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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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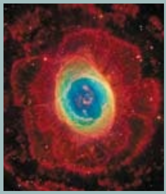

The vast hydrogen petals of M57 glow red in this colorized image.

ROBERT GENDLER / STOCKTREK IMAGES / GETTY IMAGES

ONLINE

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A Mystery for the Age

EVERYBODY LOVES A CLIFFHANGER, and Tabby's star delivers a doozy. As many *S&T* readers know by now, this otherwise nondescript main-sequence star in Cygnus displayed a series of unpredictable and unexplained dimmings of its starshine in the four years the Kepler spacecraft observed it (*S&T:* Feb. 2016, p. 14). In that short stretch, the star's usual complement of photons streaming towards our planet diminished significantly no fewer than 10 times. The dips lasted from days to weeks and showed no regularity in duration, periodicity, or the "shape" of the light curve.

Perhaps most surprisingly, during these brief periods the amount of starlight from KIC 8462852 — as Tabby's star is officially known — declined by anywhere from half a percent to a humongous 20%. Imagine how big an object out in space would have to be to block *one-fifth* of the Sun's light from reaching Earth! Hollywood could have a field day with that one.

As Benjamin Montet and Tabetha Boyajian (Tabby herself) describe beginning on page 16, astronomers are flummoxed by what caused the erratic drops. They've ruled out some possible culprits, such as a glitch in the Kepler instruments that recorded the dips. But they've been unable to either confirm or deny many other hypotheses. The answer to this riddle remains deliciously elusive.

Could a collision of comets or asteroids (seen here in an artist's concept) have dimmed the light from Tabby's star?

NASA / JPL-CALTECH / R. HURT (IPAC)

What I like most about this who- or whatdunit is the wide net it has thrown. First brought to astronomers' notice by a citizen scientist, the strange dips have captured the attention of myriad amateurs and professionals. Since the discovery, astronomers have examined Tabby's star with both space- and ground-based telescopes, in optical, infrared, and submillimeter wavelengths. They've pored over modern and historical data. They've thrown at the problem all they know about the aging of stars, the formation of planets and solar systems, and the light-blocking potential of everything from moonlet-size planetesimals to vast interstellar clouds. They've even gone so far as to invoke an alien megastructure as a not-entirely-inconceivable perpetrator (*S&T:* March 2016, p. 16).

In essence, the stumper cooked up by Tabby's star's anomalous behavior is what astronomy is all about. As with pondering the night sky itself, it has appeal for everyone. Who among us Earthlings would not be fascinated to hear the solution to this celestial brainteaser, when and if it comes?

Peter

Editor in Chief

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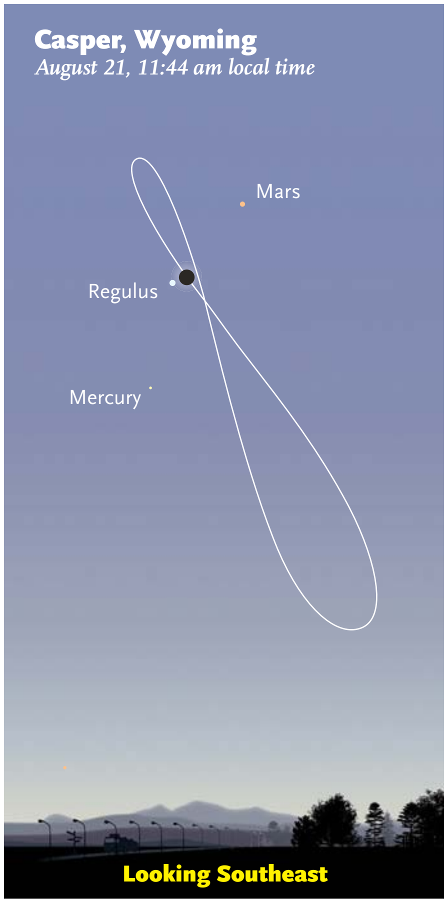
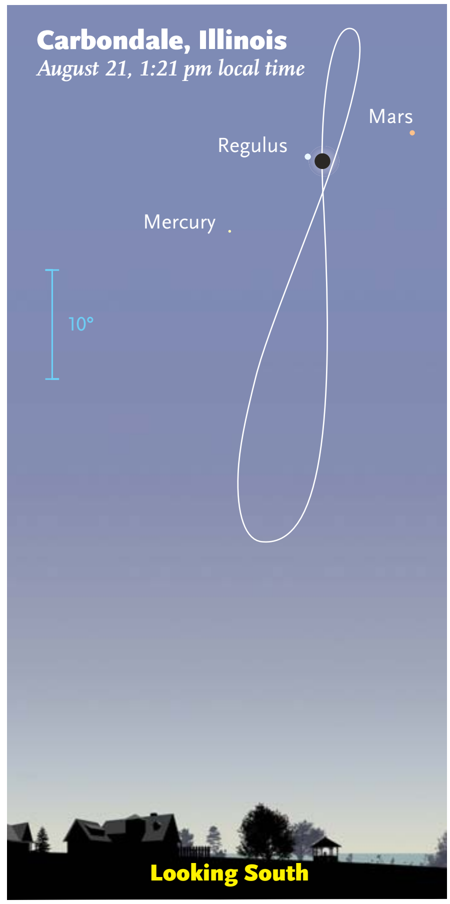
Revised "Tutulemmas"

Observers anywhere on Earth will see the Sun trace out the exact same analemma pattern projected against the sky through the course of a year. The only differences will be its altitude and orientation relative to the horizon. So it appears that the sky charts depicting analemmas from two locations along the 2017 path of totality (*S&T:* Dec. 2016, p. 68) show the distortion that results from plotting such a huge pattern seen on a curved dome of the sky onto a flat graphic representation. The two analemmas depicted should be identical except for altitude and tilt.

Clyde Simpson
Cleveland, Ohio





If you're planning to capture a "tutulemma" (an analemma that includes August's eclipsed Sun), these plots show its correct orientation in the sky from two sites along the path of totality.

GREGG DINDERMAN / S&T, SOURCE: TUNÇ TEZEL

Astronomy Takes Flight

You've covered many amazing topics in these pages — quasars, supermassive black holes, dark matter, accelerating expansion — but none as amazing as "Launching Astronomy into the Wilds of Colombia" (*S&T:* March 2017, p. 66). I was skeptical, then surprised, then impressed, then amazed, touched, emotional, and even tearful. I'm so humbled.

Tom Wright
San Diego, California

Marja Seidel and Kira Buelhoff are two brave young women who care about people and astronomical outreach. I have lived in Ibero-America and particularly appreciated their narrative. They overcame their trepidation and said to themselves, "Well, life belongs to the bold." However, I am an aircraft nut as well as an amateur astronomer. Pilots, both civil and military, have a saying that certainly applies to paragliding and other kinds of dangerous flying: "There are old pilots and bold pilots, but no old, bold pilots."

Julian Grajewski
Hamburg, Germany

Sure Footing on Crater Rims

Chuck Wood provides excellent information and portrayals of how crater rims are made (*S&T:* Feb. 2017, p. 52). But I found his short bio at the very end a bit *repelling* as he repels getting scraped by scarps. I would ask you to repeal the repelling by getting roped into *rappelling* instead!

Carl Masthay
Creve Coeur, Missouri

The Moon's Mystery Ray

I always look forward to reading Charles Wood's excellent articles on the Moon. By chance, after reading his description of the so-called "Bessel ray" (*S&T:* Dec. 2016, p. 52), I had an opportunity to see this feature last November 9th with the 8-inch f/12 refractor at Garvey Ranch Observatory in Monterey Park, California. I also examined a friend's photo of the ray taken November 14th.

I agree with Wood that the five proposed candidates don't seem to line up correctly, or are too far away, to be the source of that ray. But might it originate from the farside? One candidate might be the large farside crater Bel'kovich, which is close to the Bessel region.

David Nakamoto
Azusa, California

Chuck Wood replies: *The bright, rayed crater you refer to is likely Hayn, on the rim of the ancient crater Bel'kovich. Hayn's rays do not seem to stretch far enough to reach Bessel, and they are strongest in directions that do not align with the Bessel ray. I've found that a number of prominent lunar rays also don't seem to have obvious sources.*

Small Details Matter

I very much enjoyed retracing Alan Whitman's tour of edge-on galaxies in Ursa Major (*S&T:* March 2017, p. 57). A small but very significant detail in the caption under the fine picture of NGC 4085/4088 caught my eye.

Many of us visual astronomers use the work of astrophotographers like Jim Thommes, who took that shot, in the same way I imagine earlier observers used the photographic plates to which they had access. These are invaluable to us because they serve to verify our observational notes and often prompt further observing of an object or area.

The significant detail is your inclusion of the width of the image field. This is appreciated. It increases the illustration's value as a reference and guide to visual observing. I hope that you'll consider including this crucial detail in all the astrophotos that you publish.

Dick Gentry
Dallas, Texas

How Do Astronomers Gauge Intergalactic Divides?

Thanks for the timely publication of the fascinating Perseus Galaxy Cluster article (*S&T:* Jan. 2017, p. 57), since Abell 426 dominates my observing at the moment. How certain is author Ted Forte that NGC 1293 and 1294 are "more than a hundred light-years apart" or that "about 129 million light-years" separate NGC 1282 and 1283? If those distances are determined by standard candles, such as type Ia supernovae, no problem. Redshifts, on the other hand, are presumably rather less reliable in such a densely packed cluster because of gravitational interference. M31 actually shows a negative redshift, but nobody (I hope!) claims it's at a negative distance from us.

Paul Dawson
Olancha, California

Ted Forte replies: *Distance estimates made by different methods often vary greatly for the same object — and, as you've noted, redshift can be most problematic to interpret. Yet for some galaxies only redshift surveys are available. So some of the comparisons made in my article are not at all certain. Also, it's important to remind ourselves of the three-dimensional nature of objects like the Perseus Galaxy Cluster. Visual observing, limited to two dimensions, is an imaginative exercise. My intent was simply to offer a reminder of that elusive third dimension.*

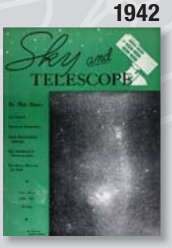
FOR THE RECORD

- The large nighttime image (*S&T:* March 2017, p. 30) combines the summertime Milky Way with a winter foreground scene.
- The two open clusters in Cancer are M44 and M67, not M26 (*S&T:* April 2017, p. 43).

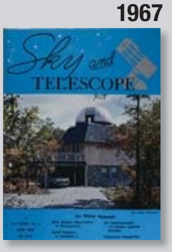
LETTERS TO THE EDITOR: Sky & Telescope, 90 Sherman St., Cambridge, MA 02140-3264 or email: letters@skyandtelescope.com. Please limit comments to 250 words.

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

1942



1967



1992

◖ June 1942

Deep Sky "Behind the stars of Virgo lies the richest cluster of galaxies that can be seen through amateur telescopes. This nest . . . dominates northern Virgo and scatters across into southern Coma Berenices. . . .

"In amateur telescopes these marvels appear wee and ghostly.

"The Sombrero, one of the brightest spirals, lies between [the neighboring finder stars] Porrima and δ Corvi. . . . If you have a telescope, be sure to look for this handsome deep-sky wonder. . . ."

Columnist Leland S. Copeland, always a colorful wordsmith, seems to be the first person ever to use "deep sky" when speaking of the universe beyond naked-eye stars — and so a new expression was born. In November that year, editor Charles A. Federer, Jr., made Deep-Sky Wonders the title of Copeland's department, and it has endured under Copeland's successors, Walter Scott Houston and Sue French.

◖ June 1967

Evolving Galaxies "In general, elliptical galaxies are many times more massive than spirals, and in some parts of the sky we see a single very large elliptical in association with one or more spiral or irregular systems. The members of such groups seem to be moving away from each other, as if expanding from an explosion. This possibility is discussed by Jose Luis Sersic of Cordoba Observatory, Argentina . . .

"He and H. A. Abt of Kitt Peak National Observatory have proposed that many galaxies may be fragments of larger masses that exploded some time ago. Statistical data indicate that it is the giant ellipticals which produce the fragments seen now as smaller elliptical, spiral, and irregular systems."

Today most cosmologists would reverse this process. Collisions seem common among galaxy groups and clusters, and their giant ellipticals probably grew that way by mergers with smaller galaxies.

◖ June 1992

Gravitational Waves "Groundbreaking for a revolutionary type of astronomical telescope may occur by the end of the year. In late February the National Science Foundation announced the selection of sites for a pair of observatories designed to detect gravitational radiation. Hanford, Washington, and Livingston, Louisiana, beat out 17 other prospective sites for the Laser Interferometer Gravitational-Wave Observatory (LIGO). . . .

"Nevertheless, a third site will still be needed to pinpoint the origin of [a candidate] signal in the sky. A LIGO clone is planned for Europe, but financial concerns among the countries involved have cast considerable doubt on its completion."

Called Virgo, the European sister facility was completed near Pisa, Italy, in 2003, but was then turned off in 2011 for a major upgrade. So when the two LIGOs successfully detected gravitational waves in 2015, scientists couldn't say what direction they came from. Virgo should rejoin the search soon.

MISSIONS

Juno Will Stay in Current Orbit Around Jupiter

▲ Jupiter's swirling cloudtops from an altitude of about 14,500 km (9,000 miles), taken on February 2, 2017, during Juno's fourth flyby.

NASA HAS DECIDED to leave the Juno spacecraft in its current, 53-day orbit around Jupiter for the remainder of the mission, instead of shrinking the orbit to 14 days as originally planned.

The decision follows the discovery in October 2016 of an engine malfunction, which sent Juno into safe mode (*S&T:* Feb. 2017, p. 10). Telemetry later indicated that a pair of valves in the main engine took several minutes to open, longer than during previous firings. The October maneuver was supposed to be the final one that would move the craft from its initial capture orbit (which it's still in) into a series of 34 shorter, 14-day science orbits.

Engineers have decided that it's best for the spacecraft to stay put, rather than risk another firing of the main engine. Maintaining a wide-ranging orbit will enable the spacecraft's instruments to safely complete the mission's science objectives, while avoiding a possible malfunction that could strand the craft in an undesirable orbit.

Despite the change, the quality of the data gathered on each pass will remain the same, as the closest passage on the current trajectory is identical to those on the hoped-for science orbits. The only difference now is the span of time between passes. The path takes Juno from a perijove of just 4,100 km (2,600 miles) over the Jovian cloudtops to far out past Callisto, with an apojove of 8.1 million km (5 million miles).

There's another silver lining: Due to the lower level of radiation Juno will receive in its wider orbit, NASA now plans to operate the primary mission for five extra months, through July 2018. That will yield a total of 12 orbits around the giant planet.

■ DAVID DICKINSON

COSMOLOGY

Hubble Spies Faint Galaxies in Early Universe

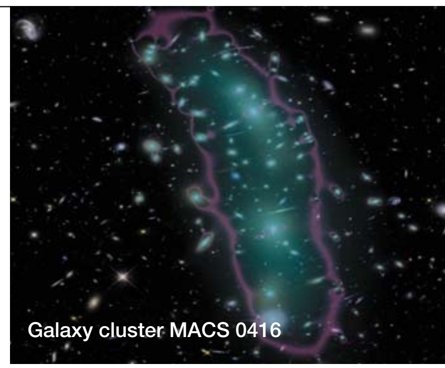
ASTRONOMERS USING the Hubble Space Telescope have spotted 167 small galaxies in the early universe — the faintest ones yet detected in that era. The result sheds light on a poorly understood epoch in the early history of our cosmos.

According to Rachael Livermore (University of Texas, Austin), these galaxies emit less than 1% of the Milky Way's luminosity. They are the precursors of *ultra-faint dwarf galaxies*, like the nearby Fornax Galaxy (*S&T:* March 2017, p. 16).

Livermore's team found the faint galaxies have redshifts between 5.3 and 8.8, so their light has traveled between 12.6 and 13.1 billion years to reach Earth. Normally, even Hubble would never be able to spot them. They were only detected because two intervening galaxy clusters (one shown at right) boosted their brightness via gravitational lensing. The work is part of the Frontier Fields program (*S&T:* Jan. 2015, p. 20).

To detect the galaxies, the researchers filtered out light from the clusters' own crowded central regions using a technique known as *wavelet decomposition*, which is comparable to the technique behind noise-canceling headphones. The technique enabled them to detect the most strongly magnified images of background objects, which appear in the foreground clusters' busy centers.

With these objects, Hubble is finally seeing the most common galaxies from this ancient time period, giving astronomers a better picture of how much light these galaxies emitted as a population.



Galaxy cluster MACS 0416

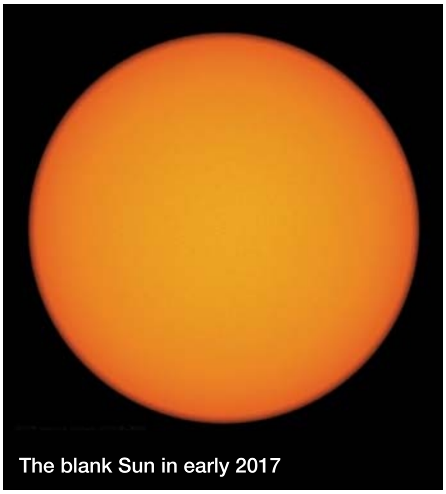
As the authors observe in the February 1st *Astrophysical Journal*, there's now strong evidence that, thanks to their sheer numbers, these small galaxies were responsible for a major transformation: the ionization of the neutral hydrogen filling the universe. This *Epoch of Reionization* occurred a few hundred million years after the Big Bang (see page 30).

■ GOVERT SCHILLING

JUNO: NASA / JPL-CALTECH / SWRI / MSSS / ROMAN TKACHENKO;
GALAXY: STSCI / NASA / CATS TEAM / R. LIVERMORE (UT AUSTIN)

SUN

Another Maunder Minimum?



The blank Sun in early 2017

SCIENTISTS HAVE reconstructed the Sun's conditions during a 17th-century lull in activity with the hope of understanding what our star might look like if history repeats itself.

Around 1645, the Sun became nearly spotless. During the 70-year period that followed, known as the Maunder Minimum, sunspots appeared only rarely on the surface of the Sun — though our star did continue its 11-year cycle of activity during this time.

This spotless period doesn't just have historical significance: After a peak in magnetic activity that produced a multitude of sunspots during the 1950s and '60s, the Sun again appears to be headed toward a minimum. The current 11-year cycle, known as Cycle 24, peaked in 2013, but the peak was the weakest recorded in 100 years. Early 2017 has had two spotless stretches, each nearly two weeks long. Many experts anticipate that Cycle 25 will be weaker still. If the trend continues — and it *is* speculative to predict activity based on an individual cycle — we could be looking at a largely blank Sun in the next few years.

In *Nature*'s January 31st *Scientific Reports*, Mathew Owens (University of Reading, UK) and colleagues look back to the Maunder Minimum in order to anticipate solar and auroral activity (or the lack thereof) in our near future.

Based on modern data, the researchers replayed the past 30 years of activity on a computational model of the Sun's magnetic field, comparing the number of sunspots to other properties, such as the speed of the solar wind. The team then took the model back in time, retracing the Maunder Minimum. With only the records of sparse sunspots as input, the model postdicted what the Sun and the solar wind would have looked like, reconstructing the space weather of 400 years ago. The result: The solar magnetic field and solar wind near Earth would have been half as strong during the minimum as they are in the modern era.

The postdiction makes sense, given the lack of auroras reported during that period. But it's risky to extrapolate a model so far back in time, cautions Tom Schad (University of Hawai'i), who was not involved in the study. "Multiple approaches to the investigation of deep minima are paramount," he says.

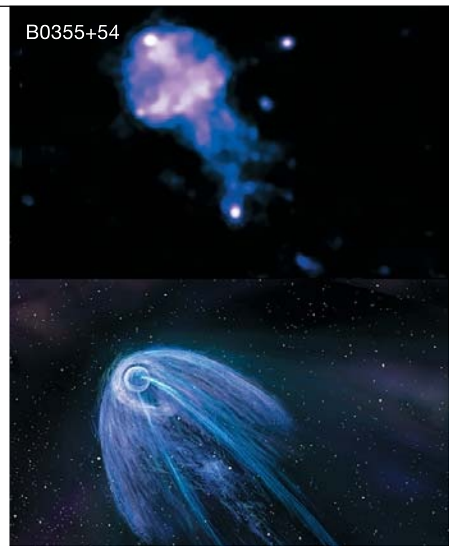
If we are heading for a deep minimum, we'll perhaps see fewer northern lights — and those auroras that do appear will concentrate more around the poles than they do right now, Owens says.

■ MONICA YOUNG

STELLAR

Two Pulsars Blowing in the Wind

THESE X-RAY IMAGES of two pulsars (top two panels) show beautiful, complex clouds of charged particles created as the spinning neutron stars move through space. Although a pulsar's beat is its most defining characteristic, it's not all we see. Huge electric forces, generated by the spinning magnetic field, rip charged particles off the pulsar's surface. Some of these particles escape as jets from the poles. Others form a donut-shaped cloud around the pulsar, which sweeps around as the star rotates.

