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SKY & TELESCOPE

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FEBRUARY 2018

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SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

February 2018 VOL. 135, NO. 2

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ON THE COVER

Artist's concept of two neutron stars smash-ing together.
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Lonely Wanderer

WHEN *S&T* SENIOR EDITOR Kelly Beatty first broke the story, last October 25th, of the strange new object now known as ‘Oumuamua — see his original reporting at **https://is.gd/R2jTHK** and his update on page 10 of this issue — he did so not because of its odd, highly elongated shape. Nor because of its spectrum, which suggests a dark red surface, nor its very high inclination with respect to Earth’s orbit, nor its rapid rotation period of roughly 7 hours. Most of these particulars weren’t even clarified at the time.

The reason Kelly rushed that morning to tell the world about this mysterious monolith was due to one extraordinary fact about it: It’s not from around here.

Based on its orbit, astronomers believe this near-Earth object arrived from outside our solar system. It’s the first such object ever identified. Asteroids and comets we’re familiar with round the Sun on elliptical orbits that have an eccentricity — a measure of orbital shape — of less than 1. This rogue’s value is 1.2, meaning it follows a *hyperbolic*, or unbound, orbit.

It’s easy to think that, on human timescales at least, our solar system is off by itself, essentially never interacting with other sectors of the galaxy. And then this stone cigar cartwheels past, shaking up astronomers’ worldview. It’s like Easter Islanders, after centuries of perfect isolation on their remote volcanic nub, seeing that first Dutch ship on the horizon on Easter Sunday, 1722. In an instant, everything changed: The world *is* more than this! Other people *do* exist!

Artist’s concept of ‘Oumuamua

EUROPEAN SOUTHERN OBSERVATORY / M. KORNMESSER

The discovery of 1I/2017 U1, as the interloper is officially known, isn’t quite as mind-altering as that. After all, astronomers have long assumed that countless such interstellar renegades exist. But it unleashes a shower of stimulating questions: Where did this rock originate? How long has it been sauntering solo among the stars? Was it flung our way by collision or by gravitational slingshot out of another planetary system during its formation, as happened to asteroids and comets in the early days of our own solar system?

Alas, the window for studying ‘Oumuamua is quickly closing. Space telescopes like Hubble will get the last dibs on it as the object retreats from Earth at roughly 50 kilometers per second. Then it will be gone forever, back into the inky depths of space from whence it came. Courtesy of our star’s gravity, it’s on a new trajectory — and so are we, knowing for the first time that such interstellar travelers *do* occasionally drop by.

Peter

Editor in Chief

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Subscription Rates: U.S. and possessions: $42.95 per year (12 issues); Canada: $49.95 (including GST); all other countries: $61.95, by expedited delivery. All prices are in U.S. dollars.

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

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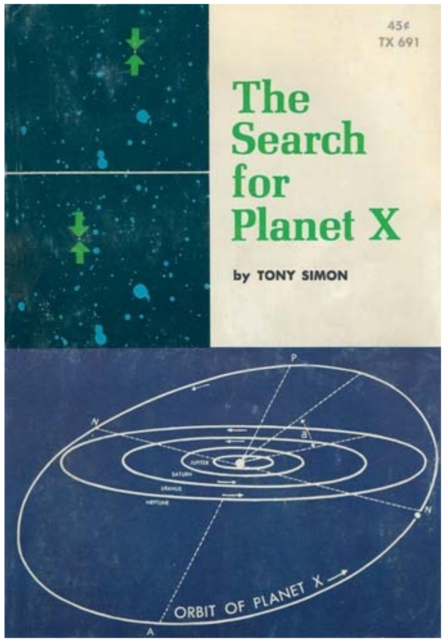
Finding “Planet X” — Then and Now

I enjoyed immensely Scott Sheppard’s recent article (*S&T:* Oct. 2017, p. 16) about solar-system resonances and the methods being used by him and others to locate a hypothesized distant, massive planet. But I couldn’t stop thinking that I had read this story before. So I did a search in my library and located a copy of Tony Simon’s *The Search for Planet X*, a book about Clyde Tombaugh’s discovery of Pluto, which I’d read in 1965. Will history repeat itself — first in February 1930 and perhaps very soon, some 88 years later? Thanks for reawakening a 52-year-old memory.

Curtis Urban
Pueblo, Colorado



▶ *The Search for Planet X*, published in 1962, recounts the events that led to Pluto’s discovery.

CURTIS URBAN

Spacetime Speed Limit

After reading “Three Cosmic Chirps & Counting” (*S&T:* Sept. 2017, p. 24), I paused to reflect on this question: Do gravitational waves really travel at the speed of light — or, instead, do electromagnetic waves travel at the speed of gravity? Perhaps they both travel at the speed that waves propagate through spacetime, and we need a better way to talk about them both.

Paul Gallez
Mariposa, California

Camille Carlisle replies: I suppose we could say that both electromagnetic and gravitational waves travel at the maximum speed possible in spacetime: 300,000 kilometers (186,000 miles) per second. We first knew this value, called *c*, as the speed of light in a vacuum, so we’re accustomed to calling it by this name. But your question makes me wonder if talking about *c* in a different way would bring new insights. On the other hand, many other holdover terms in astronomy continue to endure. For example, astronomers once referred to spirals like M31 in Andromeda as “late-type galaxies,” because they were thought to evolve from elliptical galaxies. We now know that’s not true, yet astronomers still use the term. So we might be stuck with “light speed” for awhile.

A Month on Mars?

Your excellent article “The Race to Mars” (*S&T:* Nov. 2017, p. 14) included the confusing term “three Martian months” as the expected operational lifetime of a planned Chinese rover. So I must ask: What is a “Martian month”?

Here on Earth, our notion of the month began as a single revolution of the Moon. But Mars has *two* moons, one of which revolves more quickly than the planet rotates. So this definition doesn’t seem likely. Alternatively, the modern month on Earth is usually 30 or 31 days long. So a Martian month could be 30 or 31 *sols*, the 24.66-hour length of one Martian rotation. Yet the difference between a day here and there is small enough that the adjective “Martian” would seem superfluous.

Meanwhile, the Gregorian calendar’s 12 months suggests that three Martian months could be defined as one quarter of a Martian year. This seems likeliest, though confirmation would be nice.

A fourth alternative is the Darian calendar, proposed in 1986 by Thomas Gangale (and named for his son). It divides the Martian year into 24 months of 27 or 28 days each. With this scheme, three Martian months would equal one eighth of a Martian year.

So which is it?

John F. Fay
Mary Esther, Florida

Camille Carlisle replies: We asked science writer Renjiang Xie to track down the answer. According to Chinese space officials, the rover’s expected lifetime is about 92 days — three months on Earth, but as experienced on Mars.

The Other Southern Sky

Brian Ventrudo’s history of Nicolas-Louis de Lacaille (*S&T:* Oct. 2017, p. 34) should at least have mentioned that the indigenous peoples of southern Africa — as well as aboriginal Australians, Pacific Islanders, and South Americans — had their own traditional maps of the sky long before European colonization. Lacaille’s vague and uninspired constellations only provide a window into the impoverished imagination of one 18th-century nerd.

Learning about these ancient constellations helps us to connect with our ancestors of millennia past. *Sky & Telescope* could express some respect for cultural diversity by publishing one or more feature articles on the sky lore of people from the Southern Hemisphere. Howard Ritter’s beautiful photograph of “the Emu” on pages 72–73 in that same issue would be a fitting illustration.

Anthony Barreiro
San Francisco, California

Worth the Wait

Mr. Tyson, I need to tell you how great *S&T* is. I’m 85 years old now, and just a few years ago I got interested in astronomy again. In the 1950s I was building telescopes and into grinding mirrors. When my kids were small, I delighted in showing them Saturn and its rings. Now my daughter is always bugging me to tell her what I want for Christmas, so a few years ago I asked for an *S&T* subscription.

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I enjoy all the columns but mostly the telescope reviews. When Tony Flanders reviewed the Zhumell Z130 tabletop telescope (*S&T:* Aug. 2017, p. 58), I got excited and called the company to order one. I guess I wasn't alone — I got put on a waiting list, and the person I talked to said it might be Christmas or longer before I'll get mine. So I opted for the larger Z8 Dobsonian instead.

Thanks for a great product. Keep up the good work.

Warren Mitchell
Alexandria, Indiana

Wanted: Eclipse Reports

As an *S&T* subscriber for nearly 50 years, I was looking forward to your coverage of August 21st's total solar eclipse. Suspecting that the October issue went to press too soon, I awaited the November issue with great expectation. "Now, where's that eclipse?" I asked myself while impatiently perusing its pages. Nothing. Not a single mention or photo. After all the build-up and hype, I found not one word of post-eclipse coverage. You could have at least put in a brief acknowledgment that the greatest celestial event in decades, one that generated immense popular interest, had happened. Truly dismaying!

Ralph Mathisen
Champaign, Illinois

Kelly Beatty replies: We hear you — and share your frustration. The November issue had to be sent to the printer on August 25th, four days after the eclipse, and we *did* consider including some eclipse coverage. But we editors were still scattered across the country with *S&T*'s tour groups or having watched the eclipse ourselves. That said, I hope you enjoyed the nice roundup of images that appeared in Gallery section of December's issue — and our extensive online reports (https://is.gd/eclipse_stories).

A Crater for Rükl?

Given the recent passing of Antonín Rükl (*S&T:* Nov. 2016, p. 14), I'd like to express my support for the designation of a lunar feature in his name. If left to me, I would look at one of the members of the chain of descending-sized craterlets inside Clavius (see sheet 72 in Rükl's *Atlas of the Moon*). Pick one near the crater on the rim of Clavius that already honors Russell W. Porter. That would certainly be a fitting pairing!

Milt Hays, Jr.
Jacksonville, Florida

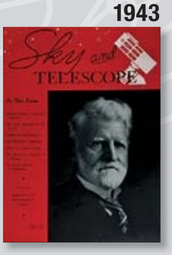
FOR THE RECORD

- In the illustration titled "Life Cycle of the Sun" (*S&T:* Oct. 2017, pp. 24–25), the label "Gradual warming" should have been "Gradual brightening."
- Big Bear Lake is situated in the San Bernardino Mountains (*S&T:* Nov. 2017, p. 43).

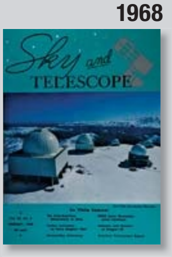
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

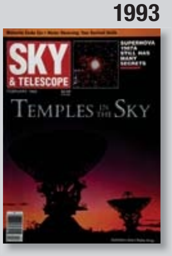
1943



1968



1993



February 1943

Wartime Astronomy "The American Astronomical Society's Committee on the Continued Distribution of Astronomical Literature has just received a packet of various German astronomical journals and publications from seven German observatories, issued in 1939-41 and the first half of 1942. . . . Solar research, studies of Cepheid variables and of the zodiacal light are especially prominent. . . .

"Numerous issues give abstracts of astronomical papers published in Italy; one, a list of those published in Japan. . . .

"These publications are entirely devoted to astronomy. Their only reference to the war is in the personnel notes in the directors' reports. They serve no propaganda purposes. . . . May our common understanding in this science eventually be extended to life in general."

This report by astronomer Dorrit Hoffleit was made into an editorial.

February 1968

Hide and Seek "Any binary star system will be an eclipsing variable if its orbit plane is nearly enough edgewise to us. . . . So far, no trustworthy case is known of a visual binary system having shown an eclipse.

"Paul Couteau [at Nice Observatory] calls attention . . . to the remote chance that this phenomenon will occur in 1968. The visual binary OΣ 536 [near Rho Pegasi] has a period of 27 years and an orbital inclination of approximately 90 degrees, according to G. Van Biesbroeck. . . .

"Dr. Couteau calculates that if eclipses occur, one will happen around mid-April, 1968, with a maximum duration of 5.8 days. . . ."

No one reported seeing that eclipse. A more famous case of missed but likely eclipses is Alpha Comae Berenices, a visual binary with a 26-year period. A secondary eclipse might occur about January 11, 2026, and a likely primary eclipse near September 24, 2040.

February 1993

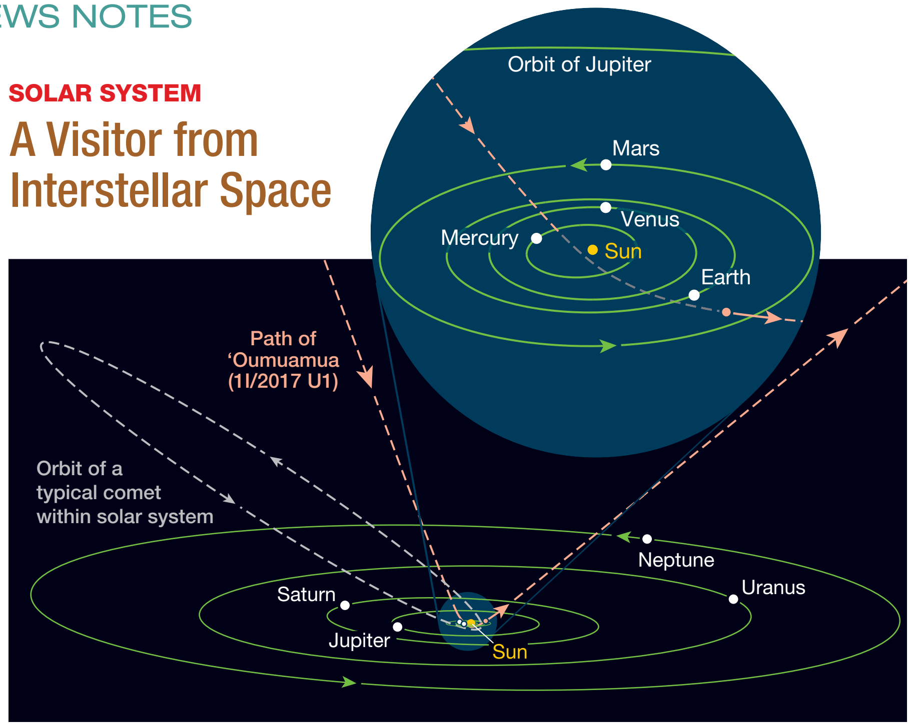
Mirror-Image Galaxy "A remarkable example of gravitational lensing in a distant cluster of galaxies is giving astronomers second thoughts about the nature of dark matter.

"The Hubble Space Telescope made the discovery while peering into the heart of AC 114, a galaxy cluster some 4 billion light-years away. Two 6-hour exposures with Hubble's Wide Field and Planetary Camera revealed a pair of faint objects that look almost exactly like mirror images of each other. At a press conference at NASA headquarters on October 8th, "Richard Ellis (Durham University, England) identified them as gravitational mirages of a more distant galaxy produced by the lensing action of the intervening cluster's mass. . . .

"Ellis and his colleagues have computed the amount and distribution of mass needed to produce the mirages. Their model requires up to 50 times more matter than is visible in the cluster's galaxies."

SOLAR SYSTEM

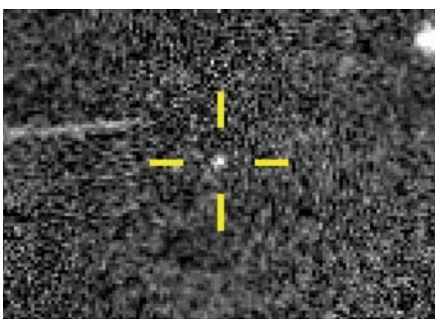
A Visitor from Interstellar Space



▲ The track of the first-known interstellar object, now named 'Oumuamua, as it passed through the inner solar system. The inset shows its location when found on October 19th.

WHEN THE PAN-STARRS 1 telescope atop Haleakala on Maui swept up a 20th-magnitude object on October 19th, observer Robert Weryk (University of Hawai'i) noticed right away that its motion didn't make sense. Orbital computations soon showed that it had passed within 0.26 astronomical unit (38,200,000 km) of the Sun on September 9th. But its extreme orbital eccentricity, 1.19, meant that it's following a hyperbolic trajectory that's not bound to the Sun. For the first time, observers had spotted an object visiting from interstellar space.

At first astronomers suspected it was a comet, so the International Astronomical Union's Minor Planet Center (MPC) applied the designation C/2017 U1. However, when even the deepest telescopic images revealed no hint of a coma or tail, they decided it must be asteroidal, so the designation morphed to A/2017 U1.



▲ 'Oumuamua appeared as a faint fuzz (in cross-hairs) as recorded by Tenagra Observatory in Arizona on October 21st.

Behind the scenes, IAU and MPC officials mounted an unusual effort to name the new object quickly. The chosen name, 'Oumuamua, is a Hawai'ian construct combining *'ou* (to reach out) and *mua* (meaning first or in advance of); the second *mua* is for emphasis.

But asteroids aren't cataloged by name alone, and this is the first of an entirely new class of object. So, at the suggestion of MPC associate director Gareth Williams, the IAU adopted the identifier "I," for interstellar. As noted in the naming announcement, "Correct forms for referring to this object are therefore: 1I; 1I/2017 U1; 1I/'Oumuamua; and 1I/2017 U1 ('Oumuamua)."

Although the arrival of a faint object from beyond the solar system caught astronomers by surprise, they quickly mobilized for follow-up observations with powerful ground-based telescopes.

One lucky break came immediately after the MPC's discovery announcement. Observer Joseph Masiero (Jet Propulsion Laboratory) just happened to be in the middle of a run with the 5-m Hale Telescope at Palomar Observatory, and he quickly obtained a spectrum at visible and near-infrared wavelengths. 'Oumuamua is slightly reddish overall, with the kind of unremarkable spectrum that a rocky surface would exhibit after being "weathered" by long-term exposure to space radiation.

While its spectrum seems reasonable, its shape borders on bizarre. Based on pooled, rapid-response observations from five big telescopes in Hawai'i and Chile, the light curve for 1I/2017 U1 shows a 2½-magnitude range. As Karen Meech (University of Hawai'i) and others explain in the November 20th *Nature*, this wide swing implies that the object has an extremely elongated shape — maybe 10 times longer than it is wide.

Moreover, the spin rate is relatively fast, about 7.34 hours, so 'Oumuamua must be made of rocky or metallic compounds with significant tensile strength. As the *Nature* researchers note, "It raises the question of why the first known [interstellar object] is so unusual."

The Hubble Space Telescope might have the final word on the character of 1I/2017 U1. A team led by Meech was granted enough Hubble time to study the quickly disappearing interloper three times before the end of 2017.

This object entered the solar system moving at 26 km per second (58,000 mph). At that speed, in 10 million years it would traverse nearly 850 light-years. Eric Mamajek (Jet Propulsion Laboratory) points out that the object's incoming velocity is close to that of the mean galactic velocity of stars that lie within 25 parsecs (80 light-years) of the Sun, but it does not match the relative velocity of any of the dozen nearest systems. These characteristics all suggest that 'Oumuamua has been drifting among the stars for a very long time, perhaps billions of years.

The object entered from the direction of the constellation Lyra, close to right ascension 18^h 50^m, declination +35° 13′. Now it's headed out of the solar system, never to return, toward the Great Square of Pegasus at 23^h 51^m, +24° 44′.

■ J. KELLY BEATTY

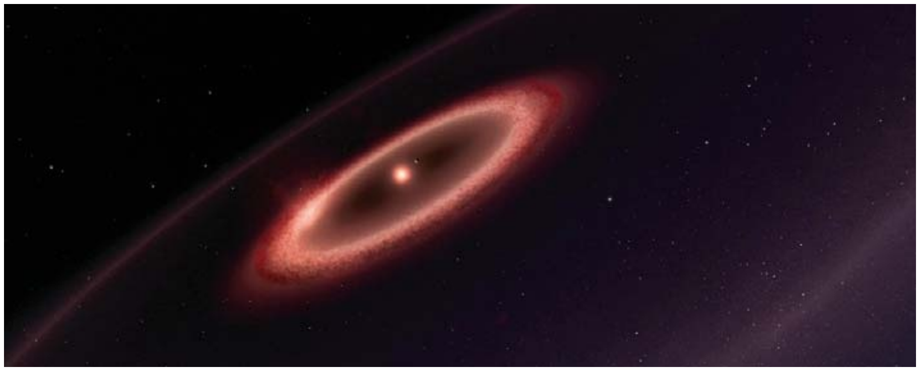
ORBIT DIAGRAM: LEAH TISCIONE, SOURCE: BROOKS BAYS / SOEST PUBLICATION SERVICES / UNIV. OF HAWAI'I; 'OUMUAMUA: PAULO HOLVORCEM & MICHAEL SCHWARTZ (NASA GRANT #NNX15AE89G)

EXOPLANETS

Cool Dust Discovered Around Proxima Centauri

TANTALIZING OBSERVATIONS reveal a dusty ring and additional dust structures in the Proxima Centauri system — the one that hosts the nearest exoplanet to Earth (*S&T:* Dec. 2016, p. 10).

A team of astronomers led by Guillem Anglada (Institute of Astrophysics of Andalucía, Spain; not to be confused with Guillem Anglada-Escudé, Proxima Cen b's discoverer) pointed the Atacama Large Millimeter/submillimeter Array (ALMA) at Proxima Centauri for more than 20 hours, revealing the presence of a dusty ring around the star. The planet Proxima Cen b circles its star at a distance of just 7½ million km, or 0.05 astronomical unit (for reference, Mercury orbits the Sun at 0.39 a.u.). The dusty ring lies well beyond that, extending from 1 to 4 a.u. The results will appear in *Astrophysical Journal Letters*.



▲ An artist visualizes the inner and outer dust belts around Proxima Centauri.

ESO / M. KORNMESSER

Like our solar system's Kuiper Belt, the Proxima belt contains fine grains with similar average temperature and total mass. The Kuiper Belt might be debris leftover from planet formation, and the existence of a dusty belt around Proxima Centauri could mean more planets wander around this dim star.

In addition to the belt, the team notes hints of other dusty features. The most speculative of these, but also the most intriguing, is the possible discovery of an asymmetry in the dust belt, which could be due to a planet embedded within the dust. The team also found hints of a second, colder belt of dust about 30 a.u. from the star, as well as a possible shroud of warmer dust closer to the star (but still outside Proxima Cen b's orbit), at roughly 0.4 a.u. More observations are needed to confirm these additional features.

■ **JOHN BOCHANSKI**

PHYSICS

LIGO Sees Its Smallest Black Hole Binary Yet

ON NOVEMBER 15TH, the LIGO and Virgo collaborations announced the sixth gravitational-wave discovery. The event, GW170608, came from the union of the smallest black holes scientists have yet "seen" using this technique and is the fifth black hole merger discovered so far.

The waves hit LIGO at 2:01:16 Universal Time on June 8th during the project's second observing run, which ran from November 30, 2016, to August 25, 2017. Their passage triggered the alarm at the site in Livingston, Louisiana, but the Hanford, Washington, detector was under routine maintenance and had its alert system turned off. Even with the ongoing tinkering, the Hanford interferometer detected GW170608, too.

Europe's Virgo gravitational-wave observatory was still in its commissioning phase and didn't observe the event, but the team contributed to the analysis.

Based on the signal's characteristics, the two teams infer that the initial black holes were roughly 7 and 12 solar masses and created an 18-solar-mass black hole, radiating away a Sun's worth of energy in gravitational waves. The marriage happened more than a billion light-years away. With only two detectors involved, the team can only say that the signal came from somewhere in a huge, 520-square-degree swath of sky in the Northern Hemisphere.

The spin of the final black hole is 69% of the maximum value it could be — once again matching predictions for black holes created by mergers. The two initial objects' spins are unclear, but their axes seem to have been roughly aligned with the plane of the orbit as the pair spiraled into each other.

The interesting thing about this latest detection is the black holes' small sizes. They're similar to those from LIGO's second discovery, GW151226, which combined objects of about 8 and 14 solar masses, and to the two dozen black holes found in binary systems with stars, which astronomers can spot by the X-ray glow of the gas the black holes are tearing from their stellar companions.

This is exciting not only because researchers can start comparing black holes of similar masses discovered in vastly different ways, but also because of a tantalizing possibility: If black holes discovered with LIGO and Virgo fall into two distinct mass groups, then it's possible that they're made different ways. Once they've amassed enough gravitational-wave events, astronomers could start figuring out where each group comes from.

GW170608's announcement came five months after it happened in part because the teams were busy analyzing their two 3-site detections from August: the fourth black hole merger, GW170814, and the first-ever neutron star merger, GW170817 (see p. 32).

■ **CAMILLE M. CARLISLE**

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

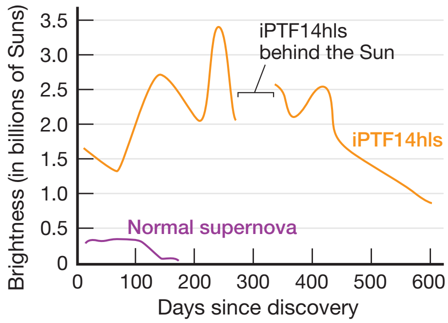
STELLAR

The Star That Wouldn't Die

A SUPER-LONG SUPERNOVA has astronomers reaching for new explanations of stellar explosions.

In a typical *core-collapse supernova*, the inner collapse occurs so quickly that infalling layers of stellar material rebound off the core, driving a shock wave that sends much of the star flying outward. The expanding outer shells of ionized hydrogen glow for roughly 100 days before beginning to fade.

Iair Arcavi (Las Cumbres Observatory) and colleagues thought they were seeing a typical core-collapse supernova when the Intermediate Palomar Transient Factory (iPTF) caught the 18th-magnitude explosion dubbed iPTF14hls. But the supernova kept on going, not for 100 days but for almost two years, as reported in the November 9th *Nature*. What's more, it exhibited at least five distinct peaks in luminosity, including the initial burst. A look back at the Palomar Observatory Sky Survey found that the star might have had another outburst back in 1954. There are other oddities too: The glowing gas maintains a roughly constant temperature, which implies that its radius stays the same. Yet it also maintains its speed — unexpected behavior for shells of ionized gas that ought to expand, thin, and cool.



▲ Instead of fading away, the unusually long-lasting supernova iPTF14hls brightened again four more times over two years.

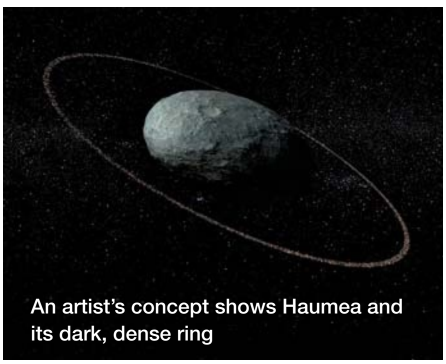
So Arcavi and colleagues rule out standard models of stellar explosions and turn instead to *pulsational pair-instability supernovae*. If a star is massive enough (but not too massive), its core can convert photons into electrons and their antimatter partners, positrons. The resulting instability sets off blasts that carry away tens of solar masses.

A star with an initial mass just above 100 Suns could have caused iPTF14hls's multiple blasts. Yet this scenario still can't explain all of the observations.

"As of now," writes Stan Woosley (University of California, Santa Cruz), author of an accompanying perspective piece, "no detailed model has been published that can explain the observed emission and constant temperature of iPTF14hls, let alone the possible eruption 60 years before the supernova."

■ **MONICA YOUNG**

SOLAR SYSTEM



An artist's concept shows Haumea and its dark, dense ring

Dwarf Planet Haumea Has a Ring

THE DWARF PLANET 136108 Haumea briefly slipped in front of an 18th-magnitude star in January 2017. Observers at a network of 10 observatories across central Europe recorded the cover-up, discovering something unexpected: A ring encircles this little world.

Haumea, which orbits in the realm beyond Neptune, was already a well-known oddball. It's among the largest objects in the Kuiper Belt, has a highly elongated shape, spins rapidly, and possesses two moons.

Now, as José Luis Ortiz (Institute of Astrophysics of Andalucía, Spain) and colleagues detail in October 12th's *Nature*, several observing teams have detected a ring via secondary dips in the star's light roughly 2 minutes before and after the main occultation. The ring is dark, narrow (70 km wide), and dense enough to block half the star's light.

The ring appears to lie in Haumea's equatorial plane, which is shared by the larger, outer moon Hi'iaka. The ring's orbit has a radius of about 2,287 km (1,421 miles) — that's too close to Haumea, well inside a gravitational threshold called the *Roche limit*, to be able to collect into a single body.

Haumea isn't the only outer-solar-system body with a ring; occultations by the Centaur objects 10199 Chariklo (*S&T:* July 2014, p. 14) and 2060 Chiron, both in 2013, also turned up rings. So while the origin of Haumea's ring isn't yet clear, the feature might be common to the trans-Neptunian region.

■ **J. KELLY BEATTY**

IN BRIEF

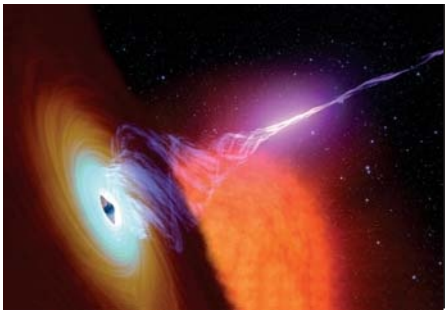
Comet Heinze to Fly by in January

Discovered on October 2, 2017, Comet Heinze (C/2017 T1) will fly 33 million km from Earth on January 4th before coming within 87 million km of the Sun on February 21st. Aren Heinze (University of Hawai'i) found the object using the Asteroid Terrestrial-impact Last Alert System (ATLAS) project, which employs two telescopes positioned 160 km apart. The two "eyes" enable distance determination using parallax, which helps calculate a new object's orbit. Heinze confirmed the comet's orbit using additional ATLAS observations. Despite its intrinsic faintness, both JPL Horizons and Seichi Yoshida predict the comet will peak at magnitude 8.8, putting it within range of small telescopes. For observing guidance and detailed sky charts go to **https://is.gd/CometHeinze**.

■ **BOB KING**

SUPERNOVA: LEAH TISCIONE, SOURCE: LAS CUMBRES OBSERVATORY / S. WILKINSON; HAUMEA: IAA-CSIC / UHU

BLACK HOLES



Decoding a Black Hole Jet

VISIBLE LIGHT AND X-RAYS helped astronomers paint a detailed picture of the relativistic jet in V404 Cygni, a black hole–star system. The results appear in *Nature Astronomy*, published online on October 30th.

Poshak Gandhi (University of Southampton, UK) and colleagues employed NASA's NUSTAR X-ray satellite and the super-fast UltraCam on the William Herschel Telescope in La Palma, Spain, to track emissions from V404 Cygni. The black hole tugs gas away from its stellar partner as they whip around each other, resulting in flares. In June 2015 V404 Cygni underwent the brightest binary outburst in the 21st century.

Astronomers had previously monitored visible light from black hole systems, but they hadn't been able to pinpoint its origin — the photons could arise in the gaseous disk that feeds the black hole, the stellar companion that feeds the disk, or the jets that the black hole–disk system powers.

The addition of X-ray data resolves this ambiguity. By exactly timing incoming X-rays and visible photons, Gandhi and colleagues discovered that visible-light flashes trailed X-ray flares by 0.1 second. So the visible-emitting region has to be in the jet, some 30,000 km (19,000 miles) downstream from its X-ray-emitting origin. The two regions bookend the *acceleration and collimation zone*, a poorly understood space where the jet's plasma narrows and achieves relativistic speeds.

The results mesh nicely with previous studies of some supermassive black holes, says Alan Marscher (Boston University), but not all of them: The supermassive black hole at the center of the galaxy M87, for example, exhibits a different delay, suggesting that some details remain to be worked out.

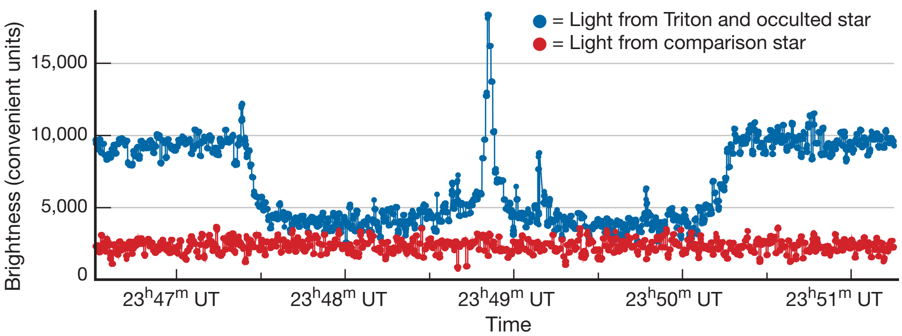
■ **MONICA YOUNG**

IN BRIEF

Cassini's Saturn Surprises

During October's meeting of the American Astronomical Society's Division for Planetary Sciences, a parade of Cassini scientists explained some of the insights they gained during the unprecedented scrutiny offered by the spacecraft's "Grand Finale" orbits. Those last orbits sent the spacecraft dashing at 35 km per second (78,000 mph) through a planet-ring gap about 2,400 km wide, giving Cassini the chance to directly sample the compounds present in Saturn's uppermost atmosphere. In theory, material is leaking from the innermost threads of the water-ice ring and drifting toward the planet. But the craft's mass spectrometer swept up many heavier compounds, which might include methane and carbon monoxide — gases that would be chemically out of place in the water-ice rings, and shouldn't be percolating up from the atmosphere either. Cassini's close-in flybys also gave mission scientists a chance to examine the rings in extreme detail, including new views of structures that astronomers still struggle to explain. Watch *S&T*'s interview with Cassini project scientist Linda Spilker at **https://is.gd/LindaSpilker**.

■ **J. KELLY BEATTY**



SOLAR SYSTEM

Preliminary Results from Triton Cover-Up

WHEN A STAR disappeared behind Triton on October 5th, astronomers watched to monitor the atmosphere around Neptune's largest moon.

The 12.6-magnitude star UCAC4 410-143659 was the brightest star occulted by the moon in 20 years. The last such occultation, in 1997, had showed that Triton had experienced seasonal global warming since the Voyager 2 flyby in 1989. Now, these new observations will determine if the trend has continued.

Observers recorded the October 5th event from more than 75 stations in mainland Europe, the UK, northern Africa, and the United States, making it the best-recorded occultation by any object with an atmosphere. The plot at left shows some of these observations, revealing the decrease in light when the moon blocks the background star.

