△ TANGLED SPAGHETTI

Jérôme Astreoud

The Spaghetti Nebula, also known as Simeis 147 and Sharpless 2-240, is 3° wide and lies along the Taurus-Auriga border. It's what remains of a star that exploded some 40,000 years ago about 3,000 light-years away.
DETAILS: *Canon 200-mm lens with SBIG STL-11000M CCD camera and Hα filter. Total exposure: 4.5 hours.*

△ DUSTY SPINDLE

Dan Crowson

The edge-on spiral galaxy NGC 891 in Andromeda is well placed for northern observers but a rather distant 30 million light-years away. It appears as an elongated, 11th-magnitude smudge in smaller scopes; larger apertures reveal its central dust lane.

DETAILS: *Astro-Tech AT12RCT Ritchey-Chrétien astrograph with SBIG STF-8300M CCD camera and LRGB filters. Total exposure: 6 hours.*

▷ SWADDLED STARS

Gerald Rhemann

The compact star cluster NGC 2477 (at top right) and sparse but pretty NGC 2451 accent the Gum Nebula, a broad swath of glowing interstellar hydrogen in southeastern Puppis. The field is 6° wide, with north toward right; 3rd-magnitude Sigma (σ) Puppis is at lower left.

DETAILS: *Astrosysteme Austria 8-inch H astrograph and FLI ProLine 16803 CCD camera with Hα and LRGB filters. Four-panel mosaic. Total exposure: 12.7 hours.*

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◁ TECHNICOLOR MOON

Jesús Navas Fernandez

To the eye the Moon shows only the barest hint of color, but combining ultraviolet, visible, and infrared video frames reveals dramatic hues.

DETAILS: *Takahashi FS-78 apochromatic refractor, ZWO ASI1600MM video camera, and Astrodon filters. Total exposure (2,700 frames): 8.2 minutes.*

▽ GHOST CLOUDS

Eric Africa

The Teardrop Nebula (IC 423) adorns Orion's midsection between the Belt stars Alnilam and Mintaka. Note the dark lane along its center. To its right is smaller IC 424, which seems to have engulfed two paired stars.

DETAILS: *PlaneWave CDK 12.5 astrograph, SBIG STL-6303 CCD camera, and LRGB filters. Total exposure: 18.7 hours.*

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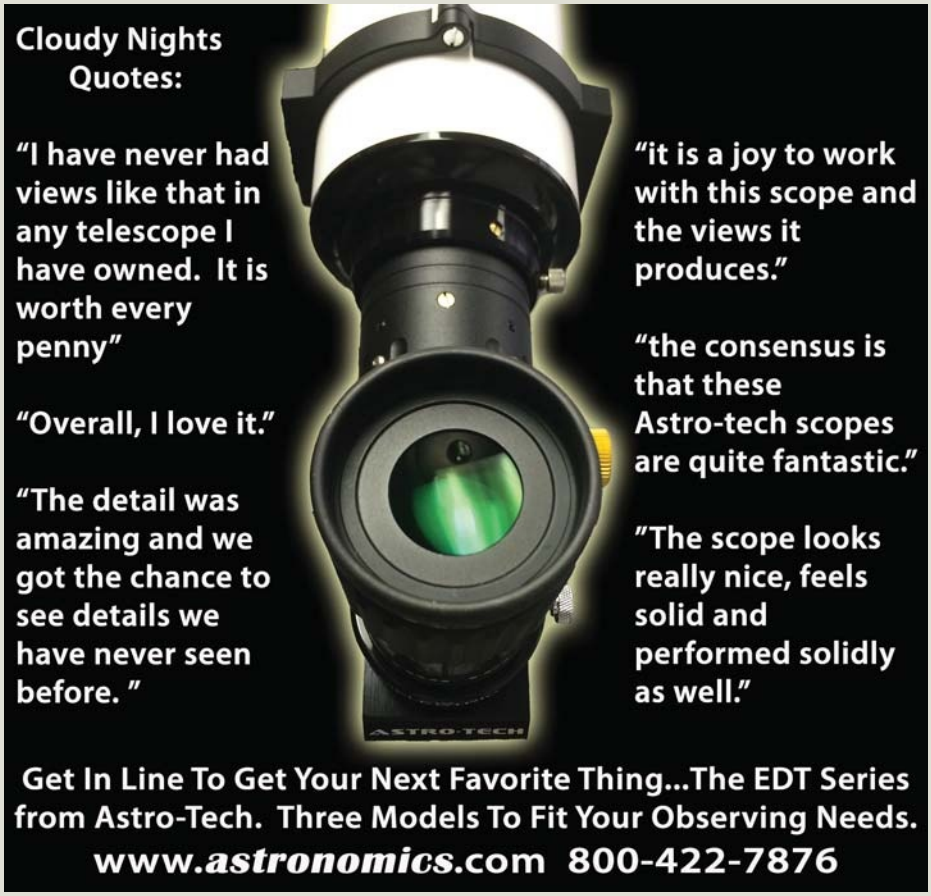

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AD INDEX

A Rainbow in the Velvet of the Night

Solving a mystery of northern lights in southern skies

MY GRANDMOTHER, Laurie Pfau Sanders (1902–2001), witnessed the remarkable world events and technological advances of nearly the entire 20th century. But some of her most vivid recollections involved celestial marvels. "There's nothing more wonderful than watching the sky," she once told me, eloquently describing the stars as "diamonds in the velvet of the night."