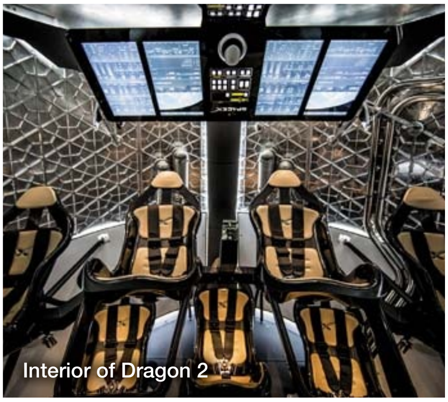


Using the Chandra X-ray Observatory, Bettina Posselt (Penn State University) and colleagues studied two very different pulsars, Geminga (left) and B0355+54, both of which are surrounded by clouds of X-ray-emitting particles, called *pulsar wind nebulae*, that are swept back by the pulsars' passage. The observations, paired here with artist's concepts for clarity, reveal the pulsars' orientations and explain why astronomers see Geminga pulse in gamma rays but not B0355+54: Gamma rays come from near a pulsar's equator, and while we see Geminga from the side, B0355+54 has its poles pointed at us. Conversely, radio emission comes from the star's magnetic poles, explaining why Geminga seems to be radio quiet when B0355+54 isn't. The papers appear in the December 20th and January 20th issues of the *Astrophysical Journal*.

■ TIARA DIAMOND

SUN: SDO / HMI; PULSARS: GEMINGA X-RAY: NASA / CXC / PSU / B. POSSELT ET AL., B0355+54 X-RAY: NASA / CXC / GWU / N. KLINGER ET AL., INFRARED BACKGROUND: NASA / JPL-CALTECH. ILLUSTRATIONS: NAHKS TREHNL

SPACE & SOCIETY


Interior of Dragon 2

SpaceX's 2018 Moonshot

SPACEX CEO and founder Elon Musk announced on February 27th the company's intention to slingshot two people around the Moon in late 2018.

The as-yet-unnamed individuals approached SpaceX about the possible mission and have reportedly already paid a "significant deposit" toward the flight. While not divulging the exact price tag, Musk said that the total amount would cost more than a seat on a Russian Soyuz bound for the International Space Station (ISS) — $58 million.

SpaceX plans to conduct health and fitness tests with the applicants and release additional information on just who's going later this year.

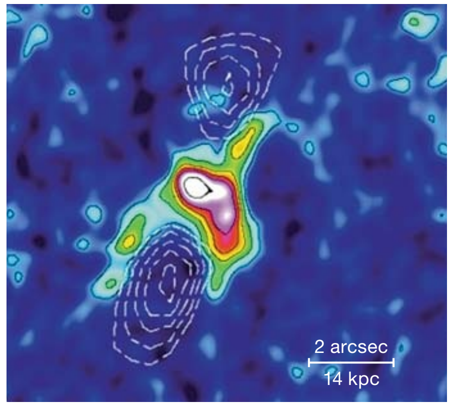
The flight will be with the company's upcoming Falcon Heavy rocket and Dragon 2 capsule, the latter developed mostly with funding from NASA's Commercial Crew Program. Both have yet to leave the launch pad. However, SpaceX is under contract with the space agency to resupply the ISS with cargo and crew, with the first crewed Dragon 2 mission expected in 2018. To date, the company has launched nine automated cargo resupply missions to the station (eight of them successful). These missions used the Falcon 9 rocket and an uncrewed Dragon capsule.

The announced plan calls for the inaugural flight of the Falcon Heavy rocket this summer, followed by an uncrewed flight of Dragon 2 to the ISS toward the end of 2017.

Meanwhile, NASA is exploring the possibility of flying a crew on the first Space Launch System (SLS) mission, slated for launch at the end of 2019. It will also circle the Moon and return. And China is already ahead of the game in terms of big rockets that can reach beyond low-altitude Earth orbit, launching its Long March 5 rocket from Wenchang Space Center last year on November 3rd.

■ DAVID DICKINSON

BLACK HOLES



▲ This radio map reveals three strands of cool gas along the borders of X-ray cavities (dotted line contours) blown out by the galaxy's central black hole.

Black Holes Spur Starbirth

ASTRONOMERS HAVE discovered long filaments of cold gas — the main ingredient for making stars — cocooning giant bubbles inflated by a black hole.

The filaments are part of the central galaxy in the hefty Phoenix Cluster. Reporting in the February 10th *Astrophysical Journal*, Helen Russell (University of Cambridge, UK) and colleagues used ALMA to find that the galaxy's black hole is powering intense jets that have inflated huge bubbles of hot gas (visible in X-ray observations). Seemingly wrapped around these cavities are three gigantic filaments of cold, molecular hydrogen gas — the stuff that stars are made of. Each filament is tens of thousands of light-years long.

Astronomers have seen hints of filament-wrapped cavities before, but the gaseous strands have generally been messier, says Megan Donahue (Michigan State University). Her team has looked at more than two dozen central galaxies as part of the Hubble CLASH project and seen very similar filaments, some even with stars forming inside. Those that are forming stars rank among the most prolific starbirthing galaxies in the universe's last 5 billion years.

"It's kind of ironic, because they're 'supposed' to be red and dead," Donahue says. Clusters' central galaxies are awash in hot gas, which doesn't form stars. Read more at **https://is.gd/bhthermostat**.

■ CAMILLE M. CARLISLE

IN BRIEF

Intermediate Black Hole?

Reporting in the February 9th *Nature*, Bülent Kızıltan (Harvard-Smithsonian Center for Astrophysics) and colleagues think they've found signs of an *intermediate-mass black hole* (IMBH). IMBHs are the long-sought "middle children" in the spectrum of black holes, neither supermassive beasts nor small, star-made holes. No one has yet found a definitive IMBH. But thanks to a mathematical tool called *Kullback–Leibler divergence*, originally developed by mathematicians and cryptanalysts, Kızıltan's team thinks an IMBH lurks inside the massive globular cluster 47 Tucanae. The team analyzed the movements of 25 pulsars in the cluster and concluded that they're orbiting an unseen mass some 2,200 times the mass of the Sun. However, skepticism remains. Read more at **https://is.gd/imbh47tuc**.

■ SHANNON HALL

Organics on Ceres

NASA's Dawn spacecraft has found a big patch of organic compounds high in the northern hemisphere of the dwarf planet Ceres. Although organics are unsurprising, the spectrum Dawn picked up is clearer than hints of these materials previously seen on other main-belt asteroids, Maria Cristina De Sanctis (INAF IAPS, Italy) and others report in the February 17th *Science*. The compounds drape over the southwestern floor and rim of the 50-km-wide crater Ernutet; there's also a much smaller deposit in Inamahari, about 400 km away. The compounds aren't related to the craters or delivered by impacts; they likely come from Ceres itself. Along with water ice, carbonates, and salts — not to mention possible ice volcanism — the organic material makes this world a promising environment for prebiotic chemistry.

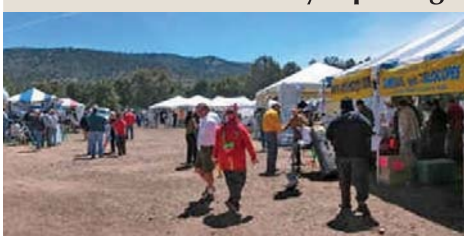
■ CAMILLE M. CARLISLE

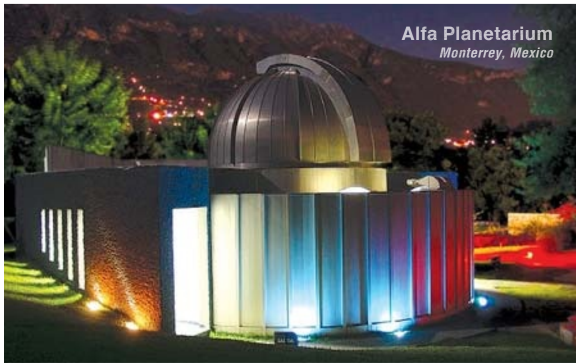


Beginner's Corner
Answers to Your Questions



WELCOME TO CAMP OAKES





Alfa Planetarium
Monterrey, Mexico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7 Earth-Size Planets Orbit Dim Star

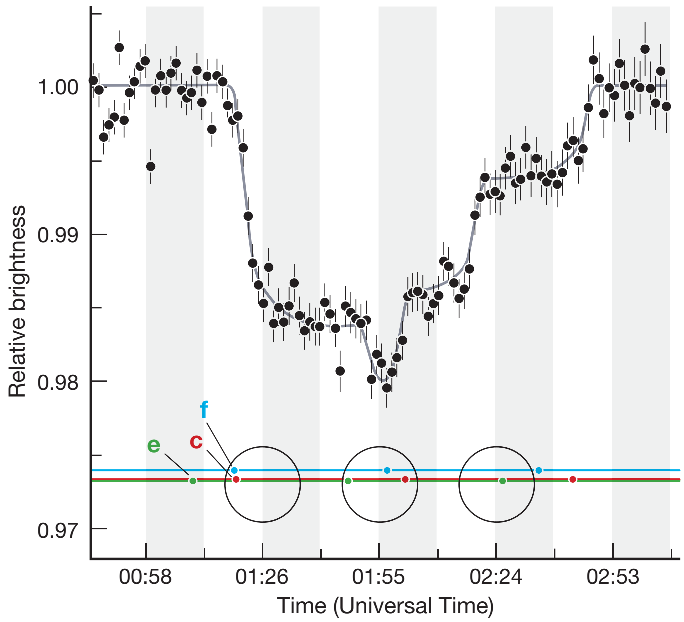
Several of TRAPPIST-1's worlds might have the potential for liquid surface water — or have had their atmospheres torn off.

▼ **ALIEN SKY** Artist's concept of what the sky might look like from above one of the seven known terrestrial planets in the TRAPPIST-1 system.

The star TRAPPIST-1 is an unassuming, *M*8 red dwarf star. It lies 39 light-years away in the constellation Aquarius, shining at a measly apparent magnitude of 19. Closer in size to Jupiter than to the Sun, the dwarf puts out less than a thousandth as much light as our star.

Last year, Michaël Gillon (University of Liège, Belgium) and colleagues announced that a trio of small exoplanets orbits this pipsqueak star (*S&T:* Aug. 2016, p. 12). The team detected the exoplanets using the transit technique, which catches the tiny dip in starlight when a planet passes in front of its host star from our perspective. Now, after an intensive

ESO / M. KORNMESSER



▲ **STARLIGHT DIPS** This plot shows how the brightness of the faint dwarf star TRAPPIST-1 varied as three of its planets passed across its face in a triple transit on December 11, 2015. Data come from the HAWK-I instrument on ESO's Very Large Telescope. The cartoon below the light curve shows possible configurations for the planets crossing in front of the stellar disk at three times during the triple transit.

follow-up campaign, the observers have discovered that there are actually *seven* planets, not three. All are likely rocky. At least three lie in TRAPPIST-1's putative habitable zone — the region where, given an Earth-like composition, liquid water could be stable on the surface.

From Three to Seven

The discovery roller coaster began when the team found that what it had thought was a combined transit of two planets was in fact the crossing of *three*.

The astronomers next assailed TRAPPIST-1 with an impressive flurry of ground-based observations. But the big breakthrough came with NASA's Spitzer Space Telescope, which observed the star for 20 days. These data include 34 clear transits. Gillon and his colleagues were then able to combine their ground- and space-based observations and slice and dice them to determine that the various signals likely came from seven different planets. (Incidentally, the original third planet doesn't exist.)

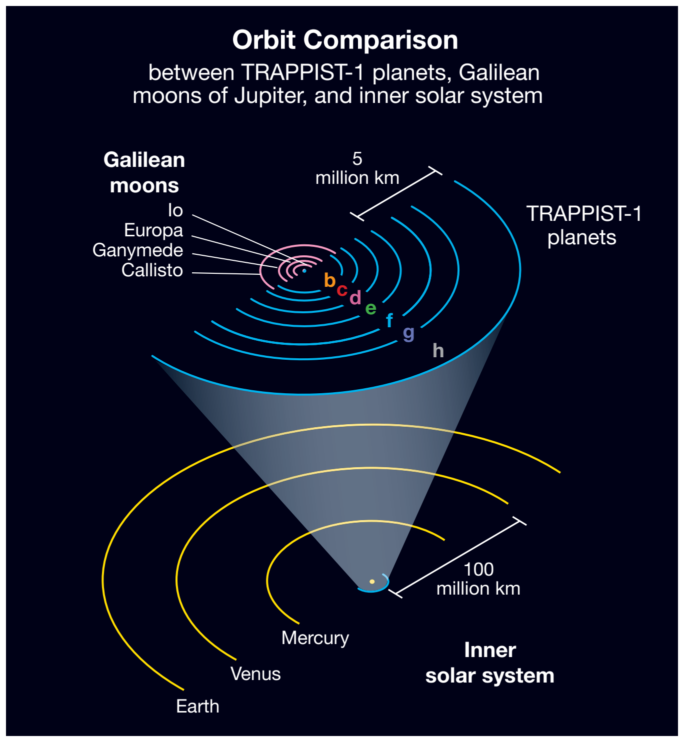
Only six of those are firm detections, however. The seventh planet, designated h, is iffy in its specs: The team only detected a single transit for it, and astronomers prefer to see three transits before calling something a candidate planet. Expect astronomers to haggle over this one.

But let's assume for now that all seven exoplanets are real. All their orbits would easily fit inside Mercury's circuit around the Sun. The years of the inner six range from 1.5 to 12 Earth days, with the period of outermost h being between 14 and 35 days — giving it an orbit less than 20% as large as Mercury's.

Based on their transits, the smallest two worlds are about three-fourths the diameter of Earth, the largest 10% greater than it. Transits don't reveal masses, but changes in their timing can. One of the wonderful things about this system is that the exoplanets have *resonant* orbits: Their orbital periods are roughly integer ratios of one another, a setup that gravitationally links the planets together and can lead to tiny shifts in their positions — and the times of their transits. Based on these shifts, the researchers calculated the planets' shared gravitational influences, and hence their approximate masses and densities. All are consistent with being rocky, the team concludes in the February 23rd *Nature*.

Such resonant orbits arise when worlds migrate from their original locations, Gillon explains. Astronomers think that when lightweight planets form far out in a star's planet-forming disk, gas drag and such will make them advance inward. During this inbound migration, the worlds catch one another in resonant orbits, such that they can form a "chain of planets," he says. But it's unclear when that happened, or whether these orbits are stable: The researchers haven't determined the seventh planet's path, nor do they know if there are other worlds in the system mucking things up.

The planets are all likely tidally locked with their star, meaning they always point the same hemisphere at it, as the Moon does to Earth. So close to the star, the planets might



▲ **GALILEAN PLANETS** All of the seven exoplanets discovered around TRAPPIST-1 orbit much closer to their star than Mercury does to the Sun, as shown here in this comparison of their orbits with those of the Galilean moons of Jupiter and the planets of the inner solar system. But because TRAPPIST-1 is far fainter than the Sun, the worlds are exposed to similar levels of irradiation as Venus, Earth, and Mars.

LEAH TISCIONE / *S&T*, ESO / M. GILLON ET AL. (2)

experience huge tidal pulls, stretching and squeezing their interiors and spurring heating and even volcanism, similar to what we see on Jupiter's Galilean moons.

Are These Worlds Habitable?

TRAPPIST-1 is quiet for an *M* dwarf — notably less active that Proxima Centauri, which also has a planet (*S&T:* Dec. 2016, p. 10). It's what's called an *ultracool dwarf*, a common type of star that lives for trillions of years.

Unfortunately, astronomers don't know how old the star is. They know it's at least 500 million years old, the time needed to "settle" into being an adult. The ratio of its X-ray to ultraviolet emission, which changes with age, suggests it is "relatively young," Vincent Bourrier (University of Geneva Observatory, Switzerland) and colleagues posit in the March 2017 *Astronomy & Astrophysics*. What "relatively young" means is an open question.

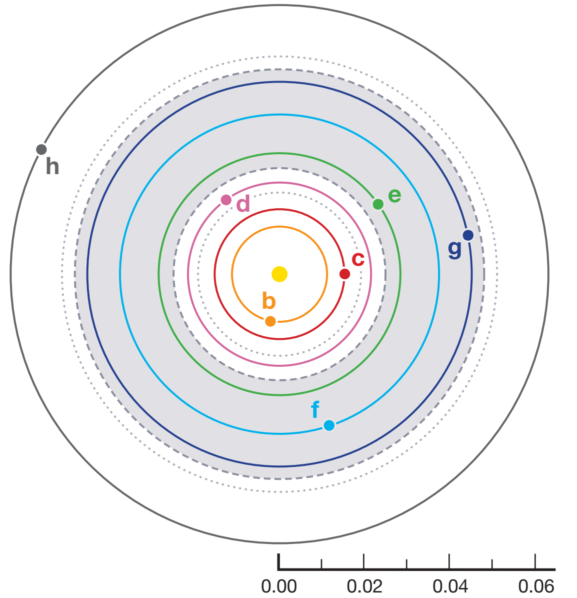
Jeffrey Linsky (University of Colorado, Boulder), who has worked extensively on *M* dwarfs, says that TRAPPIST-1 seems both old and young. Stars are born spinning quickly, then slow as they age. This star whirls around every 1½ days, which at face value would point to it being young, he says — but astronomers don't know how fast ultracool dwarfs spin down. Conversely, the star's fast motion through space usually would indicate it's a member of the old stellar population that comprises the galaxy's halo, but maybe that's a fluke.

Bourrier's team also speculated on how TRAPPIST-1's X-ray and ultraviolet levels would matter for habitability. Although the star's ultraviolet output is less than half that from other cool, exoplanet-hosting *M* dwarfs, the radiation overall is still high enough that it could strip an Earth-like atmosphere from the inner two planets, b and c, in 1 to 3 billion years. For the planets d, e, f, and g (the latter three are in the star's habitable zone), the process could take anywhere from 5 to 22 billion years. The team does see a hint of atmospheric escape from b and c, based on dips in starlight around the time of their transits, but this effect might instead be due to coronal variability.

The next goal is to look for atmospheres. If any of these worlds hosts life, then it might leave chemical fingerprints in the atmosphere. No single compound is a smoking gun — for example, oxygen can come from photosynthesis or from water molecules broken up by starlight into their constituent hydrogen and oxygen. But certain combinations of chemical compounds (such as methane, carbon dioxide, and molecular oxygen) would be highly suggestive.

TEMPERATE VS. HABITABLE

◖All of TRAPPIST-1's planets lie in what the discoverers call the "temperate zone" — orbits with enough incoming starlight that, with the right conditions, the planets might at least sometimes have liquid surface water. It's a looser definition than that for the more commonly used "habitable zone."



▲ **HABITABLE?** This diagram shows the relative sizes of the orbits of the seven planets circling TRAPPIST-1. The shaded area is the habitable zone. Although drawn here, planet h's orbit is not well known. The dotted lines show alternative limits to the habitable zone based on different theoretical assumptions. Note that a more optimistic definition includes planet d.

Gillon's team hopes to use the Hubble Space Telescope to look at the starlight passing through the planets' (maybe extant) atmospheres as they transit, to detect any compounds that might have absorbed light. Follow-up will come with the James Webb Space Telescope, more apt for this project because it focuses on infrared wavelengths, in which TRAPPIST-1 puts out most of its light. Meanwhile, NASA has released three months of observations by the Kepler space telescope and invited astronomers to dive into the data.

Co-discoverer Amaury Triaud (Institute of Astronomy, UK) favors planet f as the most promising for life. With a girth of 1.05 Earths and about 60% Earth's density, TRAPPIST-1f might be rich in liquid water or ice. It receives about as much energy from its star as Mars does from the Sun, and with a good atmosphere it could be habitable. (Mars is technically in the Sun's habitable zone.)

During a February 21st press briefing, Triaud painted this picture of what we might see from one of these worlds:

The amount of light reaching your eye would be something like 1⁄200 as much as you receive from the Sun on Earth — similar to what you experience at the end of sunset. However, it'd still be quite warm, because there's still about the same amount of energy reaching you from the star as Earth receives from the Sun — it's just that most of that comes in infrared, which you can't see but your skin can feel. The star would be a salmon-like color. Viewed from TRAPPIST-1f, he estimates, the star would appear three times wider in the sky than the Sun is to us.

"The spectacle would be beautiful," he said.

■ Science Editor **CAMILLE M. CARLISLE**'s favorite planet is the remarkable world called Earth.