Moreover, NASA's Stratospheric Observatory for Infrared Astronomy, as well as 25 observers in Europe close to the centerline of the occultation's path, recorded the *central flash* (seen as the central peak at left), when the moon's atmosphere briefly focused the background star's light. Observations of the central flash probe a deeper level of the atmosphere than the gradual disappearances and reappearances of the star recorded by observers elsewhere in the path of Triton's shadow.

Visit **https://is.gd/tritonoccultation** for more details on the observations. Ongoing analysis should reveal how Triton's atmosphere has changed with Neptune's seasons.

■ **DAVID DUNHAM**

 by Laura Fissel

Science in the Stratosphere

NASA'S GODDARD SPACE FLIGHT CENTER CONCEPTUAL IMAGE LAB

Balloon-borne instruments give astronomers a taste of space without the need for rockets or satellites.

Our universe emits radiation over an incredible range of wavelengths, from the infrared glow of dust that shields the youngest stars to gamma rays from distant supernovae. Earth's atmosphere blocks all but a tiny fraction of these colors, though, and the light that does make it to Earth's surface blurs as it passes through the air.

To compensate, astronomers build high-tech telescopes on tall mountains. Yet even the highest astronomical observatory in the world, the University of Tokyo Atacama Observatory (5,640 meters), sits above only about half of Earth's atmosphere. An even better solution is to place telescopes in space, but such projects are expensive: NASA's exoplanet-hunting Kepler mission cost $600 million, and that's on the low end. The high cost of space-based telescopes means that scientists can construct few such satellites.

A cheaper alternative is to attach a telescope to a helium balloon and launch it into the stratosphere, typically for less than $1 million per flight. A giant balloon can carry a telescope weighing thousands of kilograms to altitudes more than 30 kilometers (20 miles) above Earth's surface — approximately three times the cruising altitude of a commercial jet airliner. Such balloons are significantly closer to Earth than, say, the Hubble Space Telescope, which orbits at 547 km. But because atmospheric density drops nearly exponentially with altitude, these balloons fly above 99% of Earth's atmosphere.

Because balloon telescopes can reach almost space-like conditions for a small fraction of the cost of an equivalent satellite, we can use them to test new technology and train students, all the while obtaining cutting-edge scientific data.

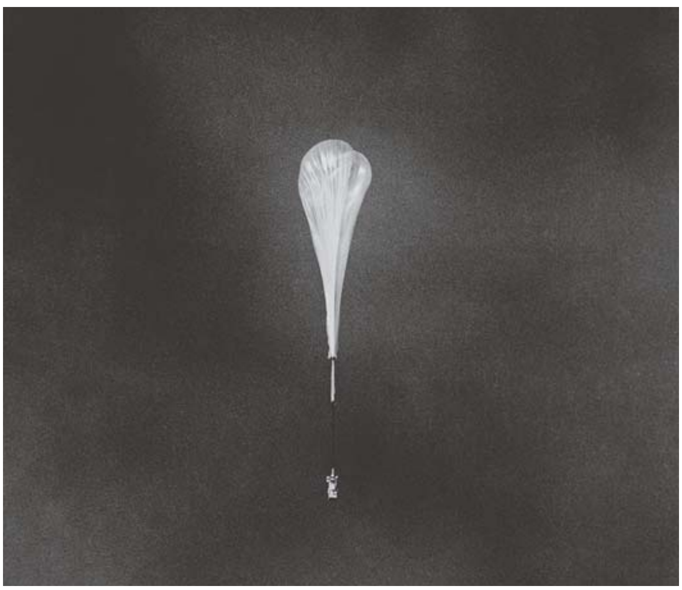
The Birth of Flight

The modern era of human flight began on November 21, 1783, when a hot-air balloon swept over Paris, carrying Jean-François Pilâtre de Rozier and the Marquis d'Arlandes.

The balloon, a creation of Joseph and Étienne Montgolfier, was made of linen paper and silk, then coated with the compound alum to reduce the risk of fire. Outside, lavish decorations included signs of the zodiac and illustrations of King Louis XVI. But the scene inside was more adrenaline-inducing than elegant: The first aeronauts frantically threw wool and straw from a circular balcony onto a brazier as fast as they could to keep their balloon from sinking. In just 25 minutes, they traveled 9 km.

This was a remarkably dangerous endeavor: In addition to the potential for smashing into buildings, or the balloon catching fire, no one was sure how high they would ascend and whether humans could survive at such heights.

▲ **FIRST FLIGHT** The Montgolfier balloon was lavishly decorated with the signs of the zodiac and illustrations of King Louis XVI, as shown here, but inside Jean-François Pilâtre de Rozier and François Laurent, Marquis d'Arlandes, had to work hard to keep the balloon afloat.



▲ **STRATOSCOPE** The first uncrewed, balloon-borne astronomical telescope, Stratoscope I, flew aboard the Skyhook in the 1950s. It took detailed images of turbulence and granulation in the Sun's photosphere.

Less than two weeks later, the physicist Jacques Charles made the first ascent in a hydrogen balloon, which launched before a crowd of 400,000 people in Tuileries Gardens, Paris. This balloon was much easier to control than the Montgolfier: Charles had bags of ballast to drop and a valve to release hydrogen gas as needed. After landing 40 km away, his assistant, Nicolas-Louis Robert, climbed out of the wicker passenger basket. With the balloon's weight reduced, Charles shot up to an astonishing 3,000 meters (10,000 feet) in only 10 minutes. He measured the temperature and atmospheric pressure during his ascent, declaring himself the first man to see the Sun set twice on the same day.

One of the first balloons' most important contributions was the new and unique viewpoint they offered humankind, one that we perhaps take for granted in this age of airplanes and spaceflight. From a balloon, one could look down on clouds, see how roads and rivers wound through vast mountain ranges dotted with villages, and observe the whole curved disk of the Earth beneath you "like a beautifully coloured map or carpet," as John Jeffries wrote after a flight in November 1784.

But balloons offer us more than a new view of our planet. They also give us access to the sky.

The aeronauts Joseph Croce-Spinelli and Théodore Sivel wielded a spectroscope from a balloon in 1874, but it wasn't until the 20th century that a complete astronomical telescope made the journey. In 1954 the father-and-son team Charles and Audouin Dollfus took a 28-cm Cassegrain to 7,000 meters to look for water vapor in Mars's atmosphere. A few years later saw the first uncrewed astronomy flight with Stratoscope I, a 12-inch reflector launched to study turbulence on the Sun (*S&T:* Jan. 1958, p. 112).

To the Stratosphere

Balloon astronomy has changed a great deal in the intervening decades. Balloons themselves have grown larger and lighter, enabling them to climb into the upper stratosphere. Rather than using paper or rubberized silk, we now build them from polyethylene film, the same material used to make plastic bags — although the stuff used for balloons is only half as thick as a typical sandwich bag. Improvements in electric motors, microcontrollers, computers, and satellite communications mean that astronomers are (thankfully) no longer expected to accompany their telescopes to these extreme heights.

How we launch a balloon has changed quite a bit, too. We start with it mostly empty — helium fills less than a percent. This creates a small, tightly secured bubble with a long, uninflated tail. Laid out on the ground with the tail are a parachute (for the payload's return to Earth) and the gondola that contains the telescope. The gondola is suspended from a motorized crane on a truck. We align the balloon-parachute-gondola sequence with the direction of the wind that's blowing about 1,000 feet above the ground. That way, once the balloon launches, it will lift the payload as it passes overhead.

After we release the balloon, it shoots up into the air at several meters per second, catching the wind. As it flies

▲ **THE EDGE OF SPACE** Although the stratosphere is far from the official boundary of space (defined as 100 km, or 62 miles, above Earth's surface), stratospheric balloons nevertheless climb above more than 99% of the atmosphere. The Pi camera that took this image was attached to a Montana State University high-altitude balloon, which soared to a grand view of the Tetons on August 21, 2017.

overhead, the launch vehicle operator hits the gas, driving the gondola-holding truck to match the balloon's speed and drift, so that the telescope remains directly underneath it. As the balloon struggles against this tether, the operator releases the gondola, and the whole contraption takes off.

After two or three hours the balloon reaches a stable altitude of 35 to 42 km. By now it has expanded by a factor of 100 in the stratosphere's lower-pressure environment. Large, fully inflated scientific balloons extend up to 140 meters in diameter at their widest point — they wouldn't fit within a football field.

The balloon stays visible for several hours after launch, like a perfectly round, small cloud — indeed, its kind is often mistaken for UFOs — until stratospheric winds push it over the horizon. During this extremely busy period, the scientists left behind on the ground can communicate directly with the balloon gondola. We turn on the motors that point the telescope, focus the optics, test the star-tracking cameras that let the onboard computer know where we are looking, and make sure that the solar panels give us enough power to run everything.

Every system on the telescope needs to be working before the balloon crosses the horizon. After that, we can only monitor the progress of the telescope by the data streamed via satellite. We can send occasional commands to the telescope, but these satellite links are intermittent and can have a lag of up to several minutes, so the telescope has to be able to operate completely free of human intervention. It's essentially a stratospheric robot.

The balloon and the equipment it carries must adjust to their surroundings in the stratosphere. The balloon bobs up and down over the course of a day, rising and sinking as it warms in the sunlight and cools at night. Venting gas or dropping ballast can help maintain a stable altitude, but it may still fluctuate by several hundred to thousands of meters. In addition, energetic particles from space called cosmic rays can cause problems in the electronics. If they hit one of the control computers in just the wrong place, causing it to crash, circuits monitoring computer status must initiate a reboot.

Observatories on the Go

Balloon telescopes are inherently mobile — they could theoretically launch from anywhere on Earth. Usually, they're flown from airports or designated ballooning facilities. In most cases, after the flight is over they can be recovered, upgraded, and flown again.

In the U.S., short-duration balloon flights generally last less than 24 hours and are launched from either the Columbia Scientific Balloon Facility headquarters in Palestine, Texas, or from Fort Sumner, New Mexico. These flights are limited by the flight trajectory: Stratospheric winds tend to blow westward, toward southern California, with its millions of inhabitants, and toward the balmy coastline. It's generally inadvisable to fly conventional balloons over the Pacific Ocean — astrono-

HISTORIC DISCOVERY
◖ Victor Hess (right) detected **cosmic rays** — energetic particles speeding through space — when he accompanied his equipment aboard balloon flights launched in 1911 and 1912.

STRATOSPHERE: MONTANA STATE UNIVERSITY; VICTOR HESS: WIKICOMMONS / PD-OLD-70

▲ **PREPPING FOR FLIGHT** *Left:* The Super Balloon-borne Imaging Telescope (SuperBIT) payload hangs from a launch vehicle dubbed Big Bill, waiting for winds to die down enough for launch. *Right:* Members of the Balloon Array for Radiation-belt Relativistic Electron Losses (BARREL) experiment jump up and down in what they call the "low wind dance" as they hope for the wind conditions needed to launch their balloon.

mers don't like having to dive to retrieve their equipment — and it's definitely unwise to fly a several-ton telescope over a dense urban area.

Conventional balloons can take longer flights from Arctic or Antarctic sites. In these regions the Sun never sets in the summer, so balloons' altitudes stay relatively stable and flights have to drop less ballast to stay afloat. (Of course, flying astronomy balloons under the midnight Sun does limit the wavelengths accessible to detectors: Antarctic flights primarily host microwave, far-infrared, and particle detectors.) Flights from Kiruna, Sweden, for example, can last at most six days before they land in the Canadian Arctic Archipelago 2,500 kilometers away.

For the longest flights, we launch from Antarctica. During the Antarctic summer, high-altitude winds create a vast polar vortex above the continent, which carries the telescope around and around like a horse on a gigantic merry-go-round. These flights usually last more than two weeks. The Super-TIGER experiment set the record flight time in 2013 with 55 days afloat.

Taking Chances: BLAST's Story

Ballooning is not without its risks. As with space telescopes, there's always a chance that the telescope might not function after launch, and even if it does, it has to survive the harrowing ordeal of landing. The adventures of the Balloon-borne Large Aperture Submillimeter Telescope (BLAST; *S&T:* June 2011, p. 20) show both the advantages and perils of flying from a balloon.

BLAST was designed to detect infrared radiation from glowing dust grains in three different far-infrared color bands (centered at 250, 350, and 500 microns). We can map cold dust using these colors, tracing stellar nurseries within our galaxy. Imaging more distant galaxies at the same wavelengths also reveals light from bright, young stars that was absorbed by dust and then re-emitted in the infrared.

The original BLAST telescope took three flights: the first in 2003 from Fort Sumner, to test the telescope systems; a four-day science flight in 2005 from Kiruna, Sweden; and in 2006 a 12-day flight from McMurdo Station, Antarctica. BLAST mapped star formation in the Milky Way and nearby galax-

BIG BILL: STEVE BENTON; ASTRONOMERS: NASA / BARREL / BRETT ANDERSON; LAUNCH: BARTH NETTERFIELD

GO FOR LAUNCH Just before BLAST's first flight over Antarctica, the balloon and payload are readied for launch near McMurdo Station. The 5,500-pound (2,500-kilogram) payload is at the right of this image, the red parachute is in the center, and the partially inflated balloon is at the left.

ies, as well as faraway galaxies in the adolescent universe. The observations went forward nearly perfectly — but the 2006 outing turned out to be the telescope's last.

Once a balloon is finished collecting data and ready to descend, NASA sends a radio signal that severs the connection between the balloon and the science payload, sending the telescope into free fall. After a few seconds, the parachute rapidly spreads out to slow the telescope's descent. When the instrument eventually reaches the ground, its speed is a relatively gentle 7 meters per second (15 mph). These days, NASA has the parachute release automatically upon landing, but back in 2006 the engineers had to send a second radio signal to separate the parachute from the balloon once it had landed.

But for BLAST, sitting on the Antarctic plateau after landing, this second signal didn't get through.

Antarctica is known for extremely high winds — indeed, adventurers attempting to cross the continent on skis often bring wind sails. BLAST's parachute acted like a giant sail. A plane sent to find BLAST saw the 2,000-kg (5,000-lb) telescope being dragged across the Antarctic plateau, leaving a scarred trail of ice peppered with occasional debris where pieces of the experiment had been ripped off.

After the wind had dragged BLAST almost 200 km, what was left of the instrument entered a crevasse field. It lodged in one of these chasms, where it remains stuck and inaccessible to this day.

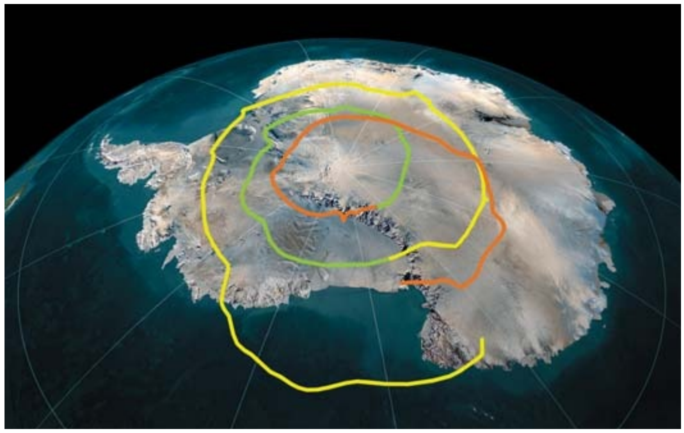
But luck was on the researchers' side. The vessel containing BLAST's hard drives — which held all the science data — was torn off the telescope a few kilometers before it entered the crevasse field. Mountaineers from the National Science Foundation Polar Program skied in to recover the drives and return them to the grateful science team.

BLAST Comes Back

Even though the original BLAST telescope was destroyed, the far-infrared maps it made of hundreds of star-forming regions were groundbreaking. BLAST charted young, cold clouds of gas and dust crisscrossed by long filamentary structures, wherein stars may be starting to form. In addition, it spotted young star clusters emitting so much radiation that they are destroying their parent cloud.

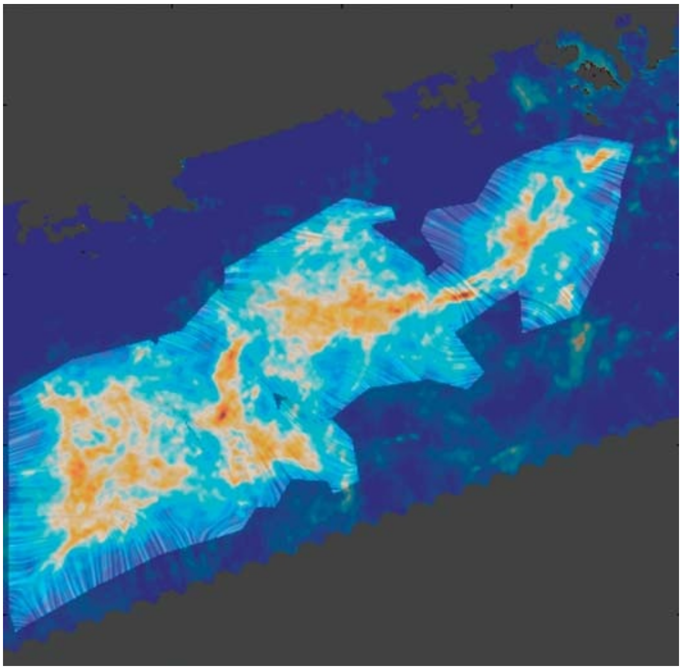
BLAST also made much deeper images of the distant universe, mapping small patches of sky that contained so many sources, the individual galaxies blended together. In this case, the three BLAST bands were used to assess the galaxies' apparent dust temperatures and thereby their redshift. Younger galaxies in the early universe appear redder and cooler because of their higher redshift, while older, nearby galaxies appear somewhat more blue and warm because of their lower redshift. Combining the BLAST maps with other infrared data that probes the light from young stars directly, BLAST found that star formation in the universe peaked about 10 billion years ago. These observations have since been confirmed and extended by many studies from the ground and space.

More recently, we rebuilt the BLAST telescope as BLAST-Pol ("Pol" for polarization), mainly using pieces of the original telescope that fell off as it was dragged along the Antarctic plateau. This time, we added special optics that allowed



▲ **POLAR VORTEX** During the Antarctic summer, high-altitude winds carry balloons on longer flights of a week or more. The Cosmic Ray Energetics And Mass (CREAM) project flew for 42 days in a single flight. Its three orbits about the polar vortex are pictured here.

POLAR VORTEX: NASA'S GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO



▲ **THROUGH THE VEIL** BLAST-Pol measured the polarization of submillimeter-wavelength radiation from the star-forming Vela C region. From the polarized light, the team inferred the cloud's magnetic fields (white lines), finding that the field tended to cross dense cloud structures. The Herschel satellite provided the far-infrared background image.

BLAST to detect not only the brightness of the glowing dust but also the light's polarization.

This extra information gives us a measure of the light waves' orientation. In most cases, light waves are oriented randomly, canceling out any polarization; however, spinning dust grains that line up perpendicular to a magnetic field will emit polarized light. We use this polarization to chart our galaxy's magnetic field. Launching BLAST-Pol in 2012, we made the most detailed map to date of magnetic fields in a massive star-forming cloud.

Strong enough magnetic fields can actually slow down the rate at which stars form by stopping gas from moving across field lines. BLAST-Pol's map of a giant gas cloud in the constellation Vela revealed that the magnetic field direction is almost always related with the cloud structure we see: Faint, wispy cloud features tend to run parallel to the field, while denser regions, where we expect the stars to form, are more often perpendicular to the field. This result suggests that the magnetic field is strong enough to have shaped the formation of the cloud. It may even partially explain why the observed rate of star formation in our galaxy is only a few percent of what we predict using simple assumptions.

As balloon telescopes become more powerful, the amount of science data they can collect is growing accordingly. My collaborators and I hope to launch a new, upgraded version of BLAST-Pol, known as BLAST-TNG (for "the next generation") above Antarctica in late 2018. We are using the newest version to test arrays of *microwave kinetic inductance detectors*, a new type of superconducting detector that enables us to build large, inexpensive pixel arrays for faster survey imaging. BLAST-TNG will also carry a cryogenic system to keep those detectors cold throughout the flight's duration. By testing new detector technologies in the upper stratosphere, we can demonstrate their operation in space-like conditions — an important step for making these advances available for future satellite telescopes.

We expect BLAST-TNG to map 20 times the area of sky surveyed by BLAST-Pol during its first flight in 2010. We're also inviting other astronomers to submit their ideas for how to use our telescope, making BLAST-TNG the first ever balloon-borne observatory to accept proposals from the community.

Science Takes to the Skies

Hundreds of balloons launched over the decades have tackled questions across astronomy. For example, some of these stratospheric observatories enable us to observe our universe's infancy by mapping its oldest detectable light, radiation known as the cosmic microwave background (CMB). This snapshot of our universe, released 370,000 years after the Big Bang, contains the seeds of all the large-scale structure we see around us today. By 2000 balloon telescopes Boomerang and Maxima had measured tiny fluctuations in this radiation, clearly showing that our universe's shape is flat (see "How Shape Determines Fate" below).

Today, many different balloon telescopes (such as Spider, EBEX, and PIPER) are looking for an even fainter signal buried in the CMB: specific patterns in polarization that are expected to be a billion times fainter than the total CMB signal. If detected, this polarization pattern would enable astronomers to probe a much earlier era, a mere 10^{-35} second after the Big Bang, when the universe was rapidly expanding (*S&T:* Oct. 2013, p. 22).

Astronomers also use balloons to measure the energy and composition of cosmic-ray particles. One of the most successful of these experiments is the Cosmic Ray Energetics And Mass (CREAM) experiment. It logged a record-breaking 161 total days of science operation over six separate Antarctic flights from 2004 to 2011. The data it collected showed many more high-energy cosmic rays than predicted, which has prompted astronomers to rethink ideas about cosmic-ray origins.

After the instrument's success on a balloon platform, the CREAM team adapted their experiment for even higher altitudes: onboard the International Space Station. The new experiment is called ISS-CREAM (and yes, that's pronounced "ice cream").

THE SHAPE OF THE UNIVERSE

Density determines the universe's geometry: A jam-packed universe would be closed, like the surface of a sphere to use a 2D analogy, whereas a sparse universe would be open, like the surface of a saddle. Balloon-borne observations showed that our universe is remarkably flat, with just enough density to lie almost exactly between these two extremes.

J. D. SOLER ET AL. / *ASTRONOMY & ASTROPHYSICS* 2017 (603:A64)

The Next Generation

What are the limits for balloon astronomy? Can we ever hope to do the equivalent of space-based astronomy (read: Hubble-quality images) from the stratosphere? Advances in balloon and control technology make this a real possibility. Among the major recent developments are *super-pressure balloons*, which will enable longer and higher flights.

Conventional balloons maintain what's called *zero pressure*: They vent helium as they fly in order to keep the pressure inside the balloon equal to the atmospheric pressure outside. But at night these balloons sink as the helium cools, so they must drop ballast. The next day, the balloon once again ascends in the warmth of the sunlight, venting helium to stabilize altitude. And the next night, it will cool again and drop more ballast — and so on. This cycle makes long flights impossible.

Super-pressure balloons, however, are closed systems made of strong material that can maintain positive pressure (that is, higher pressure inside the balloon than outside). As such, they fly at nearly constant altitudes, even when the Sun sets. These balloons can be launched from anywhere on Earth and stay afloat for months, tracing a wandering path around the planet.

NASA's super-pressure balloon program has only been available to science experiments for a few years, but already the record for one of these flights at mid-latitudes is 46 days — much longer than previously possible. The goal is to routinely have flights of up to 100 days.

Another major development has been in telescope control. It remains a challenge to take deep visible-light images without smearing them, as the telescope must drift less than a fraction of an arcsecond when pointing at a target — that's like threading a needle from a kilometer away. The Stratoscope II telescope, which operated about 50 years ago, achieved a remarkable 0.2-arcsecond resolution for images with 5 to 20 seconds of exposure time. To image faint objects, though, we'd need similar stability for at least a few minutes.

The Super-pressure Balloon-borne Imaging Telescope (SuperBIT) has made huge advances in this area. It uses motors to point the balloon gondola; the telescope, which is mounted to an inner frame, can then be positioned to compensate for any rocking motion. Motors can also adjust a mirror inside the camera to keep the image center from drifting.

SuperBIT should have its first full science flight on a super-pressure balloon in about a year. Launching from Wanaka, New Zealand, it will make deep, high-resolution maps of hundreds of galaxy clusters. Astronomers can then use strong and weak gravitational lensing to map dark matter around and between the galaxies (*S&T:* Sept. 2016, p. 34).

This next-gen technology will make balloon-borne telescopes an excellent option for long views of the sky in visible light as well as ultraviolet and near-infrared wavelengths, all of which require the dark-sky conditions of middle latitudes (as opposed to the midnight Sun of Antarctica). Soon we may have balloon telescopes mapping distant galaxies with image clarity similar to the Hubble Space Telescope or searching for planets around other stars. For balloon astronomers, the sky is no longer the limit!

■ **LAURA FISSEL** is a Jansky Postdoctoral Research Fellow at the National Radio Astronomy Observatory and a member of the BLAST team. She studies star formation in our galaxy.

• **Watch balloons launch at https://is.gd/balloonastro and follow the BLAST team's progress on Twitter: @BLAST_TNG.**

NASA / BILL RODMAN

THE NEXT GENERATION A super-pressure balloon is readied for launch from Wanaka, New Zealand. The May 16, 2016, take-off marked the first time a super-pressure balloon carried a scientific payload, called the Compton Spectrometer and Imager.

The Inconstancy of

NASA & THE HUBBLE HERITAGE TEAM (STSCI / AURA)

Nebulae

Variable nebulae have intrigued observers for centuries due to their changeable nature on potentially short timescales. Grab your telescope and see if you can spot any changes.

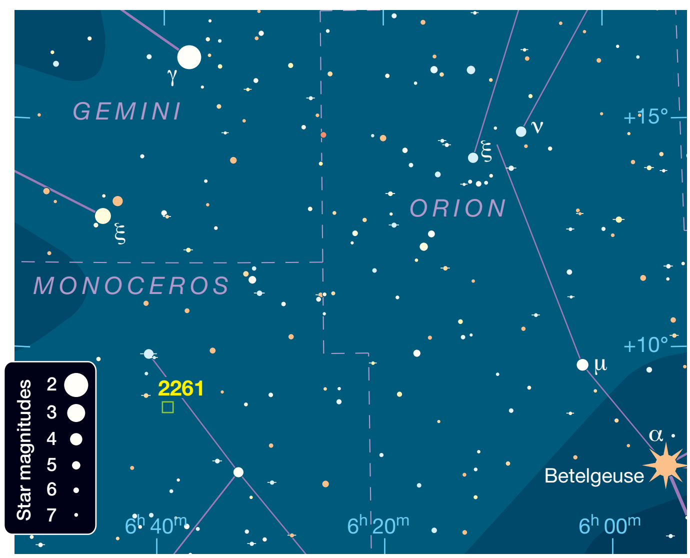
▲ **VARIATIONS OVER TIME** These photos in the V-band, obtained several months apart at the Steward Observatory on Kitt Peak, clearly show how Hubble's Variable Nebula changes with time.

Deep-sky observers have a seemingly endless reservoir of nebulous objects to observe. Galaxies, unresolved star clusters, planetary nebulae, and diffuse nebulae of many types abound. The vast majority are static and unchanging on human timescales, but a few defy constancy. *Variable nebulae* constitute a small but intriguing class of reflection nebulae illuminated by variable stars that make interesting and fun targets. Changes visible on timescales as short as weeks or months endow these mysterious clouds with the ability to excite our imagination and pique our curiosity. February's sky contains some notable examples.

The most famous and best understood of these enigmatic jewels is **Hubble's Variable Nebula** (NGC 2261), which is the peculiar nebula associated with R Monocerotis (R Mon). The brightest and largest of the variable nebula genre, it stands out among its brethren and is a well-known showpiece of the winter sky. It has long been a personal favorite of mine, and my observing notes emphasize how very easy it is to witness the changes in its shape and brightness distribution from year to year, and even month to month. One might imagine an embedded star dragging and twisting the nebula with it as it spins. Over time, the impression of rotation is quite powerful. That effect, however, is an illusion — what we see are really just shadows causing the changing illumination in the nebula.

◀ **ENIGMATIC JEWEL** Despite observations of it going back some hundreds of years, the great astronomer Edwin Hubble was the first to notice, in 1916, that this nebula varied greatly in brightness, hence its moniker. Lively debate on this object's true nature continued well into the late 20th century.

NGC 2261 was discovered on December 26, 1783, by Sir William Herschel, who described the object as "fan-shaped" and placed it in his Class IV — *Planetary Nebula*. He reserved this classification for unusual objects that didn't fit into the other classes. Herschel's Class IV contains only 20 true planetary nebulae; the remaining objects include several "foreign bodies," such as IV 2, or NGC 2261 as it came to be known. It



has since been identified as the prototypical *cometary nebula*, a class of fan-shaped reflection nebulae that are often associated with T Tauri stars (very young, variable, low-mass stars often in binary systems; some have circumstellar disks and are likely progenitors of planetary systems). It is also an example of a *cocoon nebula*, a term that describes the dusty envelope that surrounds some newborn stars in the process of forming planets.

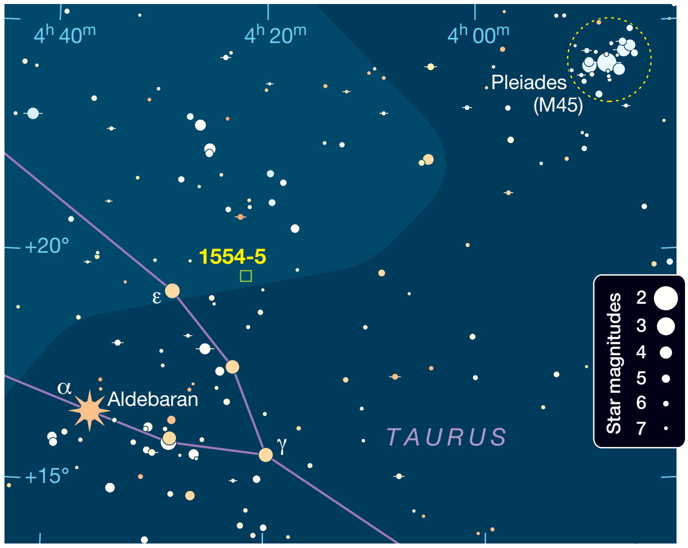
Our evolving understanding of this system began in earnest in 1861 when J. F. Julius Schmidt discovered the variability of R Mon using the 6-inch refractor at the National Observatory of Athens in Greece. The bright knot that forms the southern tip of the nebula varies in brightness from about magnitude 10 to magnitude 13. William Lassell was one of the earliest observers to propose that R Mon was composed of a luminous knot rather than a star. Edward Emerson Barnard agreed with this assessment, and, even with the 40-inch refractor at Yerkes, the famed observer could not resolve R Mon into a star.

In 1916, Edwin Hubble discovered that the nebula itself varied in shape and brightness. His pronouncement, arrived at by studying photographs of the object taken between 1900 and 1916, is the source of its popular moniker. Hubble's discovery prompted the research of Lowell Observatory's Carl Otto Lampland, who produced some 1,000 photos of the nebula between 1916 and 1951. It was from these important images that astronomers concluded that variations in the nebula did not correspond to the star's fluctuations. Using the 42-inch reflector at Lowell, Lampland recorded variabilities that showed features displaced by as much as 1 arcsecond in as little as 4 days. He concluded that these displacements could not be the result of physical movement since that would require superluminal velocities. Instead, he postulated that dark shadows from dust clouds close to the light source were sweeping across the nebula. The intense interest in this object within the astronomical community is evidenced by the fact that NGC 2261 was the first official target (first light) photographed by Edwin Hubble using the 200-inch Hale telescope at Palomar in 1949.

George Herbig noted R Mon to be a tiny triangular nebula about 15″ long that increased in brightness at its southern tip. Using the 120-inch reflector at the Lick Observatory in 1959, Herbig, too, was unable to resolve R Mon as a star. Some five years later, in 1964, Richard C. Hall (Goethe Link Observatory) measured the polarization of the nebula and found that it too was variable, with the eastern part more highly polarized than the western part, and the overall polarization increasing with distance from R Mon. Subsequently, in 1966, Frank Low and Bruce J. Smith recorded large amounts of infrared radiation relative to R Mon's visible light output and announced that the object was a cocoon nebula, the first such identified, about 200 light-years across.

◀ **NOW YOU SEE IT, NOW YOU DON'T** Hind's Nebula was first discovered in 1852, when astronomers were still debating the very nature of this class of object. It's the subject of much discussion, since it has a tendency to "disappear" from time to time. It's currently visible, so take out your telescope, point it toward Taurus, and look for this nebula while you still can.

T. A. RECTOR / UNIVERSITY OF ALASKA ANCHORAGE, H. SCHWEIKER / WYIN, NOAO / AURA / NSF



By the 1980s, the prevailing view was that R Mon was a star surrounded by a dust disk containing about five Earth masses of coarse dust grains. According to this model, most of the visible light from the star is absorbed by these grains and re-emitted at infrared wavelengths. Reporting on Hubble Space Telescope observations in an *Astrophysical Journal* article in 1997, Laird M. Close and collaborators confirmed that dust enshrouds the star, shielding it from detection at visible wavelengths. With the Canada-France-Hawaii Telescope on Mauna Kea, Close's team found R Mon to be a binary star 2,500 light-years away. A *B*-type primary of 10 solar masses is orbited by a secondary star that's 200 times fainter, with a separation of 0.7″. That secondary is a very young T Tauri star about 1.5 times the mass of the Sun.

> Variable nebulae can be challenging to observe, but the effort is immensely rewarding.