As a child growing up under the sweeping firmament of South Texas, she saw the spectacular return of Halley's Comet in 1910. At the other end of the century, in 1996, she and I shared a memorable September night in our Texas backyard as we viewed the Moon's russet face during a total lunar eclipse.

Thoughtful and not prone to exaggeration, she recounted many stories, and I learned to trust her accounts as valuable assets that I relied on when writing about local history.

One reminiscence that still burned bright for her after many decades had long presented a mystery. She recalled that when she was a teenager living in the South Texas town of Victoria, she and her mother had observed a "peculiar atmospheric disturbance" in the night sky. On this particular Saturday, the recent rain of a norther had swept clean and chilled the air.

> Brilliant bands of light — pastels of lavender, rose, chartreuse, and blue — danced in the heavens.

As Laurie glanced out of her bedroom window, she beheld a breathtaking sight. Brilliant bands of light — pastels of lavender, rose, chartreuse, and blue — danced in the heavens. "Looked like if you took a rainbow and stretched it out," she explained. She called to her mother, and they watched the luminous spectacle ebb and pulse for more than 20 minutes.

▲ Laurie Sanders in 1921, the year she saw mystifying lights in the Texas sky.

Initially frightened, Laurie's mother suddenly remembered the northern lights she had seen while living in Ohio. "But I never heard of seeing those lights down here in this part of the world!" she told her wide-eyed daughter.

To their chagrin, no one in the brightly lit, tree-lined streets of downtown Victoria had apparently seen the bizarre phenomenon, and the local newspaper made no report of it. Their fantastic observation remained an enigma for some eight decades.

I took this intriguing puzzle to my former astronomy professor and longtime friend Don Olson (Texas State University). A self-described "celestial sleuth," he helped me discover that, on the evening of Saturday, May 14, 1921, an aurora did indeed grace the skies over South Texas — as well as over many other parts of the world as far south as Puerto Rico and Samoa.

In fact, the *Monthly Weather Review* of July 1921 characterized the great appearance of May 14–15 as "exceptionally noteworthy." The aurora caused the greatest disruption to telegraphic communication ever recorded, the review stated, and static electricity from it was even believed to have triggered a fire that destroyed a railway station in Brewster, New York. In Texas, while the Victoria paper was mute, the *Dallas Times* reported that the "brilliant display" over San Antonio resulted in hundreds of phone calls to police headquarters by concerned citizens.

Dr. Olson and I were able to confirm every detail to validate my grandmother's recollection. This included local weather records that revealed that a cool front accompanied by rain had swept through Victoria and left clear, chilly air in its wake. More importantly, unraveling this mystery allowed my grandmother and me to share a celestial adventure down her memory lane.

As an 18-year-old, she often gazed out of her window in the hope of seeing the return of those beautiful lights in the "velvet of the night." With the puzzle now solved, in her mind's eye she could travel back to that wondrous night, and her story carried me with her.

■ **LAURIE E. JASINSKI** is a research editor with the Texas State Historical Association. She has co-authored articles in *S&T* with Contributing Editor Don Olson, most recently "Stonewall Jackson in the Moonlight" (*S&T*: May 2013, p. 32).

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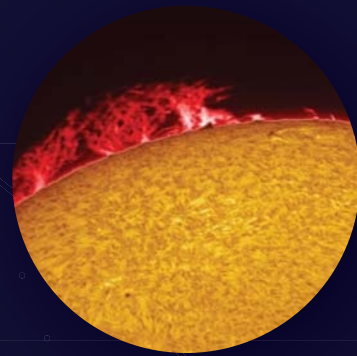

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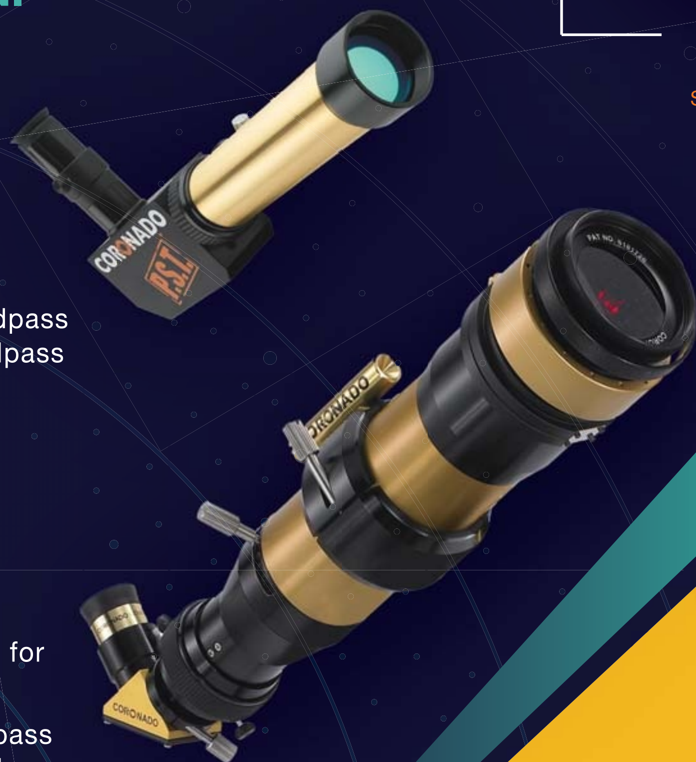

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