LEAH TISCIONE / *S&T*, SOURCE: ESO / O. FURTAK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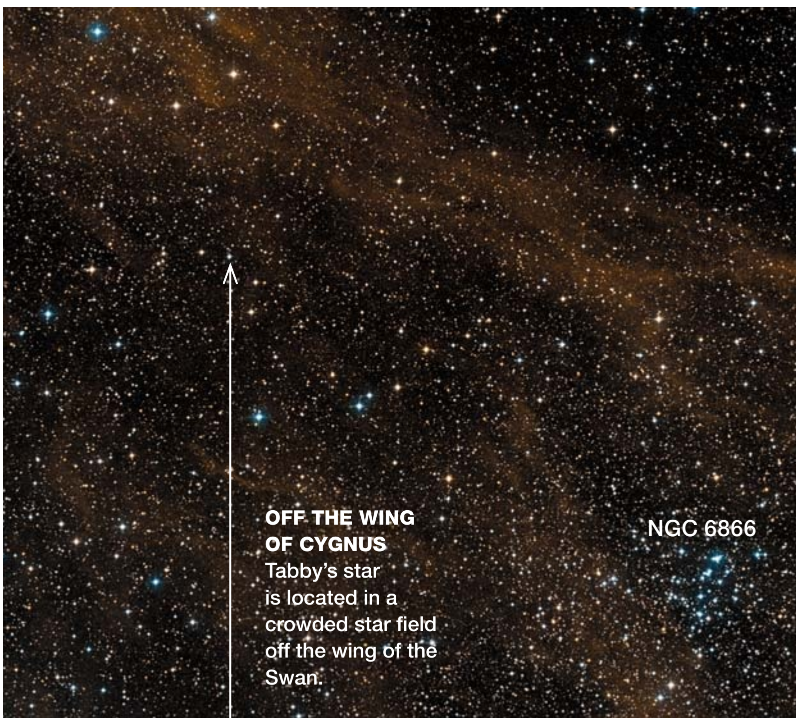
The Most Mys

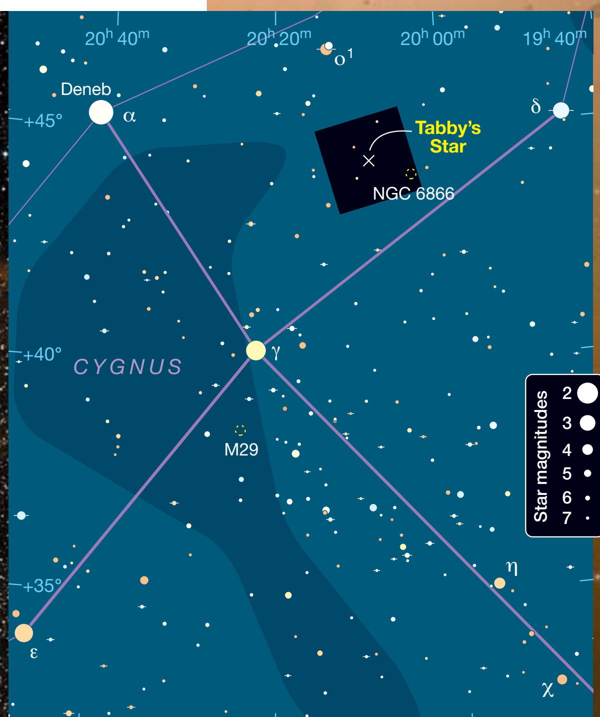
"Bizarre peak - a giant transit."

Those words, posted on an online forum in 2010, brought a star's weird behavior to the attention of Planet Hunters, a group of citizen scientists combing through data from NASA's Kepler mission.

During its four-year primary mission, Kepler had simultaneously observed more than 150,000 stars in search of transiting planets. In the process, the spacecraft downlinked some 15 terabytes of measurements. While automated algorithms had already dug through this mountain of data to find more than 4,500 exoplanet candidates, a team at Yale University created the Planet Hunters citizen science project with the hope that human eyes would discern details that computers had missed.

And they did. A user named copernicus123 first noted the unusual dip in starlight from the Kepler star KIC 8462852 and wrote a post on the Planet Hunters' message board. Then, two years later, the same star dimmed again, but even more dramatically — plunging in brightness by 15% over five days before rebounding entirely over the next two. The change garnered a flurry of attention on the message board: "Amazing!" "Wow." "Definitely SETI should look at it as quickly as possible."



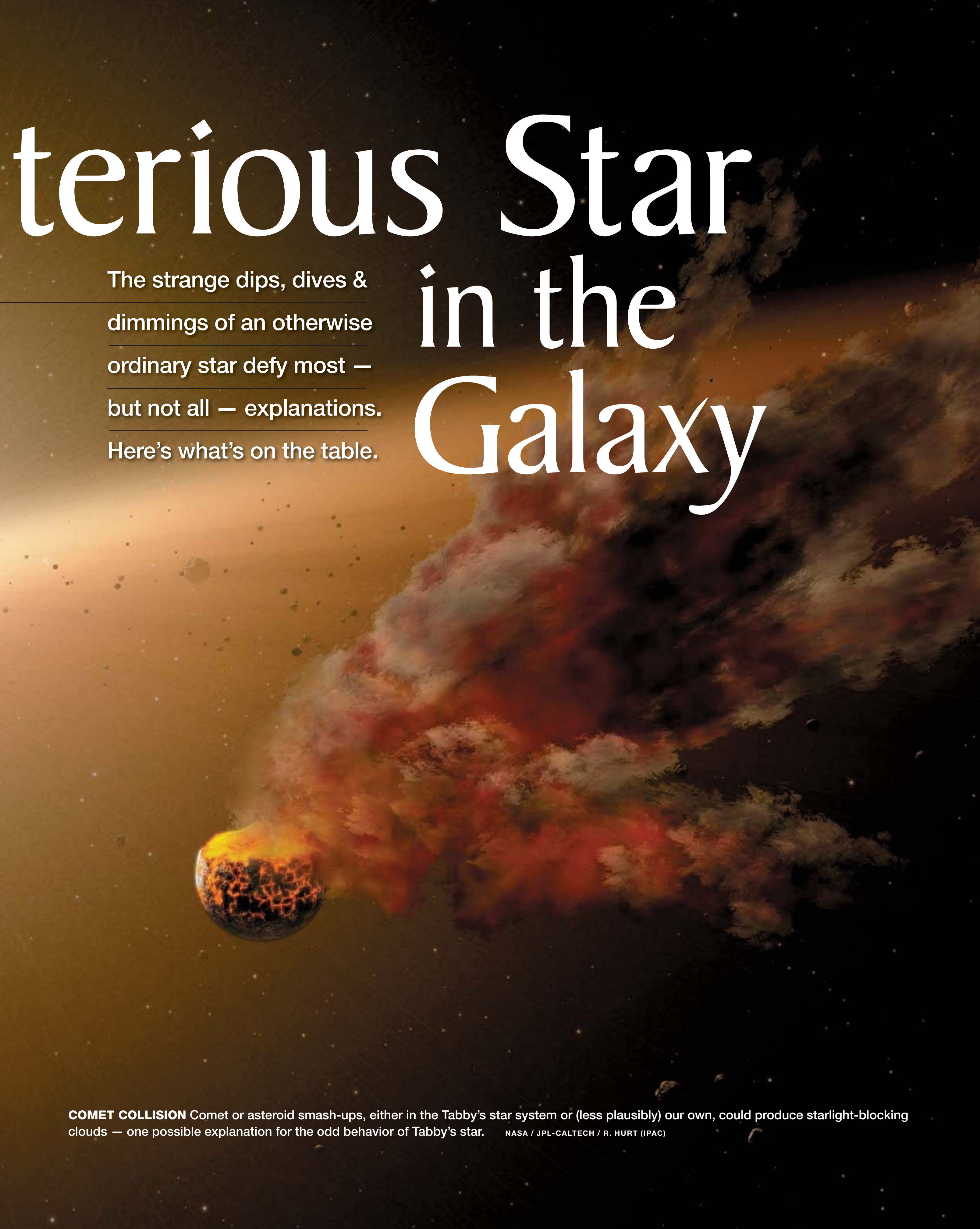


OFF THE WING OF CYGNUS Tabby's star is located in a crowded star field off the wing of the Swan.

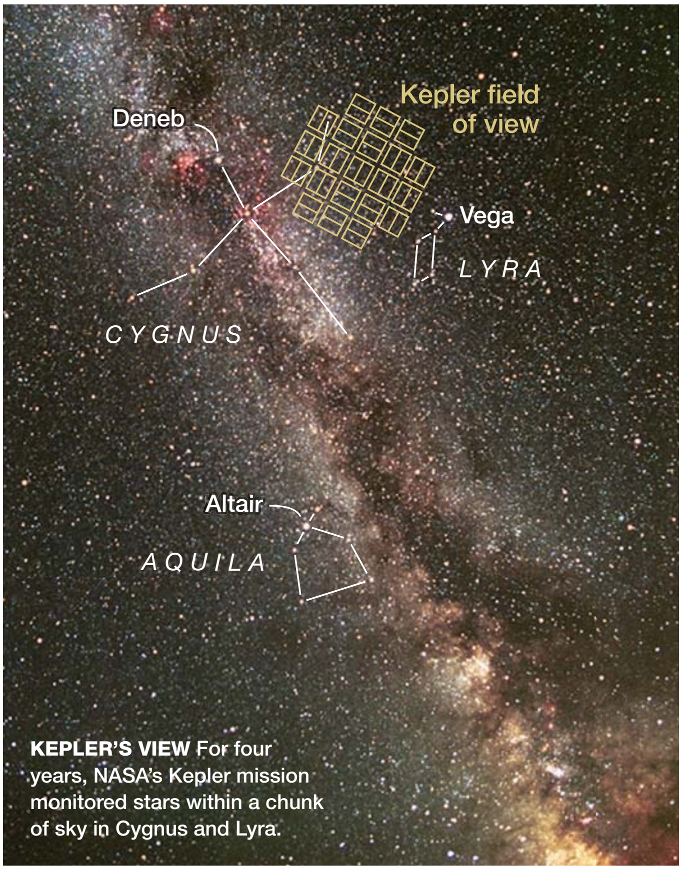
GREGG DINDERMAN / S&T / POSS II

terious Star in the Galaxy

The strange dips, dives & dimmings of an otherwise ordinary star defy most — but not all — explanations. Here's what's on the table.



COMET COLLISION Comet or asteroid smash-ups, either in the Tabby's star system or (less plausibly) our own, could produce starlight-blocking clouds — one possible explanation for the odd behavior of Tabby's star. NASA / JPL-CALTECH / R. HURT (IPAC)



KEPLER'S VIEW For four years, NASA's Kepler mission monitored stars within a chunk of sky in Cygnus and Lyra.

One of us (Boyajian) announced the discovery with colleagues in the April 2016 *Monthly Notices of the Royal Astronomical Society*. We found that, by the end of Kepler's primary mission, this star had dimmed 10 times, each time by a different amount between 0.5% and 20%. After every plunge, which could last from days to weeks, the star's brightness recovered completely.

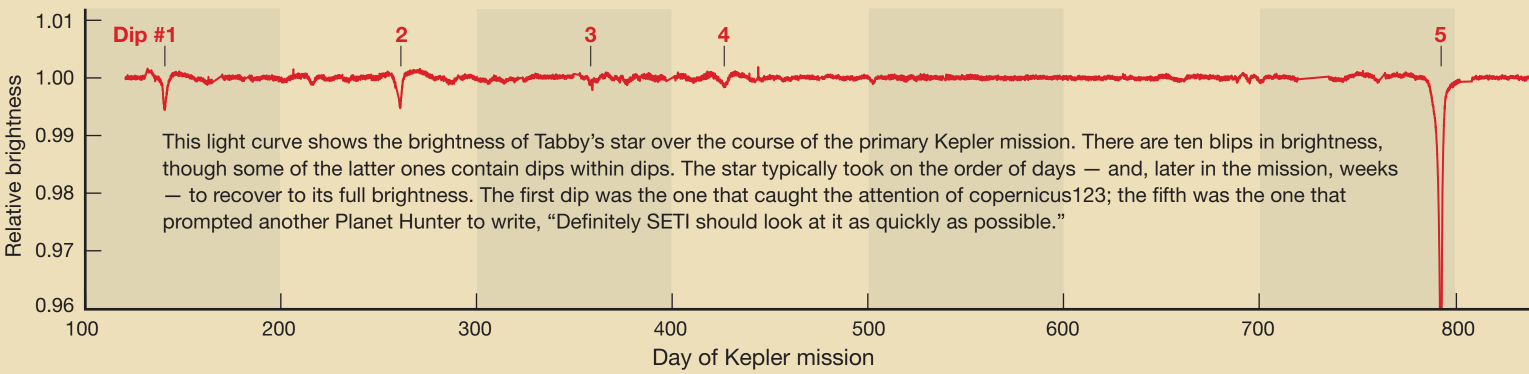
Intriguingly, each dip in the light curve had a different "shape," indicating irregular changes in brightness. The changes are far too deep to be due to a planet — whatever's causing these dips has to be much larger. Moreover, the spacing between events isn't periodic, as you would expect from the transit of a single orbiting object.

The star almost immediately captured the attention of not just astronomers but also the general public — especially when Jason Wright (Penn State University) and colleagues published a paper exploring potential alien origins of the star's strange behavior. Meanwhile, professional and amateur astronomers alike have pointed their telescopes at the star to search for possible causes of the previously observed changes and to perhaps find additional dimmings.

To date, no additional dips have been detected, although the smallest dips observed by Kepler are too small to be detectable from the ground. Yet with four years of Kepler data and a bevy of follow-up observations at other wavelengths including infrared and submillimeter, astronomers have more than enough for scientifically sound speculation.

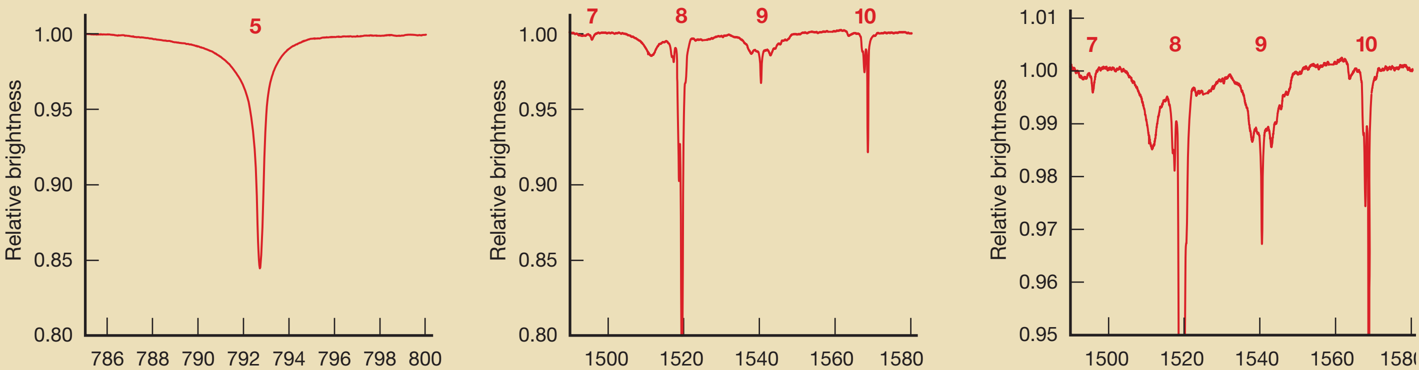
KEPLER / CARTER ROBERTS

A Strange Four Years



This light curve shows the brightness of Tabby's star over the course of the primary Kepler mission. There are ten blips in brightness, though some of the latter ones contain dips within dips. The star typically took on the order of days — and, later in the mission, weeks — to recover to its full brightness. The first dip was the one that caught the attention of copernicus123; the fifth was the one that prompted another Planet Hunter to write, "Definitely SETI should look at it as quickly as possible."

Close-ups



T. BOYAJIAN ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY*, 2016 JANUARY 27

An Outwardly Ordinary Star

One of the most bizarre aspects of what is now called "Boyajian's star" or "Tabby's star" is just how average it looks. A spectrum of the star reveals an outwardly normal, middle-aged *F*-class star, almost half again as massive as the Sun. The spectrum also shows that the star doesn't wobble in the way we'd expect if a massive companion, such as a black hole or another star, were in orbit around it.

While there are a handful of other (non-Kepler) stars where the brightness dips irregularly similar to Tabby's star, these objects are all young stars, surrounded by dusty disks, which occasionally pass along Earth's line of sight. Archival and follow-up observations of Tabby's star at infrared and submillimeter wavelengths, on the other hand, demonstrates that it has no such massive disk.

In January 2016, it became clear that Tabby's star was even weirder than we thought. Bradley Schaefer (Louisiana State University) published evidence that the star had been fading over the past century. Analyzing a series of photographic plates at the Harvard College Observatory, Schaefer determined that between 1890 and 1989, the apparent brightness of the star had decreased by approximately 15%.

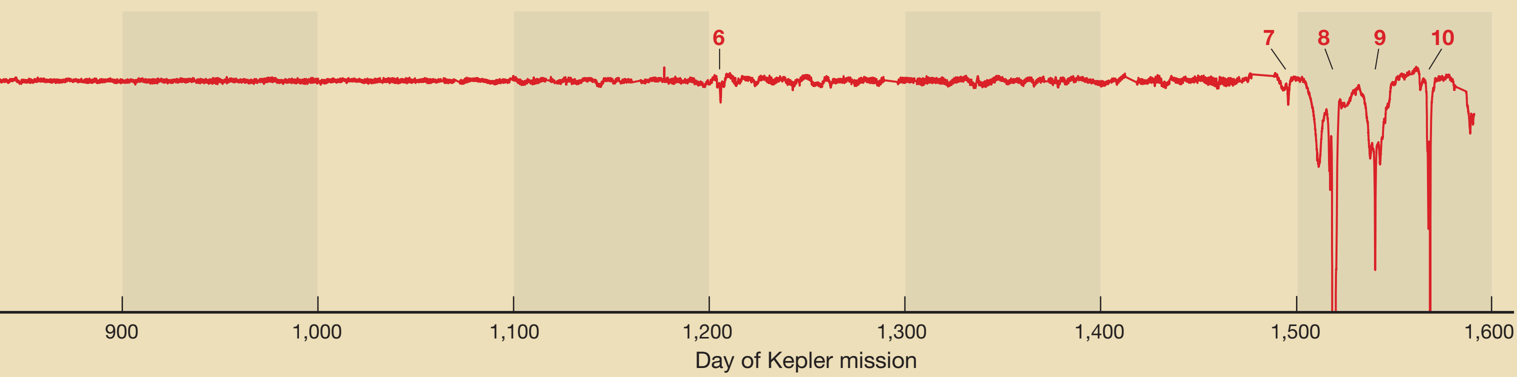
This result was quickly called into question: Independent researcher Michael Hippke and colleagues claimed the long-term fade wasn't real. Instead, they argued, a shift in photographic plate technology and data collection techniques in the 1960s had created artificial changes in the star's light curve.

Yet at least some long-term dimming appears to be real. One of us (Montet) analyzed calibration data from the Kepler mission, revealing that the star had dimmed by a whopping 3% over a period of four years, with a third of the fade occurring over just six months. (Automatic data analysis removes long-term changes in order to improve the efficiency of the search for transiting planets, but Kepler's calibration frames reveal the trend.)

This four-year brightness change happened at a faster rate than the change observed in Harvard's photographic plates. But the Kepler observations proved the irregularity of Tabby's star, so we can't rule out the possibility that we'd observe different dimming rates over a century compared to a single four-year stretch. Furthermore, while the Kepler data don't directly confirm Schaefer's result, it does seem unlikely that errors made while measuring photographic plates would happen to predict a trend in Kepler data.

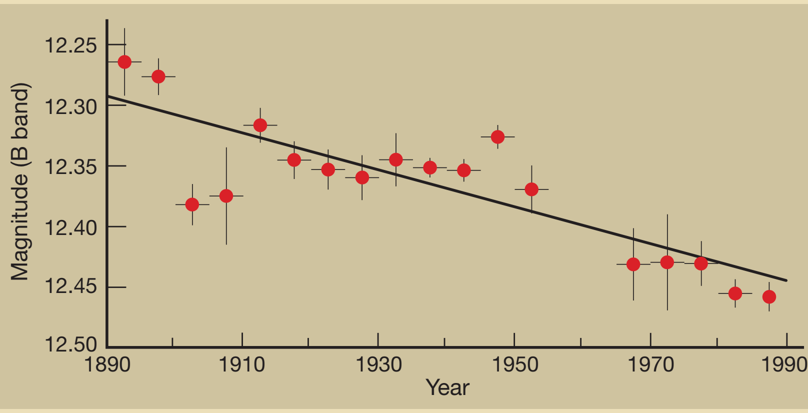
So any explanation of the star's behavior must explain not only the short, extreme dips recorded by Kepler, but also the slower dimming observed over the same four-year time period, as well as potentially a long-term fade over the course of the 20th century.

Let's investigate a few possibilities by following a single photon on its 1,300-year-long journey from Tabby's star to Kepler's detector, all the while considering what could happen along the way. We'll weigh each scenario by how well it explains the data, as well as how plausible it is (see box on page 20).



Century's Fade

Data from the Harvard photographic plate collection shows a possible drop in Tabby's star's brightness between 1890 and 1989. The century-long change is documented here in five-year intervals. The line shows the trend that best matches the data. The brightness of 12 nearby *F* stars, which served to check the trend, stayed level over the same time period.



B. SCHAEFER / *ASTROPHYSICAL JOURNAL*, 2016 MAY 6

How Likely Is It?

To determine whether a given scenario is "likely," astronomers consider two metrics: How well does the explanation match our observations? And how plausible is the scenario based on what we already know? Both of these questions are important!

If someone were to tell me that they flipped a quarter six times and it came up heads each time, the likelihood that this coin has two heads is 60 times higher than that the coin is perfectly fair. However, I've seen lots of quarters, but I've never seen one with two heads. I also know that someone is more likely to tell me about their strange coin-flipping experience than their normal one.

Therefore, my prior knowledge tells me that it's significantly more likely that the quarter does indeed have a tails side, even though our two-headed model provides a much better fit to the data. Astronomers make the same calculations every time we analyze possible explanations for our observations.