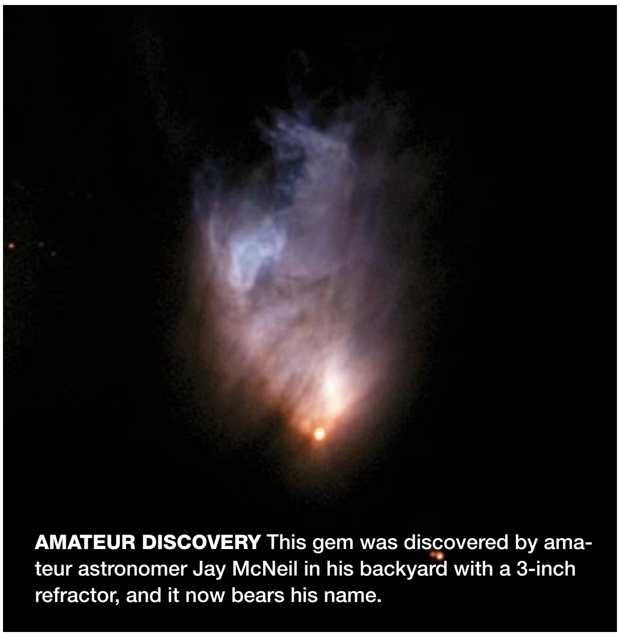
The current picture of the surrounding nebula is best described as a hollow cone, shaped by energetic jets of hot gas from the primary star, which is surrounded by a dusty disk inclined 20° from edge-on. Darker filaments, following twisted magnetic field lines, spiral around the cone, creating the shadows that cause the nebula's brightness fluctuations. A second, similar cone probably extends in the opposite direction, but it is obscured from our view.

In the eyepiece, Hubble's Variable Nebula looks like a celestial badminton shuttlecock with a very dense knot on its southern end and a wide, irregular fan extending north. Walter Scott Houston noted that sometimes the nebula can be seen with a 3-inch telescope, but at other times it requires a 10-inch. Variations in brightness are apparent to the careful visual observer who checks it on a regular basis but, unlike most of the other known variable nebulae, it never completely fades and is always detectable in mid-size scopes. Its popularity as an observing target is no doubt enhanced by that fact and by its proximity to the remarkable open cluster NGC 2264 (also known as the Christmas Tree Cluster, so named by L. S. Copeland), an easy star-hop away.

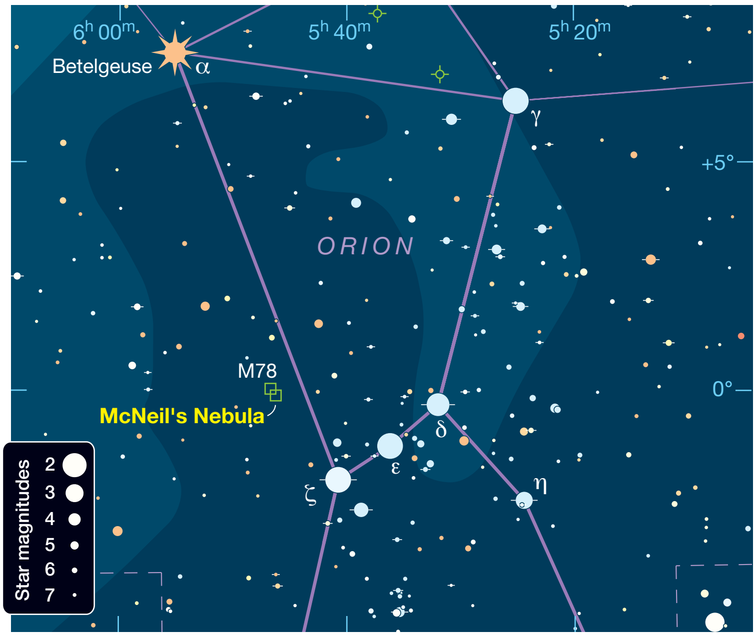
The star T Tauri itself is responsible for illuminating **Hind's Variable Nebula** (NGC 1555). Both the star and the nebula were discovered by John Russell Hind on October 11, 1852, using the 7-inch Dolland refractor at Bishop's Observatory in London. He was quite surprised to find a 10th-magnitude star that didn't appear on a recently published ecliptic chart and suspected it might, therefore, be variable. His published report of the star included the description of an adjacent nebula that he supposed would prove to be new. The nebula would become the prototype of the variable nebula class and would spark debate and misunderstandings that stretched well into the 20th century.

Astronomers of the time were still arguing about the true nature of nebulae. Herschel, who had once believed all nebulae to be composed of unresolved stars, had changed his mind by the turn of the 19th century. He put forth a theory that at least some nebulae were composed of a form of luminous matter and that they slowly evolved over time under the influence of gravity. Astronomers looking to confirm this idea became quite fascinated with Hind's new nebula.

The nebula was confirmed in 1854 by Jean Chacornac observing at Marseille Observatory, but then it faded around 1861 and disappeared completely in 1868, sparking debate not only about its nature but also its very existence. It was "missing" until its rediscovery by Barnard and Sherburne Wesley Burnham in 1890 using the 36-inch reflector at the Lick Observatory. Barnard also reported a second "excessively faint, round" nebulosity surrounding the star. Throughout its early observational history, visual observers contributed to the enigmas surrounding this object through a number of misunderstandings, confused positions, and suspect observations: Almost all of the important observers of the time submitted reports either of its detection or non-detection. Even Hind's original report is plagued by contradictory positions for the nebula. Adding to the muddled state of affairs, Otto Struve reported in 1868 in a private communication to Heinrich Louis d'Arrest that Hind's nebula had disappeared,



AMATEUR DISCOVERY This gem was discovered by amateur astronomer Jay McNeil in his backyard with a 3-inch refractor, and it now bears his name.

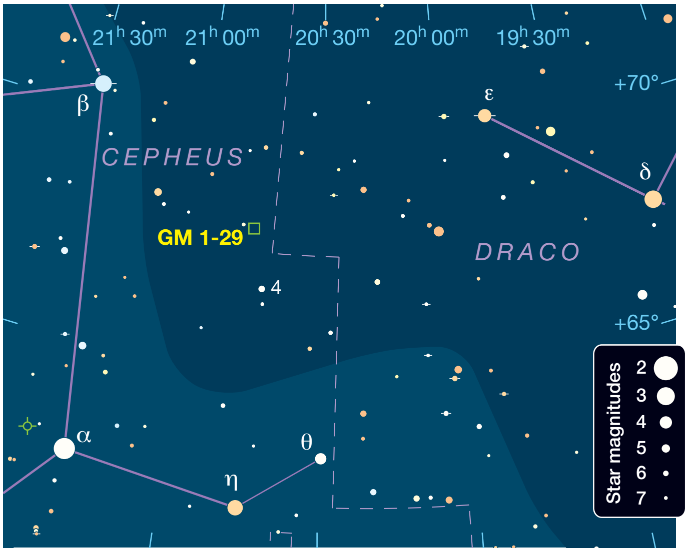


GEMINI OBSERVATORY IMAGE

Variable Nebulae and Where to Find Them

Object	Name	Associated Star	Mag(v)	Size/Sep	RA	Dec.
NGC 2261	Hubble's Variable Nebula	R Mon	10–13	3.5′ × 1.5′	06^h 39.2^m	+08° 44′
NGC 1555	Hind's Variable Nebula	T Tau	8.5–13.5	1′ × 1′	04^h 22.0^m	+19° 32′
	McNeil's Nebula	V1647 Ori	15–16	1′	05^h 46.2^m	–00° 06′
GM 1-29	Gyulbudaghian's Nebula	PV Cep	12–13	0.8′	20^h 45.9^m	+67° 58′

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.



▲ **GYULBUDAGHIAN'S NEBULA** Observing at Byurakan Astrophysical Observatory, on the southern slope of the Armenian mountain Aragats, Armen Gyulbudaghian and his collaborators first discovered this jewel.

ESA / HUBBLE / NASA

but that a new nebula had become visible nearby. This nebula (NGC 1554) subsequently also disappeared and today is known as Struve's Lost Nebula.

Hind's Variable Nebula is usually visible as two or three faint arcs of nebulosity about 40″ west or southwest of the irregular variable star, T Tauri, which varies erratically between magnitude 9 and 13. The nebula also significantly varies in brightness and orientation from the star, and an emission nebula surrounding the star is also sometimes detectable. Struve's Lost Nebula is still lost and may never have actually existed.

An exciting discovery of a new variable nebula was announced by the amateur astronomer Julian "Jay" McNeil in 2004. This object, **McNeil's Nebula**, was detected on a CCD image he took of Messier 78 in Orion on January 23rd of that year with a 3-inch refractor from his backyard in Paducah, Kentucky. The object is illuminated by a star, previously designated IRAS 05436–0007 and now identified as V1647 Orionis, a protostar seen in a rarely captured outburst. Professional astronomers rushed to exploit the opportunity, which spawned a flurry of more than 50 scientific papers, and amateur astronomers flocked in great numbers to make visual observations of the object. The nebula remained bright for about 26 months.

From the moment of discovery, researchers, both amateur and professional, scoured the photographic archives for evidence of previous outbursts and found that the nebula was indeed present in images taken in 1966. Astronomers anticipated that perhaps another brightening could be expected around the year 2042 and so were taken by surprise at a new outburst of the star already in August 2008 which again illuminated McNeil's Nebula.

The nebula is currently visible in images and detectable visually, at least in larger scopes. This tiny cometary nebula is located southwest of M78 about 13′ from the brightest part of the nebula and just 5′ south of NGC 2064. It lies 1′ west of a pair of 15th-magnitude stars.

Gyulbudaghian's Nebula (GM 1-29) is illuminated by PV Cephei, a Herbig-Haro object (a newly born star that exhibits jets) cataloged as HH 215. Armen Gyulbudaghian described the nebula in 1977 and, along with Tygran Magakyan and V. R. Amirkhanyan, is credited with its discovery. The nebula was independently reported by the team of Cohen, Kuhl, and Harlan that same year based on Lick Observatory data.

Similar to NGC 2261, Gyulbudaghian's Nebula is illuminated by a very young star, orbited by a dusty disk of material, with two energetic jets perpendicular to the spinning disk streaming away from the star. The northern jet creates a visible cometary nebula as it fans out; the southern jet is apparently obscured by dust. The variability of the nebula is well established: Images from 1951 show a streak of nebulosity that obscures PV Cephei, and by 1952 the streak is seen streaming away from the small red star. The *Palomar Observatory Sky Survey* plates from 1975 show the star, but there's none of the nebulosity seen in the 1977 discovery image. Recent amateur observations also describe variability, with various observers reporting alternately on the nebula's presence and absence. Detections range from a relatively bright fan to a faint streak interspersed with periods of invisibility. Gyulbudaghian's Nebula lies in western Cepheus about 1.5° west of the Iris Nebula and an easy star-hop from 4 Cephei.

Mercurial in nature, variable nebulae can add a fun smidgen of unpredictability to your observing list. They are certainly worth the effort to observe repeatedly to build your own record of their changing brightness. They can reward you with the thrill of discovery at every observation and may quickly become favorites.

■ Contributing Editor **TED FORTE** enjoys chasing faint fuzzies from his backyard observatory outside of Sierra Vista, Arizona.

Collimating a Schmidt-Cassegrain

Follow these steps to get your telescope into perfect alignment.

The versatile and portable Schmidt-Cassegrain telescope is without question among the most popular commercial telescopes ever sold. However, some amateur astronomers don't respect the SCT, regarding it as an also-ran optically compared to other designs. The fact is, SCTs are better telescopes than observers often acknowledge. At least they *can* be, if properly collimated by ensuring that the telescope's large primary and smaller secondary mirrors are properly aligned.

Unfortunately, many of the SCTs I encounter are out of collimation, and yet the owners are sometimes afraid to adjust their telescopes' optics. The idea of collimating a complicated — looking telescope is admittedly scary, but there's really nothing to fear. The SCT is actually easier to collimate than any other design. Only one optical element needs to be, or can be, adjusted: the secondary mirror.

COLLIMATION TEAM Getting your Schmidt-Cassegrain telescope in perfect optical alignment can be quick and easy, particularly if you have a friend to adjust the screws while you monitor the progress at the eyepiece.

SEAN WALKER / *S&T*

▲ **TRIPLE PLAY** The secondary-mirror collimation screws are spaced 120° apart, making adjustments easy and intuitive.

It's fortunate that collimating a Schmidt-Cassegrain is this simple, because good collimation is critical for peak performance. The standard f/10 SCT uses a 5× magnifying secondary mirror to increase the focal ratio of the scope's "fast" f/2 primary mirror to f/10. That gives the SCT a long focal length packed into a short tube, but this magnifying secondary mirror also exaggerates collimation errors.

So, how do you collimate an SCT? Which accessories do you need? Forget basic Newtonian collimation tools like lasers and Cheshire sights. Variations in the mechanical alignment of the commercial SCT render most of these devices useless. Only one "tool" is needed, and it's free: the bright star Polaris. While you can collimate a Schmidt-Cassegrain using an artificial star device, the 2nd-magnitude North Star is nearly perfect and is available every clear night in the Northern Hemisphere. (Southern Hemisphere observers are welcome to use any comparably bright star, though you'll benefit from having a tracking mount.)

Polaris is bright enough to make collimation easy. Thanks to its position near the celestial pole, it doesn't move much, so there's no worrying about precise telescope tracking during collimation. Also, having a friend to adjust the collimation screws while you watch the movement in the eyepiece can greatly speed up the process.

Before beginning, it's important to know how the SCT's secondary-mirror adjustments work. On almost all modern SCTs, you'll find three Allen- or Phillips-head screws on the secondary mount in the center of the corrector lens. They are arranged in a triangle and thread into a metal backing plate that the convex secondary mirror is glued onto. This backing plate rides on a central hump on the secondary mount; tightening and loosening the screws tilts the mirror on this hump. Never remove or completely loosen all three screws. Unless your telescope has a fourth central screw, these three are all that holds the mirror onto the mount — removing them will drop the secondary mirror onto the primary mirror.

Your first step in collimation is determining whether the telescope actually needs to be adjusted. On a night of good seeing — that is, steady atmospheric conditions when stars are not twinkling madly — remove the star diagonal and insert a medium-power eyepiece so that you're looking straight through the instrument. The eyepiece should yield a magnification of about 150×. Now center Polaris in the eyepiece field, bring the star to sharp focus, and then defocus just slightly. If the star looks like a big donut, you've gone too far. Defocus only until the star looks like a small bull's-eye target, when you see a series of diffraction rings surrounding a small bright point, the star's disk.

Take a critical look at the bull's eye. Are the rings concentric, or are they compressed on one side? Does the whole thing look squished? If it is, you've got collimating to do. Before beginning, however, double-check that the star is centered in the eyepiece. Due to the curved field of the standard SCT, an off-center star might appear distorted, implying that the scope needs collimation even if it doesn't.

Ballpark Collimation

The only reason to do "ballpark" collimation is if stars look like comets and it's impossible to see diffraction rings. Stand about 2 meters in front of the telescope and look straight down the tube. Observe the series of your reflections that are visible in the primary mirror. Are they concentric? Does everything line up, or do these reflections look tilted to the side? If they're skewed, adjust collimation with the three screws on the secondary mount until the reflections are centered.

▲ **ROUGH ALIGNMENT** If your telescope is significantly out of collimation, like this one is, stand about 2 meters (6 feet) in front of the scope and look straight down the tube. If the reflections aren't perfectly concentric, you'll need to adjust the collimation screws a fair amount before moving on to the next stage.

TOP: ROD MOLLISE; BOTTOM: SEAN WALKER / S&T

▲ **SMALL TURNS** When performing the fine collimation steps, limit the amount you turn your tool to no more than ⅛ of a turn to avoid pushing Polaris out of the eyepiece field.

You can begin collimation with any of the screws. Just pick one and, using the proper tool, tighten it experimentally. In this stage, you may need to turn screws a fair amount; but even so, make only ⅛ turn at a time. If the reflections moved in the proper direction, continue turning the screw in small amounts until the reflections in the telescope's primary mirror are concentric. If not, pick another screw, tighten it, and check to see if you are going in the correct direction. When all the reflections line up, it's time to move to rough collimation.

In all stages of adjustment, try to avoid loosening the screws; that will ensure the secondary is snug and the telescope will remain in collimation for months or even years. If you still need to move the secondary in a particular direction but the corresponding screw is alredy hand-tight, you can still make the adjustment in the same direction by loosening the other two screws slightly.

Rough Collimation

Start with Polaris centered in the field and defocus until the star looks like a donut with a dark center. Is that donut hole (which is actually the shadow of the secondary mirror) in the middle, or is it off to the side? If it's not centered, adjust the screws as described above until it is.

Note that turning a screw will move Polaris to the edge of the field, so be sure to re-center it following each adjustment. When the donut looks good, move the focus in to make the donut half the size as it was previously, and then see if the dark hole is still centered. If it is, you can move on to fine collimation. If not, follow the same steps until it's as well centered as you can get it. Some people stop at this "donut stage," but that is rarely good enough for demanding tasks like planetary observing.

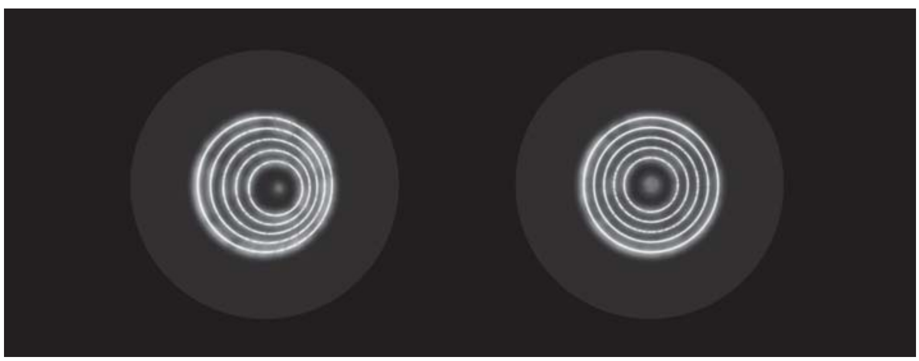
Fine Collimation

Re-focus Polaris until it is almost sharp, such that diffraction rings appear around the star. If the bull's eye of these rings isn't concentric, then adjust the secondary screws until it is. There are various methods that can be used to determine which screw needs to be adjusted, but I like to keep things simple, so I use a variation of my low-tech "pick one" strategy.

Look at the bull's eye. Which side is squished? Move the telescope until that side is against the edge of the eyepiece field. Now, move the screws by small amounts until you find the ones that move the star toward the center. Use that screw or screws to put the star back in the center of the field. Keep repeating this, moving the star to the field edge closest to the compressed side of the bull's eye and re-centering it with the screws, until the rings are concentric.

In-focus Collimation

If you have excellent seeing conditions, you can attempt the ultimate in SCT collimation — in-focus collimation. This is made possible by the fact that,



▲ **FINE COLLIMATION** *Left*: While aimed at Polaris, rack the focus out slightly so the star's diffraction rings are visible. Imperfect collimation will make the rings appear skewed in one direction. *Right*: Adjust the collimation screws until the rings are perfectly concentric, so that the star looks like a perfect bull's-eye target.

TOP: ROD MOLLISE; BOTTOM: *SKY & TELESCOPE* thanks to the laws of physics, when a star is in precise focus, it is not a minute pinpoint. It is actually a small disk, known as the Airy disk, surrounded by a series of diffraction rings, with the first ring being prominent and the rest dim.

Once again, center Polaris in the eyepiece and switch to a high-power eyepiece, magnifying the view enough so that when the star is in focus you can see the Airy disk and the first diffraction ring. For the Airy disk and ring to be visible, the atmosphere must be steady and the telescope well acclimated to outdoor temperatures. Often the best time to try in-focus collimation is as soon after sunset as possible.

▲ **IN FOCUS** Final adjustments to establish perfect collimation should be done under good to excellent seeing conditions. Focus Polaris while it's centered in the field and look for the first diffraction ring around the Airy disk. If it appears like the arc at left, adjust the corresponding screw using very small turns until it appears to surround the star as seen at right.

Examine the first diffraction ring. Is it unbroken around the Airy disk? Or is it incomplete? If it is broken, move the collimation screws by tiny amounts until it is a perfect ring. Is in-focus collimation necessary? If you intend to observe or image the Moon and planets at high power, yes, it can make a significant difference in images.

I mentioned earlier that it's possible to collimate with an artificial star. You can buy commercial artificial stars, which are battery powered and use high-intensity LEDs, or you can make one by punching a small hole in a piece of aluminum foil with a needle and placing that in front of a bright light source. The hole needs to be small to produce a suitably pinpoint "star." In a pinch, however, I've used the filament of a miniature Christmas tree bulb as an artificial star. That's not perfect, but it can get a telescope well into the fine-collimation stage. An illuminated ball bearing also works well, particularly in the daytime when no stars are available.

Place the artificial star far enough from the telescope so it can be brought close enough to focus to show diffraction rings. The star must be far enough away that it will almost come to perfect focus. When the rings are visible, perform fine collimation as normal. In-focus collimation should be done on the truly pinpoint source of a real star, but an artificial star collimation can be good enough for most purposes.

How long does it take to collimate a Schmidt-Cassegrain? When you're new to the process, and especially if you have to begin with ballpark or rough collimation, expect to spend as much as an hour adjusting the telescope. Once you've gained some experience and have got your SCT's collimation dialed in well enough that it only needs minor tweaks, you'll likely be finished and ready to observe in around 5 to 10 minutes.

Collimating a Schmidt-Cassegrain sounds tedious, but it gets easier with practice and the payoff is huge. I've seen good collimation turn an optically so-so SCT into a planetary powerhouse. In some cases, it can be like having a whole new telescope. Enjoying sharp images under a beautiful, starry sky is more than enough reward for sweating in the dark over those three pesky little screws.

▲ **TOOL-FREE** Replacement thumbscrews that eliminate the need for additional tools are available from several manufacturers, including **bobsknobs.com** and **scopestuff.com**. Be careful to replace only one screw at a time so that you keep all the screw holes aligned and avoid dropping the secondary mirror onto your telescope's primary.

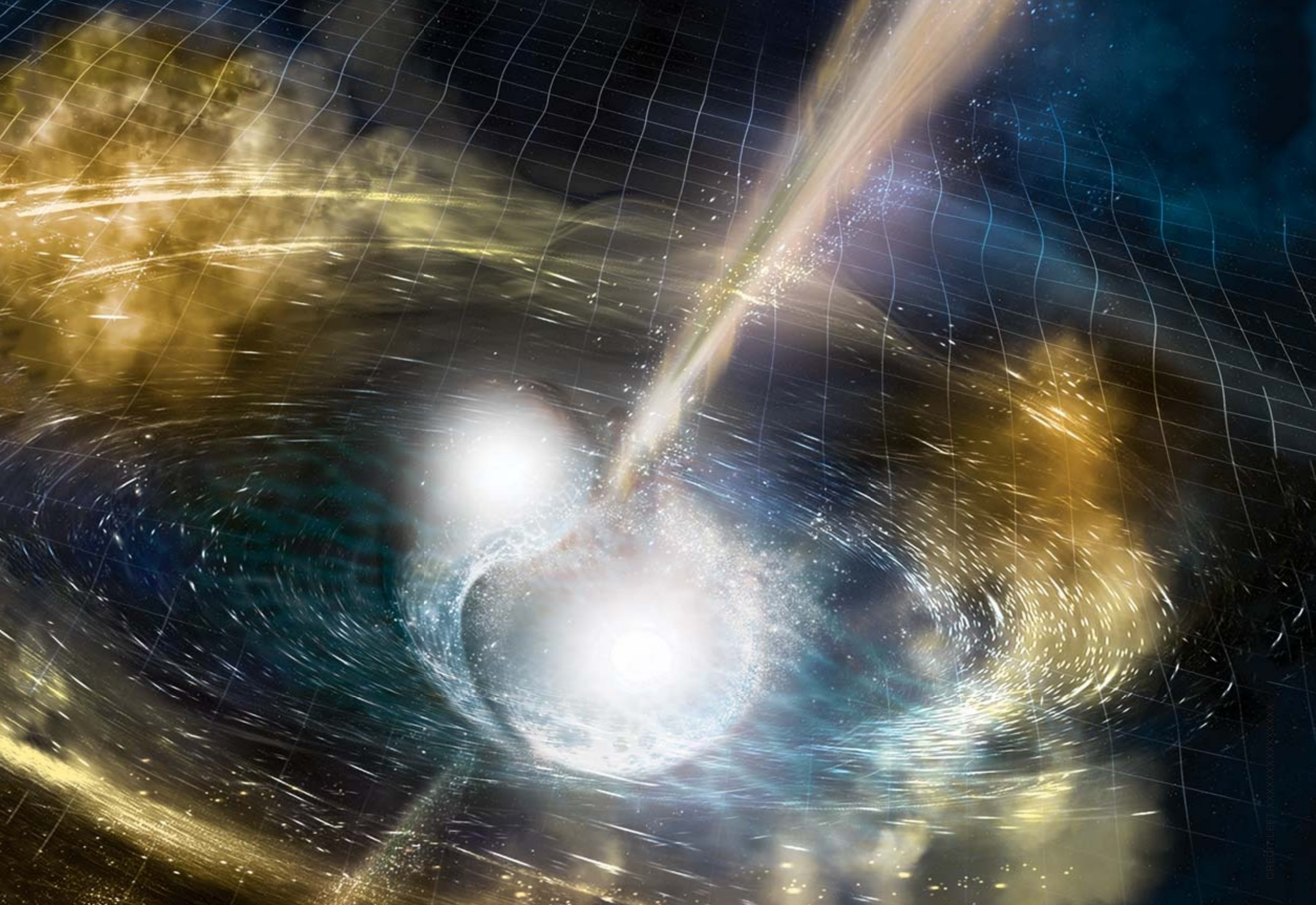
TOP: *SKY & TELESCOPE*; BOTTOM: BOB'S KNOBS

■ Contributing Editor **ROD MOLLISE** is a well-known expert on all aspects of Schmidt-Cassegrain telescopes.

GRAVITATIONAL WAVES by Govert Schilling

When Neutron Stars Collide

After decades of hard work, astronomers have caught their first spacetime ripples from the smash-up of two dead stars.



On August 17th, a new age of astronomy began. That day, the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) registered tiny ripples in spacetime, produced by a pair of frantically orbiting neutron stars right before they collided. But the reason that they herald a new age is that they didn't come alone: Telescopes on the ground and in space detected the cosmic smash-up and the fading glow of its radioactive fireball all across the electromagnetic spectrum (*S&T:* Jan. 2018, p. 10).

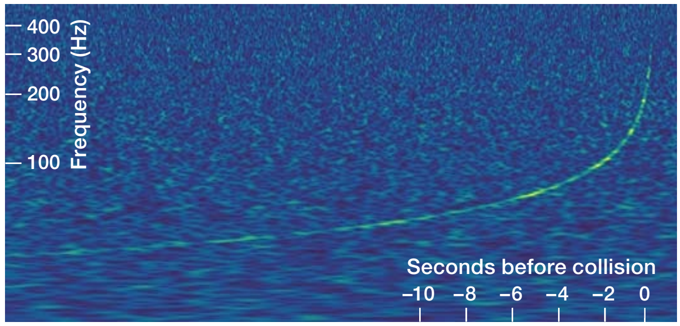
Astronomers have known neutron star binaries exist since 1974, when Russell Hulse and Joseph Taylor (then at the University of Massachusetts, Amherst) discovered the first one, PSR 1913+16. The two objects have an average separation of less than a million kilometers and an orbital period of 7.75 hours. But that separation and period are shrinking with time. In fact, the binary's very slow decrease in orbital period, measured over subsequent years by Taylor, Joel Weisberg (now at Carleton College), and others, perfectly matches Einstein's prediction for energy loss due to the emission of gravitational waves. Some 300 million years from now, the two neutron stars in the Hulse-Taylor binary will collide and merge.

This slow death dance provided the first hard evidence, even if it was indirect, that gravitational waves were real, and the discovery of PSR 1913+16 ultimately earned Hulse and Taylor the 1993 Nobel Prize in Physics. The objects' inexorable inspiral also gave a huge boost of confidence for physicists such as Rainer Weiss (MIT) and Kip Thorne (Caltech), who were designing the first prototypes of LIGO-like laser interferometers. If one binary neutron star would coalesce in 300 million years, others might do so tomorrow — and the energetic burst of gravitational waves the collision produced should be detectable with extremely sensitive instruments here on Earth.

On August 17th, tomorrow arrived. "We've been waiting for this for 40 years," says Ralph Wijers (University of Amsterdam, The Netherlands).

"I couldn't believe my eyes," adds LIGO lead astrophysicist Vicky Kalogera (Northwestern University). Back when LIGO caught its first event in September 2015, many team members didn't believe it was real (*S&T:* Sept. 2017, p. 24). But in the neutron stars' case, it was immediately clear that here was the thing they'd all been waiting for. "It's a lot more exciting than the first gravitational-wave detection."

Astronomers around the world share Kalogera's elation. Observing both gravitational waves and electromagnetic radiation from the catastrophic coalescence of two hyperdense neutron stars provides astronomers with a wealth of new, detailed information. The new buzzword is *multi-messenger astronomy*, the study of objects or phenomena in the universe using fundamentally different types of emission. The detection of neutrinos from supernova 1987A had provided a tantalizing glimpse of this future, but as Edo Berger (Harvard) comments, "2017 August 17 will always be remembered as the singular moment when multi-messenger astronomy was born."

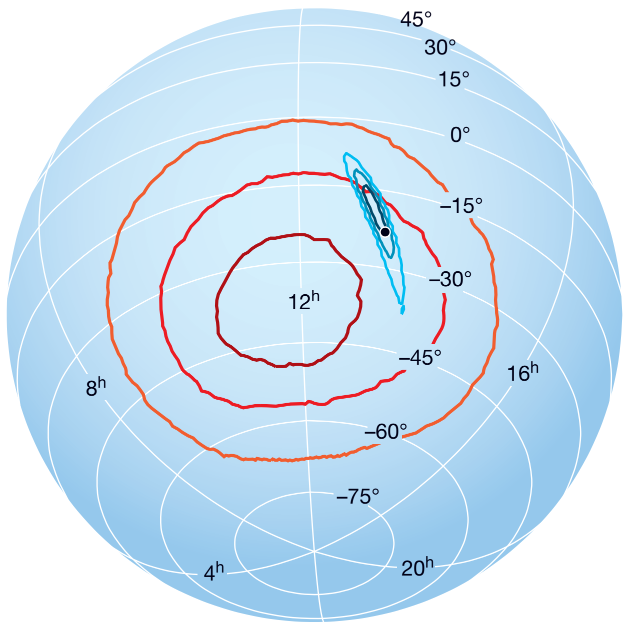


▲ **THE CHIRP** This spectrogram combines the signals from both LIGO detectors to show the characteristic sweeping "chirp" signal of a merger. As the neutron stars came closer to each other, circling faster, they produced higher-frequency gravitational waves, shown by the greenish line sweeping upwards, until eventually they merged (not shown).

How History Was Made

Rumors about the neutron star event had circulated since August 18th, when Craig Wheeler (University of Texas, Austin) tweeted: "New LIGO. Source with optical counterpart. Blow your sox off!" Then, on September 27th, the LIGO and Virgo collaborations announced the detection of GW170814, the gravitational-wave signal of a black hole merger. The discovery led some to assume that the earlier rumors had been just hype: Because these colliding black holes shouldn't give off any light, you wouldn't expect an optical counterpart.

But in a speech October 3rd after his co-reception of the 2017 Nobel Prize in Physics (shared with Thorne and former LIGO director Barry Barish of Caltech), Weiss confirmed another announcement was coming — and wouldn't say



▲ **FINDING GW170817** Gravitational-wave data homed in on a banana-shaped region in the Southern Hemisphere (blue lines), more specific than the region specified by gamma-ray data (red lines). The black dot marks the location of the kilonova, in the galaxy NGC 4993.

ILLUSTRATION: NSF / LIGO / SONOMA STATE UNIVERSITY / A. SIMONNET; CHIRP: LSC / ALEX NITZ; SKY MAP: DATA SOURCE: IAIR ARCAVI ET AL. / *NATURE* 2017 what. Thirteen days later on October 16th, at a large press conference at the National Press Club in Washington, D.C., astronomers and physicists finally revealed their secret.

Here's what happened. On Thursday, August 17th, at 12:41:04 UT, LIGO bagged its fifth confirmed gravitational-wave signal, now designated GW170817. But this signal had a much longer duration than the first four: Instead of a second or less, like the earlier detections, the spacetime ripples were seen for roughly 100 seconds, increasing in frequency from a few tens of hertz to above 600 Hz before disappearing into the detectors' noise.

This is the gravitational-wave signal expected from closely orbiting neutron stars, with masses of about 1.2 and 1.6 times the mass of the Sun. Eventually, they whirled around each other many hundreds of times per second (faster than your kitchen blender), a fair fraction of the speed of light. As the "Einstein waves" emitted by the accelerating masses drained the system of orbital energy, the neutron stars drew closer together. Ultimately, the two merged. (This finale went undetected by LIGO: The waves' frequency was too high.) From the LIGO data, astronomers determined that the collision took place roughly 130 million light-years from Earth.

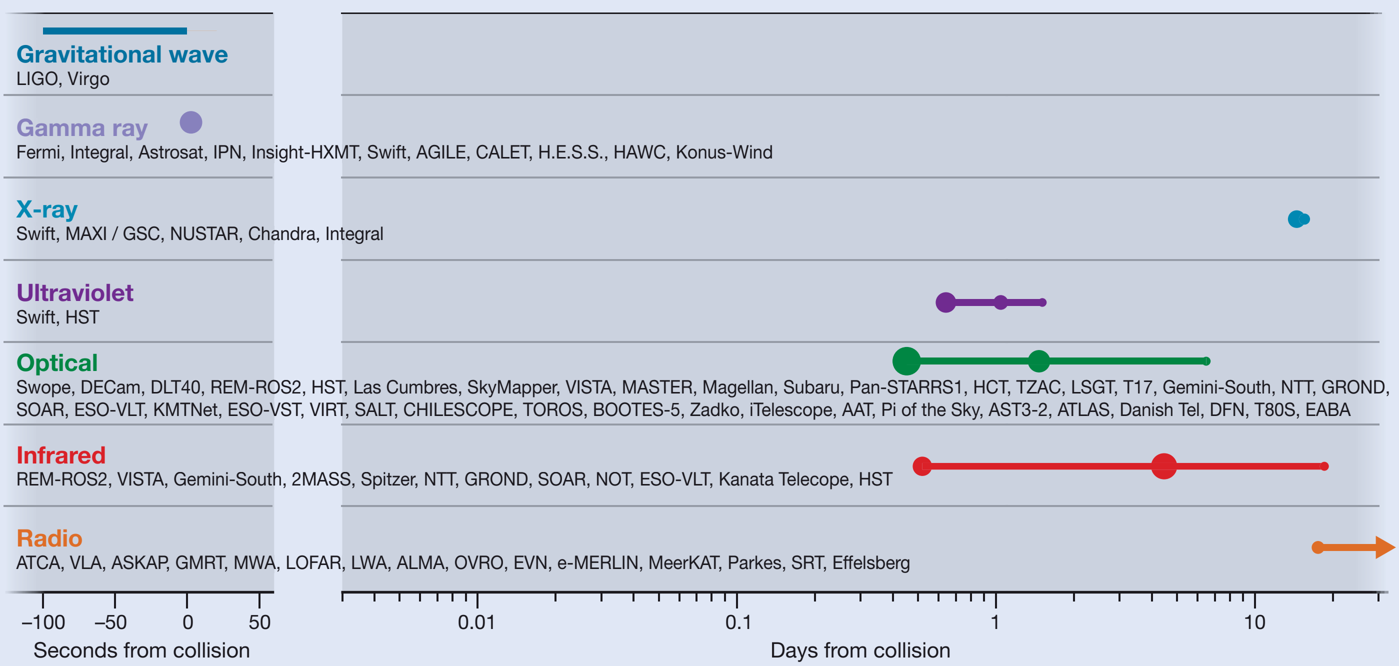
A mere 1.7 seconds after the gravitational-wave event, at 12:41:06 UT, NASA's Fermi Gamma-ray Space Telescope detected a 2-second gamma-ray burst — a brief, powerful flash of the most energetic electromagnetic radiation in nature. The European Space Agency's Integral gamma-ray observatory confirmed the outburst.

Short gamma-ray bursts were already thought to be produced by colliding neutron stars. The merger would blast two narrow, energetic jets of particles and radiation into space (probably perpendicular to the neutron stars' orbital plane). If one of the jets were directed toward Earth, we would see a gamma-ray burst lasting less than two seconds or so. The natural question was, could GRB 170817A possibly be related to the LIGO event that was observed just 1.7 seconds before?

Initially, astronomers had doubts. Gamma-ray bursts usually occur at distances of billions of light-years. GRB 170817A looked about as bright to Fermi as other GRBs, so if this 2-second burst had indeed occurred at a mere 130 million light-years distance, it must have been unusually wimpy.

In principle, one might think researchers could answer the question by simply looking to see if the two signals came from the same place on the sky. But astronomers unfortunately couldn't precisely pinpoint the source of the gamma-rays. Fermi's "error box" measured a few tens of degrees in diameter (the full Moon is only half a degree wide), and NASA's Swift satellite, which sometimes can catch a Fermi event with its more precise X-ray telescope, didn't see any X-ray emission immediately after the GRB.

Discovery Timeline



SEQUENCE OF DISCOVERIES This timeline breaks down the discovery and follow-up observations of the neutron-star merger, relative to the inferred collision time. After the initial gravitational-wave and gamma-ray detections, the time scale is logarithmic. The colored dots represent observations from each wavelength range, with areas approximately scaled by brightness; the lines indicate when the source was detectable by at least one telescope in that band. The names of the relevant instruments or teams appear in each section.

GREGG DINDERMAN / S&T, SOURCE: B. P. ABBOTT ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2017 (848:L12, DOI 10.3847)

However, once the LIGO team dug the gravitational-wave signal out of the data from both detectors — it took a while before the Livingston signal was retrieved from the data stream because of a technical glitch — the researchers used the 3-millisecond difference in arrival time to trace the origin of the waves back to somewhere within two thin, banana-shaped strips of sky in the southern celestial hemisphere. These "bananas" were extremely narrow in this particular case, thanks to the long duration of the event. And one overlapped with Fermi's error box.

Virgo to the Rescue

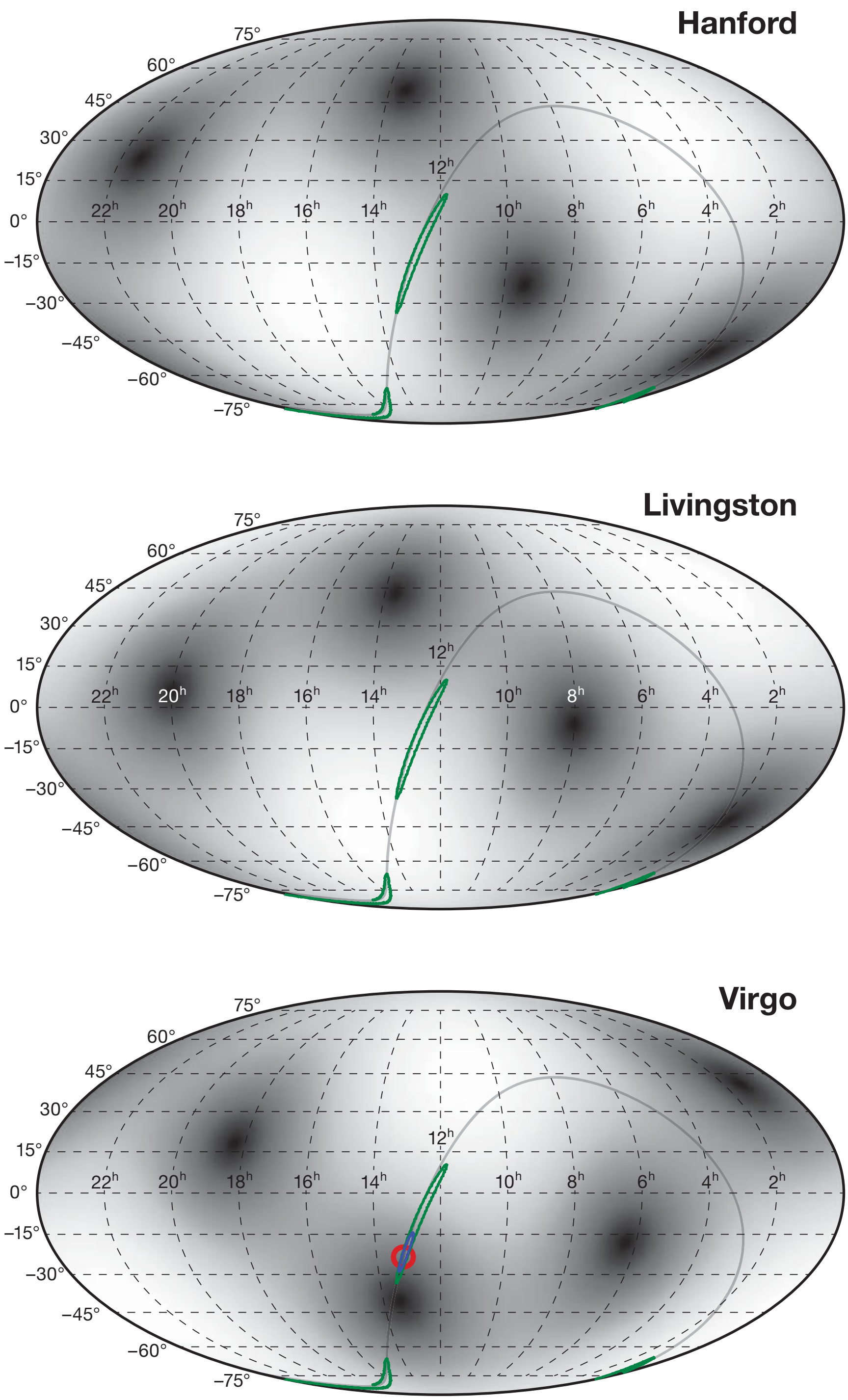
Finding an optical counterpart to the gamma-ray burst would settle the issue, because the debris from colliding neutron stars should glow at other wavelengths. But on the basis of the LIGO and gamma-ray data alone, astronomers could only narrow the search area to some 60 square degrees — still far too much area to search effectively.

Luckily, a third gravitational-wave detector was up and running: Europe's Virgo observatory, in Italy, had been observing in tandem with LIGO since August 1st. Using the differences in a signal's arrival time at three detectors makes it possible for scientists to identify the source's location much more precisely than with just two. In fact, they had used this technique three days before, to trace the black hole merger GW170814 back to a large region on the border of the southern constellations Horologium and Eridanus (*S&T:* Jan. 2018, p. 10).

Yet surprisingly, Virgo had not "triggered" on GW170817. The Einstein-wave signal of the coalescing neutron stars arrived 22 milliseconds earlier at Virgo than it did at Livingston, but it almost doesn't show up in Virgo's data stream — even though the European instrument shouldn't have had any problem detecting it, given its amplitude.

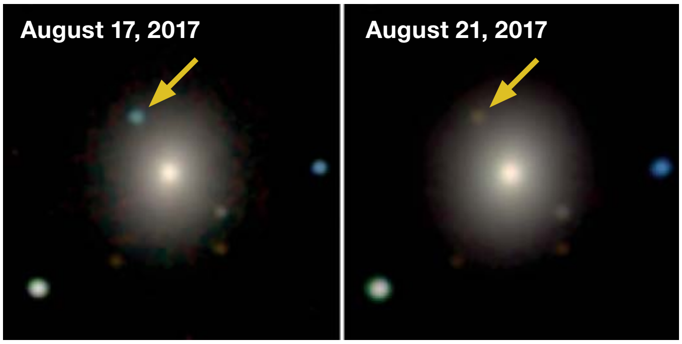
It soon became clear why. Laser interferometers like LIGO and Virgo can detect gravitational waves from nearly every direction. But because of their design, there are four regions of sky on the instrument's local horizon for which the detection sensitivity is much lower than average. At the very center of those regions are blind spots. It turned out that the source of the spacetime ripples nearly coincided with one of Virgo's blind spots.

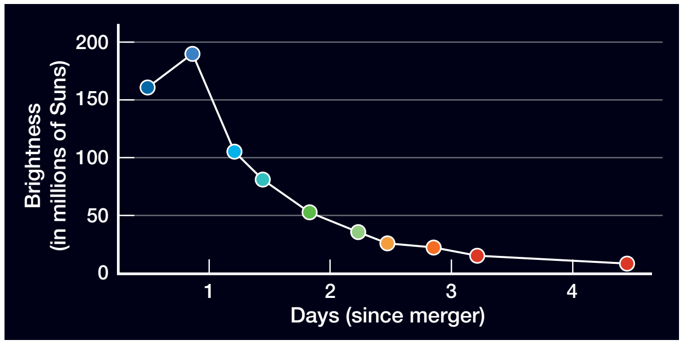
By combining the LIGO data with the weak Virgo signal, astronomers were able to fence off a much smaller, elongated part of the sky, with an area of just some 28 square degrees. The sector lay in southern Virgo and eastern Hydra and smack in the overlap region between LIGO's thin "banana" and Fermi's error box.



▲ **BLIND LEADING THE BLIND** Each of the gravitational-wave detectors has four blind spots across the sky, but the three patterns do not match. Based on the time delay between the signal's arrival at LIGO's two sites, the source of GW170817 lay somewhere along the large gray circle's edge; the signal's strength narrowed the possibilities to the two green regions. Because the signal was so weak in Virgo's data, researchers realized that the source lay near one of that observatory's blind spots, but not near LIGO's — and one of Virgo's spots abuts the region LIGO's data favored (three-site localization in purple). The red circle is the real location.

REED ESSICK / LIGO





▲ **FIRST LIGHT** *Left:* These composite images of NGC 4993 show the kilonova (marked by yellow arrows) upon discovery on August 17th and four days later, on August 21st, when it had dramatically reddened. Both images use data from the Swope and Magellan telescopes, taken in different filters. The left-hand image contains the first optical photons received from the afterglow, called SSS17a. *Right:* The kilonova reddened and faded by a factor of more than 20 in just a few days, as shown here in data from Las Cumbres Observatory telescopes.

Counterpart Search

Now the hunt was on. Over recent years, the LIGO-Virgo Collaboration had signed a formal agreement with about 100 teams of astronomers all over the world to share this kind of information under strict embargo, meaning they couldn't go public with it before a specified date. The alert system would enable the teams to search for electromagnetic counterparts of any gravitational-wave signals with telescopes on the ground and in space, preferably right after the detection. With the latest coordinates of the search area for GW170817 in hand, some 70 teams trained their instruments at the suspected crime scene.

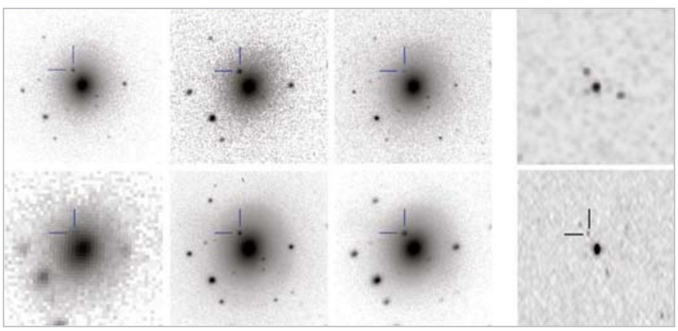
The 1-meter Henrietta Swope Telescope at the Las Campanas Observatory in northern Chile was the first to strike gold. The team's success depended on a clever strategy. The LIGO data provided them with a rough indication of the source's distance, and within the search area there were only a few dozen galaxies at this distance range. Astronomers with the Swope Supernova Survey rapidly checked the galaxies one by one, in order of probability, to see if they could find an optical transient in any of them.

Around 23:33 UT, they found a 17th-magnitude point of light some 10 arcseconds (7,000 light-years) northeast of the core of the lenticular (S0) galaxy NGC 4993, which lies near the binary star Gamma Hydrae. The source was surprisingly bright, enough for experienced amateur astronomers to have picked it out with large (16-inch) telescopes. The galaxy's red-shift puts it at a distance of 130 million light-years, the same distance as inferred from the gravitational waves.

Without doubt, here was the optical counterpart of both the neutron star collision that produced the gravitational-wave signal and the short gamma-ray burst.

In the subsequent days and weeks, dozens of ground-based telescopes and space observatories observed that point, including the Hubble Space Telescope, Gemini South, Keck, the European Southern Observatory's Very Large Telescope, ALMA, the Chandra X-ray Observatory (it picked up X-rays some 9 days after the event), and the Very Large Array (radio waves 16 days after the crash). Researchers even searched for high-energy neutrinos in data from the IceCube neutrino detector in Antarctica and the Pierre Auger Observatory in Argentina, but they found no matches.

"I would think this is the most intensely observed astronomical event in history," Kalogera says. The paper describing the follow-up observations (unofficially known as the "multi-messenger paper") is coauthored by some 3,600 physicists and astronomers from more than 900 institutions. According to some estimates, a whopping 15% of the worldwide astronomical community are on the author list. And it's only one of many dozens of papers on GW170817 released on October 16th, in journals including *Physical Review Letters*, *The Astrophysical Journal Letters*, *Science*, and *Nature*.



▲ **FIRST IMAGES** These are the first six observations of the kilonova (three left-hand columns), all taken within 12 hours of the gravitational-wave signal. On the right are the first detection in X-rays 9 days later (top) and in radio 16 days later.

Striking Gold

Astronomers have now observed the fading aftermath of the neutron star collision at every possible electromagnetic wavelength. The aftermath phenomenon is known as a *kilonova* — a bright, transient event less luminous than a supernova, but about a thousand times as bright as a normal nova and some 100 million times more luminous than the Sun. Only once before, in June 2013, have astronomers found a possible kilonova in conjunction with a short gamma-ray burst, but that one was extremely faint, due to its distance of some 4 billion light-years (*S&T:* Nov. 2013, p. 12).

MULTIWAVELENGTH THUMBNAILS: B. P. ABBOTT ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2017 (848:L12, DOI 10.3847); IMAGES: 1M2H / U.C. SANTA CRUZ AND CARNEGIE OBSERVATORIES / RYAN FOLEY; GRAPH: LEAH TISCIONE / *S&T*, SOURCE: SARAH WILKINSON / LCO

The kilonova — a term coined in 2010 by Vahe Petrosian (Stanford), Brian Metzger (Columbia University), and others — is basically the sizzling fireball from the neutron star smash-up. Chunks of hot, dense nuclear matter are hurled into space, in all possible directions, with velocities easily reaching 20% or 30% the speed of light. Liberated from the neutron stars' extreme gravity, the debris expands, rapidly losing its ultra-high density. This debris is primarily neutrons but has some protons, too. The neutrons and protons in the resulting thermonuclear cauldron quickly combine into heavy atomic nuclei. These nuclei capture more neutrons, making them unstable and, therefore, highly radioactive. The extra neutrons decay more slowly into protons, releasing the energy that makes the ejecta glow. What remains is an incredibly hot expanding shell, loaded with some of the heaviest elements in the periodic table.

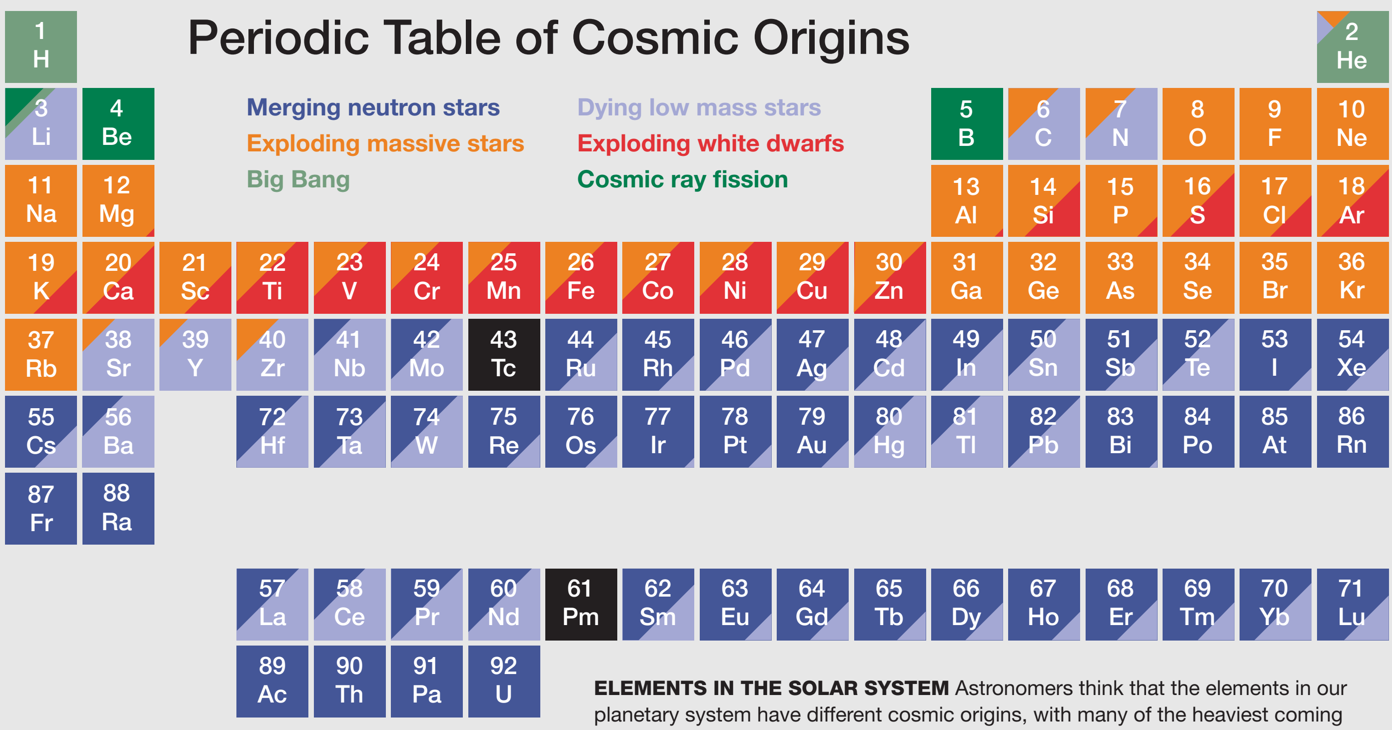
Spectroscopic observations by the X-shooter instrument at the Very Large Telescope and other instruments have indeed indicated the existence of heavy *rare earth elements* (also known as lanthanides) in the fireball that resulted from the neutron star merger. According to Metzger, "It would take improbable fine-tuning to not also produce much heavier elements." The observations thus appear to confirm the theory that the majority of elements more massive than iron are produced by the decay of nuclear matter in the aftermath of neutron star collisions, rather than in supernova explosions — a possibility first suggested way back in 1974 by the late David Schramm and his then-PhD student James Lattimer (Stony Brook University).

For example, Harvard's Berger once calculated that a run-of-the-mill neutron star merger might produce some 10 times the mass of the Moon in pure gold. Gijs Nelemans (Radboud University, The Netherlands) thinks it may well be much higher, up to at least a few Earth masses. Metzger agrees. "From the optical light curve of the kilonova," he says, "it appears that the collision ejected some 5% of a solar mass of material into space, more than enough for the formation of many Earth masses' worth of gold."

So apparently, with the discovery of the counterpart of GW170817, scientists also literally struck gold. According to Edward van den Heuvel (University of Amsterdam), a retired expert on compact binary star evolution, astronomers have discovered 16 binary neutron stars so far in the Milky Way. "From this number, I estimate that neutron star collisions occur once every 50,000 years or so in our Milky Way Galaxy," he says. "Over the age of the Milky Way, that amounts to a few hundred thousand of these gold-spawning events in just one galaxy. That's a lot of gold."

To Be Determined

A few mysteries remain, though. One is the nature of the gamma-ray signal observed by Fermi. If GRB 170817A was a regular gamma-ray burst, one of its jets must have been aimed at our home planet in order for us to see it. But in that



ELEMENTS IN THE SOLAR SYSTEM Astronomers think that the elements in our planetary system have different cosmic origins, with many of the heaviest coming from neutron-star mergers (dark purple). Those with more than one source are divided according to the approximate proportions from each process. Technetium (Tc), promethium (Pc), and elements heavier than uranium don't have stable isotopes and are therefore blacked out or excluded.

LEAH TISCIONE / S&T; SOURCE: JENNIFER JOHNSON / SDSS / CC BY 2.0

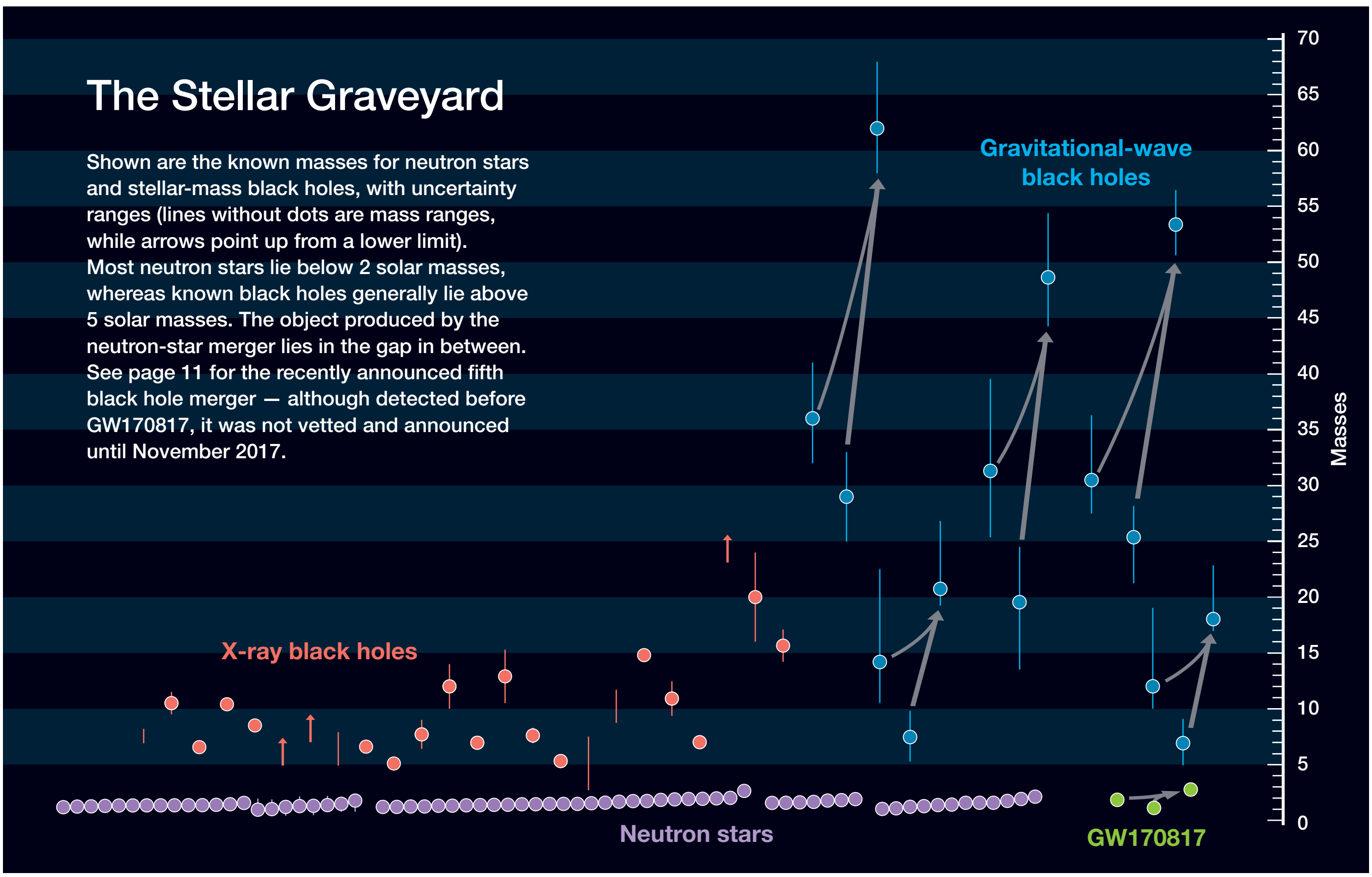
case, astronomers would have expected it to be at least 10,000 times more powerful in gamma rays than they detected, given how close it was. Moreover, the jets should also have produced prompt X-ray emission, which was not detected. So maybe we observed the gamma-ray burst slightly from the side? Many astronomers, including Kalogera and Eleonora Troja (NASA Goddard), who led the X-ray follow-up, think that is the most likely explanation for the weakness of the gamma-ray burst. Troja also says that the delay in X-rays — observed 9 days later — would be natural when looking at the jet from an angle. The same holds for the radio waves from the source, which didn't show up until early September. While the optical and infrared glow of the kilonova is thermal radiation from the radioactive fireball, the X-rays and radio waves are produced by the energetic gamma-ray burst jet after it started to broaden as it slowed down.

Mansi Kasliwal (Caltech) and colleagues suggest a more complex version of this scenario, in which the jets get stuck (either temporarily or permanently) in a thick cocoon of material that the jets inflated as they drilled through the collision ejecta. In this setup, the jet is still off-axis, but the cocoon itself would emit the gamma rays, at a much weaker level than seen from a jet pointed straight at Earth. Wijers and his colleagues had put forward a similar scenario to explain the strange behavior of the long gamma-ray burst GRB 980425, which was also relatively close and surprisingly weak, and coincided with a supernova explosion known as SN 1998bw. Wijers also notes that this model neatly accounts for the transition of the optical counterpart of GRB 170817A from blue to red wavelengths within 48 hours.

A detailed analysis of all existing kilonova observations may eventually solve the issue. And future observations of the site of the cosmic catastrophe could also shed light on another as-yet-unsolved mystery: What was the fate of the two neutron stars? A small fraction of their combined mass was ejected into space, but what happened to the rest? Did the two city-sized stars merge into a hyper-massive neutron star of a few solar masses, or did they collapse into a stellar-mass black hole? Astronomers have only detected a few neutron stars that weigh in just above 2 solar masses — an upper limit that might have implications for the physics of these stars. The merger remnant might be extremely informative.

Unfortunately, the LIGO data can't provide a definitive answer: The final stages of the merger event weren't observed. With the earlier black hole crashes, LIGO could detect hints of the collision's "ring-down phase," a brief period in which the amplitude of the gravitational waves rapidly dwindles to zero. From the characteristics of this ring-down, astronomers were able to estimate the final mass of the merged black hole.

But in the case of GW170817, the rising wave frequency moved out of LIGO's detection range before the two neutron



The Stellar Graveyard

Shown are the known masses for neutron stars and stellar-mass black holes, with uncertainty ranges (lines without dots are mass ranges, while arrows point up from a lower limit). Most neutron stars lie below 2 solar masses, whereas known black holes generally lie above 5 solar masses. The object produced by the neutron-star merger lies in the gap in between. See page 11 for the recently announced fifth black hole merger — although detected before GW170817, it was not vetted and announced until November 2017.

LEAH TISCIONE / *S&T*, LIGO SOURCES: LIGO AND VIRGO COLLABORATIONS
NEUTRON STARS: F. ÖZEL AND P. FREIRE / *ANNUAL REVIEWS OF ASTRONOMY AND ASTROPHYSICS* 2016
BLACK HOLES: GRZEGORZ WIKTOROWICZ AND CHRIS BELCZYNSKI / STELLARCOLLAPSE.ORG

stars actually collided, and the signal was lost, says Kalogera. So astronomers do not have strong observational data to constrain the properties of the merged object, even though the LIGO observations indicate a total system mass on the order of 2.7 to 2.8 solar masses (the individual masses of the two neutron stars are not known very precisely).

Nelemans is confident enough to claim that the collision must have produced a new black hole. "If there was a hyper-massive neutron star there right now, it would be extremely hot, and we would have detected it in X-rays," he says.

Metzger agrees. "But," he adds, "if there had been an immediate collapse into a black hole, you wouldn't expect so much ejecta." Instead, the two neutron stars may first have coalesced into a hyper-massive object of some 2.8 solar masses, held up by its incredibly fast rotation, before further collapsing into a black hole after a fraction of a second.

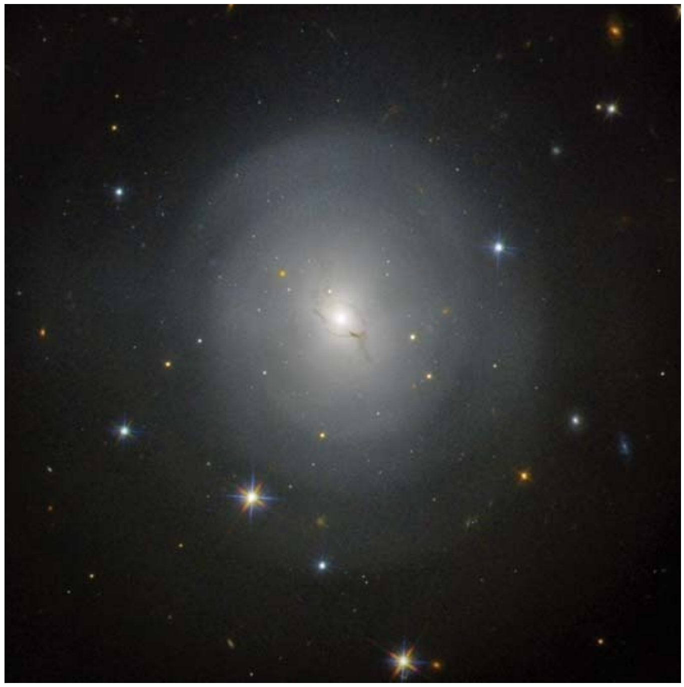
Making History

The GW170817 observations, spectacular as they are, may turn out to be the proverbial tip of the iceberg of future revelations on gamma-ray bursts, binary star evolution, heavy element synthesis, general relativity, the behavior of matter in extreme environments, and the properties of neutron stars. Physicists are particularly interested in the material properties of these hyper-dense stellar remnants, which easily pack a hundred thousand tons of matter into a volume of one cubic millimeter. We can't yet recreate such extreme conditions in a laboratory on Earth.

In principle, a detailed study of gravitational-wave signals such as GW170817 should provide more information on neutron-star structure, especially when the high-frequency waves from the final stages of the merger can also be observed in detail. As the two neutron stars draw closer and closer, they will be stretched and squeezed by mutual tidal forces. The magnitude of the resulting deformations tells physicists something about the interior structure of the star, the way its density changes with depth, the material's stiffness, and so forth. This so-called *equation of state* has not yet been determined on the basis of the current GW170817 observations, says Lattimer. But so far, everything appears to be consistent with constraints from nuclear experiments in laboratories on Earth.

Moreover, he adds, the fact that the merger produced such a massive, relativistically expanding fireball puts some constraints on the tidal deformations of the two neutron stars. "More compact stars can get closer together before they coalesce," he says. "As a result, they collide more powerfully and eject more mass." From the estimated ejecta mass, it follows that the neutron stars are at most 27 kilometers in diameter; another line of evidence indicates that they cannot be smaller than 22 kilometers across. The smaller neutron stars are, the more likely it is that they may contain extreme forms of matter deep within their cores, although theoretical details are still pretty sketchy (*S&T:* July 2017, p. 16). "It's remarkable that one single event can yield so much information," Lattimer says.

NASA AND ESA



▲ **NGC 4993** This Hubble image shows the lenticular galaxy NGC 4993, which lies near the border of the constellation Hydra, the Sea Serpent. The orange dot upper left of the galaxy's center is the kilonova.

And there's more. From the near-simultaneous arrival time of the gamma rays and the gravitational waves, it follows that spacetime ripples propagate at the speed of light to within a few parts in a quadrillion — confirming predictions of Einstein's theory of relativity. And an independent measure of the host galaxy's distance (based on the observed Einstein-wave amplitude), combined with NGC 4993's recession velocity, yields a Hubble constant between 62 and 82 kilometers per second per megaparsec — nicely in line with existing measurements. With future observations, astronomers expect to significantly crank up the precision in this estimate.

As 2017 Nobel laureate Barry Barish noted when GW170817 was announced, the new discovery establishes gravitational-wave science as an emerging field. And it's emerging fast, too. In the fall of 2018, both LIGO and Virgo will start yet another observing run, at an even higher sensitivity. Van den Heuvel can't wait to see the next spectacular breakthrough. "These measurements are incredibly hard," he says. When the Einstein waves passed, the length of LIGO and Virgo's detector arms changed by less than an atomic nucleus, he explains. "But within 20 years or so, gravitational-wave measurements may be just as routine as X-ray observations have become over the past 40 years. It's really beyond my wildest dreams."

■ *Sky & Telescope* Contributing Editor **GOVERT SCHILLING** lives in the Netherlands but loves to explore his home planet. His latest book is *Ripples in Spacetime: Einstein, Gravitational Waves, and the Future of Astronomy*, published by Harvard University Press in 2017.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OBSERVING
February 2018

1 **EVENING:** Look low in the east to see the Moon, just past full, trailing Regulus by 5° or 6° as they rise in tandem. An occultation of Leo's brightest star will be visible for northwestern Alaska and most northern parts of Europe and Asia.