■ BENJAMIN MONTET

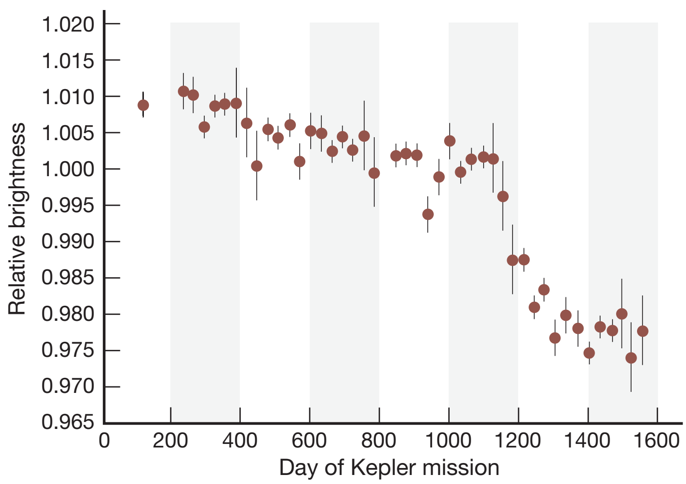
Inside the Star

Let's start tracking our photon at the moment it's created: via a hydrogen fusion reaction in the star's core. One popular suggestion to explain Tabby's star's long-term dimming is the sputtering out of hydrogen fusion in its core. We expect at least one of the many stars that Kepler observed to exist at this particular stage of evolution, so it's a plausible scenario. However, it doesn't fit the data well at all. It takes more than 100,000 years for a photon to escape the star's core. So even if fusion suddenly stopped completely, causing the star to contract, the change required to dim the star's brightness by 1% would span hundreds of thousands of years. Fusion's end couldn't produce 4% dimming over four years, much less 15% dips over a day.

After rising towards the star's surface our photon will escape the star — but not quite in a random way. Concentrations in magnetic field lines may cause dark patches to appear briefly on a star's surface. On the Sun such spots are small. From minimum to maximum sunspot activity, the Sun's brightness changes by less than 0.1%. But on other stars, spots can be bigger and their effects more dramatic. The brightnesses of some stars in the Kepler field have varied by as much as 5% as spots rotate in and out of our view.

So could Tabby's star be exhibiting an extreme case of starspots? Probably not. Because of the way they form, starspots similar to the ones observed on the Sun require that the star have a convective zone near its surface, where boiling motions carry out energy produced within the star. Less massive stars have thicker convective zones, while more massive stars have shallower ones. With 1.4 times the mass of the Sun, Tabby's star should have a small convection zone or maybe even none at all. We'd be surprised to see starspots as big as the Sun's, much less ones big enough to cause 20% variability.

Even if giant starspots were plausible, the dips we observe don't look like the spots observed on other stars. Starspots tend to evolve fairly slowly, taking a few stellar rotations to grow and then slowly fade away, so we see the same spots over and over. Yet on Tabby's star each dip appears only once. What's even more concerning is that the single dips last much longer than the star's rotation period, when they should be rotating in and out of view. Starspots simply couldn't create the signals we see.



▲ **THE FOUR-YEAR DIM** While Kepler photographed every star in its field every 30 minutes, it only recorded the brightness from a few pixels near each star. (Data is expensive to store and transmit, so the less data saved on board the spacecraft, the better.) This strategy induced long-term trends that overwhelmed any slow astrophysical signals. But about once a month, the Kepler spacecraft downlinked raw calibration frames of the entire field. Investigating these frames, Montet and coauthor Joshua Simon found that Tabby's star had faded for the entire primary Kepler mission, with a more precipitous drop in the final few months.

Around the Star

Once our photon has left Tabby's star and begins traversing space, it will first encounter any material in orbit around the star. It's possible that the cause of the dips isn't something intrinsic to the star itself but some material that occasionally passes between the star and us.

We can narrow down the orbit of this presumed material in two ways. First, objects close to the star will become hot and emit infrared radiation. However, observations from the Spitzer Space Telescope and others haven't detected any unusual infrared radiation other than the amount expected from Tabby's star itself. So we know that the material, if it's there, can't be too close to the star.

Second, based on the durations of the dips, the material would need to take several days to pass in front of the star.

CHART: LEAH TISCIONE / S&T / B. MONTET & J. SIMON; COIN: BIGSTOCKPHOTOS.COM / VECTORKAT

From Kepler's laws (the man, not the spacecraft), we know that objects in small orbits move quickly, so they would transit the star quickly, too. If an object were on a circular orbit, it would have to be at least a few times the Earth-Sun distance from Tabby's star to create a transit lasting a few days. If it were on an elliptical track, the object may lie farther out than the orbit of Pluto. At these distances, material would be pretty cold, so it's possible that it could evade infrared detection.

Objects within the star's system are credible based on what we know about our solar system, which has a large cloud of material at these distances called the Kuiper Belt. Lots of other stars have also been found hosting Kuiper Belt analogs, some of them considerably more massive than our own.

Alternatively, a large cluster of asteroids might transit the star. We think Tabby's star could be roughly the same age as the Sun was during our system's period of Late Heavy Bombardment, so it's conceivable that a family of asteroids might have scattered through the young system. Astronomers have created computer models of asteroid or comet clusters transiting Tabby's star, and they match some of the short-term observations reasonably well.

Recently, Brian Metzger (Columbia University) and colleagues proposed that this scenario could be augmented to explain the long-term dimming, too. If Tabby's star had recently (within the past 10,000 years) swallowed a planet-sized companion, the star may have brightened during a time period when we weren't watching. The long-term dimming we've observed might then be a slow return to normal. Remnant clouds of planetary fragments and gas orbiting the star could cause the shorter dips.

An argument against this scenario's plausibility is that we'd expect such material to still radiate in the infrared. Still, we can't quite rule out the possibility. Perhaps there's just enough material to cause the dips but not enough to be detected by infrared telescopes.

Thinking farther outside the box, some astronomers have suggested that material around the star may have a less natural origin: The dips could indicate the presence of an alien megastructure, perhaps a *Dyson sphere* designed to extract energy from the star. Needless to say, this scenario has received considerable media attention. Let's investigate it the same way we investigated the others.

It's workable. An alien megastructure can explain the observations easily enough — almost too easily, since scientists can tweak the megastructure model to match the data. Therein lies the problem with this idea: There are no data on what alien megastructures "should" look like. However it appears, though, it's hard to imagine how a giant structure near the star could avoid heating up and radiating brightly in the infrared.

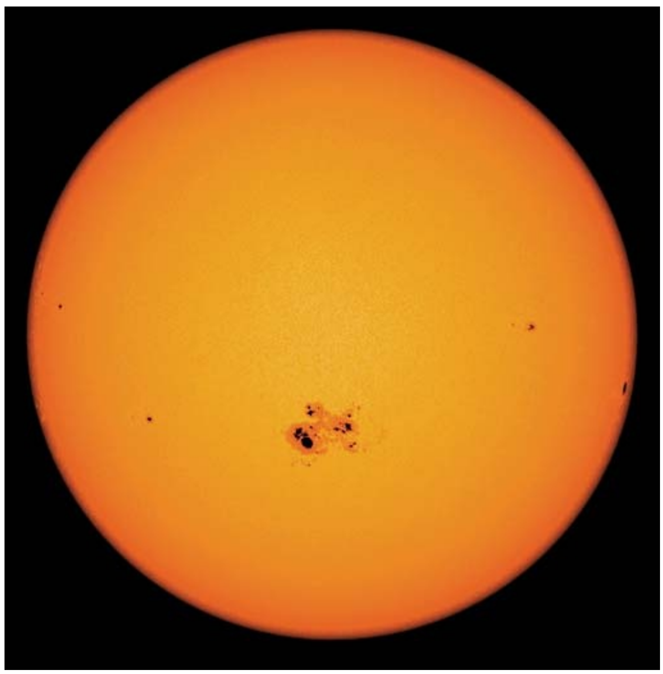
Through Deep Space

After leaving the star's system, the photon will encounter material between the stars. Although this space is a near vacuum, the spectrum of Tabby's star reveals two interstellar gas clouds that lie between the star and us. The spectrum reveals dust in that space, too. Interstellar dust preferentially scatters bluer light while letting redder light through. From the shape of the star's spectrum, we know that about a quarter of the starlight never makes it to our solar system.

Interstellar dust and gas isn't distributed smoothly throughout space; there's significant structure on every measured scale, from hundreds of light-years to tens of astronomical units (a.u.). We don't have a lot of evidence for structure on smaller scales, if only because our instruments aren't sensitive enough yet to measure it. So perhaps small clumps of dusty material are moving along our line of sight, blocking the light from Tabby's star every now and then. The star's long-term dimming may in turn be due to the slow motion of additional interstellar material into our line of sight, which scatters more and more photons.

This scenario is plausible, but it has its faults, too. For example, we might expect other stars, especially those at large distances, to display similar dips. Yet none of the other Kepler stars displays similar changes.

Still, interstellar dust clouds provide an excellent match to observations. The timescales of the short dips seem to make sense: Based on the speeds at which material moves through our galaxy's disk, we would expect interstellar clumps spanning less than 1 a.u. to transit the star over several days in an irregular way. This model would predict no periodicity to the dips, nor any consistency in their depths, just as observed. The hardest detail for this model to explain is the extreme depth of some short dips. A 20% decrease in starlight over a period of days requires a fairly compact clump of dense mate-



▲ **GIANT SUNSPOT** This sunspot, imaged on the surface of the Sun on October 23, 2014, was the largest spot of the current solar cycle, spanning almost 80,000 miles. Spots on other stars may be bigger still, but the size depends on the depth of the stellar convective zones.

NASA / SDO

DICK LOCKE

▲ **THE DUST BETWEEN** Evidence exists for structure within interstellar dust and gas on every scale that we can measure. This image, centered on the Snake (Barnard 72) in Ophiuchus, shows dense concentrations of dust and gas that block out the light from background stars. The Snake is a few light-years across. The concentrations required to explain the brightness variations of Tabby's star would have to be much smaller, less than 1⁄10,000 of a light-year.

rial; it could exist, but we don't know of any such clumps toward the Kepler field.

As in the case of previous scenarios, we can't confirm this one or rule it out with the available data; we can only say it's reasonable and fits the observations.

Into the Solar System

After 1,300 years of traveling through interstellar space, our photon reaches the outer edges of our solar system. What if it came across a cloud of material, perhaps originating from a recent collision between a few comets?

This interesting idea isn't a great fit to the data, nor is it as likely as some of the other ideas. Tabby's star shines at a declination far above the ecliptic plane, where planets and most comets live, and we don't have any evidence for comet collision clouds in the outer solar system so far from the ecliptic.

Also, thanks to Kepler's orbital motion, any nearby object in the solar system would appear to move quickly across the sky relative to more distant stars, so it would have to be huge (spanning an a.u.) to block Tabby's star throughout the year. Any such object ought to affect other Kepler stars as well, and it doesn't, making this scenario unlikely.

Finally, our photon reaches the end of its journey, landing on Kepler's CCD detector and marking its presence by exciting an electron. It's possible that some artificial effect in the instrument caused both the short-term dips and long-term dimming. Such an idea isn't completely implausible; instrumental defects do happen. For every planet that makes it into the Kepler catalog, the automated planet-finding pipeline identifies 10 instrumental artifacts. Such defects might alter a single grouping of pixels; however, Kepler rotates four times by 90° during each orbit around the Sun, in order to keep its solar panels pointed sunward, and we observe Tabby's star's strange behavior across multiple orientations of the telescope. So we can all but rule out instrumental effects.

By the time a photon has landed on Kepler's detector, it has spent more than 100,000 years working through the insides of Tabby's star and traveled another 1,300 years through interstellar space. What conclusions has it led us to? The most likely scenario, it seems, is that a cloud of interstellar or circumstellar material crossed between Tabby's star and Earth.

It's the photons that we observe in the future that will separate the chaff from the wheat.

Let the Experiment Begin

Our favorite scenario, interstellar material crossing between us and Tabby's star, naturally explains both the short-term dips and the long-term dimming. It makes testable predictions, too. First, the overall brightness of the star should continue to change. Because interstellar material preferentially absorbs bluer photons, we would expect that the rate of

• Find more information on AAVSO's campaign to observe Tabby's star here: **https://is.gd/AAVSOTabbysStar**.

change would be different at different wavelengths. The scattering of blue photons would also create different shapes for the short-term dips when measured at various wavelengths, a prediction that we can test if another one happens.

Finally, we would expect the always-present spectral lines, created when interstellar material absorbs the star's light, to change over time. While the lines would look obviously different during a dip, they also ought to change slowly as the long-term dimming continues or reverses.

But interstellar material isn't the only viable scenario. At this point we can't rule out clouds of material orbiting Tabby's star, nor can we rule out the recent ingestion of a planet to explain the long-term dimming. Under these conditions, we would expect the short-term dips to eventually show some periodic behavior and, like the interstellar material scenario, they ought to look different at different wavelengths. However, in this case, we wouldn't expect any significant changes in the interstellar absorption lines during or between dips.

If the star truly is brighter than it should be because it consumed a planet, then we might also expect geometric (parallax) measurements of the star's distance, as will be provided by the Gaia mission, to show that the star is farther away than we think it is.

The remaining scenario under consideration is the one that we can't easily describe as likely or unlikely: an alien megastructure. The real test comes down to what this idea predicts that other ideas do not.

If we were seeing the rotation of a gigantic structure, then we'd expect the star's dips to appear the same at every wavelength, as opposed to the color-dependent dips of circumstellar or interstellar dust, because the giant, solid structures would block all of the star's photons. We would also expect no changes in the shape or strength of the interstellar features observed in the star's spectrum. If any of these turn out not to be true, then natural hypotheses would provide a better fit to the data.

On the other hand, the detection of radio signals, laser pulses, or other signs of alien intelligence from this area of the sky would support the idea of an extraterrestrial megastructure. So far, though, SETI researchers haven't found anything.

Other groups are looking, too, including the Las Cumbres Observatory's global telescope network (see box at right), as well as members of the American Association of Variable Star Observers, who are patiently watching and waiting for another dip that may or may not arrive.

Astronomers are also monitoring the shape and strength of the interstellar absorption features with spectroscopic observations, looking for telltale changes that would suggest pockets of denser interstellar material. Future data releases from the Gaia mission will improve not only our estimate of the star's distance, but also the measurement of the amount of obscuring material that lies between us and the star.

Additionally, the Transiting Exoplanet Survey Satellite (TESS), in many ways Kepler's successor, will search much of the sky for transiting planets. Scheduled for a March 2018 launch, TESS will observe each field, including the Kepler field, for four weeks at a time. If Tabby's star were to dim during this time, TESS would detect it. Moreover, TESS will monitor 500,000 nearby stars during its two-year mission, providing plenty of opportunity to detect analogs to Tabby's star — if they exist — across the Milky Way.

Within a few years, we may understand what makes this star's behavior so out of this world.

■ **BENJAMIN MONTET** is a NASA Carl Sagan Fellow at the University of Chicago, where he studies planetary systems and their host stars.

■ **TABETHA BOYAJIAN** is an Assistant Professor of Astronomy at Louisiana State University.


Las Cumbres Observatory

JOHN MARTINEZ / CC0 1.0

Tabby's Star: Kickstarter Campaign

We can make a strong case to continue monitoring KIC 8462852, but actually doing so isn't trivial. For starters, the Kepler space telescope has moved on to another mission, and we can no longer use its excellent photometric capabilities to keep an eye on the star. That leaves us with ground-based observatories, which are limited by the Sun's daily appearance. For a typical astronomical case, such a limitation wouldn't be an issue, but we can't predict when and what this star will do next. We need around-the-clock coverage so we don't miss a thing. Fortunately, there's a private facility uniquely suited to our needs: the Las Cumbres Observatory (*S&T:* Oct. 2012, p. 36), a global network of robotic telescopes. To help acquire the data, we launched a crowd-funding campaign via Kickstarter. Thanks to the public's enthusiastic response, we raised enough funds to monitor the star for the next couple of years. We're especially excited to see what happens in the next several months — stay tuned!
■ TABETHA BOYAJIAN

 by Govert Schilling

The Square KILOME ARRAY

Spread across two continents, the SKA will be the largest astronomical facility ever built.

TRE

SUNSET OVER THE KAROO MeerKAT dishes stand sentinel at dusk in South Africa's growing radio observatory.
GOVERT SCHILLING

It's a spectacular sunset, with hues ranging from subtle pink and pearl to flaming orange and gold. Venus shines high in the west; Earth's shadow creeps up in the east. Low, thorny vegetation makes it hard to wander around. And dangerous, too — there are scorpions here. I'm in the Great Karoo, a vast semi-arid region, some five hundred kilometers northeast of Cape Town. It's incredibly quiet. Hardly anyone lives here; the nearest small town, Carnarvon, is roughly a hundred kilometers away.

Still, there's ample sign of human activity. Silhouetted against the colorful clouds are the dishes of the South African MeerKAT radio telescope array, which is still very much under construction during my visit in late November 2016. "By the end of 2017, all 64 MeerKAT antennas will hopefully be in place," says my host Angus Flowers, the project's media liaison, as he drives us back to the Losberg Lodge, a former farmstead close to the observatory's central area now operated by radio astronomers.

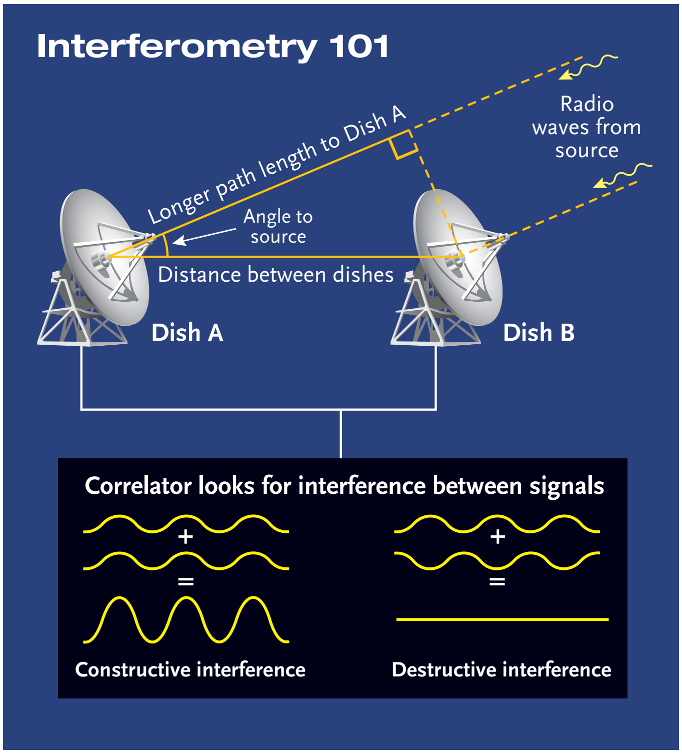
A few kilometers away from the budding MeerKAT is a broken ring of low mountains that help to keep out unwanted radio interference from distant farms and towns. Later that night, when we are outside under the stars, enjoying our *braai* dinner (the popular South African version of barbecue), I imagine what the site may look like some 15 years from now. If you could fly up, high above the flat-topped mesas, you'd be looking down at the largest collection of radio dishes ever built: the South African part of the Square Kilometre Array (SKA). Consisting of 2,000 antennas, it will spread out over much of the Karoo, way beyond the horizon, and even into other African countries.

And that's only part of the story. While the African array (called SKA-mid) will focus on mid-frequency radio waves, its Australian counterpart (SKA-low), made up of more than a million simple antennas, will study the low-frequency radio universe. So far, only the first phase of the ambitious, two-continent project (SKA1) has been funded. SKA1, cost-capped at 650 million euros (nearly $700 million U.S.), will consist of 200 dishes in South Africa and many tens of thousands of antennas in Australia. The hope is to complete the second phase (SKA2) in 2030, with a whopping tenfold increase in observing power.

The SKA is an unprecedented multi-phase, multi-wavelength, multi-continent endeavor. "It never ceases to impress me," says Flowers.

Aperture Synthesis

Radio astronomy is a young discipline. After Karl Jansky's 1933 discovery of radio waves from the Milky Way, it took until the late 1950s before giant dishes were erected, like the venerable 76-meter Lovell Telescope at the Jodrell Bank Observatory in northern England. But only with the advent of the techniques called *radio interferometry* and *aperture*



▲ **HOW INTERFEROMETRY WORKS** *(Above)* When two radio antennas observe a source that's not at the zenith, the signal travels slightly different distances to reach each of them (here, the path to Dish A is longer than to Dish B). A supercomputer correlator then compares the signals and determines how much of a shift is necessary to make the signals constructively interfere. That shift corresponds to the time delay, and thus the path length difference and angle to the source. Combining this information from many pairs of antennas improves the position's accuracy.

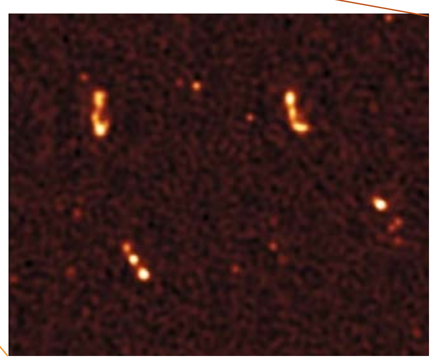
synthesis in the 1960s did astronomers succeed in obtaining detailed "images" of the radio sky. These are the techniques behind famous facilities like the Westerbork Synthesis Radio Telescope in the Netherlands, the Karl G. Jansky Very Large Array (VLA) in New Mexico, and the Atacama Large Millimeter/submillimeter Array (ALMA) in northern Chile (*S&T:* Nov. 2013, p. 22).