PREDAWN: If you're still looking low toward the east, you'll see Jupiter rising in Libra a couple of hours after midnight, followed shortly by the tight pair of Mars and the bluish white subgiant Beta (β) Scorpii (Graffias), in the head of the Scorpion.

EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:30 p.m. EST (8:30 p.m. PST); see page 50.

2–16 **EVENING:** The zodiacal light is visible at mid-northern latitudes from dark sites: Look toward the west after sunset for a tall, hazy pyramid of light.

8 **DAWN:** Antares, Mars, the waning crescent Moon, and Jupiter form a celestial arc that straddles Scorpio and Libra.

11 **MORNING:** Mars exchanges companions, and now accompanies Antares as it climbs up the ecliptic. The planet is about 5° above or upper left of the star.

DAWN: Low in the southeast, a sliver of the crescent Moon hangs 2° above Saturn, which in turn floats some 3° above the Teapot in Sagittarius.

23 **EVENING:** Look high in the sky to see the first quarter Moon in Taurus, less than 5° left or upper left of Aldebaran; the Moon occults the star for northeastern North America, most of Europe, and northern Asia.

24 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:05 p.m. EST (7:05 p.m. PST).

28 **ALL NIGHT:** Follow the almost-full Moon as it begins the night by leading Regulus across the sky. Watch as the gap decreases, with the Moon eventually occulting the star for much of northern North America, Greenland, and northern and western Europe; see page 49.

▲ During the first two weeks of February, viewers at mid-northern latitudes may witness the zodiacal light from dark locations.
ESO / Y. BELETSKY

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			

LAST QUARTER
February 7
15:54 UT

NEW MOON
February 15
21:05 UT

FIRST QUARTER
February 23
08:09 UT

DISTANCES

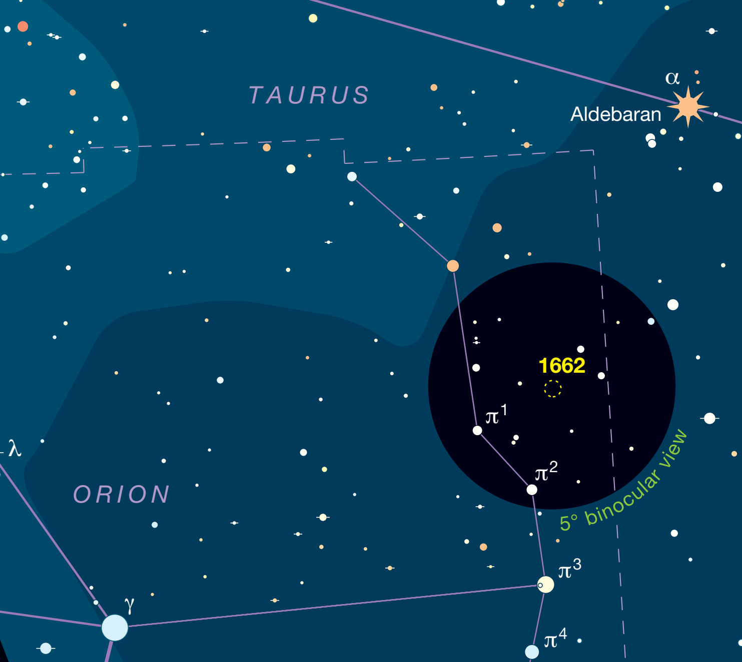
Apogee	February 11, 14h UT
405,700 km	Diameter 29′ 27″
Perigee	February 27, 15h UT
363,933 km	Diameter 32′ 50″

FAVORABLE LIBRATIONS

- Boguslawsky Crater — February 1
- Mare Orientale — February 14
- Petermann Crater — February 23
- Anaxagoras Crater — February 25

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

Past, Present & Future

In the western reaches of the constellation Orion, the Hunter, floats the open cluster **NGC 1662**. It's pretty easy to find — draw a line from Gamma (γ) Orionis westward to Pi[1] (π^1) Orionis and on another couple of degrees and you'll spot it. The cluster at first appears small and distant. Half of that perception is accurate — it is small, only 8 light-years in diameter, compared to 20–50 light-years for most of the better-known Messier and Caldwell clusters. But NGC 1662 isn't particularly far off. At just over 1,400 light-years away, it's only slightly farther than the Orion Nebula (~1,340 light-years) and considerably closer than most of the other prominent NGC clusters in this stretch of sky. In fact, the Orion Nebula, NGC 1662, and the giant molecular clouds around Lambda (λ) Orionis are all roughly the same distance from the Sun.

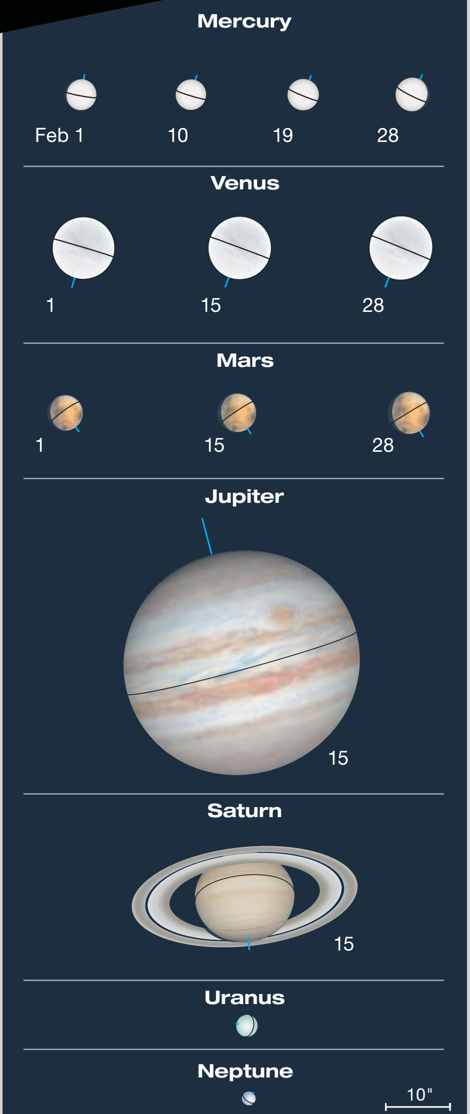
Many of the prominent stars and bright and dark nebulae in Orion are associated with the pulse of star formation that's going on there right now. It's tempting to suspect that NGC 1662 is a product of that process, but the cluster is much older. With an estimated age of 420 million years, NGC 1662 has been floating through the Milky Way for about two galactic rotations. It's a cosmic fossil of a much earlier burst of star formation, one that took place before our fishy ancestors first struggled up onto land. Our own Sun is, of course, much older still — more than 10 times the age of NGC 1662, and long since separated from the sister stars of its own birth cluster. The Orion Nebula represents NGC 1662's past, the process that brought it (and us) into being, and we represent its future, when its member stars will be dispersed across the disk of the Milky Way Galaxy. We're all in this together.

■ **MATT WEDEL** is probably looking up unhappily at the bottoms of clouds right now, but he's thinking about the stars.

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.



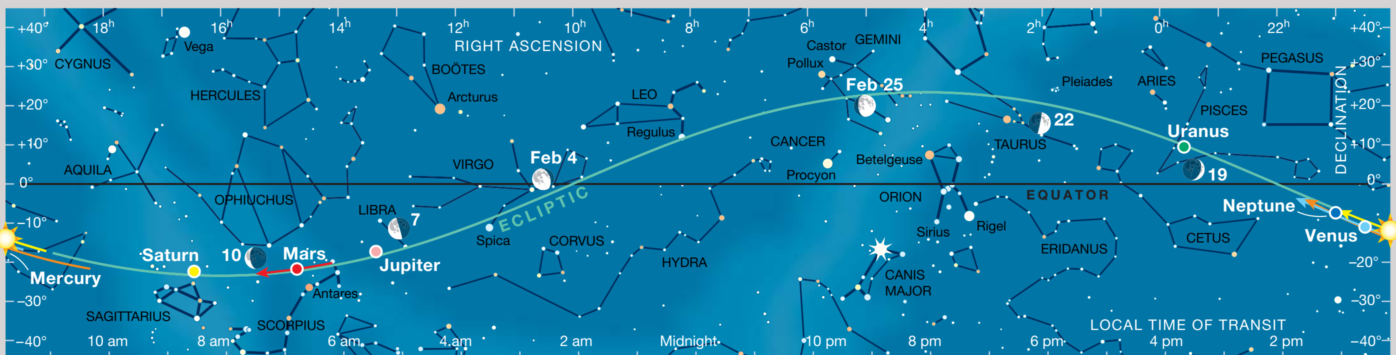
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: **Mercury:** Hidden in the Sun's glow all month. • **Venus:** Visible at dusk after the 5th. • **Mars:** Visible in early morning, highest at dawn. • **Jupiter:** Rises after or near midnight, highest before dawn. • **Saturn:** Visible at dawn.

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h\ 57.1^m$	–17° 15′	—	–26.8	32′ 28″	—	0.985
	28	$22^h\ 42.7^m$	–8° 10′	—	–26.8	32′ 18″	—	0.990
Mercury	1	$20^h\ 12.1^m$	–21° 44′	11° Mo	–0.6	4.9″	95%	1.382
	10	$21^h\ 13.6^m$	–18° 14′	6° Mo	–1.1	4.8″	99%	1.403
	19	$22^h\ 15.9^m$	–12° 49′	2° Ev	–1.7	4.9″	100%	1.375
	28	$23^h\ 17.9^m$	–5° 37′	9° Ev	–1.4	5.3″	94%	1.278
Venus	1	$21^h\ 20.5^m$	–16° 57′	6° Ev	–3.9	9.8″	100%	1.702
	10	$22^h\ 04.8^m$	–13° 20′	8° Ev	–3.9	9.9″	99%	1.693
	19	$22^h\ 47.6^m$	–9° 15′	10° Ev	–3.9	9.9″	99%	1.681
	28	$23^h\ 29.3^m$	–4° 49′	12° Ev	–3.9	10.0″	98%	1.665
Mars	1	$16^h\ 04.8^m$	–20° 09′	69° Mo	+1.2	5.6″	91%	1.671
	15	$16^h\ 40.7^m$	–21° 42′	74° Mo	+1.0	6.1″	90%	1.537
	28	$17^h\ 14.0^m$	–22° 43′	80° Mo	+0.8	6.6″	89%	1.412
Jupiter	1	$15^h\ 15.5^m$	–16° 56′	81° Mo	–2.0	35.9″	99%	5.497
	28	$15^h\ 23.0^m$	–17° 20′	106° Mo	–2.2	38.9″	99%	5.062
Saturn	1	$18^h\ 19.9^m$	–22° 29′	37° Mo	+0.6	15.3″	100%	10.832
	28	$18^h\ 30.3^m$	–22° 23′	62° Mo	+0.6	15.8″	100%	10.491
Uranus	15	$1^h\ 33.9^m$	+9° 13′	59° Ev	+5.9	3.5″	100%	20.387
Neptune	15	$22^h\ 58.8^m$	–7° 30′	17° Ev	+8.0	2.2″	100%	30.887

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.

The Great Overdog

Sirius isn't the only star that shines brightly in Canis Major.

LIBRARY OF CONGRESS / RESTORATION: ADAM CUERDEN

The great Overdog,
That heavenly beast
With a star in one eye,
Gives a leap in the east.

He dances upright
All the way to the west
And never once drops
On his forefeet to rest.

I'm a poor underdog,
But tonight I will bark
With the great Overdog
That romps through the dark.

—Robert Frost, "Canis Major"

The first serious poem I ever recall being read to me and discussed was Robert Frost's "Stopping by the Woods on a Snowy Evening." I think I was only five years old at the time, but it certainly made a great impression on me. A few more years passed before I, already a budding stargazer, first had the pleasure of coming across one of Frost's other winter poems, "Canis Major." Strangely, I don't remember ever quoting it in any of my astronomical writings. I'm finally doing it now, however, and for a good reason: This month I want to begin a two-part exploration and celebration of this constellation of the Big Dog that at times I've found to be a bit neglected.

The 22nd star. Surely Sirius, by far the most brilliant star in the night sky, steals a lot of attention away from the rest of its constellation. But Canis Major features four other stars brighter than magnitude 2.5. One of those four is occasionally even included in the ranks of 1st-magnitude stars — though as the least bright 1st-magnitude star. It's far more often considered to be the brightest of the 2nd-magnitude class. I'm speaking of Adhara, which at magnitude 1.5 is the 22nd brightest star in all the heavens. Adhara slightly outshines the far more famous Castor. Castor can ascribe its greater fame both to being a star in a zodiac constellation, Gemini, and also from passing far higher in the sky of mid-northern latitudes than Adhara. Of course, Castor's biggest source of renown is being one of the pair of "twin" luminaries of Gemini, the Twins, the other being Pollux. But, as I've argued before, Adhara is actually part of a starry trio, not duo, which is quite impressive in its own right.

The Southern Canis Triangle. In the southern part of the Canis Major constellation, at the opposite end from Sirius, shines this compact triangle. It's composed of 1.5-magnitude Epsilon (ε) Canis Majoris (Adhara), 1.8-magnitude Delta (δ) Canis Majoris (Wezen), and 2.5-magnitude Eta (η) Canis Majoris (Aludra). I call it the Southern Canis Triangle. And, remarkably, these stars' brightnesses closely rival those of the three stars in Orion's Belt: 1.7 (Alnilam), 1.7 (Alnitak), and 2.3 (Mintaka). Orion's Belt straddles the celestial equator and therefore sparkles 50° above the southern horizon when on the meridian for observers at latitude 40° north. The Southern Canis Triangle never climbs more than 20° to 24° high at that latitude — but those are also the maximum altitudes of Fomalhaut and Antares, respectively, and they manage to peek above the treeline or city skyline for us to enjoy.

These three stars of the Southern Canis Triangle are mighty suns. At distances of 405 light-years (Adhara), about 1,800 light-years (Wezen), and possibly about 3,000 light-years (Aludra), the absolute magnitudes of these stars are around –4, –7, and –7.5. James Kaler's wonderful "Stars" website (**https://is.gd/kalerstars**) tells us that Wezen is cooler than the other two stars; it's a rare yellow supergiant that in less than 100,000 years should become a red supergiant somewhat like Antares. Kaler also notes that Aludra is probably only about 12 million years old and that if our eyes were sensitive to ultraviolet light, Adhara would shine brighter than any other star in our sky.

Next month: I'll discuss further marvels of Orion's Big Dog, including clusters and other mighty stars.

■ **FRED SCHAAF** had his first book, *Wonders of the Sky* (Dover Publications), published about 35 years ago.

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

Before Dawn

Stay up late or rise early to watch Mars, Jupiter, and Saturn glide across the sky.

Other than Venus, which sets early in twilight, there are still no bright planets visible in the evening hours this month. Between midnight and morning twilight, however, Jupiter, Mars, and Saturn each rise, with Mars gliding above Scorpius and having a fine conjunction with Antares during the month.

DUSK

Venus was at superior conjunction with the Sun on January 9th; farthest from Earth on January 11th; and at aphelion — farthest from the Sun in space — on January 23rd. As February opens, Venus will be very challenging to see even with optical aid, for it will be less than 4° high at sunset and will set less than a half hour after the Sun. On the other hand, by month's end the –3.9-magnitude planet appears about 10° high at sunset and should be reasonably easy to find before it sets about an hour after sundown.

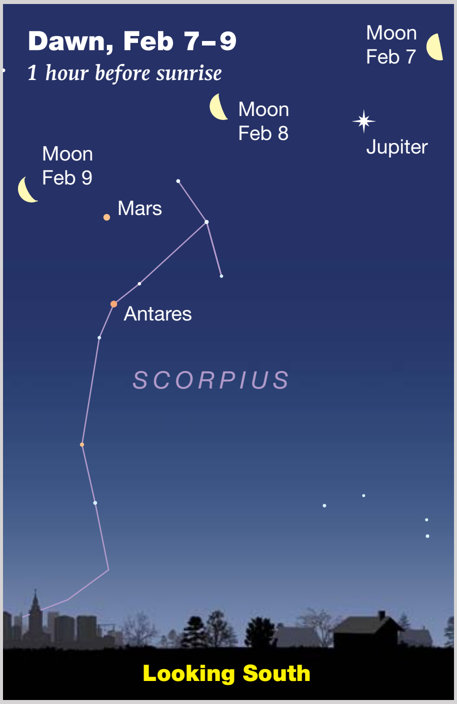
Mercury goes through superior conjunction on February 17th and enters the evening sky, pursuing Venus. But even though Mercury reaches an unusually bright magnitude of –1.5 during the second half of February, it's too low in the Sun's afterglow to observe until perhaps the last day of the month.

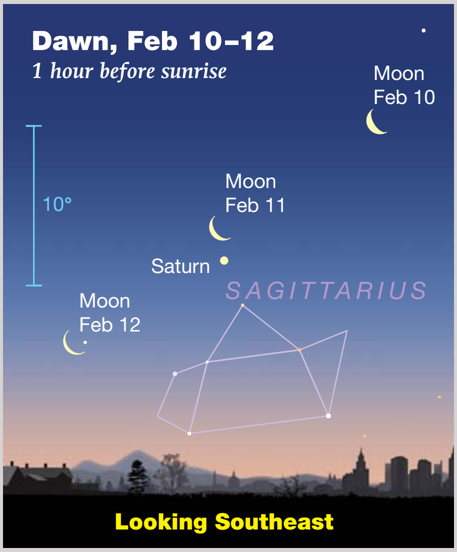
Uranus is visible for a few hours after evening twilight but is highest just as twilight ends. See **https://is.gd/urnep/** for a finder chart.

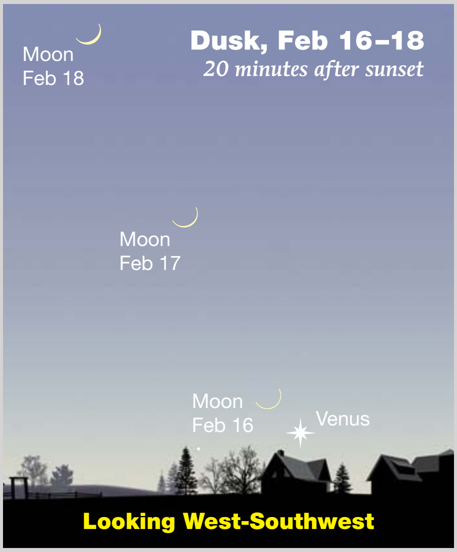
MIDNIGHT TO DAWN

Jupiter rises before 2 a.m. as February begins, and a little while before midnight as the month ends. The giant planet gleams in Libra, brightening from magnitude –2.0 to –2.2 during the month. Jupiter's globe grows from 36″ to 39″ wide in telescopes in February. The planet reaches west quadrature (90° west of the Sun) this month, a position that improves our view of some of the Galilean satellite events.

Mars begins the month about 12° lower left of Jupiter and less than 1° from the wide double star Beta (β) Scorpii (Graffias) in the head of Scorpius. During February, however, the Red Planet races east above the pattern of the Scorpion, increasing its separation from slowing Jupiter to 19° at mid-month and to almost 27° at month's end. The relatively rapid eastward movement of Mars keeps it from rising







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

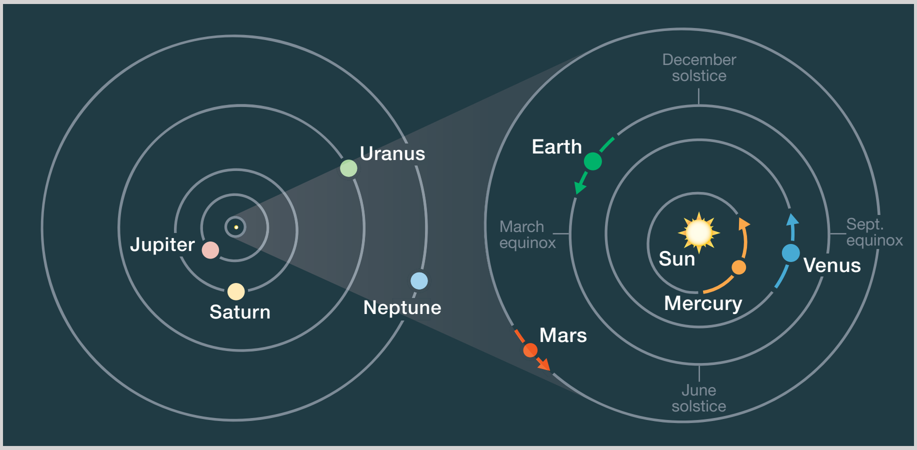
much earlier as the month progresses, only gaining a half hour between February 1st when it rises at 2:30 a.m. local time and February 28th when it rises around 2 a.m.

An interesting observing project throughout February is to compare Mars with Antares, which means "rival of Mars." The separation between the two is 8° as the month begins, is less than 6° from February 7th to 16th, and shrinks to a minimum of about 5° on February 11th and 12th. These similar-colored points of light are also similar in brightness during this month of their conjunction. Though variable, Antares usually shines at around magnitude 1.0. Mars starts the month at magnitude 1.2, is 1.1 on the American morning of February 11th, 1.0 on the 16th, and +0.8 by month's end (though dust storm activity can change its predicted brightness a bit).

In the eyepiece, Mars increases from about 5½″ to just over 6½″ in angular diameter during February, still too small to show any real detail.

Saturn comes up a little before 5 a.m. as February starts and a little after 3 a.m. as the month ends. The ringed planet shines at magnitude +0.6 all month in Sagittarius. Mars closes the gap between it and Saturn from 31° to around 17° during February, shining about halfway between Saturn and Jupiter around February 19–21.

Saturn isn't very high in the southeast as morning twilight begins but its current starry background is fascinating. It hovers some 3° above the topmost star of the Teapot of Sagittarius. Not far from the planet are such deep-sky marvels as the globular cluster M22, below and to the left, at 4° separation on the 1st, 3° separation on the 14th, and 2° separation on the 28th, and the Small Sagittarius Star Cloud (M24) some 4° to 5° above. If you turn a telescope on Saturn itself, you can see that although the planet's globe is still less than 16″ wide in equatorial diameter, the glorious rings have a much greater span and remain tilted at 26° for our line of sight, nearly their most open.

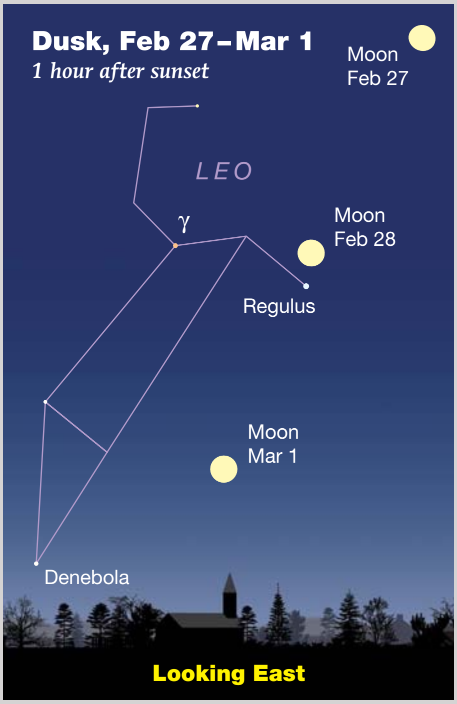


ORBITS OF THE PLANETS
The curved arrows show each planet's movement during February. The outer planets don't change position enough in a month to notice at this scale.

SUN AND MOON

The Sun undergoes a partial eclipse on February 15th for observers in most of Antarctica and southern South America.

The Moon is near its last quarter phase when it poses just over 6° upper right of Jupiter before dawn on February 7th. The next morning, the Moon is almost 8° to the planet's left. A thin waning lunar crescent hangs some 2° above Saturn at dawn on February 11th. A hair-thin waxing lunar crescent floats just under 3° to the upper left of Venus on February 16th, but the two must be observed low near the west-southwest horizon only about 20 to 30 minutes after sunset. A slightly gibbous Moon is about 4½° left of Aldebaran at nightfall on February 23rd. The nearly full Moon beams above Regulus on the evening of February 28th and occults the 1st-magnitude star for observers in northern North America; see page 49.



■ **FRED SCHAAF** teaches astronomy at Rowan University and Rowan College in Gloucester County, both in southern New Jersey.

Fast Times in the Charioteer

AE Aurigae may appear modest, but it's really a troubled, hot star, trying to outrun its past.

AE Aurigae burns hot and blue inside IC 405, the Flaming Star Nebula. The relative position of star and nebula is coincidental. AE Aur is on a quick journey away from its birthplace in Orion and is a short-time visitor to this particular dust cloud. This false-color image was created by combining emission-line images taken in H-alpha (yellow), O III (violet), and S II (blue).

T. A. RECTOR / B. A. WOLPA / NOAO / AURA / NSF

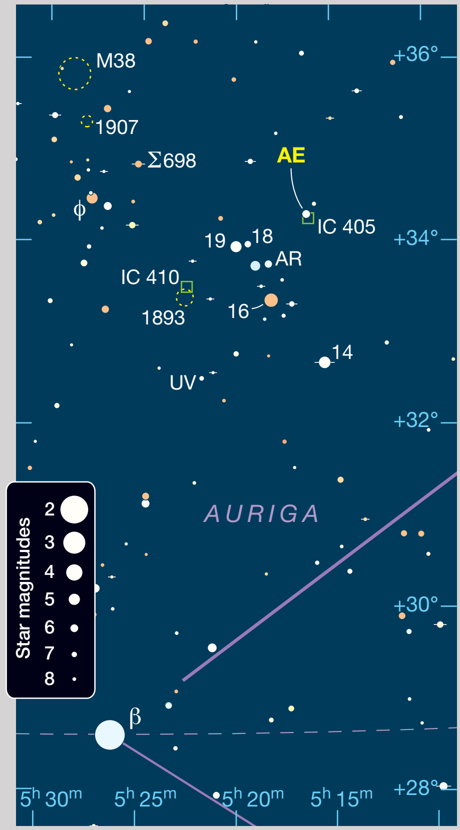
February's a good month to hunt down one of my favorite stars, AE Aurigae. Auriga, the Charioteer, transits about an hour after I get home from work and sits at a good position in my suburban sky for observing after dinner. I generally hop to AE Aur from Theta (θ) Aur or Beta (β) Tauri, via the trio of Messier objects in southern Auriga. From M37, I move northwest to M36, then to M38. For binos or wide-field scopes, these are very small hops, more like subtle shifts than actual movements. A chain of stars, headed by 18 and 19 Aur and footed by the double star 14 Aur, sparkles southwest of M38. Draw a line from 18 to 19, and extend it about 45′ west to find 6th-magnitude AE.

AE is a very hot, blue, O-type main-sequence dwarf, with a brightness ranging from 5.78 to 6.08 — not quite a full magnitude of variability, but enough to be noticeable if you watch it regularly. This variability is implied in AE Aur's designation. You've probably figured out that variable stars comprise a confused alphabet, with seemingly random letters assigned to them; think R Andromedae, T Tauri, ZZ Cygni. But there's a logic to these letters. If a newly discovered variable has a Bayer designation (a Greek letter, like Alpha or Beta), that designation remains. If it doesn't have a Bayer designation, it gets a letter from the Roman alphabet, beginning with R, assigned to it. This is how we got R Persei, for example. The next variable discovered in a constellation without a Bayer designation becomes S, and the third T. If nine variable stars in a single constellation are discovered, running the letters from R through to Z, the 10th star name jumps back and doubles up on R: RR, RS, RT, and so on, down to RZ. Then we move on to SS, ST, etc.

But there's another system for variable star names as well. Only 334 possible R to Z combinations exist, so if a constellation contains more variables than that, the 335th becomes V335 (V for Variable). However, you'll find V-numbers printed together, or entirely supplanting, R-numbers on some charts. R Andromedae may be listed as R And, or it may be denoted as V1. Or both. It's not always possible to tell if a star is variable from its name ("Beta Persei" doesn't really give away the game), but if you find yourself swimming in alphabet soup, you know you're surrounded by shifting magnitudes.

AE Aur is worth a look for its variability, but what makes it really shine for me is its dramatic past: It's a "runaway," a star tossed out of its home as the result of a binary collision or ejection. About 15% of O- and *B*-type stars are runaways, so they're not extremely rare, but there's still something intriguing about a star living far from its birthplace. AE Aur is thought to have originated in Orion, near the current location of the Trapezium cluster. About 2 million years ago, a close interaction between two high-mass binary systems compelled two of the stars to "trade places" (leaving their original companions) and form a new double-star system, Iota (ι) Orionis. The other two stars became runaways, ejected from their systems at velocities as high as 1000 km s^{-1}. Proper motion measurements have revealed AE Aur and Mu (μ) Columbae to be these lost suns.

AE Aur lights up IC 405, the Flaming Star Nebula, but its relationship with this gaseous dust cloud is coincidental; AE's just passing through. Recently, astronomers analyzed AE's spectrum to reveal, for the first time, X-ray emission from a stellar bow shock (the shock wave produced by a star's rapid movement through the interstellar medium). Prior to this discovery, bow shocks for runaways had been detected only in the radio and mid-infrared.



▲ A double line of stars southwest of M38 helps point the way to the variable AE Aurigae.

As it turns out, AE is itself a multiple-star system. It claims one close 8th-magnitude companion, B, and one distant 10th-magnitude companion, C (HD 34042). So at least it's had company on its long trip away from home.

Lunar Occultations

THE BEST VIEW of the lunar occultation of **Regulus** on February 1st is from northern Europe and Asia. Much better for our continent is the event on the night of February 28–March 1, when the Moon occults the 1st-magnitude star for northern North America, including much of Maine and eastern Canada. Those on the southern edge of the occultation path will see a grazing event, with Regulus winking in and out as the lunar limb passes in front of the star. Alaska sees the occultation early on the evening of February 28th, with Regulus just meeting the edge of the not-quite-full Moon. Quebec and eastern Canada watch after midnight, in the earliest hours of Thursday, March 1st.

Some timings: **Anchorage,** *disappearance* 7:39 p.m., *graze* 7:49 p.m., *reappearance* 8:05 p.m. AKST; **Yellowknife,** *d.* 9:57 p.m., *r.* 10:36 p.m. MST; **Quebec City,** *d.* 1:05 a.m., *gr.* 1:20 a.m., *r.* 1:29 a.m. EST; **Bangor,** *d.* 1:15 a.m., *gr.* 1:25 a.m., *r.* 1:32 a.m. EST; **Halifax,** *d.* 2:12 a.m., *gr.* 2:25 a.m., *r.* 2:45 a.m. AST.

The occultation of **Aldebaran** on February 23rd is best for Europe and northern Russia. Northeast North America and the Atlantic see a daylight occultation, but the Moon won't be too high. For Bermuda, the Moon stands only 7° high at the time of disappearance. Halifax is a bit better: The Moon is 10° high at disappearance, 20° high at reappearance. Some timings: **Hamilton, Bermuda,** *disappearance* 12:32 p.m. AST; **Halifax, NS,** *d.* 11:57 a.m. AST, *reappearance* 12:48 p.m. AST.

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skyandtelescope.com/astronomy-clubs-organizations

Asteroid Occultations

If you're in the north, plan to observe an asteroid occultation on the night of February 16th, when the 146-km-diameter asteroid **20 Massalia** passes in front of a star in Taurus. Observers along a path across southern Canada and the northern United States will see 9.2-magnitude HD 35003 (TYC 1308-01348-1) disappear for up to 19 seconds.

The region of visibility for an occultation of a star by a minor planet can be uncertain by about 0.5 path widths (pw) for most events, but because 20 Massalia is a well-known, well-tracked asteroid, the uncertainty here is only 0.05 pw. A line drawn on a map from Spokane, Washington, through Winnipeg, Manitoba, to St. John's, Newfoundland and Labrador, will give you a good idea of where you'll want to be that night.

The long duration and small pw uncertainty makes this an easier event to view than the occultation of a star by asteroid **540 Rosamunde**, visible along a path connecting Baja California Sur to central Florida on the night of February 13th. While the 7.0-magnitude drop in brightness will be dramatic

Action at Jupiter

Jupiter's westward elongation gradually increases in February, so the striped planet rises earlier each morning. By the second half of the month, it's visible half the night — the second half. Jupiter brightens from magnitude –2.0 to –2.2 over the course of February and increases its girth from 36″ to 39″.

Any telescope shows Jupiter's four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them at any date and time.

All of the February interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest in the early morning hours.

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.)

February 1, 6:26, 16:21; **2,** 2:17, 12:13, 22:08; **3,** 8:04, 18:00; **4,** 3:55, 13:51, 23:47; **5,** 9:42, 19:38; **6,** 5:34, 15:29; **7,** 1:25, 11:21, 21:17; **8,** 7:12, 17:08; **9,** 3:04, 12:59, 22:55; **10,** 8:51, 18:46; **11,** 4:42, 14:38; **12,** 0:33, 10:29, 20:25; **13,** 6:20, 16:16; **14,** 2:12, 12:07, 22:03; **15,** 7:59, 17:54; **16,** 3:50, 13:46, 23:41; **17,** 9:37, 19:33; **18,** 5:28, 15:24; **19,** 1:20, 11:15, 21:11; **20,** 7:07, 17:02; **21,** 2:58, 12:54, 22:49; **22,** 8:45, 18:41; **23,** 4:36, 14:32; **24,** 0:27, 10:23, 0:19; **25,** 6:14, 16:10; **26,** 2:06, 12:01, 21:57; **27,** 7:53, 17:48; **28,** 3:44, 13:40, 23:35.

March 1, 9:31, 19:27; **2,** 5:22, 15:18; **3,** 1:13, 11:09, 21:05; **4,** 7:00, 16:56; **5,** 2:52, 12:47, 22:43; **6,** 8:38, 18:34; **7,** 4:30, 14:25; **8,** 0:21, 10:17, 20:12; **9,** 6:08, 16:04; **10,** 1:59, 11:55, 21:50; **11,** 7:46, 17:42; **12,** 3:37, 13:33, 23:29; **13,** 9:24, 19:20; **14,** 5:15, 15:11; **15,** 1:07, 11:02, 20:58; **16,** 6:53, 16:49; **17,** 2:45, 12:40, 22:36; **18,** 8:31, 18:27; **19,** 4:23, 14:18; **20,** 0:14, 10:10, 20:05; **21,** 6:01, 15:56; **22,** 1:52, 11:48, 21:43; **23,** 7:39, 17:34; **24,** 3:30, 13:26, 23:21; **25,** 9:17, 19:12; **26,** 5:08, 15:04; **27,** 0:59, 10:55, 20:50; **28,** 6:46, 16:42; **29,** 2:37, 12:33, 22:28; **30,** 8:24, 18:20; **31,** 4:15, 14:11.