As most amateur astronomers know, a telescope's aperture determines both the instrument's light-gathering power ("sensitivity") and its angular resolution. But angular resolution also depends on wavelength. While a 4-inch optical telescope provides a resolution of approximately one arcsecond, you would need a 50-kilometer dish to "see" the same amount of detail at a radio wavelength of 21 centimeters, equivalent to a frequency of 1420 megahertz.

However, an array of smaller dishes spread out over an area 50 kilometers across works almost as well. By combining the signals detected by the individual antennas (the process called radio interferometry), you can synthesize a virtual telescope (aperture synthesis) that's as large as the distance between the dishes, albeit with a much lower sensitivity than a single huge instrument would have.

MeerKAT, with its 13.5-meter dishes, uses this same technique. More than five years ago, South African radio astronomers and engineers completed a test facility, known as KAT-7 (Karoo Array Telescope, with seven 12-meter dishes). The main goal was to demonstrate the country's ability to design, build, and operate such high-tech instruments, in support of South Africa's bid to eventually host the Square Kilometre Array. MeerKAT is now one of the four official SKA precursor telescopes. The observatory's first-light image, obtained with only 16 operational dishes, was released in July 2016. It shows more than 1,300 remote galaxies — most of them never observed before — in an area of sky measuring approximately 2° on a side.

The preliminary results bode well for the completed MeerKAT array, but even more so for SKA1-mid — the mid-frequency part of the SKA's first phase. Construction will start in 2018, using Chinese-built antennas to expand the existing array. SKA1-mid will provide a maximum baseline of 150 km and a total collecting area of some 33,000 m^2, equivalent to 126 tennis courts. It will have four times higher resolution and five times higher sensitivity than the VLA.



◀ **FIRST LIGHT** Each bright dot in the image at far left represents a distant galaxy, detected with the first 16 dishes of the MeerKAT array in 2016. The close-up *(near left)* zooms in on a few of these galaxies, revealing radio-bright outflows powered by the galaxies' supermassive black holes.

DIAGRAM: LEAH TISCIONE / S&T; FIRST LIGHT: SKA SOUTH AFRICA (2)

Prospects and Challenges

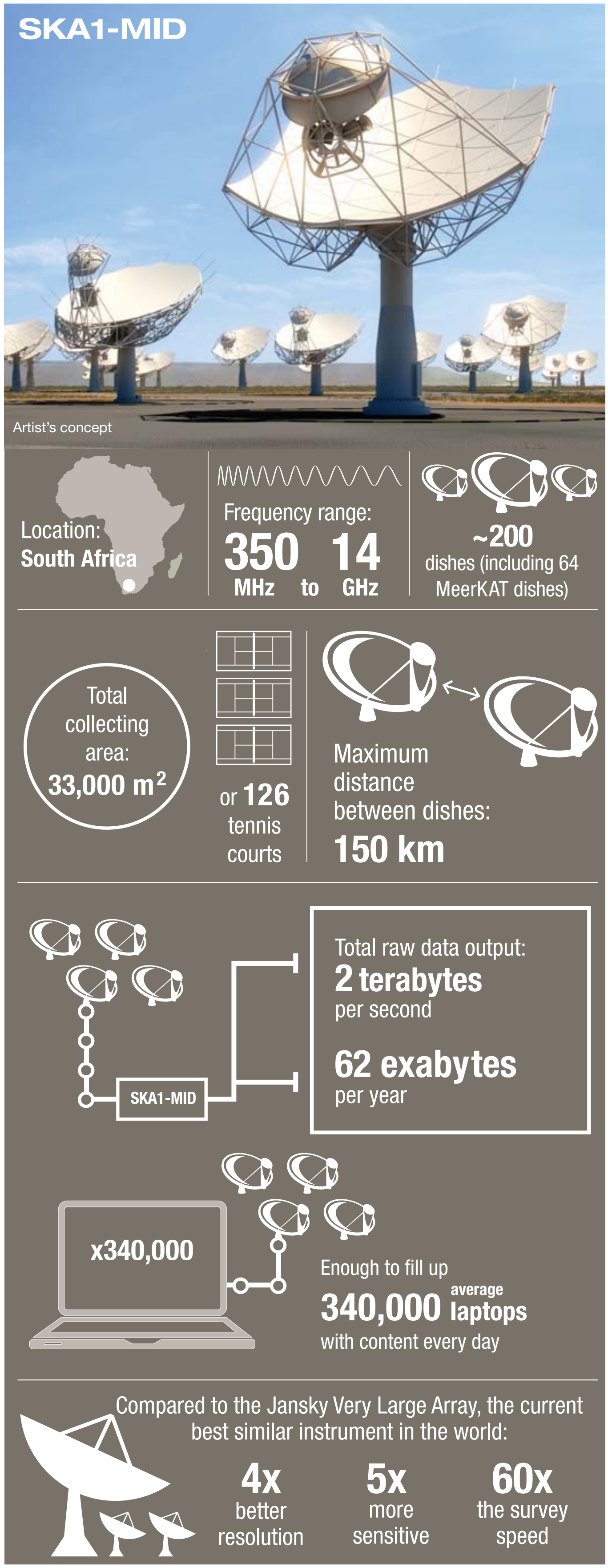
With its huge frequency range (50 to 350 megahertz for SKA-low, and 350 megahertz to 14 gigahertz for SKA-mid), the first phase of the Square Kilometre Array is already going to be an incredibly versatile instrument. According to British radio astronomer Phil Diamond, Director General of the SKA Organisation, the project is similar in scale to other big observatories such as ALMA, the James Webb Space Telescope, and the European Extremely Large Telescope, and will contribute to a vast number of science topics. “It will cover almost everything, from fundamental physics to extraterrestrial life,” he says, adding, “Yes, SETI is in the science case.”

The SKA will reveal the cosmic distribution of hydrogen gas throughout space and time, able to reach back to the universe’s first 100 million years. This distribution will shed light on the evolution of galaxies and the history of star formation, since both of these processes use hydrogen as a building block — and, when enough radiation is involved, can ionize its atoms on large scales, transforming the hydrogen landscape (see page 30). Studying cosmic evolution and the growth of the universe’s large-scale structure should also provide more information on the role and nature of dark matter and dark energy.

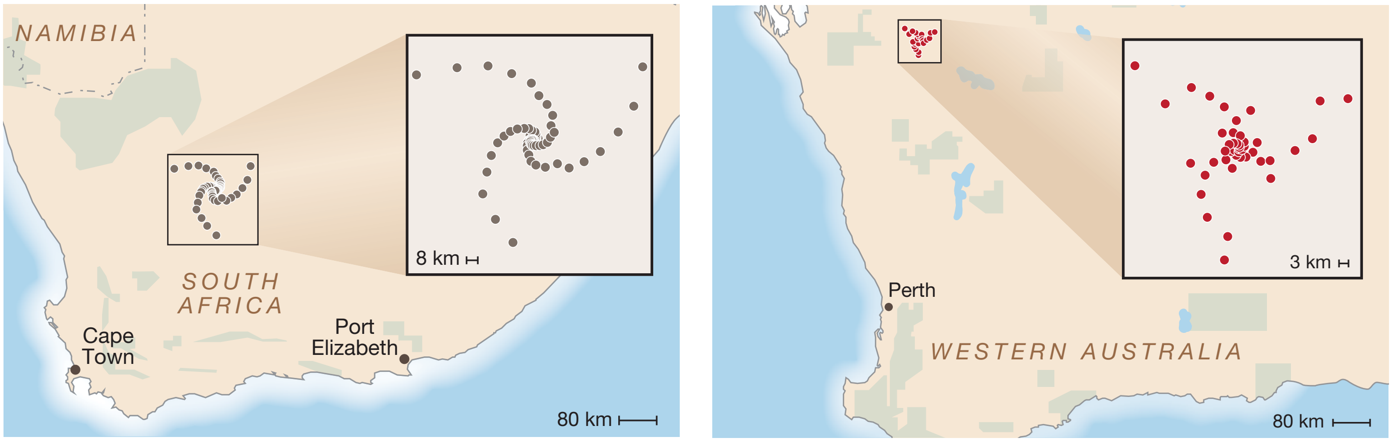
On a less cosmic scale, the SKA is sensitive enough to detect the faint radio waves that are emitted by rotating carbon-bearing molecules, both in large molecular clouds and in protoplanetary disks, giving insight into prebiotic chemistry. Its data will enable astronomers to map intergalactic magnetic fields by measuring the fields’ effects on the polarization of radio waves, or by observing synchrotron radiation from electrons spiraling around magnetic field lines.

As for fundamental physics, SKA1 will be a superb pulsar observatory. By meticulously measuring the pulse arrival times of dozens of millisecond pulsars all over the sky for many years on end, astronomers hope to finally detect extremely low-frequency gravitational waves from binary supermassive black holes in remote galaxies. Just like the recent detections of higher-frequency spacetime ripples from merging black holes (*S&T:* May 2016, p. 10), such observations would provide stringent tests of Einstein’s theory of general relativity and might lead the way to a successful description of quantum gravity. The gravitational waves will (hopefully) appear in SKA1-mid’s data, while SKA1-low’s observations will provide a baseline to clean out noise.

Building the SKA is not going to be an easy catch, though. The Great Karoo is a desert-like, almost uninhabited area. Tens of kilometers of gravel roads and tracks had to be sealed to allow easier access to the observatory from Carnarvon. Nearby farmers need to be convinced that MeerKAT (and SKA after it) is not producing harmful radiation, and conversely that they need to keep sources of radio interference to an absolute minimum. The local population turns out to be very suspicious of the ever-growing facility, with some worried it will devolve into a land grab and destroy the agricultural economy.



SKA ORGANISATION



▲ **ON THE MAP** Shown are the preliminary locations for SKA1-mid and SKA1-low. Each South African icon represents a single dish; each Australian icon represents a station of 256 individual antennas. The insets give a slightly clearer picture, although the sheer scale is still hard to grasp. Designers chose the spiral configuration because it provides a variety of baseline distances and angles between antennas, enabling very high-resolution imaging with interferometry. (The best layout would be random, but construction considerations make that undesirable.)

Then there's the technical challenge. Building the dishes, pedestals, and sensitive receivers is one thing, but hooking every single antenna up to a central supercomputer through optical fiber connections is another. SKA1-mid's total raw data output amounts to 2 terabytes per second, or over 60 exabytes (60×10^{18} bytes) per year — more than 5% of the total internet data traffic in 2016. This all has to be processed in real time by dedicated correlators and data processors to produce the final high-resolution radio images that astronomers are after. The required number-crunching power is on the order of 350 petaflops — 350 thousand trillion calculations (or *floating point operations*, hence "flop") per second; the expected yearly output of archived science data products would fill 7 billion DVDs. As Australian astronomical computing expert Andreas Wicenec (University of Western Australia) says, "The deluge continues."

Outback Struggles

I met Wicenec in June 2016 in Perth, Western Australia, where he's involved in the Australia SKA Pathfinder (ASKAP). Nearing completion at the Murchison Radio-astronomy Observatory, some 800 kilometers north of Perth, ASKAP is another SKA precursor telescope. It's a six-kilometer wide, 36-antenna array. The 12-meter dishes are each equipped with *phased array feeds*, receivers capable of detecting multiple radio beams simultaneously, providing the observatory with an unprecedented 30-square-degree field of view — 150 times the apparent area of the full Moon in the sky.

According to Wicenec, ASKAP produces some 250 terabytes per day of raw data, more than 15 times the nightly data forecast for the upcoming Large Synoptic Survey Telescope (*S&T:* Sept. 2016, p. 14). A dedicated supercomputer called Galaxy at the Pawsey Supercomputing Centre in Perth processes the flood. At present, it's the fastest radio observatory in the world in terms of survey speed. Astronomers expect ASKAP to eventually map some 70 million radio sources — a thirtyfold increase over the current number.

Like MeerKAT, the project was largely developed to support an SKA bid — in the first decade of this century, both South Africa and Australia were hoping to host the future array, back when the plan was to have it in only one place. But contrary to MeerKAT, ASKAP will not become part of the SKA: SKA-low will be at the same site, but it will use a completely different kind of antenna. Instead, says CSIRO's Astronomy and Space Science director Douglas Bock, ASKAP will be a great observatory on its own. Bock expects the array to be completed in 2018.

In May 2012, after a lot of political tugs of war, it was finally decided to build the Square Kilometre Array on *both* continents. "That wasn't necessarily the cheapest option,"

SKA Precursors

Name	Location	Frequency range	Antenna type
Australia SKA Pathfinder (ASKAP)	Australia	700 MHz–1.8 GHz	12-m dish
Hydrogen Epoch of Reionization Array (HERA)	South Africa	50–250 MHz	14-m mesh dish
MeerKAT	South Africa	300 MHz–3 GHz	13.5-m dish
Murchison Widefield Array (MWA)	Australia	80–300 MHz	dipole antenna

LEAH TISCIONE / S&T; SOURCE SKA ORGANISATION (2) admits SKA director Diamond, “but it was a nice way to exploit the best qualities of both sites.”

The original goal was to expand ASKAP to a 96-dish array. With its huge field of view, it would have become the survey part of the Square Kilometre Array — a full-fledged third observatory next to SKA-mid and SKA-low. But two years ago that plan was scrubbed — at least for the foreseeable future — because of budgetary issues. Instead, the first phase of the Australian part of the SKA will just contain about 130,000 simple dipole antennas, grouped in stations of 256 each. The relatively cheap, mass-produced antennas will look a bit like small, slender Christmas trees and stand almost two meters tall. A few years from now, the Australian outback will be decorated with some 500 patches of metal forest.

Spiders and Christmas Trees

The technique of using huge numbers of dipole antennas to create maps of the low-frequency radio sky has been pioneered over the past decade by the Low Frequency Array (LOFAR) in the Netherlands, which was inaugurated in the summer of 2010. The concept is pretty straightforward. LOFAR consists of some 50 individual “stations,” each about 100 meters across and containing dozens of dipole antennas. Radio waves from a source at the zenith, right above your head, will arrive at all the antennas in a particular station at exactly the same time. But for every other position in the sky, there will be tiny differences in the wavefront’s arrival time. By combining the signals from individual antennas according to the specific pattern of time-of-arrival differences that corresponds to a particular sky position, a LOFAR-like array can be virtually “pointed” in any direction — a process called *beam forming*.

In fact, smart computer processing allows LOFAR’s dipoles to “look” in eight different directions at once. To further enhance resolution, astronomers then combine observations from the individual stations interferometrically.

The required computer processing power for this technique is huge: SKA1-low will produce an incredible 157 terabytes of raw data *per second*, or five times the estimated global internet traffic in 2016. Because of the limited capacity of optical fibers, part of the data reduction will be done by smaller processors at the actual antenna stations.

The Murchison Radio-astronomy Observatory feels even more remote than MeerKAT in South Africa: Murchison Shire spreads about 110 inhabitants across an area larger than the Netherlands. A small propeller aircraft takes me from Perth to Boolardy Station, a former sheep farm east of the settlement. It’s a spectacular 90-minute flight over an orange-red semi-desert covered with low, shrubby vegetation. From Boolardy, it’s another 30 minutes by 4WD truck to the actual observatory. Eagles soar high in the sky; a young kangaroo hops across the bumpy gravel road. In the harsh sunlight, the white dishes of ASKAP are almost too bright to look at. Technicians are using small mobile cranes to install new phased array receivers.

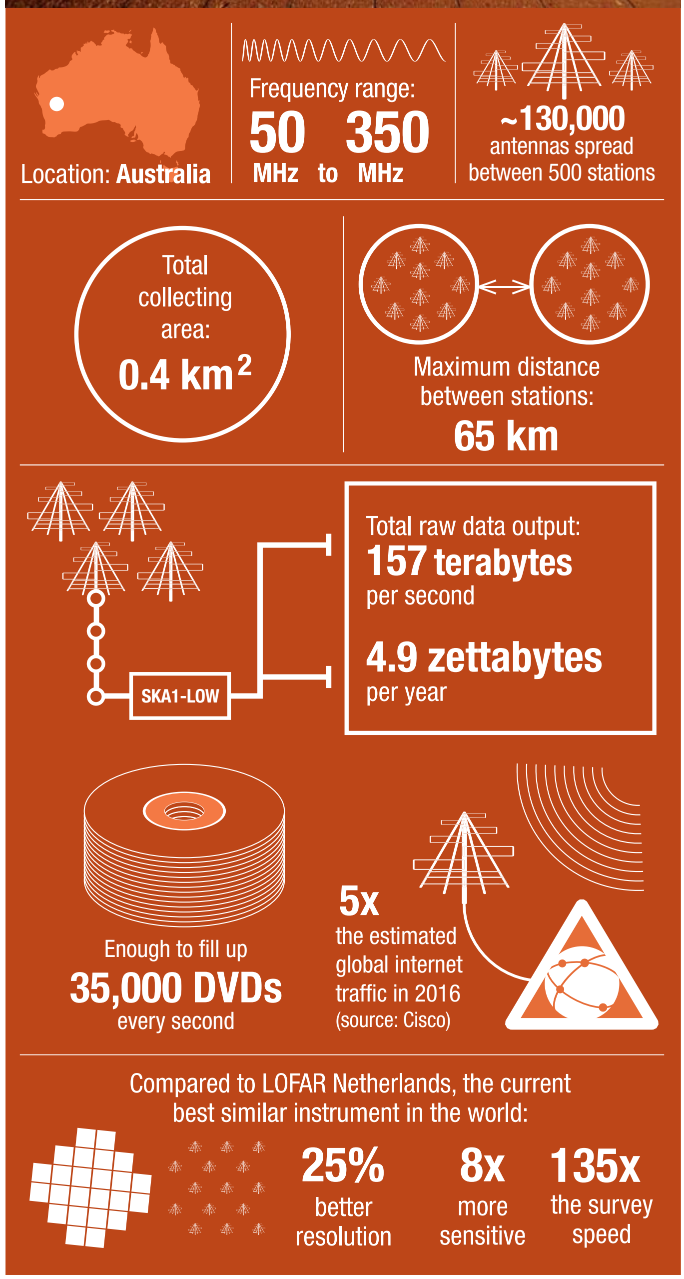
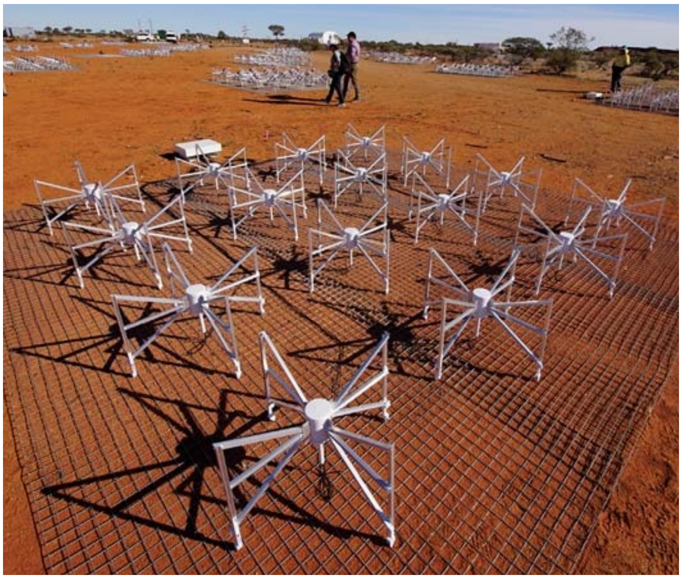


PHOTO: GOVERT SCHILLING; INFOGRAPHIC: SKA ORGANISATION



▲ **RADIO SPIDERS** About knee height, the antennas of the Murchison Widefield Array stand together in "tiles" of 16 antennas. They cover a similar frequency range as SKA1-low will but use a different antenna design.

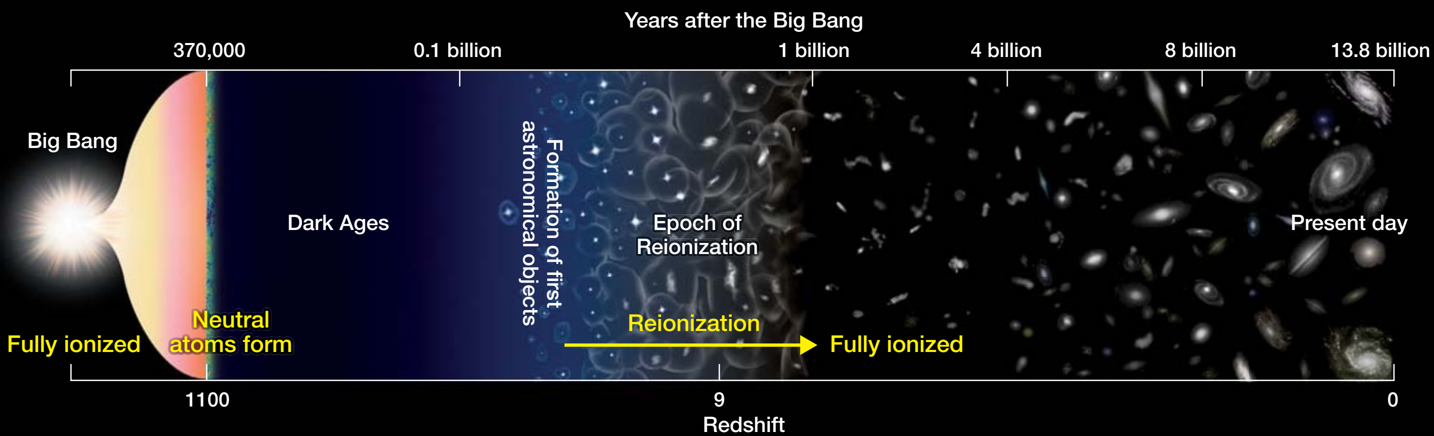
Not far from the core region of ASKAP is the Murchison Widefield Array (MWA), the third SKA precursor instrument. More or less similar to LOFAR, it consists of 128 "tiles" of 16 small, spider-like antennas each. By the time you read this, the number of tiles will probably have grown to 256 — they're really cheap and easy to deploy. For SKA1-low, the antennas will have a different design, and the tiles, or stations, will be bigger and more numerous. Eventually, a total of 512 stations will be spread out over an area 65 kilometers across. As each station will hold 256 antennas, the total number of "Christmas trees" is 131,072. In the proposed second phase of the Square Kilometre Array, the plan is to increase the number of antennas to well over a million, and to have outlier stations all over the Australian continent and even in New Zealand.