These times assume that the spot will be centered at System II longitude 285°. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 285° and $1\frac{2}{3}$ minutes later for each degree more than 285°.

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 and visibility of Jupiter's reddish and brownish markings.

Minima of Algol

Feb.	UT	Mar.	UT
2	4:30	2	20:43
5	1:19	5	17:32
7	22:09	8	14:22
10	18:58	11	11:11
13	15:47	14	8:00
16	12:37	17	4:50
19	9:26	20	1:39
22	6:15	22	22:28
25	3:05	25	19:17
27	23:54	28	16:07
		31	12:56

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.5540+ 2.86732400**E**, where **E** is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol.**

(magnitude-8.6 HD 15564 is hidden by magnitude-15.6 Rosamunde), the duration of the disappearance is predicted to last just 0.8 seconds.

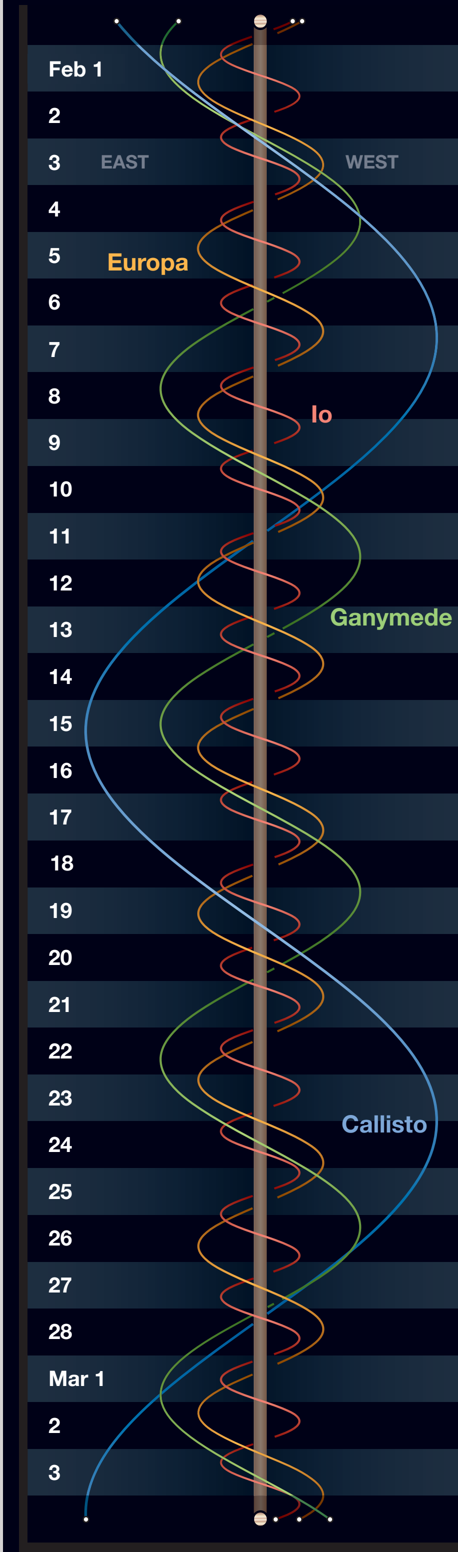
About a week before both events, more precise predictions and path maps will be available from Steve Preston's minor-planet occultation website (**asteroidoccultation.com**). For advice on timing occultations and reporting observations to the International Occultation Timing Association (IOTA), see **asteroidoccultation.com/observations**. Occultation enthusiasts may also join the online group at **groups.yahoo.com/neo/groups/IOTAoccultations**.

Phenomena of Jupiter's Moons, February 2018

Feb. 1	13:24	I.Sh.I
	14:37	I.Tr.I
	15:33	I.Sh.E
	16:46	I.Tr.E
Feb. 2	10:35	I.Ec.D
	12:45	II.Sh.I
	13:58	I.Oc.R
	15:00	II.Sh.E
	15:11	II.Tr.I
	17:22	II.Tr.E
	17:38	III.Sh.I
	19:26	III.Sh.E
	22:45	III.Tr.I
Feb. 3	0:13	III.Tr.E
	7:52	I.Sh.I
	9:06	I.Tr.I
	10:02	I.Sh.E
	11:14	I.Tr.E
Feb. 4	5:03	I.Ec.D
	7:33	II.Ec.D
	8:26	I.Oc.R
	9:51	II.Ec.R
	10:06	II.Oc.D
	12:20	II.Oc.R
Feb. 5	2:21	I.Sh.I
	3:34	I.Tr.I
	4:30	I.Sh.E
	5:43	I.Tr.E
	23:31	I.Ec.D
Feb. 6	2:02	II.Sh.I
	2:54	I.Oc.R
	4:16	II.Sh.E
	4:29	II.Tr.I
	6:39	II.Tr.E
	7:47	III.Ec.D
	9:36	III.Ec.R
	12:57	III.Oc.D
	14:25	III.Oc.R
	20:49	I.Sh.I
	22:03	I.Tr.I
	22:58	I.Sh.E
Feb. 7	0:11	I.Tr.E
	18:00	I.Ec.D
	20:51	II.Ec.D
	21:23	I.Oc.R
	23:08	II.Ec.R
	23:25	II.Oc.D
Feb. 8	1:37	II.Oc.R
	15:17	I.Sh.I
	16:31	I.Tr.I
	17:27	I.Sh.E
	18:40	I.Tr.E
Feb. 9	12:28	I.Ec.D
	15:18	II.Sh.I
	15:51	I.Oc.R
	17:33	II.Sh.E
	17:46	II.Tr.I
	19:56	II.Tr.E
	21:36	III.Sh.I
	23:23	III.Sh.E
Feb. 10	2:47	III.Tr.I
	4:11	III.Tr.E
	9:46	I.Sh.I
	11:00	I.Tr.I
	11:55	I.Sh.E
	13:08	I.Tr.E
Feb. 11	6:56	I.Ec.D
	10:09	II.Ec.D
	10:19	I.Oc.R
	12:26	II.Ec.R
	12:43	II.Oc.D
	14:56	II.Oc.R
Feb. 12	4:14	I.Sh.I
	5:28	I.Tr.I
	6:23	I.Sh.E
	7:37	I.Tr.E
Feb. 13	1:24	I.Ec.D
	4:35	II.Sh.I
	4:47	I.Oc.R
	6:49	II.Sh.E
	7:02	II.Tr.I
	9:13	II.Tr.E
	11:44	III.Ec.D
	13:33	III.Ec.R
	16:57	III.Oc.D
	18:21	III.Oc.R
	22:42	I.Sh.I
	23:56	I.Tr.I
Feb. 14	0:52	I.Sh.E
	2:05	I.Tr.E
	19:52	I.Ec.D
	23:16	I.Oc.R
	23:26	II.Ec.D
Feb. 15	1:44	II.Ec.R
	2:01	II.Oc.D
	4:13	II.Oc.R
	17:11	I.Sh.I
	18:25	I.Tr.I
	19:20	I.Sh.E
	20:33	I.Tr.E
Feb. 16	14:21	I.Ec.D
	17:44	I.Oc.R
	17:51	II.Sh.I
	20:06	II.Sh.E
	20:19	II.Tr.I
	22:29	II.Tr.E
Feb. 17	1:33	III.Sh.I
	3:20	III.Sh.E
	6:46	III.Tr.I
	8:06	III.Tr.E
	11:39	I.Sh.I
	12:53	I.Tr.I
	13:48	I.Sh.E
	15:01	I.Tr.E
Feb. 18	8:49	I.Ec.D
	12:12	I.Oc.R
	12:45	II.Ec.D
	15:02	II.Ec.R
	15:18	II.Oc.D
	17:30	II.Oc.R
Feb. 19	6:07	I.Sh.I
	7:21	I.Tr.I
	8:17	I.Sh.E
	9:29	I.Tr.E
Feb. 20	3:17	I.Ec.D
	6:40	I.Oc.R
	7:07	II.Sh.I
	9:22	II.Sh.E
	9:34	II.Tr.I
	11:44	II.Tr.E
	15:41	III.Ec.D
	17:30	III.Ec.R
	20:52	III.Oc.D
	22:13	III.Oc.R
Feb. 21	0:36	I.Sh.I
	1:49	I.Tr.I
	2:45	I.Sh.E
	3:57	I.Tr.E
	21:45	I.Ec.D
Feb. 22	1:07	I.Oc.R
	2:02	II.Ec.D
	4:19	II.Ec.R
	4:34	II.Oc.D
	6:46	II.Oc.R
	19:04	I.Sh.I
	20:17	I.Tr.I
	21:14	I.Sh.E
	22:25	I.Tr.E
Feb. 23	16:13	I.Ec.D
	19:35	I.Oc.R
	20:24	II.Sh.I
	22:39	II.Sh.E
	22:49	II.Tr.I
Feb. 24	0:59	II.Tr.E
	5:31	III.Sh.I
	7:17	III.Sh.E
	10:39	III.Tr.I
	11:56	III.Tr.E
	13:32	I.Sh.I
	14:45	I.Tr.I
	15:42	I.Sh.E
	16:53	I.Tr.E
Feb. 25	10:42	I.Ec.D
	14:03	I.Oc.R
	15:20	II.Ec.D
	17:37	II.Ec.R
	17:51	II.Oc.D
	20:02	II.Oc.R
Feb. 26	8:01	I.Sh.I
	9:13	I.Tr.I
	10:10	I.Sh.E
	11:21	I.Tr.E
Feb. 27	5:10	I.Ec.D
	8:31	I.Oc.R
	9:40	II.Sh.I
	11:55	II.Sh.E
	12:04	II.Tr.I
	14:13	II.Tr.E
	19:38	III.Ec.D
	21:27	III.Ec.R
Feb. 28	0:43	III.Oc.D
	2:01	III.Oc.R
	2:29	I.Sh.I
	3:41	I.Tr.I
	4:38	I.Sh.E
	5:49	I.Tr.E
	23:38	I.Ec.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.

Dry No More

Look closely, and you can spot places where water exists on the lunar surface.

The samples returned by six crews of Apollo astronauts from 1969 to 1972 showed us, finally, what the Moon was made of. Completely unlike the sopping-wet Earth, those lunar rocks revealed no evidence of water or even any minerals remotely related to water. I vividly recall the first science results from Apollo 11 and hearing the phrase, "The Moon is bone dry."

But during the last decade teams of researchers have used improved laboratory instrumentation to reveal water chemically bound within some lunar samples, suggesting that it came from the Moon's interior.

The Apollo samples tell us about only a half dozen locations on the lunar surface. However, thanks to the Moon Mineralogy Mapper (M^3), a visible-infrared spectrometer on the Indian lunar orbiter Chandrayaan 1, we've known for nearly 10 years that small amounts of hydrogen-oxygen bonded molecules — as either water (H_2O) or hydroxyl (OH) — exist in the uppermost millimeters of the lunar regolith.

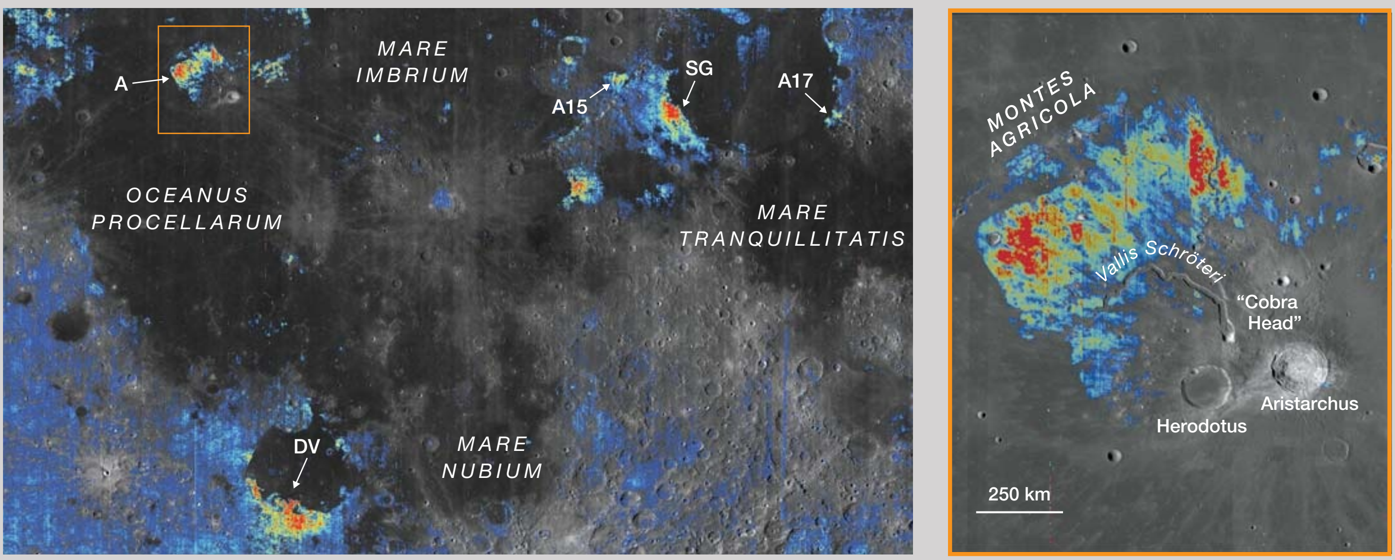
A recent detailed reanalysis of these data by Shuai Li and Ralph Milliken (Brown University) confirms that the Moon's water abundance steadily increases poleward of about 30°, not counting what might lie frozen on the shadowed floors of craters, with a maximum of 500 to 700 parts per million (ppm) at latitudes above 60° surrounding each pole. Water abundance is below 100 ppm within 30° of the equator.

This uneven distribution strongly implies that surface temperature dictates the water's abundance. Probably this latitudinally dependent water is produced when high-energy protons (hydrogen nuclei) in the solar wind slam into lunar soils and release oxygen, forming temporary molecules of H_2O that are driven toward the poles by day-night temperature fluctuations.

The new mapping has also identified localized exposures of water, nowhere near the poles, that seem to be permanent (not solar-wind driven). Nearly all of these involve volcanic deposits, consistent with water's detection in some samples collected during Apollo missions. Some of these water-rich volcanics are easy to observe visually, allowing your telescopic views to connect you to the latest lunar discoveries.

Trails of Dark Evidence

Li and Milliken find that the most obvious water-bearing exposures occur



▲ A map of the Moon's infrared brightness at 2.85 microns reveals the distribution of water (or its radical, OH) in concentrations ranging from less than 50 parts per million (dark blue) to more than 300 ppm (red). Labels mark locations discussed in the text: *A*, Aristarchus region; *DV*, Doppelmayer-Vitello region; *A15* and *A17*, landing sites of Apollo 15 and 17, respectively; and *SG*, rilles near Sulpicius Gallus crater. *Right:* The lunar surface north and west of Vallis Schröteri contains up to 500 ppm of water either adsorbed by pyroclastic particles or chemically bound to them.

S. LI & R. MILLIKEN / *NATURE GEOSCIENCE* (2) in broad *pyroclastic deposits* (involving gas-driven eruptions) — and the biggest, containing up to 500 ppm water, covers the northern half of the Aristarchus Plateau. Frothy fire fountains erupted from the "Cobra Head" volcanic cone when Vallis Schröteri (Schröter's Valley) formed. A blanket of fallout probably surrounded that vent, but ejecta from the subsequent impact that formed Aristarchus crater covered volcanic ash along the plateau's southern half.

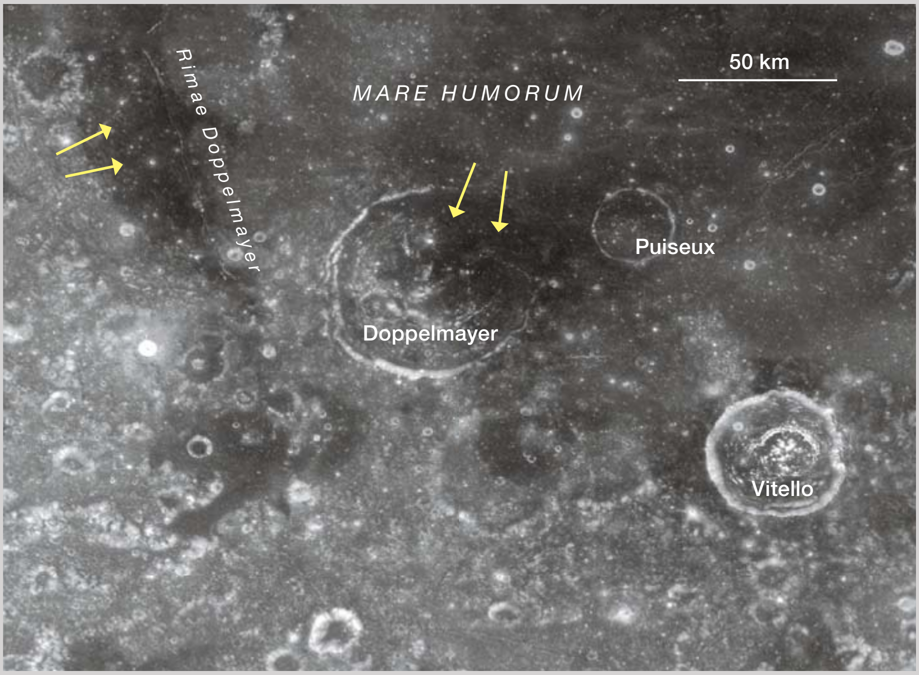
The water-infused deposits also end abruptly along the uplifted plateau's edge, because later flows that flooded the surrounding Oceanus Procellarum covered up the terrain lower down. Visually, at times near full Moon, the southern area of the Aristarchus Plateau is bright because of the crater's ejecta. The pyroclastic accumulation to the north is slightly darker, and that's where water is adsorbed or bonded with ash deposits.

You'll find another large pyroclastic deposit marked by a dark mantle around the Sulpicius Gallus rilles on the southwestern shore of Mare Serenitatis. Viewing at high magnification, you can see that the short rilles cut into older, slightly higher lavas. The water-infused ash that erupted from the rille drapes across part of the adjacent highlands but stops abruptly at the lower edge of the old flows. The mare lavas filling most of Serenitatis are younger and cover the older pyroclastic layer.

A third large lunar pyroclastic unit, also boasting up to 500 ppm of H_2O and/or OH, occurs along the southern shore of Mare Humorum. This water-infused deposit occurs within the ruined crater between Doppelmayer and Vitello, and to the west along the Rimae Doppelmayer, which was the vent for that part of the pyroclastic eruptions. These areas likewise appear dark under a high Sun.

Smaller pyroclastic deposits, including those at Apollo 15 and Apollo 17 sites and around the small dark-halo craters on the floor of Alphonsus, contain more than 250 ppm of water.

It makes geochemical sense that water would be associated with pyroclastic eruptions. These very powerful events are driven by expanding bubbles of gas within rising columns of magma that literally explode upon reaching the surface. When this occurs, the magma is torn to shreds and widely dispersed.



▲ When viewed at times near full Moon, dark expanses along the southwestern margin of Mare Humorum mark the locations of water-enriched volcanic deposits.

NASA / LUNAR RECONNAISSANCE ORBITER

However, as Li and Milliken's maps of infrared spectra show, water-bearing deposits are also associated with a few much tamer volcanic flows. These tend to involve silicic lavas (those rich in silicon), which are so sluggishly viscous that their volatiles cannot easily escape. Silicic lavas typically flow slowly and are relatively short, with steep edges.

One observable example is the silicic dome near the crater Mairan. First find Mairan T, a small, shield-shaped cone with calderas on top at the edge of Sinus Roris, 18° due north of Aristarchus. Then look for a pudgy mound to its east. That's where the water shows up.

The nearby Gruithuisen domes, a bit farther south, have classic silicic dome morphology yet are *not* water-rich. (In fact, Li and Milliken found that four other silicic volcanic formations likewise lack water's telltale infrared absorption, so perhaps the Mairan dome is an oddity.) Instead, look just northeast of the domes for a flat, mare-like surface. This doesn't seem to be a pyroclastic deposit, yet it *does* contain water.

The lack of water signatures associated with the maria themselves implies either that the sources of these massive flows didn't contain much water or that somehow it escaped to space before it could be adsorbed.

The new M^3 maps indicate that impact craters typically do not bring water-bearing deposits to the surface — with one notable exception. The central peak of 61-km-wide Bullialdus contains up to 250 ppm water, yet none occurs anywhere else within the crater or nearby. A central peak represents rock brought up from 5 to 10 km below the crater floor, and in this case those deep-seated rocks must have contained water.

So why only at Bullialdus and not in other large craters that excavated similar depths? That is a mystery not yet solved — and we didn't even know it *was* a mystery until Li and Milliken gave the M^3 data a closer look. But that's how lunar science works: More data bring more mysteries and ultimately improve our understanding of how the Moon operated billions of years ago.

■ Contributing Editor **CHUCK WOOD** explores hundreds of lunar mysteries at **www2.lpod.org**.

Winter's Mighty Hunter

Look to Orion, the embodiment of the season's night sky, to discover a diverse collection of celestial wonders.

Thou Hunter, who dost climb at eve
The vault of Ether blue,
Whose starry dagger nightly gleams
My casement-lattice through
—Anonymous, *Babylon*, 1837

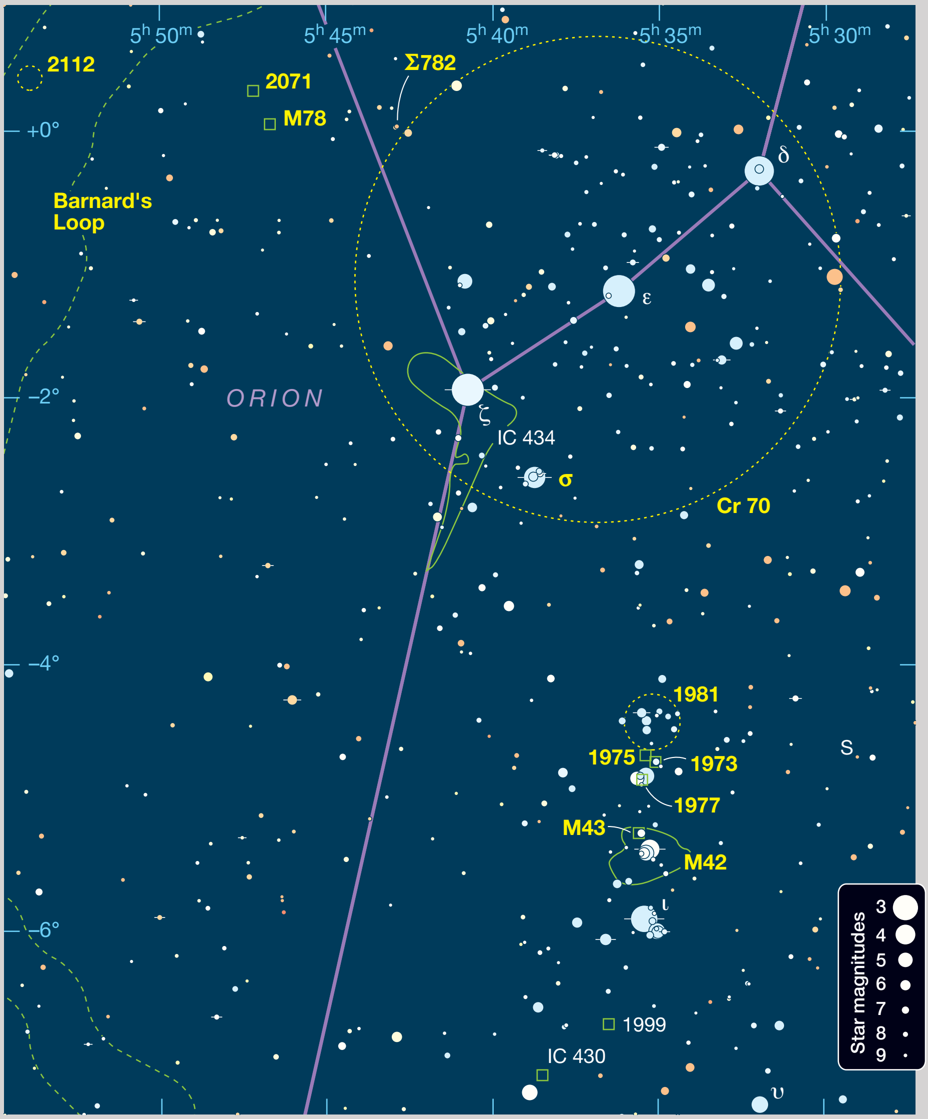
The glory of Orion, the Hunter, holds sway over winter nights with its unequaled brilliance. Our centerfold's all-sky chart depicts its attention-grabbing belt stars in a straight line straddling the celestial equator. Gleaming below his belt, Orion's starry dagger bears his foremost treasure, the Orion Nebula, an extensive tangle of nebulosity with a heart of sparkling gems.

The **Orion Nebula** (M42 and M43) is enchanting in any telescope, and the view through a large scope can never be forgotten. Georgia amateur David C. Riddle made the stunning sketch of M42 (shown far right) with his 18-inch reflector at 450×. It took five hours just to capture the tremendous amount of detail exposed in the bright region that frames the trapezoidal knot of four stars known as the Trapezium. It's truly a picture worth a thousand words.

Orion's dagger (or sword) is a wonderful sight through 15×45 image-stabilized binoculars. M42's graceful fan of lambent light wears three of the Trapezium's stars plus two more nearby. A dark notch named the Fish's Mouth juts in toward the Trapezium from the east-northeast. Petite M43 is punctuated by a single star. North of M43, a diaphanous, east-west nebula about 15′ long embraces one faint and two bright stars. It marks the site of the nebula-cluster complex **NGC 1973**, **NGC 1975**, and **NGC 1977**. Above the complex, 13 stars of magnitudes 6 through 9 form the loose cluster **NGC 1981** and charmingly trace out the path of a bouncing ball dribbled east-west for 25′.

Beyond the dagger, let's focus on the beautiful multiple star **Sigma (σ) Orionis**, visible to the unaided eye as a single point near Zeta (ζ) Orionis (Alnitak), the leftmost star of Orion's Belt. A magnification of 87× in my 105-mm refractor reveals four components arranged in a slightly wavy line, all dressed in shades of white to blue-white. The brightest member comprises two stars that are too close together to distinguish through a backyard scope. They're tightly wedded by their mutual gravity, but the visible companions are only loosely bound to the system and may go their separate ways in the distant future.

Orion's belt stars are part of the impressive star cluster **Collinder 70**, a remarkable group so large that it's best appreciated through binoculars. Swed-



ish astronomer Per Collinder called it "a very fine cluster" and assigned it a size of 250′ × 120′ in his 1931 catalog of star clusters. More than 100 stars show in the 15×45 binoculars. A particularly prominent S-shaped curve of fairly bright stars wends its way across the cluster between Alnilam and Mintaka, Orion's middle and rightmost belt stars. The belt stars are blue-white beauties, and two of the brightest non-belt stars blaze orange.

Off the southwestern side of Collinder 70, the naked-eye star **Eta (η) Orionis** is a nice double to attempt splitting during good seeing (atmospheric steadiness). The 3.6-magnitude primary guards a 4.9-magnitude companion just 1.8″ to the east-northeast. Through the 105-mm refractor at 127×, both are bluish-white, but there's more to the primary than meets the eye. Its spectrum shows that it's really composed of three stars in tight embrace.

Training the 15×45 binoculars on a patch of sky 2.5° northeast of Alnitak brings two reflection nebulae into view. **Messier 78** is an obvious roundish glow with one barely seen star, accompanied by dimmer **NGC 2071**, which hosts a brighter star. Two stars adorn M78 in the refractor at 47×, looking amusingly like the eyes of a little ghost. Sweeping the scope 57′ west takes me to the colorful double **Struve 782**. Its nearly matched, yellow-orange suns are far enough apart to separate at 28×. Shifting 1.8° east from M78 takes the scope to the open cluster **NGC 2112**, a granular haze at 17× and a pretty dusting of faint stars at 127×.

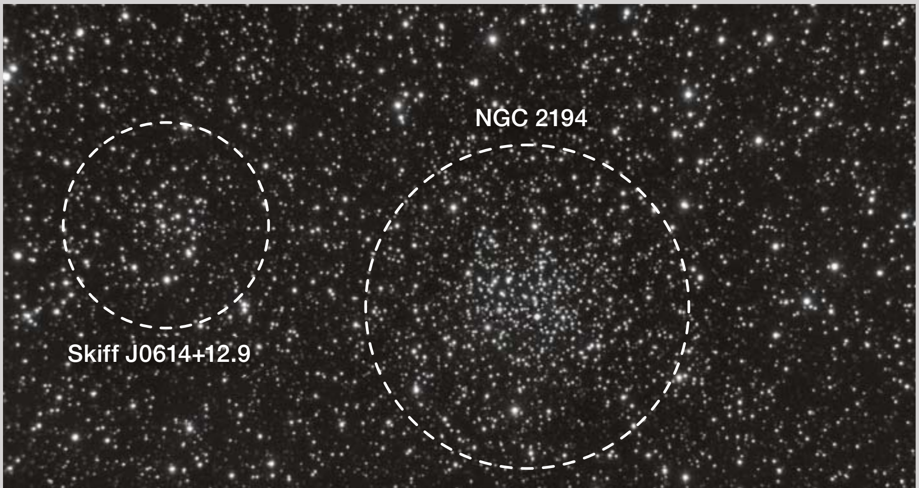
I recently observed NGC 2112 through Justin Cash's 8-inch reflector while in North Carolina. The cluster is readily visible at 35× as a small concentration of several faint stars. At 174× about 20 stars are loosely scattered across 9½′, the brightest one an orange ember at the cluster's northwestern edge.

▲ David Riddle drew this deep view of the Orion Nebula over a stretch of several evenings. It took 5 hours at his 18-inch reflector at 450× to capture just the area surrounding the four bright stars that make up the Trapezium cluster.

Objects in Orion

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M42/M43	Emission/reflection nebula	3.0	60′	5^h 35.0^m	−5° 25′
NGC 1973/75/77	Nebula/cluster complex	6.3 (nebula)	29′ × 20′	5^h 35.4^m	−4° 47′
NGC 1981	Open cluster	4.2	24′	5^h 35.2^m	−4° 26′
Sigma (σ) Orionis	Multiple star	3.8, 8.8, 6.6, 6.3	11.6″, 12.9″, 41.5″	5^h 38.7^m	−2° 36′
Collinder 70	Open cluster	0.6	4.2° × 2.0°	5^h 35.6^m	−1° 05′
Eta (η) Orionis	Double star	3.6, 4.9	1.8″	5^h 24.5^m	−2° 24′
Messier 78	Reflection nebula	8.3	8.4′ × 7.8′	5^h 46.8^m	+0° 03′
NGC 2071	Reflection nebula	—	8.0′ × 7.7′	5^h 47.1^m	+0° 18′
Struve 782 (Σ782)	Double star	8.6, 8.8	47″	5^h 42.9^m	+0° 01′
NGC 2112	Open cluster	9.1	11′	5^h 53.8^m	+0° 25′
Barnard's Loop	Emission nebula	—	13° × 1°	5^h 54.3^m	−6° 24′
Jonckheere 320	Planetary nebula	11.9	26″ × 14″	5^h 05.6^m	+10° 42′
NGC 2194	Open cluster	8.5	9′	6^h 13.8^m	+12° 48′
Skiff J0614+12.9	Open cluster	—	5.0′	6^h 14.8^m	+12° 52′
NGC 2175	Emission nebula	—	29′ × 27′	6^h 09.7^m	+20° 29′
NGC 2175.1	Open cluster	—	5.0′	6^h 10.9^m	+20° 37′
Skiff J0619+18.5	Open cluster	—	20′	6^h 19.4^m	+18° 33′

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.



William Herschel discovered the open star cluster NGC 2194 in 1784, but Skiff J0614+12.9 is a much more recent discovery. Brian Skiff (Lowell Observatory) found the latter with a 25-cm reflector around 1975 and reported it in the *Observing Handbook and Catalogue of Deep-Sky Objects* (Luginbuhl and Skiff) in 1989.

NGC 2112 lies within a 2°-length of **Barnard's Loop** visible with 15×45 binoculars from Florida's Lower Keys. In the 105-mm scope at 17× with the help of a hydrogen-beta filter, I followed the nebula's unevenly bright curve for roughly 9°, displaying a mean width of about 40′.

Next up is the planetary nebula **Jonckheere 320**, located 2.7° east-northeast of Pi^1 (π^1) Orionis in Orion's shield. J320 is visible in my 4.1-inch refractor even at 28×, but it looks like a star. At 127× it becomes a tiny disk. Through the 10-inch scope at 115×, the nebula takes on a bluish cast, and at 299× it turns into a small oval that's brighter at its east-southeastern end.

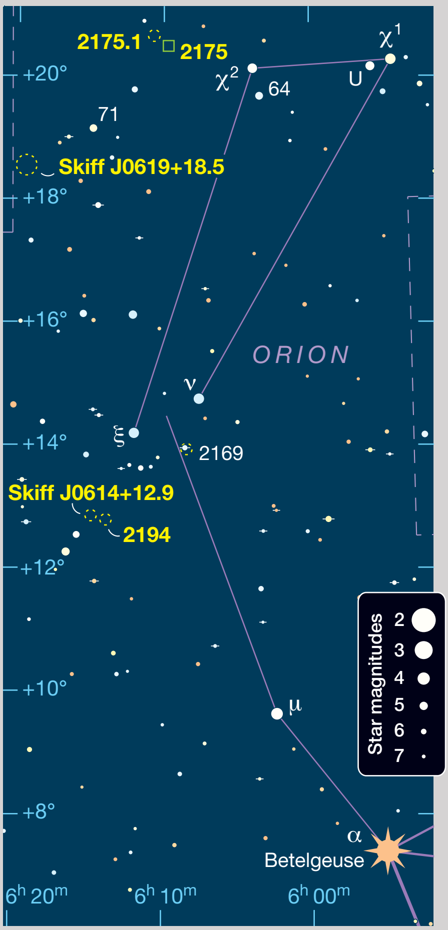
In 1911 Robert Jonckheere cataloged J320 as a pair of 9.8-magnitude stars 2.17″ apart. Five years later he wrote, "While observing with the 28-inch equatorial on January 22, I noticed that the object that I have catalogued as J320 is not a double star, but . . . it appears with the larger instrument to be an extremely small bright elongated nebula" (*The Observatory*, March 1916).