Cosmic Dawn

With 25% better resolution, eight times higher sensitivity, and 135 times faster survey speed than LOFAR, SKA1-low is poised to finally solve the riddle of cosmic dawn: when and how the cosmic dark ages came to an end, and what kind of objects — massive stars or fledgling quasars — were the first

PHOTO: GOVERT SCHILLING; ILLUSTRATION: GREGG DINDERMAN / S&T, SOURCE NAOJ

The Epoch of Reionization



MILESTONES IN COSMIC HISTORY After the Big Bang, the universe was filled with a soup of photons and subatomic particles. After 370,000 years, it cooled enough for atoms to form, mostly neutral hydrogen. (This is also when the light of the cosmic microwave background was released to fly freely through the universe.) The universe remained in a neutral state until light from the first stars and galaxies started to ionize their surroundings in the Epoch of Reionization. After several hundred million years, the gas in the universe was completely ionized.

◖ **AFTER THE VIOLENCE** of the Big Bang fully subsided, some 370,000 years later, the universe was filled with cool, neutral hydrogen gas. But those cosmic dark ages came to an end when the energetic radiation of the first stars and quasars started to ionize their surroundings. Over time, these growing bubbles of hot gas became ever more numerous. Eventually, they started to overlap each other and, in the end, intergalactic space became ionized.

Astronomers can learn a lot about the early evolution of the universe by studying this *Epoch of Reionization* (it's called *re*-ionization because the gas started out in an ionized state right after the Big Bang). Neutral hydrogen atoms naturally emit at a radio wavelength of 21.1 cm (a frequency of 1420.4 MHz), but the radiation from these very early epochs has been redshifted by the expansion of the universe to wavelengths of a couple of meters. This range falls in the low-frequency regime. By mapping the sky at various wavelengths (corresponding to various redshifts and look-back times), cosmologists will be able to reconstruct the details of how neutral hydrogen disappeared from the scene.

▲ **HERA** One of four SKA precursor projects, HERA detects radio signals from neutral hydrogen, studying the large-scale cosmic structure that existed before and during the Epoch of Reionization.

SKA SOUTH AFRICA

to make the universe shine. Similar observations will be carried out in South Africa's Great Karoo by the HERA telescope (Hydrogen Epoch of Reionization Array), which is the fourth and final SKA precursor instrument. Next year, HERA will consist of some 350 simple stationary wire-mesh dishes, each 14 meters across and sitting shoulder-to-shoulder to catch low-frequency radio waves from the zenith.

By the end of this year, the detailed design and the construction proposal for the first phase of the Square Kilometre Array will be completed. Diamond expects construction to start next year. In fact, the first 12-meter antenna has already arrived on site in South Africa.

"We'll have early science results in 2021, and SKA1 will be fully operational in 2024," Diamond says. "It's a huge challenge. We're developing and constructing something no one has ever built before." Asked about the prospects for the second phase of the project, the SKA director admits that none of the 12 member countries has committed themselves to building SKA2 yet. "There's always the risk of cancellation, but it doesn't particularly keep me awake at night," he says.

Nor me. What *does* keep me awake, both in the South African Karoo and in the Australian outback, is the unbelievable view of the star-studded night sky — a universe filled with wonder. Ten years from now, many outstanding cosmic mysteries may have been solved by the sheer power of humankind's largest and most sensitive astronomical observatory ever. And there's little doubt that the Square Kilometre Array — even if only phase 1 will ever be realized — is going to present us with a lot of scientific surprises, too. Says Diamond: "When the Hooker telescope on Mount Wilson started operations in 1917, no one expected the discovery of the expansion of the universe. I have really no idea what the SKA will be famous for a century from now."

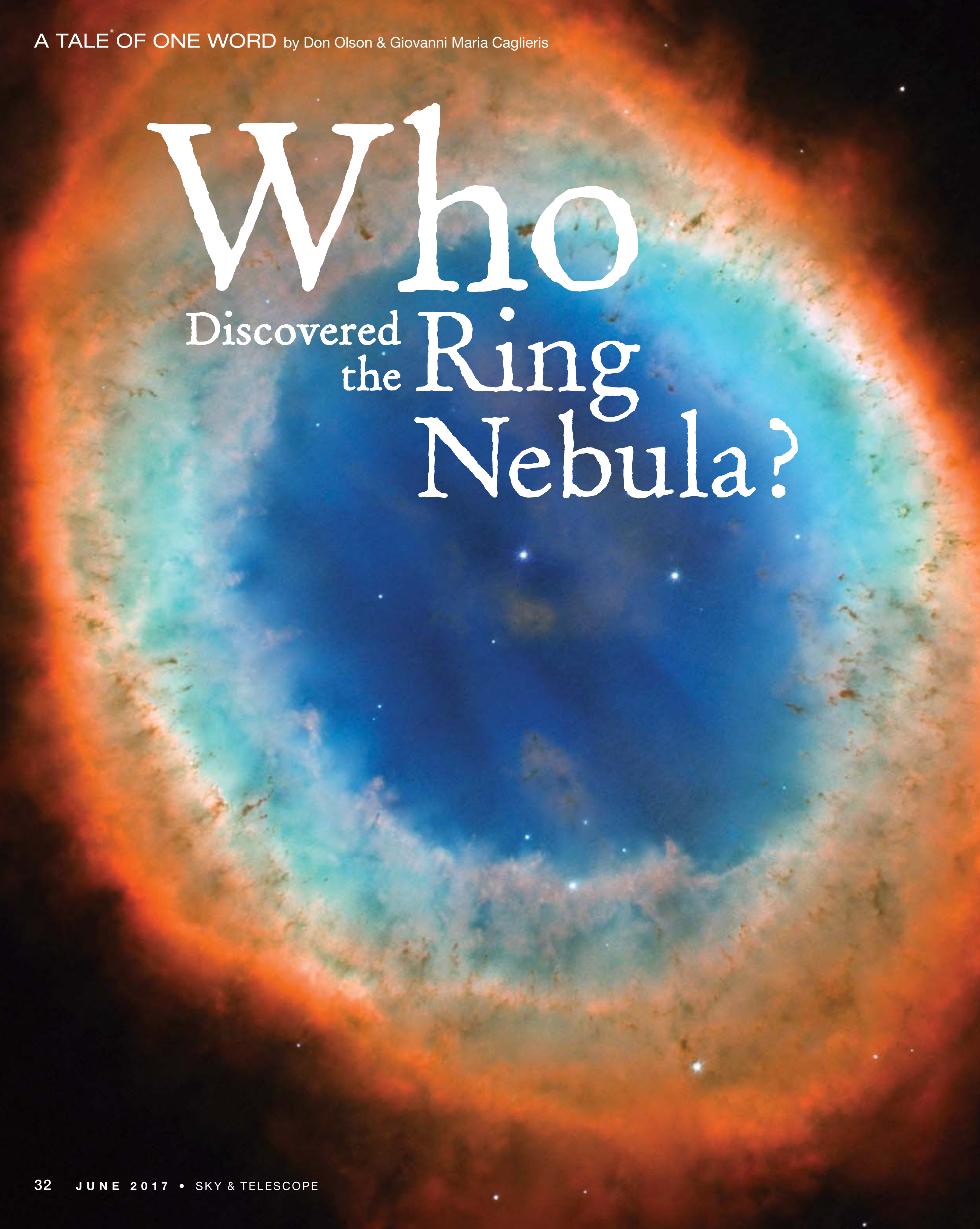
■ *S&T* Contributing Editor **GOVERT SCHILLING** lives in the Netherlands but enjoys visiting astronomical facilities all over the world. In August 2017 Harvard University Press will publish his new book, *Ripples in Spacetime: Einstein, Gravitational Waves, and the Future of Astronomy*.

WHAT SQUARE KILOMETER?

The Square Kilometre Array (British spelling) is named after the planned total collecting area of its second phase (SKA2). However, the first phase of the project (SKA1) will be much smaller. SKA1-mid, consisting of a couple hundred dishes in South Africa, will end up with a total collecting area of some 33,000 m^2 (0.033 km^2); SKA1-low, in Australia, will have a collecting area of 0.4 km^2, basically due to the large concentration of antenna fields in the core region of the array (so the collecting area won't grow by a factor of ten when SKA2 is realized). Combined, SKA1 will have a collecting area of less than half a square kilometer. For comparison: the recently completed Chinese Five-hundred-meter Aperture Spherical Radio Telescope (FAST; *S&T:* Feb. 2017, p. 26), the largest single-dish instrument in the world, has a collecting area of 0.2 km^2.

 by Don Olson & Giovanni Maria Caglieris

Who Discovered the Ring Nebula?



All the books name the wrong "discoverer" for this iconic object. Blame shifting language.

THE RING NEBULA, Messier 57 in Lyra now rising up the eastern evening sky, is a familiar target for astronomers of every stripe. It's the first deep-sky object that many new telescope users hunt, since it's easily located between two naked-eye stars. In the eyepiece it's a prototype planetary nebula: a tiny, dim-gray donut eerily distinct amid the pinpoint stars. Among astrophysicists, it's one of the most-researched examples of what happens when a moderate-mass star like the Sun ends its fuel-burning life.

Six years ago an international team directed the Hubble Space Telescope's Wide Field Camera 3 to M57 and used seven filters to take exposures in seven colors. The combined data produced the spectacular image at left, issued in 2013 by the Hubble Heritage Project.

Their press release looked back at the Ring's history among Earthly astronomers and assigned its discovery to the 18th-century French astronomer Antoine Darquier, a contemporary of Charles Messier of Messier Catalog fame.

But astrophysics is simple compared to the tangles of human affairs. Who was really the first person to see and record this iconic object? We set out to resolve, once and for all, this not-so-simple question.

Darquier the Discoverer?

According to that Hubble Heritage Project press release, "The Ring Nebula . . . was discovered in 1779 by astronomer Antoine Darquier de Pellepoix, and also observed later that same month by Charles Messier."

Darquier likewise gets the credit on the public outreach pages of the European Southern Observatory:

> Darquier . . . first saw the Ring in January 1779 by using a telescope of about 3-inch aperture. . . . A short time later, Charles Messier also saw it and added it to his catalogue . . . as M57.

A long trail of authors similarly name Darquier. The encyclopedic compilation *Cosmos,* which the famed naturalist and scholar Alexander von Humboldt published in 1850, included a discussion of Messier objects and asserted:

> No. 57, Messier . . . was first observed by Darquier at Toulouse in 1779, when the comet discovered by Bode came into its vicinity.

The influential astronomy popularizer Camille Flammarion used similar language a generation later. Today astronomical readers have a shelf-filling variety of books surveying the Messier catalog, and every one we have seen credits Darquier. But astute readers know that much popular astronomy history comes by way of long chains of authors copying each other and not consulting original sources.

One scholar, J. A. Bennett of Britain's Royal Astronomical Society, had suspicions regarding the M57 story:

> It seems strange, for example, that no sources are cited for Darquier's discovery of M57.

Since Bennett wrote those perceptive words in 1976, photoscans of primary sources, including the observation notes of Darquier and other 18th-century astronomers, have become available online. This makes it possible to answer the question conclusively: Who discovered M57?

It wasn't Darquier.

Bode's Comet and Messier's Nebulae

Most newcomers to astronomy soon learn that when Charles Messier created the world's first true catalog of deep-sky objects, his main motive was to ease his search for comets. He wanted a handy list of faint clouds that might be mistaken for comets and could be ignored. But he did other astronomical work as well.

◀ **FULL GLORY** A dim little 9th-magnitude patch of gray in backyard telescopes, the Ring Nebula reveals more of its endless intricacies in this composite of narrowband images from Hubble. The glowing blue helium that fills the "donut hole" is actually a football-shaped structure inside the brighter barrel-shaped ejecta from the central star. We see both the barrel and the football end on. Knots of dark dust erode and cast shadows in the superhot central star's ultraviolet glare. The Ring is roughly 2,500 light-years away and 1 light-year across its bright part. **Above:** Antoine Darquier (1718–1802) is shown measuring star positions with a quadrant in his private observatory at Toulouse, France. This engraving, by Géraud Vidal based on a painting by Léonard Defrance, appeared in the first volume of Darquier's *Observations Astronomiques, Faites a Toulouse* (1777).

NASA / ESA / C. R. O'DELL *ET AL.* / D. THOMPSON, PORTRAIT: COLLECTION OF DON OLSON


THE CATALOGER Charles Messier (1730–1817) wears a dress wig and formal clothes in this portrait from around 1770, attributed to the artist Nicolas Ansiaume.

Late on the night of January 18–19, 1779, as Messier wrote in the *Histoire de l'Academie Royale des Sciences* for that year, the "sky was perfectly clear" as he prepared to make a routine timing of when Jupiter's satellite Io would disappear into the planet's shadow. While waiting for this eclipse to take place, he took advantage of the clear sky to sweep for comets with a wide-field telescope. At about 5 a.m. he landed on one:

> Before making the observation of [Io's eclipse], I scanned the sky with an ordinary telescope of 2 feet focal length, very sharp and clear & with a large eye-piece, which allowed seeing a span in the sky of 5 or 6 degrees, and I discovered to the east a nebulosity which was a few minutes in extent, and which could not be seen with the naked eye. I thought that this nebulosity could only be a comet, appearing near the head of the Swan, and near a star of the fifth magnitude, the second in the constellation Cygnus [2 Cygni].

Messier then switched to an "achromatic telescope of 3½ feet [focal length] with a triple objective, made in London by Dollond," to time the Io eclipse (it began at 5:53 a.m.). The telescopes of optician John Dollond were among the best available at the time, and Messier quickly turned this one back to the new comet. At 6:08 a.m. he used a filar micrometer to determine its right ascension and declination by measuring its offset from 2 Cygni, whose coordinates were in the star catalog of John Flamsteed. Messier noted that the "nucleus of the comet seemed quite brilliant . . . surrounded by nebulosity which extended to 4 minutes; the tail appeared 33 minutes in length, directed toward the northeast." In fact the comet had already been discovered — by Johann Elert Bode, director of Berlin Observatory, for whom it became known as Bode's Comet.

Messier also made another find that morning. He saw, "not far from the comet" and with nearly the same declination, a "very faint nebula . . . . twilight prevented me from determining its place." Overcast skies prevented observations on the next three nights, but on "the 23rd in the morning, the sky was clear. . . . I saw that the comet since the 19th had approached the star γ of Lyra." Messier also looked back at the "very faint" stationary cloud that he had seen on the 19th, and carefully measured the precise position of this "nebula near the head of the Swan." Today we know it as the globular star cluster M56. On Messier's chart of the comet's path (page 36), it's noted as "Neb 1779."

A few nights later, Messier made his next major discovery:

> On January 31st in the morning, the sky was perfectly clear. . . . In comparing the comet to β Lyrae on this morning, I observed in the telescope a small patch of light, which seemed to consist of only very small stars, which we cannot distinguish with this instrument: this patch of light was round and was located between γ & β Lyrae.

Messier immediately measured its right ascension and declination. The description and position prove that Messier definitely observed the Ring Nebula on January 31, 1779.

His chart of the comet's path labels this object "Neb 1779," as with M56. Messier later included it as entry 57 in his catalog, with this description:

> Patch of light located between γ & β Lyrae, discovered while observing the Comet of 1779, which passed very close: it seemed that this patch of light, which is round, was composed of very small stars: with the best telescopes it is not possible to see them, it remains only a suspicion that they are there. M. Messier reported this patch of light on the chart of the Comet of 1779. M. Darquier in Toulouse discovered this nebula, while observing the same Comet, & he reports: "Nebula between γ & β Lyrae; it is very dim, but with a sharp boundary; it is as large as Jupiter & resembles a planet which is fading away."

That quote from Darquier may be partly responsible for the term "planetary nebula" eventually taking hold for this class of objects.

Messier's remark that Darquier "discovered this nebula," well known to Humboldt, Flammarion, and later authors, explains the consensus crediting Darquier today.

But language and usage subtly shift across the years. When did Darquier actually begin observing the comet? Did he spot the Ring Nebula before or after Messier's definite observation on January 31st? Can we find a primary source written by Darquier himself?

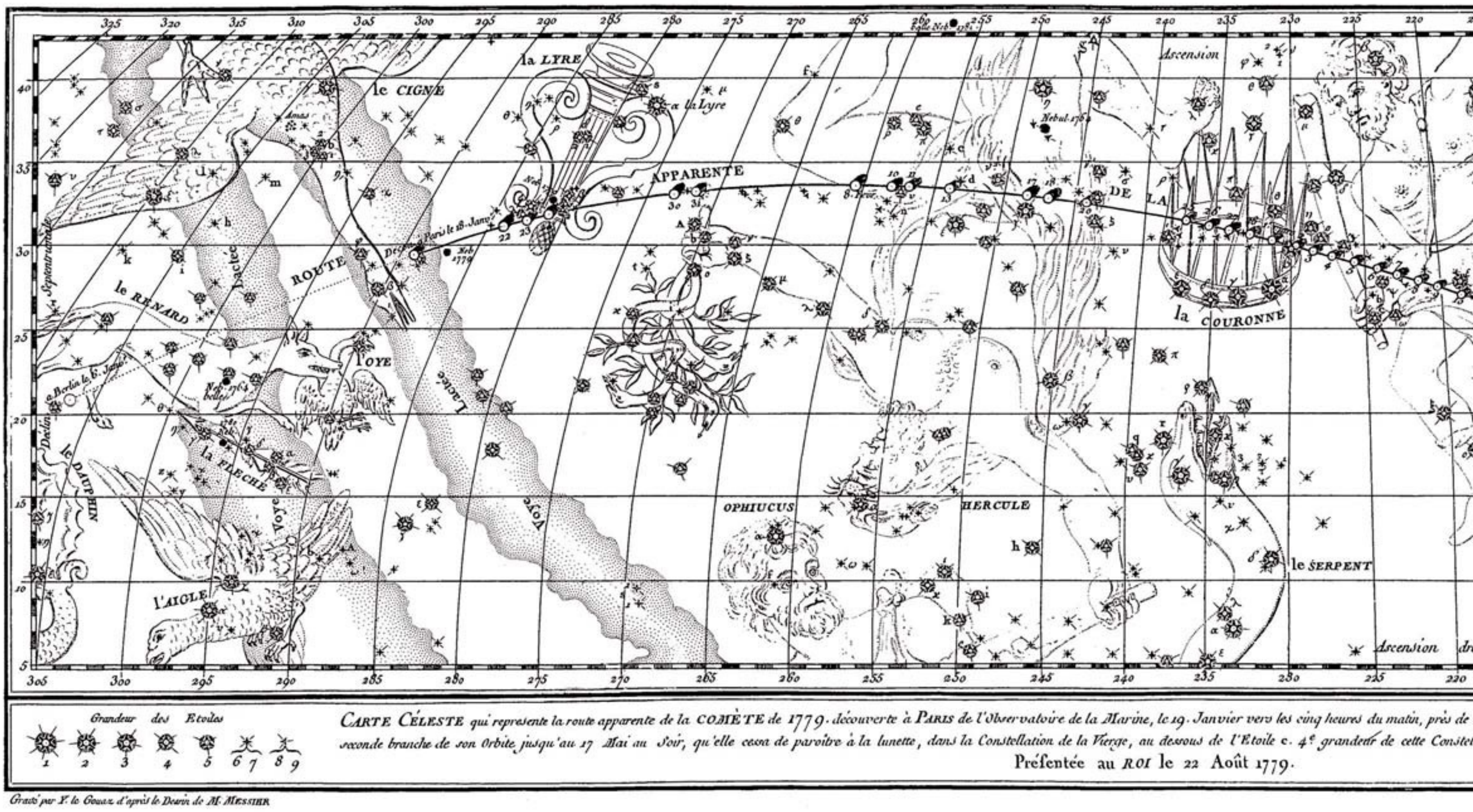
Darquier's Observations

Two such primary sources are available online. The first is a lengthy letter Darquier sent to Messier in September 1779; it appears in *Histoire de l'Academie Royale des Sciences* immediately after Messier's contribution.

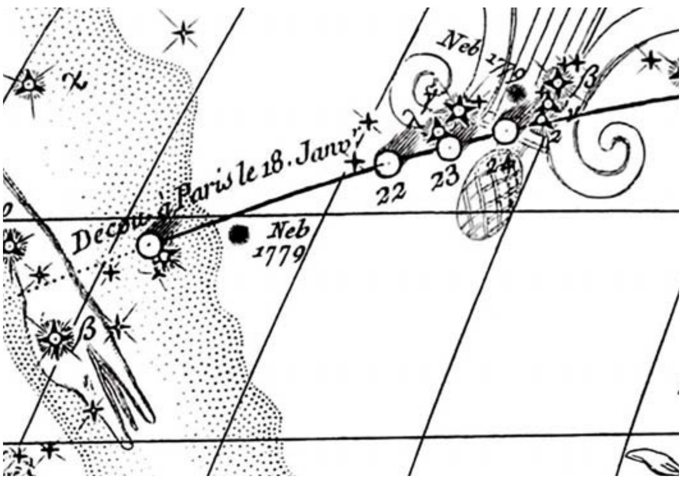
In his letter, Darquier explains why he did not even begin to follow the comet or scan the sky near its path until more than a week into February:

COLLECTION OF DON OLSON

▲ **OBSERVATORY TOWER** Through an arch of the Hôtel de Cluny in Paris, we see the tower supporting Messier's observatory, from which he discovered comets, clusters, and nebulae. This portrayal, drawn by Frederick Nash and engraved by John Pye, appeared in *Picturesque Views of the City of Paris and its Environs* (London, 1823).



▲ **COMET'S PATH** Messier published this chart showing the track of the Comet of 1779, also called Bode's Comet (today, C/1779 A1 Bode). In 1779 Messier noticed six "nebulae" near its path. He later put them in his catalog as M56 and M57 in Lyra, and M58, M59, M60, and M61 in Virgo. The chart was not published until 1782, so Messier also marked the positions in Virgo and Coma Berenices of 11 objects observed in 1781, later cataloged as M84–M91 and M98–M100.



▲ **COMET NEIGHBORS** This detail from Messier's chart shows the path of the Comet of 1779 as it moved from Cygnus across Lyra into Hercules. Messier first spotted it on January 18th by the astronomical reckoning of the date in his era (counting from noon to noon), or on the morning of January 19th by civil date (midnight to midnight). That same morning he discovered, between the Swan and the Lyre, the cloud marked "Neb 1779": the globular cluster M56. On January 31st Messier first noticed, between β and γ Lyrae, another "Neb 1779": later M57, the Ring Nebula.

> I was informed about the apparition of the Comet of 1779 only by the Gazette de France, which arrived here on February 9th, in which Monsieur Messier announced the discovery he had just made. . . . On the night of February 9–10, I searched around midnight; I found the comet by the bend of the left leg of Hercules.

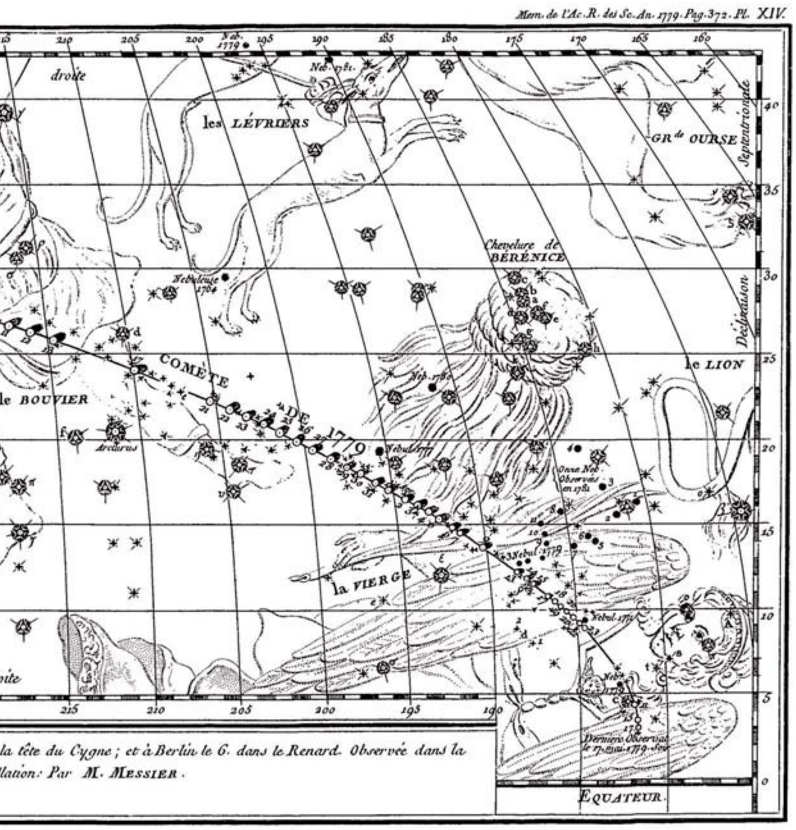
Indeed, a story about the comet appears in the *Gazette de France* for Tuesday, January 26th, and includes the lines:

> Monsieur Messier . . . discovered at l'Observatoire de la Marine, on the 19th of this month, at about five o'clock in the morning, a new comet; it appeared near the head of Cygnus, between this constellation and that of the Lyre. . . .

The newspaper reached Darquier in the south of France two weeks later, on February 9th. Such a delay was typical for the 18th century, according to Gilles Feyel, an expert on the distribution of early French newspapers.

In his letter to Messier, Darquier detailed the ambitious observing project he carried out between February 10th and the end of April. For the sky near the path of the comet, Darquier created his own catalog with measurements of right ascension and declination for 270 stars, including many not included in Flamsteed's catalog — and for one nebula, in Lyra. Darquier describes finding this nebula:

> In the course of my work, I encountered some nebulae, most of which are unknown; but one which caught my attention is a



nebula located between the two beautiful stars β & γ Lyrae; it is very dim, but with a sharp boundary . . . one finds its position determined in my catalogue.

Darquier does not give a precise date, but it cannot be earlier than February 10th. He was incredulous that such an object could be previously unknown, and he offered the (incorrect) theory that perhaps it had only recently appeared:

> If one considers that this nebula, which is located between two beautiful stars, which are very close to each other and can pass at the same time in the same telescope field, and to which astronomers had often turned their instruments, there is reason to be astonished that we have not spoken about it; it must also be admitted that it takes a rather powerful telescope to perceive it: Might this be a new production of nature?

Darquier's Meaning

In 1782 Darquier reprinted his 1779 letter to Messier in a compilation titled *Observations Astronomiques, Faites a Toulouse, par M. Darquier. . . Deuxieme partie.* At the end he added an additional remark about the nebula in Lyra:

> This nebula has not been noticed, at least as far as I know, by any astronomer; one cannot perceive it except with a powerful telescope. It does not resemble any other known: it is as large as Jupiter, perfectly round and sharply bordered; dull like the dark part of the Moon in the syzygies; it seems that its center is a little less dull than the rest of its surface.

"The dark part of the Moon in the syzygies" refers to Earthshine inside the crescent near the time of new Moon. But the last bit deserves to be given in its original French — *il semble que son centre soit un peu moins terne que le reste de sa surface* — because "*un peu moins terne*" could mean either "a little less dull," meaning brighter, or "a little less of the dullness," meaning dimmer! If the latter, we have the important result that Darquier was the first astronomer to notice that the nebula has the form of a faint ring.

Regardless, the primary sources make clear that all the books have the priority backward: Messier observed M57 first, on January 31, 1779, while Darquier did not even know about Bode's Comet and did not scan the sky near its path until after February 9th.

Discovering vs. "Discovering"

So why did Messier, in his catalog, wrongly hand away the honor of discovery to another? The answer, pretty clearly, is that he didn't. We seem to have a case of language creep.

"M. Darquier in Toulouse discovered this nebula, while observing the same Comet" sounds to us like a flat statement that Darquier was first to see M57. But "discover" may also mean simply to discern or spot something, a usage that was more common in the 18th century and has since become almost obsolete. And commas back then were thrown into sentences in ways they aren't now. In modern terms, think "Darquier spotted this nebula while observing the same comet."

Or possibly Messier was using "discover" the way we do but meant Darquier's later, *independent* discovery.

Either usage matches Messier's statements that he himself "discovered" Bode's Comet on January 19th, though by the time he wrote that in his 1779 memoir and later in his catalog, he and every other astronomer knew that Bode was the first. There's no question about this; in his memoir Messier reprints two German articles describing how Bode in Berlin had first spotted the comet on the evening of January 6th.

Moreover, Messier's chart of the comet's path begins in Vulpecula with Bode's observations plotted as a dotted line with its start labelled "at Berlin on January 6." The path marks the positions observed by Messier along a solid line continuing from a point that he labelled, "Discovered at Paris."

So "discovered" for M57 should likewise be read with Messier's slightly antique meaning. In any case, primary sources prove without a doubt that Messier was the first to sight M57.

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■ **GIOVANNI MARIA CAGLIERIS,** of the Milan Amateur Astronomers Club (*Circolo Astrofili di Milano*), has interests in visual observing and the history of astronomy.

The authors are grateful for research assistance from Margaret Vaverek at Texas State University's Alkek Library.

Make a Solar Filter

Construct this essential eclipse accessory yourself.

WITH A TOTAL SOLAR ECLIPSE coming in just a couple of months, you're going to want a solar filter for your telescope, binoculars, or camera. Even if you don't think so now, you'll want one when the moment arrives, especially if you'll be viewing the eclipse from outside the path of totality, where there will never be a safe moment to view the event directly. By eclipse day it will be too late, though, so now is the time to get busy and build yourself a filter.

Sure you can buy one, but that would be expensive. Building your own is easy and cheap — and perfectly safe, as long as you do it correctly.

The correct way is to cover the front of the telescope or whatever device you'll be using with material that's designed to filter out most of the sunlight and all the infrared and ultraviolet, leaving only enough light to safely view through the telescope. Do not attempt to filter the sunlight at the eyepiece end. The telescope will intensify the Sun's heat so much by the time it reaches the filter that the filter could shatter under the stress, and your retina will be exposed to the full blast.

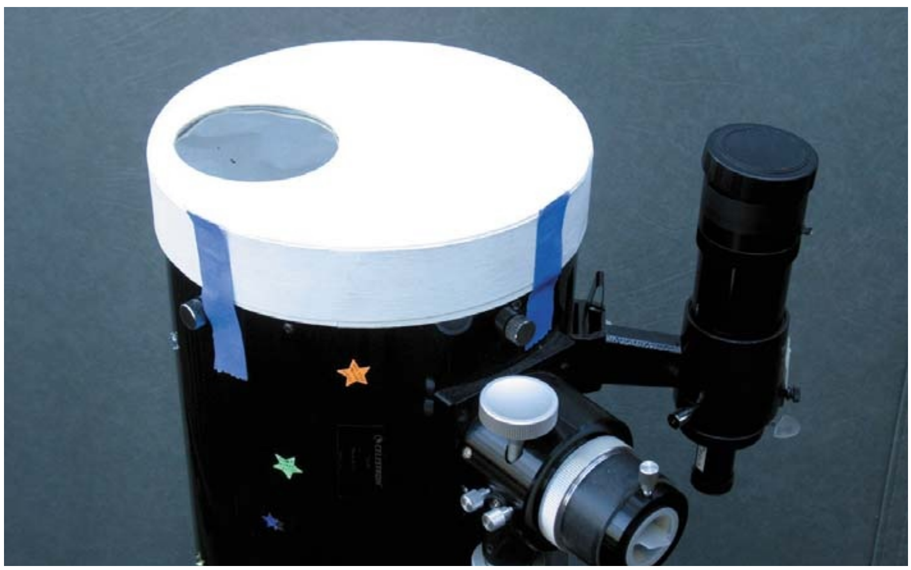
Likewise don't try to filter an open-framework (truss-style) scope. Unfiltered sunlight can enter through the open sides and wind up in the eyepiece. Even if you avoid that peril, contrast will really suffer because of the ambient daylight anyway. If you have a very dark shroud with no light leaks you can use a truss scope, but you should be extra careful here to make sure that the scope is functioning like a solid-tube design.

Given the above, making the filter is relatively straightforward. Baader Planetarium's Astrosolar filter material is designed for this very purpose and works wonderfully. It cuts just the right amount of sunlight and does it evenly across the visible spectrum, leaving you with a natural, white-light, safe view of the Sun's surface. To make your filter, you just need to build a framework that will hold an appropriately sized sheet of Astrosolar film in front of the scope and keep it there even on a breezy day.

Here's how:

Figure out how big an aperture would make your scope about f/10. In other words, divide the scope's focal length (not aperture!) by ten, and that's the size filter you need. That's the actual useable diameter; you'll need a piece of Astrosolar film at least an inch bigger than that so you can attach it safely to the filter cell.

So if you have a 1,000-mm focal-length scope, you'll want a 100-mm (4-inch) diameter filter. That means a 5-inch piece of Astrosolar film. You don't have to be exact here; you can make the filter opening as small as 3 inches in diameter for a 1,000-mm scope. That would make your filtered



Top: Contributing Editor Jerry Oltion and his wife Kathy with his homemade solar filter on an 8-inch Dobsonian. **Above:** Use tape for additional security when attaching the filter.

ALL PHOTOS BY THE AUTHOR

The proper way to install an eyepiece solar filter — that is, never! See article for why not.

scope about f/13, which would make the image a little dim but still useable. If you're making filters for binoculars or a 60-mm or smaller scope, you can make them full aperture.

I get my filter material from **Scope stuff.com**. They sell it in 10″ × 10″ or 8.2″ × 11.7″ sheets, so get together with some friends and buy a sheet that will make filters for all of you.

Get some flat cardboard (not corrugated cardboard); cereal boxes or poster board work great for this. Cut some long strips about 2″ wide and wrap them around the front of your scope, making a spiral about four or five layers thick. Glue the layers of this spiral together (but not to the scope!) The spiral should fit snugly but still be possible to slide on and off. Make sure the layer edges at the top of the spiral are nice and even: Those combined edges are going to be the glue surface for your next step.

While the spiral's glue is drying, cut out two big circles of cardboard that will span the entire outside diameter of the spiral. Then cut your filter's aperture hole in the disks. For refractors these holes should be centered, but for reflectors you want to offset them so your secondary mirror isn't in the light path (or at least not in the center of the light path). Leave half an inch or so of cardboard on the outer edge, partly for strength and partly because your primary mirror doesn't extend that far out toward the edge of the tube anyway.

Now choose a side of one of the disks to be the front and paint that white. This will help keep the filter cell cool under direct sunlight. Also paint the outside of the spiral ring white. Paint one side of the other disk black. You can paint the inside of the spiral black or just leave it cardboard. I leave mine cardboard so it doesn't shed paint flakes down onto my primary mirror.

After the paint dries, align the cardboard disks so the unpainted sides are together and the aperture holes are aligned. Mark the edges of the disks so you can sandwich them in exactly this same orientation later.

You can make a camera lens filter in a similar fashion as described in the text by sandwiching Baader Astrosolar film between two plastic disks and securing them inside a lens hood.

Top: Make a spiral edge out of strips of thin cardboard. Cereal boxes work well for this. **Below:** Cut two disks from your cardboard and sandwich the filter material between them.

Put a ring of double-stick tape around the aperture hole on the unpainted side of one of the big disks. You'll have to use little pieces to go around the circle. Lay the filter material on a piece of soft tissue paper, then lower the cardboard ring with its exposed double-stick tape gently onto the filter material, being careful to leave half an inch of filter material overlapping on all sides of the aperture hole. If all goes well, the filter material will be held firmly in place and will have no wrinkles. Some gentle wrinkling is okay, but if you have serious creases in it, carefully loosen it and try again.

When it's bonded smoothly to this first disk, put more double-stick tape on the unpainted face of the other disk, not just around the hole but in strategic spots all over, and then spread some glue around, too, for good measure. Line up the marks you made earlier and press the two circles together, making a sandwich with the filter material inside. It's important that the two holes are directly over one another, and you won't be able to see if that's the case with the filter material in place. (That's why you made the index marks!) Press the sandwich flat between some coffee-table books and let the glue dry.

Now glue the sandwich to the spiral ring. I do this gluing with the ring on the scope so it'll stay round, but be careful you don't use so much glue that it drips into the optics. After the first bead of glue has dried, you can take it off the scope and run a thick bead all around the edges — inside and out — for good measure. Make sure it's glued really well. You don't want the filter sandwich to ever come loose off the spiral ring.

After the glue has dried, hold the finished filter up toward the Sun and check for light leaks. There shouldn't be any, either within the span of the Astrosolar film or anywhere else. If you see bright specks in the film, blacken them on the inside surface with a felt-tip marker. Any other light leaks in the filter's framework should be taped over and/or filled with glue and painted.

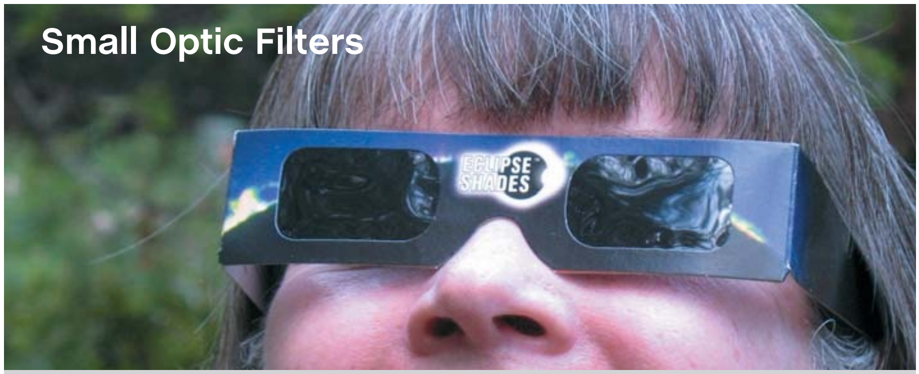
That's the filter! To use it, just slide the whole assembly down over the top of the scope. It should fit snugly enough to have zero risk of blowing off in a breeze. If there's any doubt, tape it in place. If you have kids around, tape it down anyway. Curious future scientists will want to take it off and look through it, leaving the telescope open to the unfiltered Sun.

Make a box to store it in so it won't get damaged. Even so, inspect it before every use to make sure no holes have developed in it.

This filter will give you a nice view of sunspots, faculae, and granulation in larger-aperture scopes. During the eclipse you will see the ragged edge of the Moon slowly creeping across the face of the Sun, and it will be seriously cool. Well worth the effort of making this inexpensive filter.

■ Contributing Editor **JERRY OLTION** will be observing this year's total solar eclipse from Newport, Oregon.

Small Optic Filters



Eclipse glasses provide a wonderful zero-power view of the Sun.

For small-aperture scopes and binoculars, here's a really low-cost and readily available source of filter material: buy a pair of eclipse glasses (also known as "solar shades"). They're little cardboard-framed rectangles of solar filter material that you wear on your face like glasses so you can look directly at the Sun. (Often these are not manufactured with Baader Astrosolar film, but they are equally safe, although they usually produce an orange image of the Sun rather than a white one.) If you snip a pair in two, you have two solar filters that you can build into filters as described above and place them in front of the two objective lenses of a pair of binoculars. Or you can put them side-by-side in front of a small aperture telescope (again being careful to eliminate any chance of light leaks around the edges of the individual filters). They're not guaranteed to be as optically flat as dedicated telescope filter material, but they'll do in a pinch.

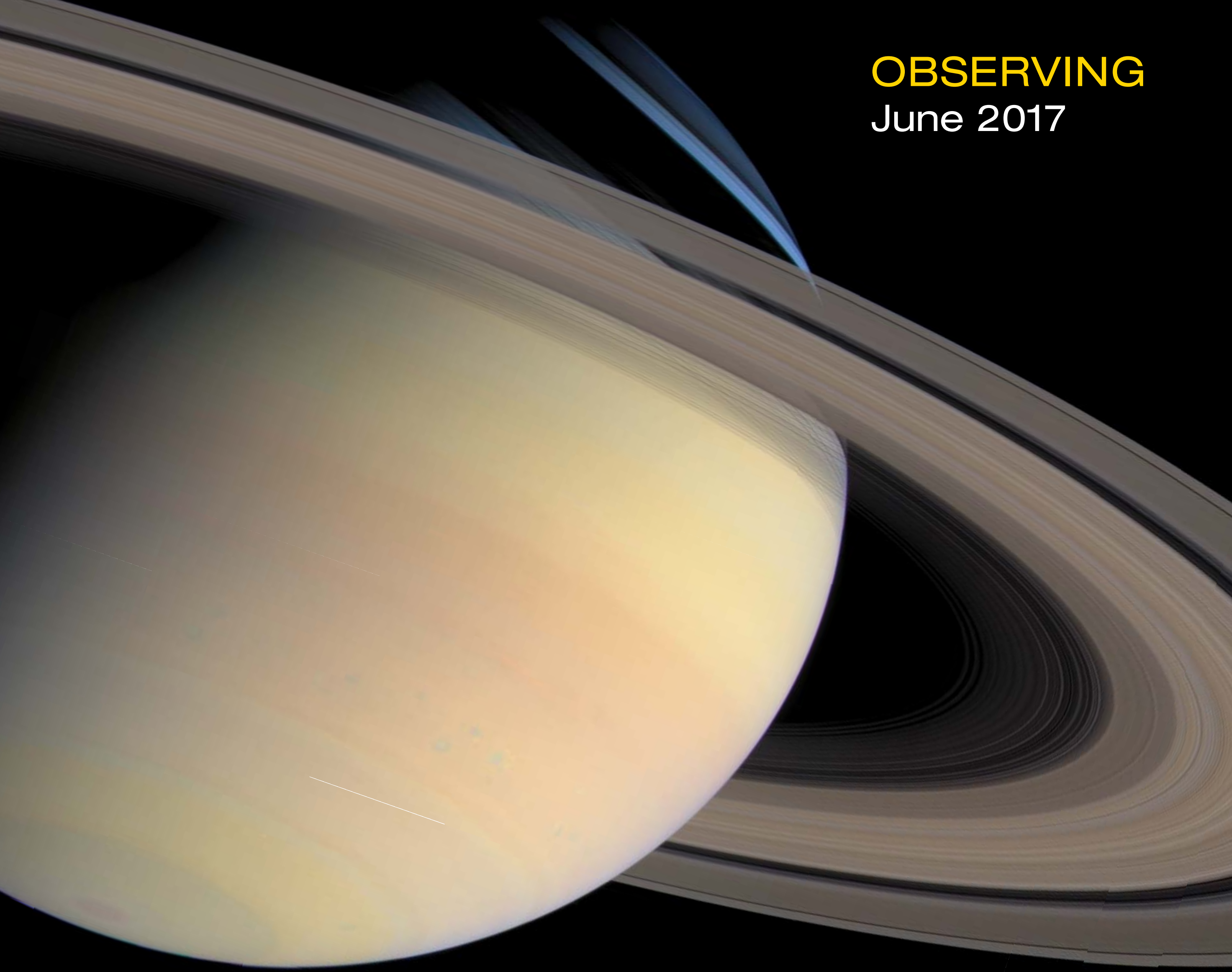
This pair of filters cost about $3 to make.