From the shield, we'll move into Orion's upraised arm, where the open-cluster pair **NGC 2194** and **Skiff J0614+12.9** rests 1.5° south-southeast of Xi (ξ) Orionis. The duo shows nicely in the field of the 10-inch scope at 70×, both speckled with very faint stars. On closer examination at 171×, NGC 2194 boasts 40 stars, many in a boxy, 5′ core with a grainy backdrop. Its scraggly 8′ halo is fertile in some places and barren in others. The Skiff cluster sports about half as many stars confined to 5′.

In northernmost Orion, we'll call on the emission nebula **NGC 2175**, 1.4° east-northeast of Chi^2 (χ^2) Orionis. It's even visible through my 9×50 finder as a sizable glow around a star. At 68× in the 10-inch reflector, it's subtle. Adding a narrowband filter, NGC 2175 is a beautiful sight, softly glowing like backlit frost on the window of the sky. Its 25′ spread is threaded with dark lanes and spangled with meandering chains and lines of stars. The nebula's northern border is particularly irregular. Just 3′ east-northeast of the nebula's central star, there's a fairly small brighter patch harboring a star of its own. A little cluster sometimes cataloged as **NGC 2175.1** resides at the nebula's east-northeastern edge. A filterless view at 115× shows 15 stars in a north-south, 4½′ × 3′ group that includes a close double.

Our final fare is another cluster found by Arizona astronomer Brian Skiff. **Skiff J0619+18.5** sits 1.2° east-southeast of 71 Orionis and consists of three clumps of stars. My 10-inch scope at 68× shows two of them forming a 13′ triangular aggregation of about 35 stars, 9th magnitude and fainter. The denser clump forms the triangle's southern point, and the looser one to the north fashions its base. A detached group to the southwest contains the golden, 8th-magnitude star HD 254874. Altogether the cluster shows at least 60 stars in an irregular gathering whose maximum diameter is roughly 20′.

Orion harbors a wealth of deep-sky objects, from the spectacular, to the challenging, to the virtually unknown. Which appeal to you?



■ Contributing Editor **SUE FRENCH** enjoys tracking down lesser-known sights in otherwise familiar skies.

MARTIN C. GERMANO

◀ FULL-FRAME CMOS

QHYCCD rolls out a new model in its COLDMOS camera series, the QHY128C ($3,499) 14-bit, full-frame CMOS camera for deep-sky astrophotography. The camera is designed around the Sony color CMOS IMX128 sensor with a 6,036 × 4,028-pixel array measuring 24 × 36 mm with 5.97-micron-square pixels. Its dual-stage thermoelectric cooling is capable of stable temperatures of 35° below ambient, producing low-noise images through its USB 3.0 interface with additional proprietary QHY amplifier glow suppression. The unit is capable of recording 5 full-resolution frames per second, and more using on-chip region-of-interest. An internal 128-megabyte DDRII image buffer ensures no frames are dropped during downloads. Each camera comes with a 1-meter, 12V threaded power cord, a 1.5-m USB 3.0 cable, and a 2-inch nosepiece, plus a CD with camera drivers and control software. See the manufacturer's website for additional details.

QHYCCD
qhyccd.com

SPECTRA TABLE ▶

RSpec now offers a unique poster of the Periodic Table of the Elements. The Periodic Table of Spectra poster ($6.95) measures 36 by 24 inches and displays the emission spectra of every known element seen in the universe. Its information is based on the NIST Atomic Spectra Database and also includes the names and positions of unstable elements. A laminated version is available for $29.95 plus shipping.

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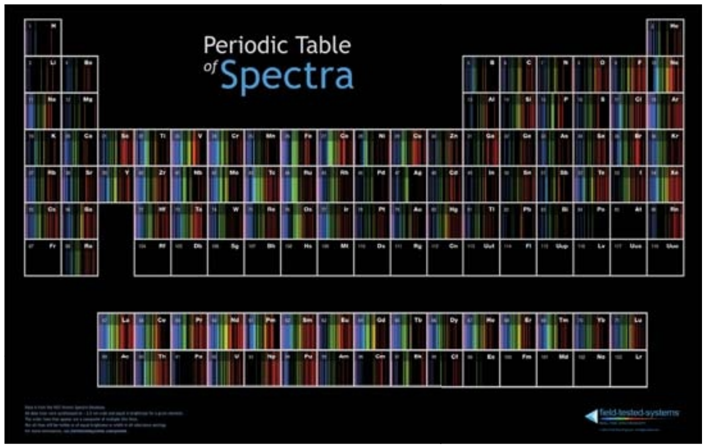


◀ NARROWBAND LUMINANCE

Oceanside Photo and Telescope announces a new filter for astrophotographers. The OPT Triad Tri-band narrowband filter is designed to pass wavelengths centered at 493 and 656.3 nanometers, where emission nebulae produce light, while blocking other wavelengths in the visible spectrum. This permits users to record full-color images from light-polluted skies using DSLR and astronomical CCD or CMOS cameras. The filter is available in 1¼-inch and 2-inch formatted cells for $375 and $775 USD, respectively.

Oceanside Photo and Telescope
918 Mission Ave., Oceanside, CA 92054
800-483-6287; optcorp.com

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

The QHY16200A CCD Camera

This camera offers a generous 16-megapixel field at an attractive price.

◀ The QHY16200A camera, filter wheel, and QHYOAG-M shown attached to the author's 102-mm William Optics refractor. Balancing the 5-lb., 10-oz. camera load on this scope was relatively easy by sliding everything forward on the scope's dovetail plate in the telescope mounting.

ALL PHOTOS BY THE AUTHOR

QHY16200A Monochrome CCD Camera and 7-Position 50-mm Filter Wheel and Off-Axis Guider

U.S. Price: $4,399
qhyccd.com

What We Like:
Generous field of view
Comfortable design

What We Don't Like:
Substantial size and weight
Gain and offset settings

ROUGHLY A DECADE AGO, ON Semiconductor (formerly Kodak) introduced the KAF-8300 CCD detector widely used in astronomical cameras. This 8.3-megapixel, 18 × 14 mm sensor offered a generous field of view for imagers on a modest budget, and cameras built around the KAF-8300 detector quickly became the tool of choice for many deep-sky astrophotographers.

Today, another ON Semiconductor CCD chip is set to make a splash in the imaging market with a detector that's nearly twice the size of the 8300 CCD: The KAF-16200, a 16-megapixel chip roughly ¾ the size of a 35-mm camera frame. With our interest piqued, we borrowed one of the first cameras to feature this chip to see how it performs in the field.

Fit and Finish

The Chinese-made QHY16200A camera with its 27 × 21.6-mm, 4,540 × 3,630-pixel "APS-H" array comes with an attractive price for such a large 16-MP chip. Its 6-micron pixels are slightly larger than the 5.4-µm pixels in the KAF-8300 CCD. The camera features two-stage thermoelectric cooling and a butterfly-shaped shutter that ensures even illumination and allows dark exposures without having to cover the telescope objective. Camera drivers, control software, and a PDF manual are available as free downloads from the manufacturer's website.

The CCD detector inside the QHY16200A isn't the camera's only large component. The camera housing and filter wheel assembly are hefty too. The system is ruggedly built with a handsome finish on all exterior surfaces.

The blue-anodized camera body measures 6 inches square and 2¾ inches deep, including the thickness of the 3-inch-diameter fan on the back. The filter wheel housing is 8¼-inch square by 1¼-inch deep. The QHY off-axis guider takes up an additional half-inch of back focus.

When it comes to chip size, housing dimensions, and weight, the QHY16200A is the largest astronomical camera I've used, and it made for a heavy imaging load. With the camera's off-axis guider attached and optional filters installed, I was dealing with a 5 lb, 10 oz. imaging package at the scope.

This load was a significant factor with all of my telescopes, but less so with my William Optics 102-mm f/6.9 refractor. Sliding the camera and telescope forward in the mount's dovetail saddle offered good balance on my Losmandy G11 German equatorial. The real dilemma came when I installed the camera on my 12½-inch f/4 Newtonian reflector. Its considerable off-axis weight had to be counterbalanced by adding a weight to the opposite side and opposite end of the OTA.

▲ This rear view of the QHY16200A camera with the filter wheel attached shows the cable inputs and cooling fan. The QHYOAG-M off-axis guider is at upper right. A short 12 VDC cable as well as several adapters at left are included to adapt the camera to 2-inch focusers (bottom), T-threaded accessories (middle), and accessories with 54mm threads (top left).

▲ The large size of the KAF-16200 CCD detector may push the capabilities of fast focal-ratio telescopes with 2-inch focusers.

My 12½-inch Newtonian has what I consider an adequate 2-inch Crayford-style focuser, though I had to considerably increase the tension on the bearings of its drawtube to reduce its sagging under the QHY16200A's weight. This sagging produced elongated star images and focus issues as I moved the scope to different parts of the sky. I dealt with some of this by securely tightening the focuser drawtube thumbscrews, but frankly I wished the scope had a 3-inch focuser.

The filter wheel housing has four ¼-20 threaded holes located at each corner. I attached lightweight steel-cable "safety lines" to a couple of these to ensure the camera wouldn't fall to the ground should it accidentally slip from the focuser.

Cable connections on the QHY16200A are thoughtfully designed. A clamp with a thumbscrew secures the USB cable from the host computer, and a knurled, threaded collar securely attaches the 12 VDC power cable, but I wondered why this connection attaches to a short (40-inch) coax cable rather than to the camera directly.

On the back of the camera are two "trigger" connections, two serial ports, and a ground connection. A 12 VDC "out" jack is conveniently placed next to the power input jack. These two jacks are wired parallel so either may be used as the 12 VDC input. A 12 VDC cable with a standard cigarette lighter plug is supplied, but no AC adapter. The plug has a convenient rocker switch to turn power on and off. There's also a power switch on back of the camera. When the camera's two-stage cooler is at 100%, the camera draws 3 amps. A 5 amp 12 VDC power supply is recommended. Finally, the onboard USB hub allows users to connect an autoguider camera with a short USB cable. This means only a single USB cable is needed between the camera and host computer — a nice touch.

The imaging chip in the camera is located 34 mm from the front of the camera with the filter wheel connected. With the OAG-M off-axis guider and adapter plate installed, the distance increases to 47 mm — well within back-focus range for most field-flatteners and coma correctors.

Two circular adapter plates come with the camera. One interfaces with a 2-inch nosepiece (included) and standard T-thread accessories. The other plate has a larger 54-mm-diameter opening with female 0.75-mm threads.

▲ The 7-position QHYOAG filter wheel accepts 50-mm filters (not included with purchase). Tools are supplied with the unit to allow easy access to the filter wheel housing for installation of the filters.

Both are secured to the filter wheel housing/QHYOAG-M with six M3 Phillips screws. Tools are included with the camera to allow removal of the filter wheel cover to permit installation of up to seven 50-mm filters.

Gain and Offset

Two unusual adjustable settings I hadn't encountered on previous cameras are for "gain" and "offset." Gain is usually permanently set by the camera manufacturer, and an offset is often added during image calibration.

Two sliders to adjust these settings are accessed in the *EZCAP_QT* software supplied with the camera. The default settings resulted in low camera sensitivity in my initial tests, so after some experimentation, I settled on settings of 10 for gain and an offset of 124.

Although the camera and filter wheel can be fully operated using the supplied *EZCAP_QT* software, I preferred to operate the camera and filter wheel using *MaxIm DL*.

Using *MaxIm DL* to control the QHY16200A required installing *ASCOM Capture* and the camera driver I downloaded from the QHY website, which also provides adjustment settings for gain and offset. Initially, the driver didn't allow the software to consistently connect to the camera. An updated driver installed later during my testing eliminated this problem.

Under the Stars

I used the QHYOAG-M off-axis guider to auto guide all of my test exposures with the camera. Besides being a solid unit, the guider features a moveable pick-off prism that can be adjusted radially then securely locked into position. I adjusted the pick-off prism's position so that it was well outside the image field of view so as not to cast its shadow on the camera's imaging area.

Guiding off axis also helps to eliminate any flexure that might arise from guiding through a separate guidescope due to the weight of the camera. I never had an issue with finding suitably bright guidestars using the OAG with a Starlight Xpress Lodestar X2 guide camera. The 1¼-inch guide camera port has three locking screws 120° apart. The guide camera is focused by sliding it in and out of the port, with a comfortable amount of focus travel available.

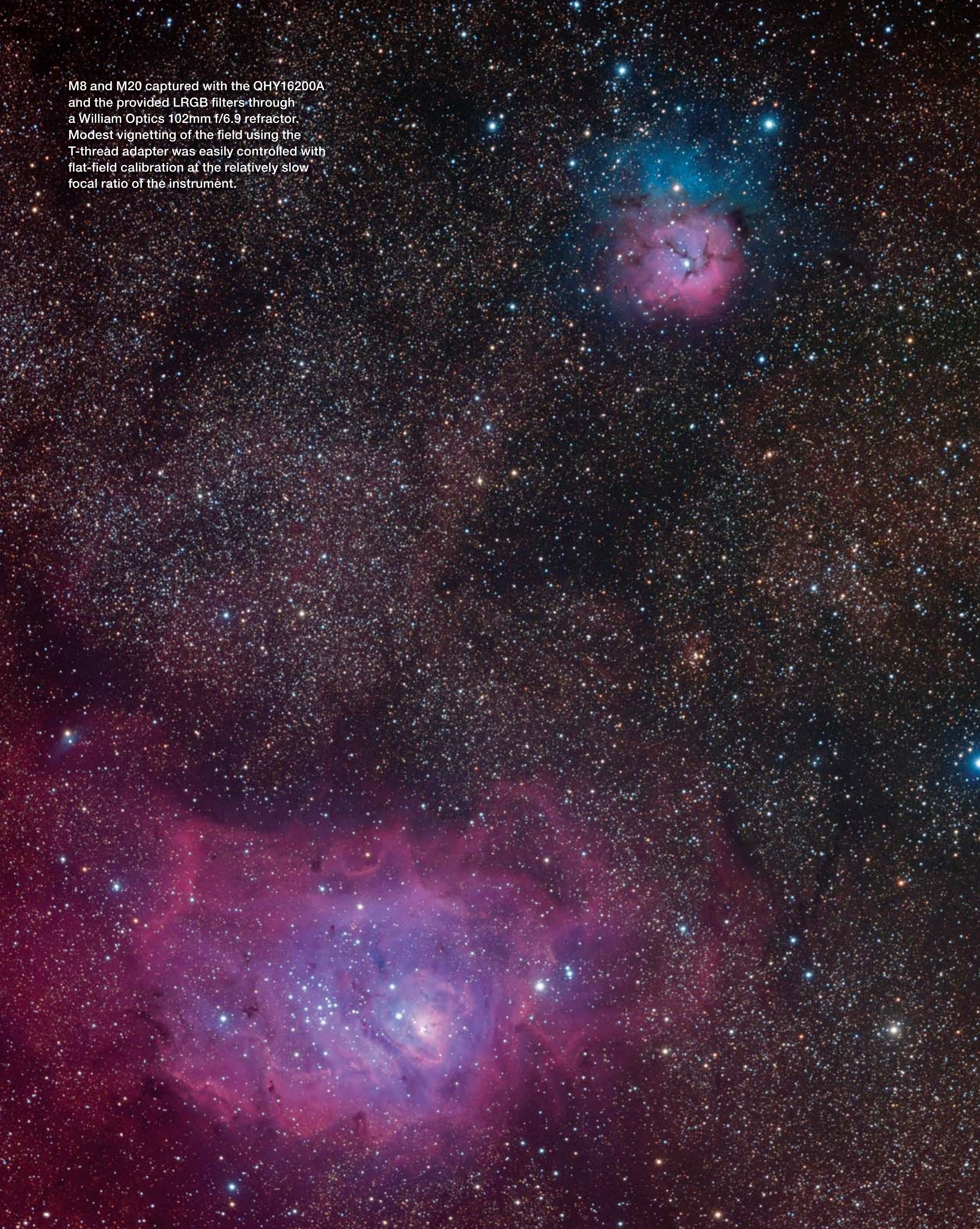
The 7-position filter wheel consistently placed each filter in the correct position as I worked through a typical LRGB imaging session. The filter wheel was surprisingly quiet as each filter rotated into place, with the only indication of the moving wheel being the "waiting on filter wheel" alert given in *MaxIm DL* for the few seconds that the filter wheel was in motion. After months of using the camera and filter wheel, there was not a single time when the selected filter didn't move into the correct position. Each time I launched the camera software, it knew which filter was already in position.

As testament to the machining and fit of the filter wheel, camera, and off-axis guider components, the stack of all three is effectively a light tight package. This allowed me to make dark frames during daylight with my observatory dome closed, even though there was still considerable ambient light inside the dome.

I used the software's 4×4 binning feature to center and compose my deep-sky targets, since the binning greatly increased the camera sensitivity. The two-stage cooler reached the set temperature quickly and was stable to a

▲ A custom-machined adapter was used with the QHY16200A camera to allow better illumination of the camera's large chip when used with the author's 12½-inch f/4 Newtonian equipped with a Tele Vue Paracorr Type 2 coma corrector. The corrector threads into the adapter, while male threads on the adapter's underside screw into the camera's 54-mm ring, producing a clear aperture of 50 mm.

◀ Two adapter rings are supplied with the QHY16200A camera. The T-thread adapter is shown here installed while the 54-mm adapter is held in front. Both are secured to the filter wheel housing by six M3 screws. The off-axis guider's pick-off prism is visible inside the T-thread opening.



M8 and M20 captured with the QHY16200A and the provided LRGB filters through a William Optics 102mm f/6.9 refractor. Modest vignetting of the field using the T-thread adapter was easily controlled with flat-field calibration at the relatively slow focal ratio of the instrument.

▲ The 7-position filter wheel holds enough filters so that imagers can install a full set of LRGB color filters, as well as 3 additional ones, such as a set of narrowband filters. This image of the North America and Pelican nebulae (NGC 7000 and IC 5067) was captured with the 102-mm refractor using 100 minutes of exposures.

tenth of a degree C throughout my test sessions. A full-resolution, 36-megabyte image took 15 seconds to read out and download to my computer.

For years I've wanted to try a large-format camera on my telescopes, but I quickly realized that covering the APS-H chip in the QHY16200A with a well-illuminated, aberration-free image was more demanding than I anticipated. The large size of the camera's imaging chip pushed the illumination limits of some of my telescope optics. My telescopes and adapters had been adequate for my KAF-8300 CCD camera as well as an APS-C chip in my modified Canon T2i DSLR.

▲ Users with fast f-ratio telescopes that require a T-adapter to connect cameras may need to upgrade their focusers. Using a 12½-inch f/4 Newtonian reflector and the T-threaded interface ring, the author experienced strong vignetting in this image of NGC 4565 that could not be corrected with flat-field calibration.

The QHY16200A's APS-H format is roughly ¾ the size of a 35-mm, and while having a camera with a large chip is generally a good "problem," astrophotographers considering the QHY16200A should be mindful of how large and well corrected the image circles offered by their telescopes are.

When using the QHY16200A with my William Optics 102-mm f/6.9 APO refractor and a 2-inch field flattener, the system produced good corner-to-corner star images with little vignetting. I also had good illumination when I used a 0.8× reducer/flattener with the refractor. Users having typical f/7 APO refractors with field flatteners are in great shape with this camera.

My 8-inch f/5 Newtonian used with a Tele Vue Paracorr Type-2 coma corrector (which produces f/5.7 with the corrector's 1.15× amplifying factor) showed some vignetting. But when I mounted the camera on my 12½-inch f/4 Newtonian reflector with its steeper light cone the image vignetted considerably. Most of the problem came from the standard diameter T-adapter I regularly use with the system. Some of this vignetting was corrected by flat-field calibration, but the short, fast Newtonian system would have benefitted from a larger focuser and coma corrector that offered better corner-to-corner illumination.

To help with the illumination problem with my f/4 Newtonian scope I had a friend machine a custom adapter to mate the camera's 54-mm adapter plate to the outer threads of the Paracorr Type 2 coma corrector. This custom adapter had a clear opening of 50 mm and was thin enough to maintain the near-optimum spacing of the imaging chip to the Paracorr.

The adapter made a huge difference in corner-to-corner illumination and should be considered a highly desirable item when using the camera with 2-inch focusers and coma correctors on fast Newtonians.

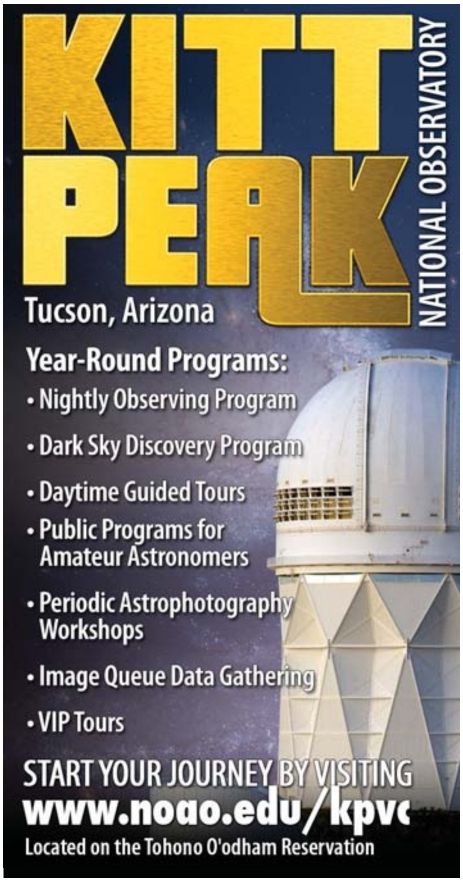
Regardless of which scope I used in my tests, the smooth images were exciting to view as they downloaded. The pictures displayed little noise. and I knew at first glance that when several were stacked together, they had the potential to produce an outstanding final image.

The Bottom Line

The QHY16200A system is a high performing, solidly built addition to the astronomical imaging market. Astrophotographers with beefy mounts, rigid OTAs, and robust focusers should have the fewest concerns over the camera's weight. Folks with lightweight instruments may need to upgrade or shore up their systems with larger clear apertures, substantial focusers, and perhaps effective counterbalance configurations to realize the camera's full potential.

If you purchase the QHY16200A filter wheel and QHYOAG-M and have an optical system that fully illuminates its chip with a relatively aberration-free image circle, you can expect to have truly outstanding imaging results. If you are, however, like me, it may be time to start tinkering with the telescope you have or consider some upgrades that would make it a worthy match to this powerful imaging system.

■ Retired news photographer and Contributing Editor **JOHNNY HORNE** has long known he needs bigger and better telescopes. Reviewing the QHY16200A only made that more apparent.



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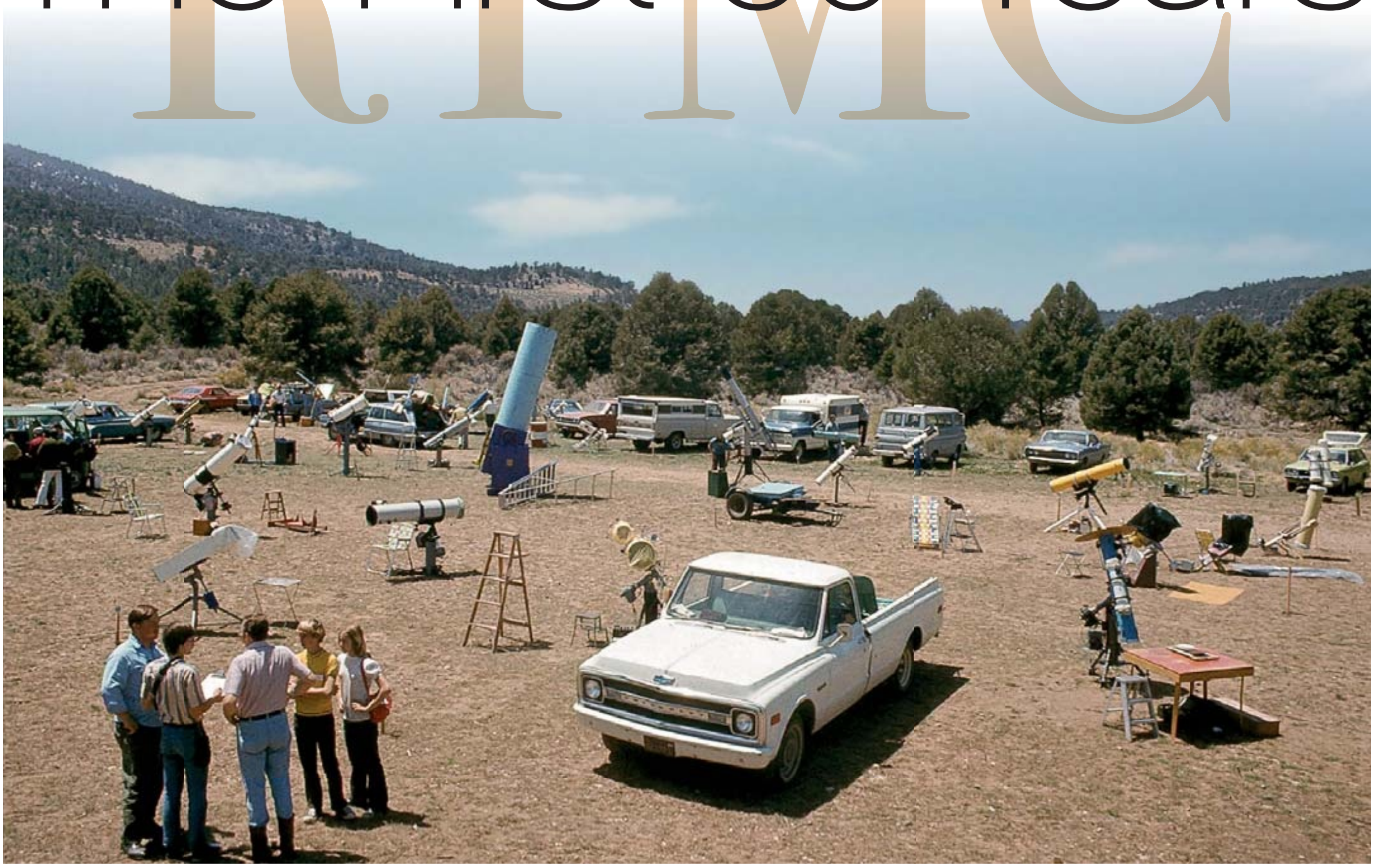
RTMC The First 50 Years



Always a trendsetter, the Riverside Telescope Maker's Conference–Astronomy Expo goes golden in 2018.

It started as a simple idea. But, oh, how it evolved over half a century.

It was California. It was home to historic Mount Wilson and Palomar Mountain, the aerospace industry, and thousands of people interested in space and handy with tools. It was home to John Dobson and the Sidewalk Astronomers. It was home to Cave, Coulter, and Celestron. It was 1969, and we were going to the Moon.

▲ **A LITTLE ELBOW ROOM** In 1975, RTMC moved to the YMCA facility, Camp Oakes, near Big Bear, California. Initially, the Telescope Field, populated by all types of telescopes, was ringed by campers.

BOB STEPHENS

Cliff Holmes, president of the Riverside Astronomical Society, together with some of his amateur telescope-making friends, invited others who liked to grind mirrors and craft telescopes to Riverside Community College. They wanted to swap ideas and a few tales. It was a "Telescope Maker's Conference," so that became the official name for the gathering. Among themselves, though, they called it the "Riverside Convention," or simply "Riverside."

Some 135 people showed at the first gathering. Two hundred came to the next, and the growth continued through the years. Soon, the telescope makers moved to the mountains in Idyllwild so they could use their scopes at night. And, after the meeting grew even larger, everyone moved to Camp Oakes, a YMCA facility near Big Bear, California. Camp Oakes had dorm rooms, vendor spaces, spacious presentation rooms, and two telescope fields for nighttime observing. A back road, dubbed "Telescope Alley," became popular for those with high-end equipment. *Sky & Telescope* at one point called the swap meet held there the "biggest on Earth." The conference eventually spread beyond telescope making itself into all things astronomical.

In these early years, before the spread of regional star parties, Riverside drew large crowds from across the western United States, including enthusiasts from Arizona, Utah, Nevada, and northern California. "Riverside" soon became the "Riverside Telescope Makers Conference" (RTMC). In the early 1990s, as attendance surpassed 2,000 people, the organizers changed the name once more, to "RTMC Astronomy Expo" (RTMC-AE), to acknowledge that the meeting was about much more than telescope making.

RTMC-AE organizers and attendees are preparing to celebrate their 50th gathering over Memorial Day weekend 2018. The event still annually draws some 600 enthusiasts to the dark skies. Yes, the internet, foreign manufacturing, and all the competing interests (including the growth of regional star parties) have taken the crush of attendance off national star parties, including RTMC-AE. But Riverside is still a wonderful place to discover the latest equipment and techniques, renew friendships, get the gossip, and have a good time.

Every major star party has its attraction. For telescope makers, nothing can match Stellafane, its Pink Clubhouse, and its Russell Porter heritage. For dark sky enthusiasts, it's hard to beat the location of the Oregon or Texas star parties. For outreach, the Grand Canyon Star Party is heaven. And for frozen northern enthusiasts, the Winter Star Party offers the steadiest seeing and a sunny refuge. RTMC-AE has a good share of all that, too, but excels particularly in its presentation program, which has a long history of being in front of trends in the amateur astronomy community. John Dobson and the Sidewalk Astronomers started in San Francisco, but it was only after he and his band of merry astronomers infected the people at Riverside with their multi-colored, floral-painted telescopes that the Dobsonian revolution really took off in other places. Digital setting circles, too, were on

▲ **RIDING IN STYLE** John Dobson and his band of merrymakers, the San Francisco Sidewalk Astronomers, traveled to RTMC and other dark-sky sites in a repurposed school bus.

▲ **STRAIGHT OUTTA THE HAIGHT** John Dobson started bringing his large telescopes to Riverside in 1970. It's too bad this photograph from 1972 isn't in color — that paint job must have been spectacular. Dobson gave a presentation on "Grinding Large Off-axis Paraboloidal Mirrors" to attendees of that year's Riverside.

◀ **DESIGNER SCOPE** Laurie Hess of the Santa Barbara Astronomy Club ground the mirror for this reflector, which was on display at the first Riverside gathering in April 1969.

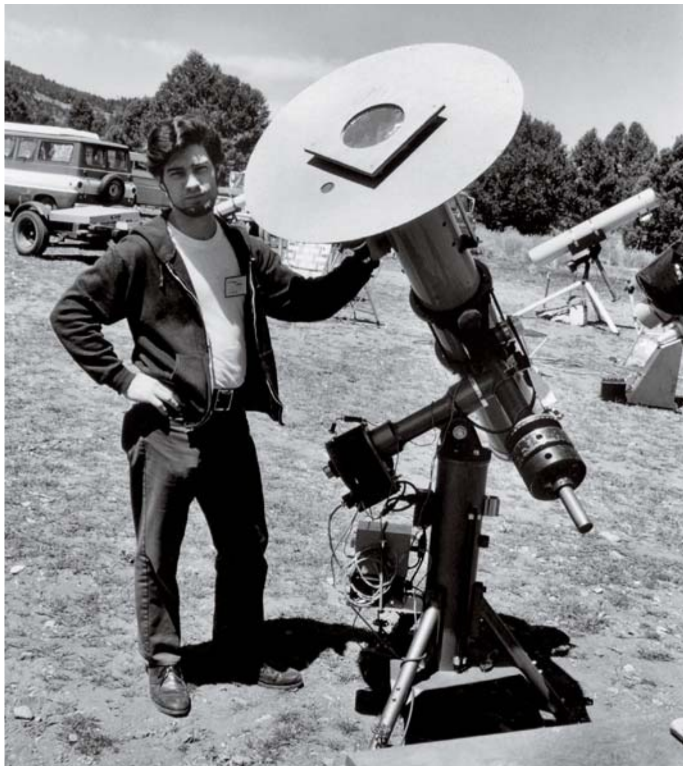
LAURIE HESS WITH TELESCOPE: CLIFFORD HOLMES ARCHIVE; DOBSONIAN: BOB STEPHENS; CAMPSITE: *S&T* ARCHIVES display at RTMC in 1978, long before they (and Go To) took over the amateur world.

On the stage of the main hall at RTMC Astronomy Expo walked a man who walked on the Moon, Harrison Schmitt. The discoverer of Pluto, Clyde Tombaugh, spoke there, along with Jim Christie, the discoverer of Charon. So did the man who "killed" Pluto, Mike Brown. Alan Hale and Thomas Bopp came and described the comet of the century. Prolific comet-hunter and author David Levy spoke to RTMC attendees on several occasions. Professional astronomers including Brian Marsden, Janett Mattei, Ed Krupp, Alex Filippenko, and many others have addressed the crowds. Bart Bok was upset because a thief had stolen his slides at the airport, but he still managed to give a complete description of the structure of the Milky Way — using only hand gestures — in one of the most memorable of RTMC's speeches. John Dobson attended and spoke many times, although there's no proof that he ever, as was rumored, slept in one of those big tubes he and his crew brought to the party. The big names of astronomy have been part of RTMC.

And these presenters were just the Saturday evening keynoters. Today, the RTMC-AE headliners speak to a packed hall, with a crowd spilling over to watch the video feed "out front" and "out back." All day on Saturday and Sunday, the main hall is filled with formal presentations on telescope making, imaging, new technology, developments in professional astronomy, and astro-history. Friday night the hall holds a "Show and Tell" where all comers give five-minute presentations on their images, their projects, and their causes.

Next door to the main hall is the "Workshop" venue, where practical aspects of the hobby, like publishing a club newsletter, eyepiece or filter selection, and hints on observing techniques are covered in panel discussions, demonstrations, and hands-on activities. Across the way, down near the lake, the "Beginner's Corner" has a classroom of its own, where 20 to 30 novices gather throughout the weekend to learn the basics of the hobby in a series of eight presentations.

Telescope making itself is still a large part of RTMC-AE. Every year, a panel of experienced telescope makers judge a dozen or more entries in the "Merit Award" program. Efforts showing excellent workmanship or innovation may be cited



▲ **SOLAR SCOPE** Michael O'Neal posed beside his 6-inch f/8 reflector (well shielded for solar observing) at the 1975 meeting.

◀ **ON THE CUTTING EDGE** John Sanford (far left) and other participants in the 8th annual RTMC in 1976 viewed solar prominences through an H-alpha filter attached to an 8-inch Celestron scope.

▼ **"FRUIT CAKE"** Vance Chin, then a member of East Bay Astronomical Society in Oakland, California, brought his 6-inch f/4 reflector, kitted out for astrophotography, to the 1979 RTMC.

GROUP: *S&T* ARCHIVES / DENNIS DI CICCO; SEATED REFLECTOR: *S&T* ARCHIVES; SOLAR SCOPE: *S&T* ARCHIVES

▲ **ALL TOGETHER NOW** In the early years of Riverside, a group photo was an organized event. Bob Stephens (*left,* standing on the Volkswagen van), *Sky & Telescope* Senior Editor Dennis di Cicco (*left,* between cars), and Cliff Holmes (*center,* directing traffic), facilitated the 1979 photograph.

▶ **NEW TECHNOLOGY** In 1978, Bob Stephens and Jon van Gelder (pictured) demonstrated digital setting circles using Bob's 14-inch Newtonian reflector.

as award winners and are authorized to sport a special brass plaque noting the accomplishment. It's not a competition but a demonstration of quality and innovation.

Before RTMC, vendors didn't attend star parties. The first gathering at Riverside Community College drew industry people, including a presentation by Thomas R. Cave of Cave Optical, but the "seconds" table from Celestron at the 1979 event was the first appearance of a vendor selling product at RTMC, starting a trend. Now, most star parties have some vendor presence. RTMC certainly benefited from being in the homeland of Celestron, Meade, and other manufacturers. They were known for unloading their surplus inventory in a feeding frenzy as soon as the vendor tables opened. And even those who didn't participate in sales found it a relatively easy place to show off their products.

Vendor participation at RTMC-AE peaked some time ago, with more than 60 tents spread through the camp at one time. With the rise of internet shopping and the easy availability of less expensive foreign telescopes, participation has moderated. But still, two dozen vendors make their way to Big Bear to show off their wares each year.

Southern California has always been in the forefront of astrophotography. Manufacturers of CCDs and other imaging equipment have enjoyed easy access to the amateur community since the days of loading film into nitrogen tanks and building cold cameras (yes, there were talks about those at early RTMCs). For years, Sunday has featured a "Premium Astro Imaging Workshop," where the likes of Adam Block, Warren Keller, Craig Stark, Tony Hallas, and other well-known imagers have shared their techniques. RTMC-AE also hosts an annual image gallery, with honors going to the favorites (as selected by the attendees).

All of this takes place at 7,600 feet in a mountain resort at the eastern end of the Los Angeles Basin. The meeting con-

▲ **NO STOPPING DEDICATED AMATEURS** Astro enthusiast Dennis Gallagher didn't let a foot injury stop him from setting up his 6-inch reflector at the 1976 meeting.

GROUP PHOTO: BOB STEPHENS / RTMC; NEW TECHNOLOGY: BOB STEPHENS; INJURED AMATEUR: BOB STEPHENS

▲ **BIG ORANGE** The first vendor booth at RTMC (or any other star party) appeared in 1979. Celestron sold “seconds” (returned or damaged items) at a steep discount. Word got out and at subsequent meetings, crowds began arriving early, in search of bargains.

► **“EYE TO THE SKY”** Although RTMC-AE has expanded beyond its original brief of amateur telescope making, attendees can still find plenty of homemade scopes on the observing field, like this giant reflector designed and built by Howard Royster.

tinues to benefit greatly from the facilities at Camp Oakes: a large camping area, dorms, food service, room for telescopes, vendors, camp activities, and especially the three presentation venues. Many amateurs bring their families. In addition to the RTMC-AE activities for families (like the ice cream social on Sunday), both kids and adults can enjoy the zip-line, canoeing on the lake, hiking, and other recreational opportunities at Camp Oakes.

Nighttime activities include observing, which turns out to be much better than you might expect, considering that reaching Big Bear requires only a three-hour drive for about 21 million people. Camp Oakes is a “green” area on the dark-sky map, with some light to the west (unless the marine air layer creeps over the valley and it gets dark!), but better to the east. Of course, RTMC-AE’s scheduling on Memorial Day weekend means that the Moon may be present at times. In those years, RTMC-AE focuses on planetary and lunar observing. But lest anyone doubt the quality of the observing, it should be noted that the skies at that altitude are clear and dark enough to discover a comet, as Don Machholz did in 1985.

It’s no wonder that RTMC-AE is still going strong. It’s always been a leader when it comes to adapting to technological developments and shifting interests within the amateur astronomy community. However, like most star parties, whether the big nationally known ones or the many regionals that have sprung up since Stellafane and Riverside, the draw over the years has been the people. Southern California is home to about a dozen astronomy clubs, and RTMC-AE has become the once-a-year meeting point for their members.

Jack Eastman, now of the Denver Astronomical Society, is typical of the veterans. He brought a 1½-inch reflector to show at the first conference in 1969 and is planning his annual pilgrimage for the upcoming 50th. He will join other veterans, and lots of newcomers, next Memorial Day weekend. Like the mountain men of the unsettled West, hundreds of amateurs “rendezvous” once a year to swap tales and gossip. Old friends renew ties, and welcome newcomers to the society. Such is the strength of RTMC Astronomy Expo.

▲ **STEP RIGHT UP** By 2005, some vendor displays had become quite elaborate, like this example of a miniature observing field populated by Meade telescopes.

■ **ALEX MCCONAHAY** is a 20-year volunteer, former board member, and merit award recipient at RTMC-AE. He is recognized as a Master Observer by the Astronomical League, and is an active member of the Riverside Astronomical Society and **TheAstroImagingChannel.com**.

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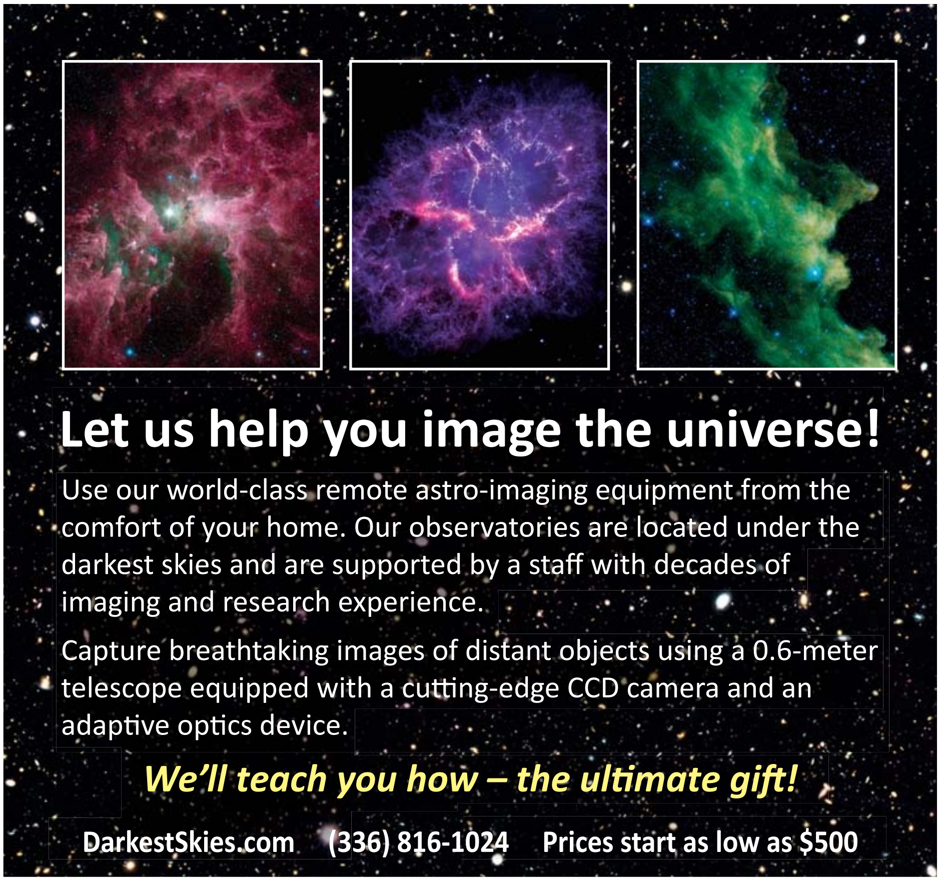
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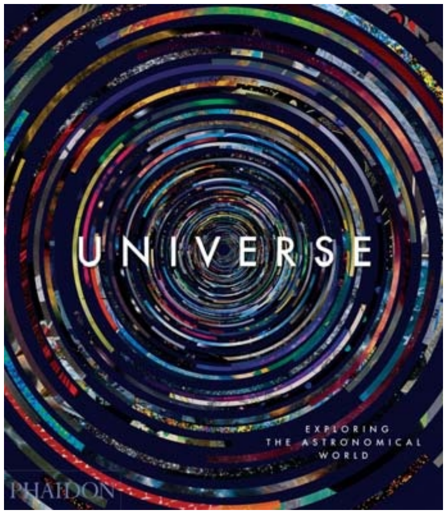
A Grand Endeavor

UNIVERSE: *Exploring the Astronomical World*

Phaidon Editors, Paul Murdin
Phaidon, 2017
352 pages, ISBN 978 0 7148 7461 6
$59.95, hardcover



PHAIDON IS KNOWN for its elegantly designed, cleanly edited art and architecture books, but the publishing house has really outdone itself with the recent release of *Universe: Exploring the Astronomical World*, a gloriously colorful celebration of humanity's contemplation of the cosmos.

Universe showcases a diverse collection of astrophotographs, scientific drawings, space souvenirs, and artworks selected by an international panel of experts in astronomy, history, and art. Several lavishly illustrated books on the history of astronomy and astrophotography exist already, but *Universe* differs in at least two significant ways. First, the editors drew about one third of the book's 300 illustrations from "outside" astronomy, that is, from the world of art, a choice that gives us a fresh perspective on how we interpret our place in the world. But the dialogs the editors set up between the selected images are what really make this book special. Almost all the illustrations are arranged in pairs, on facing pages, inviting the reader to make comparisons based on appearance, subject, age, purpose, or geographical origin.

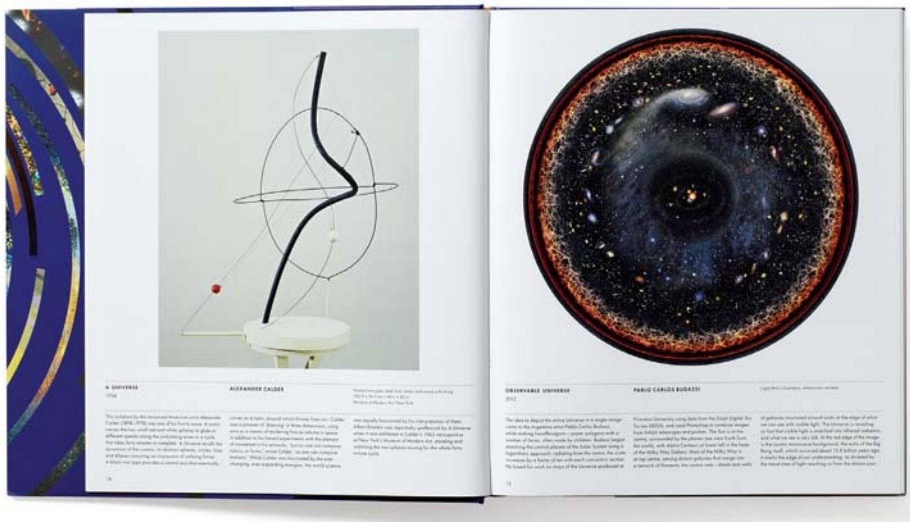
In some cases, the visual similarities between two works are obvious. For instance, the arrangement of a 15th-century Italian Renaissance depiction of the cosmos opposite a representation of the universe taken from a 16th-century Safavid Persian edition of *The Wonders of Creation and the Oddities of Existence* (shown below) emphasizes the celestial spheres in both images. The thought process behind other pairings reveals itself more slowly (so perhaps more satisfactorily). The decision to position a kinetic sculpture by American artist Alexander Calder next to a logarithmic map by Argentinian musician and artist Pablo Carlos Budassi (shown on facing page) might be puzzling at first but soon opens a discussion of suitable methods for interpreting and modeling a vast and expanding universe.

Some of the astrophotography included in *Universe* will be familiar to *Sky & Telescope* readers. The editors made liberal use of NASA, Hubble Space Telescope, JPL-Caltech, and ESA images, as well as the work of well-known photographers and space artists such as David Malin, Adam Block, Yuri Beletsky, Miloslav Druckmüller, Tamas Ladanyi, Alex Parker, and Chesley Bonestell. The David Rumsey Historical Map Collection at Stanford University, the Smithsonian, the Ashmoleon Museum, and the British Museum are also well represented here. But much of the material comes from less accessible science institutions, art museums, or university archives, and a good many of the works, like Albrecht Dürer's *Map of the Northern Sky* and *Map of the Southern Sky* (facing page), are held in private collections. So this may be the best or possibly only chance to see some of these works in print. The content is geographically and temporally wide-

▲ *Left*: In his tempera-on-wood painting of the expulsion from Paradise (1445), Italian artist Giovanni di Paolo shows the universe as a circle with a rocky Earth at its center. *Right*: Abu Yahya Zakariya ibn Muhammad al-Qazwini uses a similar design to depict the heavenly spheres in his ink drawing of the angel Ruh (c. 1550-1600).

ranging, representing almost every part of the populated world, with some works dating back to 16,500 BC.

Beyond the strictly astronomical material, the selections made by the editorial board are — in a word — astounding. The names of some of the artists represented are quite familiar: Pablo Picasso, Robert Rauschenberg, Anish Kapoor, Nancy Holt, Zarina, Yayoi Kusama, and Anselm Kiefer, to name just a few. But I was pleased to find so many contemporary artists doing work that resonates with astronomers. Each of the selected artists has compelling thoughts on the cosmos and its workings, so don't be put off if you're not "into" art. Pieces like Cornelia Parker's *Meteorite Misses Waco* and Jessica Rankin's *Field of Mars* will still make your eyes pop out of your head.

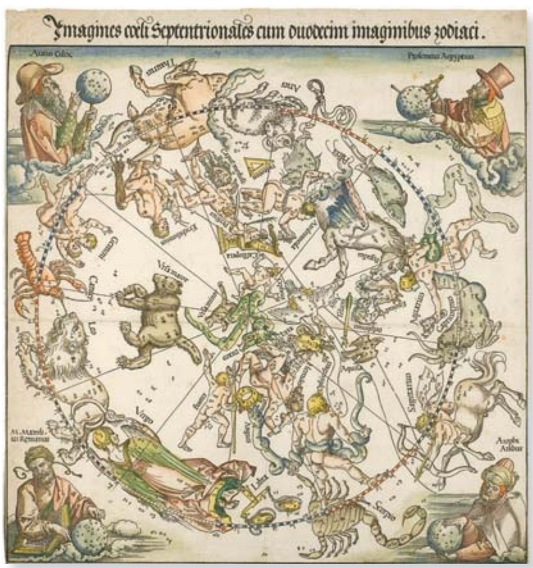


▲ *Left*: Albert Einstein was reportedly fascinated by Alexander Calder's kinetic sculpture *A Universe* (1934). A motor moves the red and white spheres along the artwork's flexible wires. *Right*: Pablo Carlos Budassi drew the data for his logarithm map, *Observable Universe*, from maps produced at Princeton University using Sloan Digital Sky Survey (SDSS) data.

Universe opens with an introduction by astronomer Paul Murdin (Institute of Astronomy, Cambridge). His essay frames the collection, preparing us for an encounter with a comprehensive visual record of humanity's interaction with the universe: through observation (with the naked eye and telescope); via exploration (crewed and uncrewed space missions); by recording (sketching and imaging); and in creative interpretations and reimaginings (art). Murdin's thoughts are bookended by an afterword on astrophotography and technology written by the renowned Australian astrophotographer David Malin.

Also included in *Universe* is a helpful timeline that begins with the Big Bang (13.8 billion years ago) and ends with the data release for NASA's Juno Probe (2017). The editors have written up a useful glossary of astronomy terms as well as biographies of some of the natural philosophers, astronomers, and artists whose work is included in the book.

Universe is an art object in and of itself. It feels solid in the hands and sports a well-fitting and eye-catching dustcover. The paper quality is high, the printing sharp, the typeface clean and elegant. The true beauty of the book comes from the quality of the images, however. Reproducing two- and three-dimensional artworks and objects in a way that makes you want to reach out and touch them is a difficult task, and the success of this project is due to publishers and editors who know how to handle visuals. This is the clearest you'll see Caroline Herschel's comet diagrams and Galileo's Moon drawings (left). The sketch of the Whirlpool Galaxy (M51) made by William Parsons, Earl of Rosse, in 1845, and placed opposite a full-color Hubble Space Telescope image of the same object, simply sings. There are no bad choices, no unnecessary illustrations in *Universe: Exploring the Astronomical World*. If you pick it up and spend a few winter afternoons reading it, you'll surely consider it time well spent.



▲ *Left*: Albrecht Dürer's woodcuts of the northern and southern skies (c. 1515) were the first printed celestial maps. *Right*: Galileo based his sepia-wash drawings on notes he took while studying the Moon in December 1609. Published in his *Siderius nuncius* in 1610, these sketches are considered the earliest images of our satellite drawn with the aid of a telescope.

DÜRER: PHAIDON / SOTHEBY'S, INC; GALILEO: PHAIDON / BIBLIOTECA NAZIONALE CENTRALE DI FIRENZE

■ Associate Editor **S. N. JOHNSON-ROEHR** can occasionally be found with a paintbrush in her hand.

Binocular Mounts

A steady hand can gain you a couple of magnitudes.

▲ Made from a set of crutches and pine boards, this mount takes its inspiration from shoulder-mounted anti-aircraft guns. Randy placed the binoculars so the eyepieces would perfectly reach his eyes when the crutch pads were firm against his shoulders. The long handle allows for stable positioning. **Right:** To gain enough height to observe standing up, Randy strapped a tripod to another tripod, which holds a pair of 25×100 binoculars with ease and gives him the height he needs. For another stand-up stand, he attached a tripod to a length of PVC pipe slipped over an umbrella stand. It rotates 360° and is also high enough to prevent neck pains.

LEFT: LYNN STRAUSS; RIGHT: RANDY STRAUSS

SHORT OF JUST STANDING outside and looking up, binoculars offer one of the easiest ways to observe the sky. Yet binoculars also present one of the most difficult problems: holding the $#@! things steady while you're doing your observing! That has led to a myriad of different strategies to stabilize them, and Nebraska binocular observer Randy Strauss has tried them all.

Well, probably not all, but he has certainly tried plenty, and he's come up with some interesting variations on his own.

Randy's interest in binoculars came about in an unusual way: His job sent him to Geneva, Switzerland, for weeks at a stretch, and he learned to appreciate the city's Saturday flea market, where he often found wonderful vintage binoculars and telescopes. The telescopes were too big to bring home, but he bought several of the binoculars and learned how to restore them. After retiring, his appreciation for binoculars continued, and he began using giant binoculars in his back yard.

Randy describes himself as "a fair weather, novice observer who, when conditions are pleasant, studies a star chart, selects a target, sets up my gear, and is pleasantly surprised when I actually find what I'm looking for." Binoculars are perfectly suited for this type of observing, but Randy soon noticed how tired his arms would get. That led him to build a mount, but he quickly realized that not all mounts are good for all things. Some are best for scanning and finding things, while others are better suited for deep study of a single object.

Randy uses the standing mounts to scan the sky, then he moves to a "tripod on a tripod" or the shoulder or sawhorse mounts when he settles on an object he wants to look at for a while. The result: "No more arm fatigue, no more neck cramps. When you need to rest your eyes, you just close them and relax. Seeing through the binoculars while lying on your back and with no more vibration than from your heartbeat, not using your arms at all, is the way to go."

For light binoculars, a padded forehead rest is sufficient. A monopod provides a long lever arm for stability. **Bottom:** Perhaps the simplest mount of them all: a lounge chair under a sawhorse. The binoculars attach to a tripod head that in turn is secured to the sawhorse. The tripod head tilts for altitude adjustment, and the central shaft can be cranked for better positioning. Randy admits it's a chore to position himself in the chair and to move the sawhorse to get just the right positioning, but once achieved, "it's an absolute delight."

TOP: LYNN STRAUSS; BOTTOM: RANDY STRAUSS

Here are several of his mounts, and because a picture is worth a thousand words, I'm going to let them speak for themselves.

I'll give Randy the last word, though. When asked how they perform, he answered, "Considering the mounts were made from garage-sale items and bits and pieces of lumber, hose clamps, and PVC pipe, they work remarkably well."

Contributing Editor **JERRY OLTION** uses binoculars ranging from 7×25 to 300×317. The latter won't fit on a tripod, but fortunately they don't need one.

◁ MILKY WAY OVER OWENS VALLEY

Mike Oria

Caltech astronomers picked an isolated area just north of Big Pine, California, to get a "quiet" environment for the Owens Valley Radio Observatory and its big 40-meter dish. But it's also an awesomely dark place for stargazing.

DETAILS: *Pentax 645Z medium-format DSLR camera at ISO 1600 and 25-mm lens. Exposure: 25 seconds.*

▽ TRIANGULUM'S PINWHEEL

David Collings

Messier 33 is the third "anchor" in our Local Group of galaxies and the second-closest spiral (after M31). Its sweeping arms, though not as distinct as those of other spiral galaxies, bristle with intense bursts of star formation.

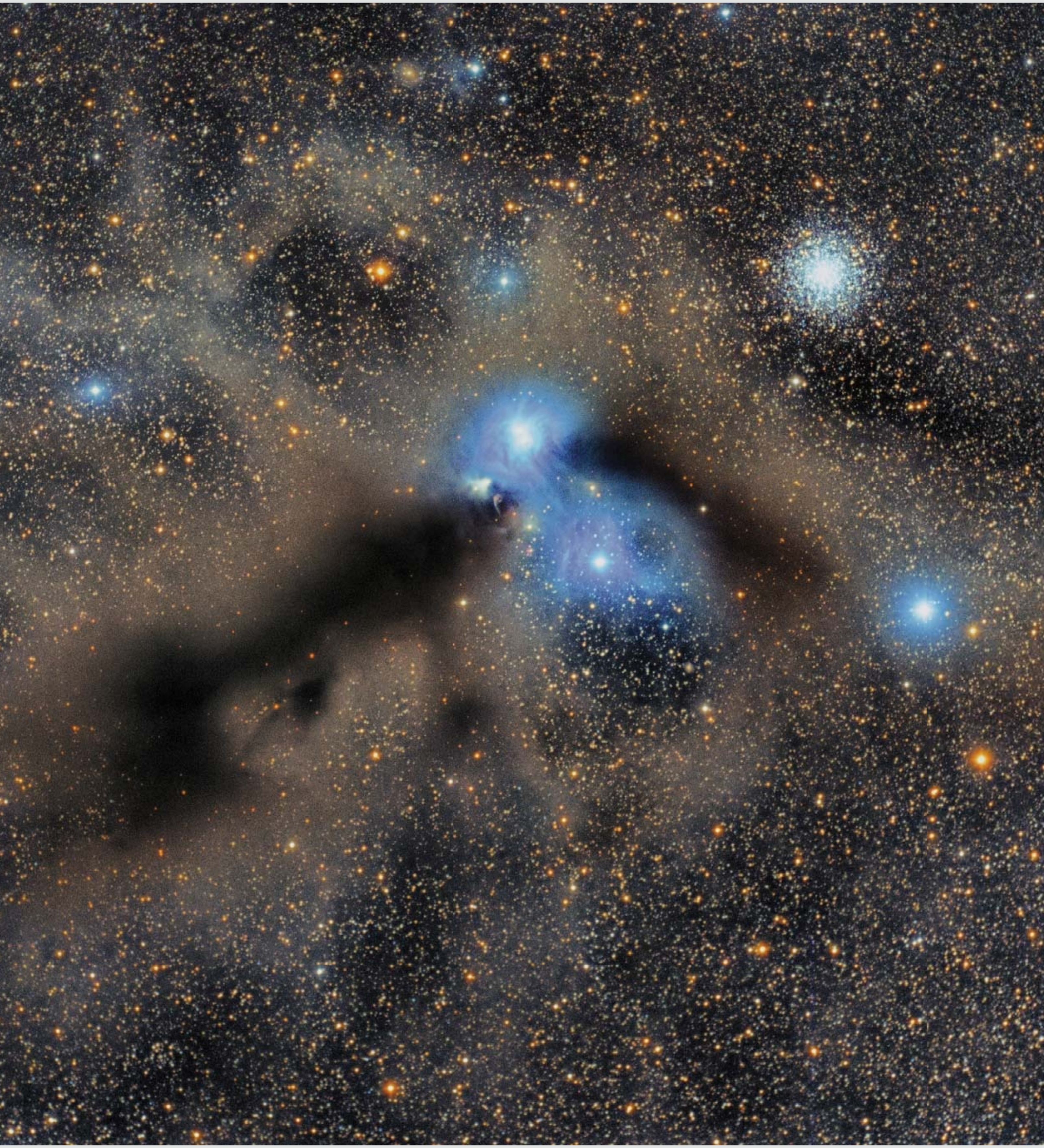
DETAILS: *Celestron EdgeHD 11 aplanatic Schmidt-Cassegrain telescope with Hyperstar and Starlight Xpress Trius-SX814C color CCD camera. Total exposure: 72 minutes.*

▽▽ STALKING THE HERON

Bruce Waddington

Arp 84, aptly named the Heron, consists of the nearly face-on spiral NGC 5395 and its entangled companion, NGC 5394. Both galaxies are tucked in southeastern Canes Venatici.

DETAILS: *PlaneWave Instruments CDK12.5 astrograph, QSI 640ws CCD camera, and LRGB filters. Total exposure: 9.8 hours.*



◁◁ CROWDED CROWN

Ivan Bok

Straddling the border between Corona Australis and Sagittarius is this complex interplay of bright, blue-tinged NGC 6726–27–29 and IC 4812, along with wreaths of dark, opaque dust clouds. The pretty globular cluster NGC 6723 lies to their northwest.

DETAILS: *Takahashi FSQ-85ED astrograph with SBIG ST-8300M CCD camera and Baader LRGB filters. Total exposure: 3.5 hours.*

◁ WIZARD NEBULA

Oleg Bouevitch

Wreathes of nebulosity, some 8,000 light-years away in Cepheus, are set aglow by strong radiation from young suns in the open cluster NGC 7380.

DETAILS: *Celestron C11 Schmidt-Cassegrain telescope and Atik 383L+ CCD camera with Hα, O III, and S II filters. Total exposure: 18.5 hours.*

▽ SOLSTICE TO SOLSTICE

Marcella Giulia Pace

The horizon is lined with 20 sunsets in a sequence shot identically at the same location, weather permitting, from December 2016 through June 2017.

DETAILS: *Nikon D7100 DSLR camera and 18-mm lens. ISO: 100 to 1600. Exposures: 1⁄30 to 1⁄400 second.*

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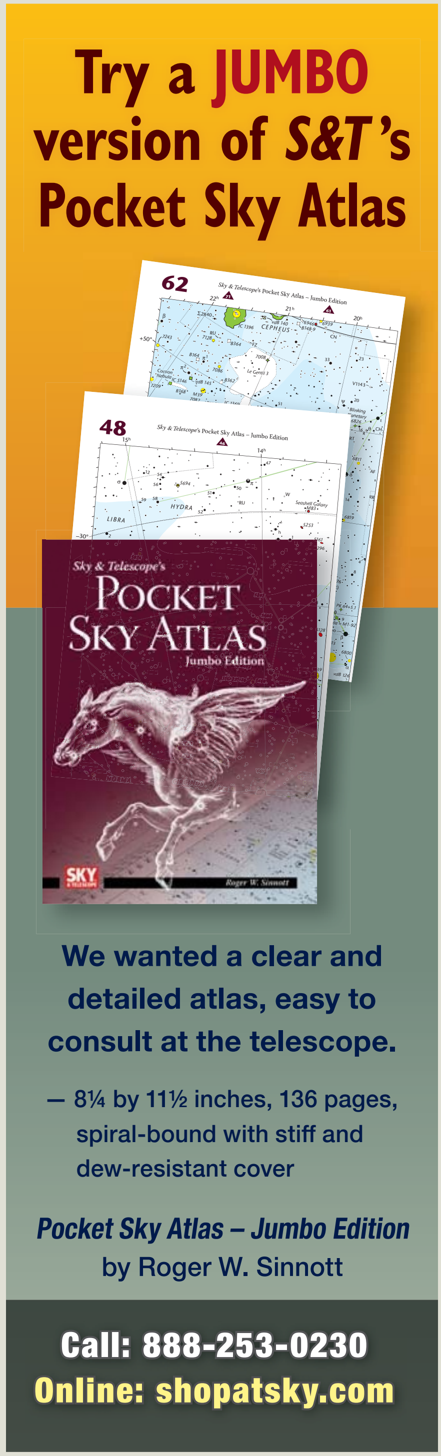

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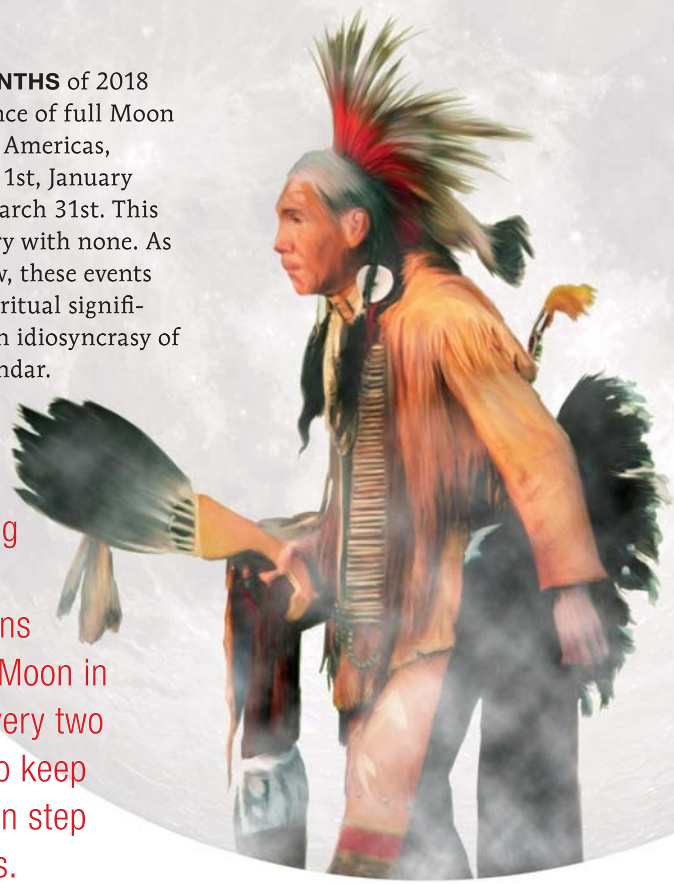
February's Missing Moon

Don't be alarmed. It's just a quirk of the Gregorian calendar.

THE FIRST THREE MONTHS of 2018 have an unusual sequence of full Moon dates. As seen from the Americas, those dates are January 1st, January 31st, March 1st, and March 31st. This sequence leaves February with none. As many *S&T* readers know, these events have no scientific or spiritual significance. They're simply an idiosyncrasy of our imperfect civil calendar.



AARON RUTTEN / BIGSTOCKPHOTOS.COM; MOON: NASA

As with other cultures following the Moon, these original Americans inserted a 13th Moon in the sequence every two to three years, to keep the lunar times in step with the seasons.

The average time between two full Moons is about 29½ days. But 11 of the 12 months are longer, 30 or 31 days. Therefore, it's possible from time to time for one of these months to contain two full Moons. Typically, a month with two full Moons occurs once every two to three years.

The outlier, of course, is February with its 28 days (29 in a leap year). February can have no full Moons, as in 2018, but never two. Moreover, if you do the math, you'll find that when February has no full Moons, then both January and March that year *must* contain two full Moons. This pattern is infrequent: It occurred most recently in 1999 and will happen again in 2037.

Some traditional calendars, such as the Hebrew and Chinese calendars, have months that exactly follow the lunar cycle. Various indigenous peoples of the Americas, including the Mi'kmaq nation of Canada's Atlantic Provinces where I live, also reckoned the passage of time this way. Each moon cycle was linked to the season by ecological descriptors such as "Rivers About To Freeze" or "Frog Croaking Time." As with other cultures following the Moon, these original Americans inserted a 13th Moon in the sequence every two to three years, to keep the lunar times in step with the seasons. Since these calendars are Moon-based, they never had a moonless month.

The ancient Roman calendar was similar. But priests continually made a mess of it until Julius Caesar, in the 1st century BC, instituted a calendar reform that divorced the months from the lunar cycle by adding days to months here and there — and, curiously, by shortening the month we know as February. The motivation was to synchronize the calendar with the Sun and the seasons, an idea imported from Egypt. Such a calendar was more in tune with annual events of agricultural importance, such as the flooding of the Nile.

In the 16th century, Pope Gregory XIII tweaked the Julian calendar, but the month lengths remained the same. It is these longer Julian and Gregorian months, now disconnected from the actual lunar cycle, that can contain two full Moons.

Eventually, the Gregorian calendar took precedence in the Americas for spiritual, legal, and political purposes, but even today many indigenous nations still observe the traditional lunar times. Once in a while, there are two full Moon names corresponding to a given month, and, more rarely, a February with no full Moon. This is a time of extreme disparity between the indigenous and European calendars, but it passes in subsequent years.

Meantime, such a disconnect offers an opportunity to reflect on how various peoples understand the passage of time — and, perhaps, on the Moon's role in helping us grapple with it.

■ **DAVE CHAPMAN** is emeritus editor of the *Observer's Handbook* of the Royal Astronomical Society of Canada, of which he is a Life Member. He lives in Dartmouth, Nova Scotia.

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