A solar filter for an Edmund Scientific Astroscan, made from eclipse glasses. It doubles as a Scheiner mask for focusing!

While you're buying the solar shades, get an extra set or two to keep intact for direct viewing of the Sun. The no-magnification view of partial eclipse phases is more impressive than you might imagine. (I get my shades from Rainbow Symphony: **tinyurl.com/lq5uefx**. *Sky & Telescope* also sells its own version at **tinyurl.com/m5xgtzl**.)

One final warning: Never wear solar shades while looking through the eyepiece of an unfiltered telescope or binoculars. In order to observe the Sun safely, solar filters must be mounted on the objective side of any optics, before the lenses or mirror can concentrate the sunlight, and the filter cell must completely cover the objective opening. Failure to heed this warning will fry your eyeballs all the way back to your cowlick. Seriously.

OBSERVING
June 2017



A mosaic of 126 images acquired in 2004 by the Cassini Orbiter reveals the subtle colors of Saturn and its rings.
NASA / JPL / SPACE SCIENCE INSTITUTE

3 EVENING: High in the south, the waxing gibbous Moon beams about 2° from the lustrous white-gold of Jupiter for viewers in North America.

NIGHT: A double shadow transit occurs on Jupiter from 10:22 p.m. to 12:22 a.m. Eastern Daylight Time; see page 50.

9 EVENING: As twilight deepens, look for zero-magnitude Saturn about 3° right of the nearly full Moon.

14–15 ALL NIGHT: Saturn is at opposition to the Sun and closest to Earth for the year.

19 NIGHT: A double shadow transit occurs on Jupiter from 10:05 to 10:39 p.m. EDT.

20,21 MORNING: The waning crescent Moon shines about 8° right of Venus on the 20th and about the same distance lower left of Venus on the 21st.

20–21 THE SHORTEST NIGHT of the year in the Northern Hemisphere. Summer begins at solstice, 4:24 UT (12:24 a.m. EDT).

27 EVENING: The waxing crescent Moon is just 1° from Regulus for North America. The Moon occults Regulus for Hawai‘i and Micronesia in the daytime and west-central South America at night.

30 EVENING: Look high in the southwest at nightfall to find Jupiter about 4° left of the Moon.

Lunar Almanac
Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
June 1
12:42 UT

FULL MOON
June 9
13:10 UT

LAST QUARTER
June 17
11:33 UT

NEW MOON
June 24
02:31 UT

DISTANCES

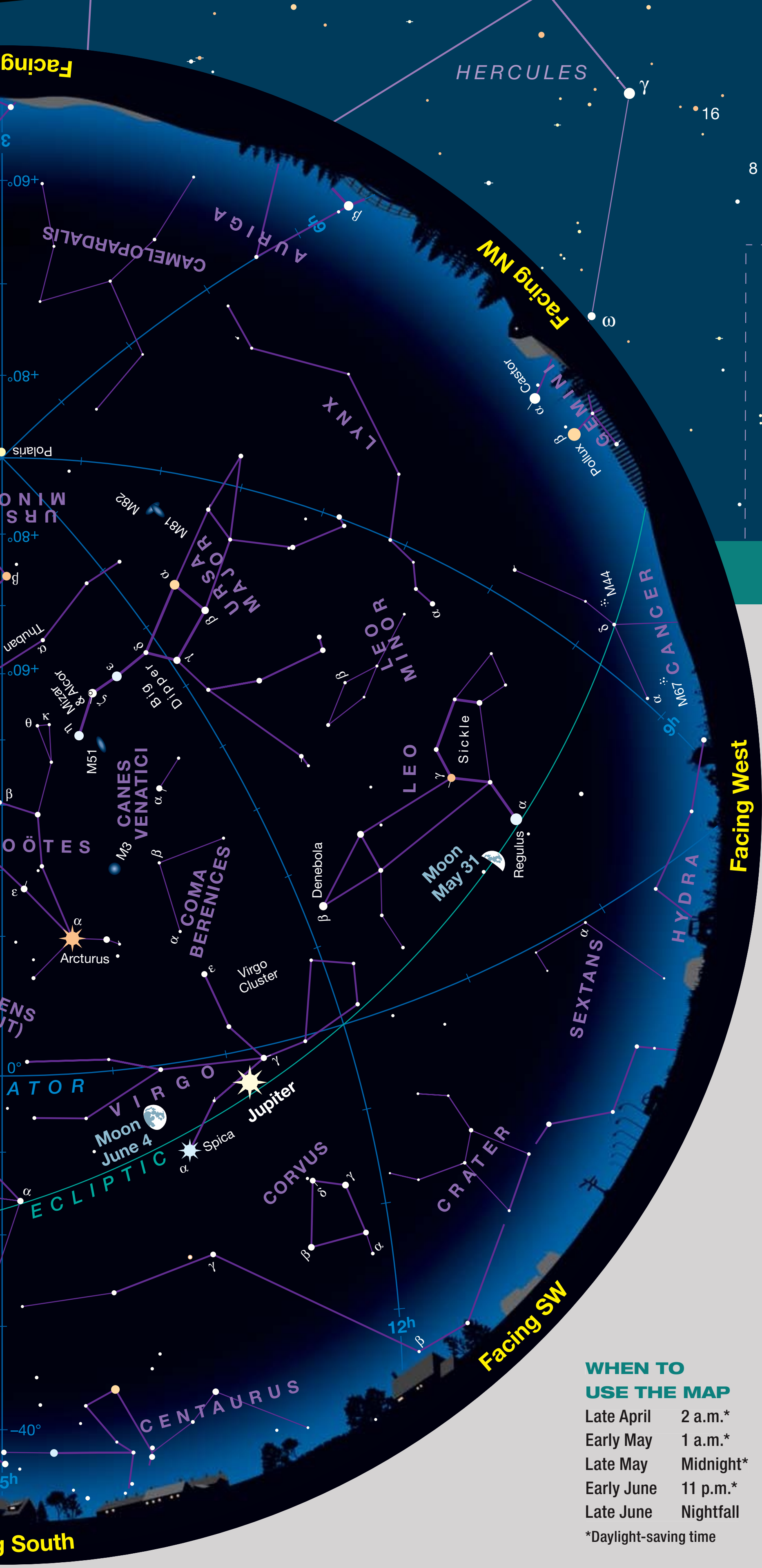
Apogee	June 8, 22^h UT
406,400 km	Diameter 29′ 24″
Perigee	June 23, 11^h UT
357,938 km	Diameter 33′ 23″

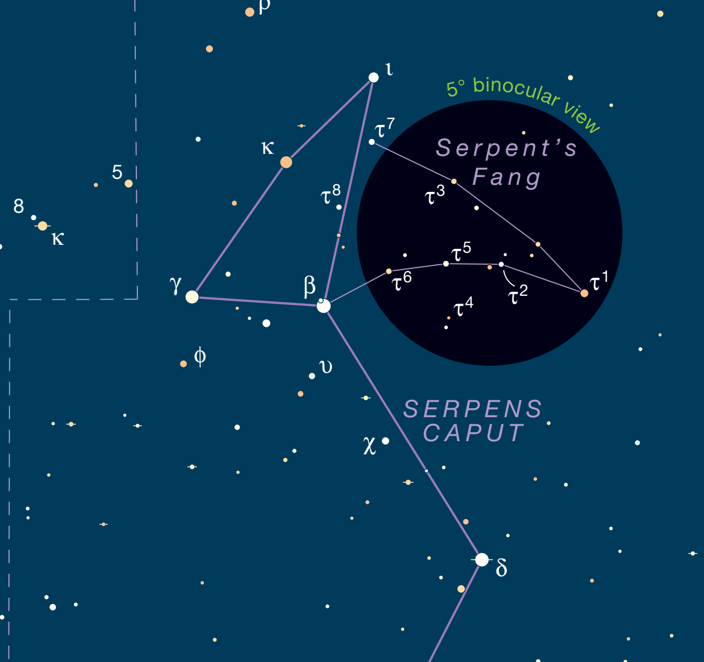
FAVORABLE LIBRATIONS

Mare Smythii	June 1
Humboldt Crater	June 3
Hausen Crater	June 11
Regnault Crater	June 21

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

The Serpent's Fang

Like a lot of stargazers, I often go observing to escape the hassles of life. Serpens Caput, the head of the celestial snake, is a pretty good getaway spot, with a variety of things to see and do. I like to start with the wide not-quite-a-triangle formed by Beta (β), Gamma (γ), Iota (ι), and Kappa (κ) Serpentis. Most atlases use this group as the "head" of the constellation. That artistic decision is fitting, because the various stars of Tau (τ) Serpentis form a fang-shaped asterism 5° long that points west. The chains of stars, culminating in bright Tau^1 Serpentis, even curve like a fang.

If the Tau stars form the serpent's fang, the group of bright stars running southwest from Gamma to Delta (δ) Serpentis can be seen as the curving hood of a cobra as it rears back to strike. The stars of the fang and the hood are not physically related, though. In both cases, they're a mix of nearby main-sequence stars with a handful of more distant giants, scattered over several hundred light-years along our line of sight. But they make felicitous groups that are fun to trace out with binoculars.

If you like binocular double stars, this is a rich area. Tau^2 and Tau^4 Serpentis are wide optical doubles that seem to mirror each other across an imaginary line extending southwest from Tau^5 Serpentis. Beta Serpentis is another optical double, tighter but still easily split in low-power binoculars. And pop over the border into Hercules to check out the pairing of Kappa and 8 Herculis. Kappa is itself a close (27″) pair of orange giants, which contrast nicely with 8 Herculis, a white *A*-class main-sequence star.

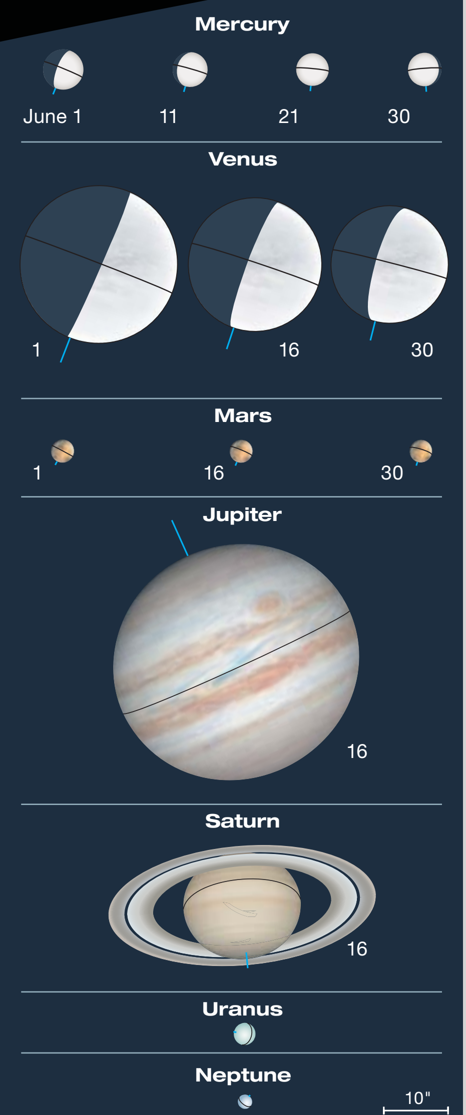
■ MATT WEDEL likes to kick back with his binoculars on a driveway in Claremont, California.

WHEN TO USE THE MAP

Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Nightfall

*Daylight-saving time

PLANET VISIBILITY: Mercury: Out of sight all June • **Venus:** Visible all month at dawn, east. **Mars:** Out of sight all June • **Jupiter:** Visible all month, dusk to early morning hours, south to west. **Saturn:** Visible all month, morning hours, SE to SW.

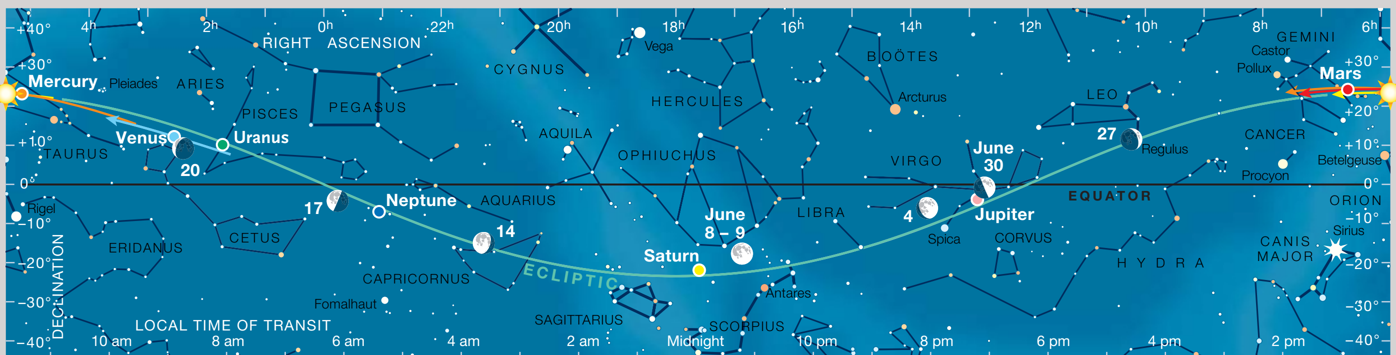


PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

June Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$4^h\ 35.5^m$	+22° 01′	—	–26.8	31′ 33″	—	1.014
	30	$6^h\ 35.6^m$	+23° 11′	—	–26.8	31′ 28″	—	1.017
Mercury	1	$3^h\ 11.1^m$	+15° 21′	21° Mo	–0.4	6.3″	66%	1.069
	11	$4^h\ 23.7^m$	+20° 52′	12° Mo	–1.1	5.4″	87%	1.237
	21	$5^h\ 55.0^m$	+24° 26′	1° Mo	–2.4	5.1″	100%	1.323
	30	$7^h\ 19.4^m$	+24° 02′	10° Ev	–1.2	5.2″	93%	1.288
Venus	1	$1^h\ 34.5^m$	+7° 34′	46° Mo	–4.5	24.5″	48%	0.680
	11	$2^h\ 12.1^m$	+10° 35′	46° Mo	–4.4	21.9″	54%	0.761
	21	$2^h\ 52.3^m$	+13° 39′	45° Mo	–4.3	19.8″	58%	0.840
	30	$3^h\ 30.5^m$	+16° 15′	44° Mo	–4.2	18.3″	62%	0.911
Mars	1	$5^h\ 48.2^m$	+24° 17′	17° Ev	+1.7	3.7″	99%	2.532
	16	$6^h\ 31.8^m$	+24° 11′	12° Ev	+1.7	3.6″	100%	2.581
	30	$7^h\ 11.9^m$	+23° 26′	8° Ev	+1.7	3.6″	100%	2.617
Jupiter	1	$12^h\ 50.4^m$	–3° 50′	123° Ev	–2.2	40.7″	99%	4.840
	30	$12^h\ 52.0^m$	–4° 09′	95° Ev	–2.1	37.5″	99%	5.262
Saturn	1	$17^h\ 39.8^m$	–21° 59′	165° Mo	+0.1	18.3″	100%	9.074
	30	$17^h\ 30.7^m$	–21° 56′	165° Ev	+0.1	18.3″	100%	9.074
Uranus	16	$1^h\ 42.5^m$	+10° 00′	57° Mo	+5.9	3.4″	100%	20.452
Neptune	16	$23^h\ 02.5^m$	–7° 07′	101° Mo	+7.9	2.3″	100%	29.742

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-June; 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.

Night Train

Summer memories are shaped by the rhythm and the motion of the sky.

Man goes nowhere
Everything comes like tomorrow
But she took that last ride there by his side
He spent his whole life pursuing the horizon
Riding the rods
Sleeping under the stars
Playing the odds from a rolling box car
— Robbie Robertson, *Hobo Jungle*

© CAN STOCK PHOTO / NUTTAWUT

Many of us who love astronomy have indeed spent our whole lives pursuing the horizon. And the zenith. And the rest of this dome of endless mystery, glory, and beauty we call the sky.

Two other major themes connected to astronomy leap out at me when I read or hear *Hobo Jungle*: sleeping under the stars, which June's warmer weather makes more comfortable; and night trains, the sound of whose rolling — regulated, slow or fast, mostly smooth but weighty — reminds me of the motions of the heavens and Earth.

Sleeping under Stellafane's stars 40 years ago. The great outdoor meeting of amateur telescope makers and amateur astronomers in Vermont called Stellafane, a name which means "the holy place of the stars," takes place near new Moon when the Green Mountain corn is high. That's typically late July or early August, long after June, of course. But summer is a great hill or plateau of similar weather and the same flowering plants. We do have to wait later at night in June to see the late summer's prime stars and Milky Way. June nights are so short at mid-northern latitudes (and are only deep twilights a little farther north) that you almost have to stay up until midnight or 1 a.m. for a sufficiently dark sky.

Surely the best place and time I've ever slept under the stars was on Breezy Hill at Stellafane in 1977. Actually, there were a lot of clouds that year — but that made the periods when the stars broke out all the more wonderful. Also a bit troublesome was the fact I arrived a day early — unannounced, an unknown 22-year-old with my 15-year-old friend and fellow Cumberland Astronomy Club member, Chuck Fuller. Chuck's folks were dropping us off because they were heading to Maine. We discovered too late that we weren't supposed to be there that day. But we were allowed to put up our little makeshift transparent tent in an unused campground spot — provided we did some chores.

In the end, the only chore we performed was clearing some brush away from the area near the camp house and Porter Turret telescope. A man who looked familiar — from the pages of *Sky & Telescope* — sat watching us. But before long he motioned us to stop and come over to him to talk. The man was one of my astronomical heroes, the greatest of deep-sky pioneers, Walter Scott Houston.

Our experiences with Scotty and other parts of the Stellafane weekend were unforgettable. But an evocative one that first night was bright but distant lightning and then a nearby fire. We learned the next day that the fire had been set to burn out a hornet's nest. But what I remember best was the silhouette of Walter Scott Houston against the mysterious fire.

The motion of trains, stars, and Earth. Even the great New England devotee of nature and wilderness, Henry David Thoreau, was thrilled by the plaintive night call of a machine — the train that passed right by his Walden Pond. One element that makes many a June nightfall a time of peace is the wonderfully slow coming out of the stars — especially the fairly low Summer Triangle — in the longest twilights of the year. The gradual movement of the stars from hour to hour across the sky is like that of a slowly rolling train. And yet it's not the stars that are in motion, it's the Earth, in its rotation. As astronomy author Guy Ottewell (**universalworkshop.com**) has so well put it, "Horizons roll, and not the standing stars."

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

Aim High

Jupiter and Saturn offer good telescopic views for late-night summer observing.

This year, June's long dusks bring us views of two bright planets. Jupiter, still near its highest, beams in the south. Saturn glows in the southeast, reaching opposition — and therefore all-night visibility — in mid-June.

In morning twilight, Venus moves a bit higher, passing through greatest elongation at the beginning of the month, while Mercury stays out of sight near the Sun.

INTO THE NIGHT

Mars finally exits from view around the beginning of June, slipping into the Sun's afterglow in the west-northwest to end an apparition that's lasted almost two years.

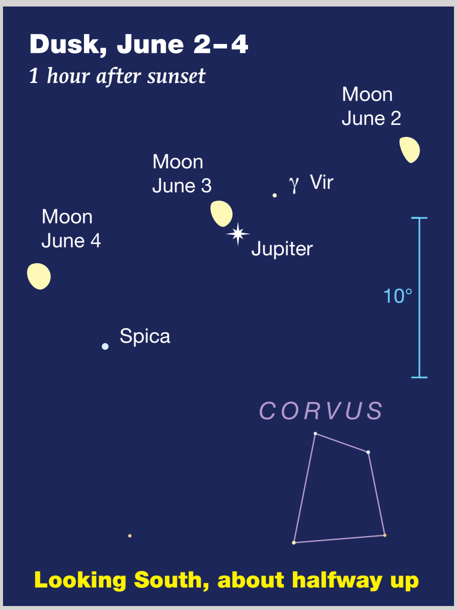
Jupiter, meanwhile, dominates the evening, shining high in the south to southwest at nightfall. It doesn't set until about 3 a.m. as June starts, 1 a.m. as the month ends. Now two months past opposition, Jupiter loses a little more luster and size, dimming from –2.3 to –2.0 and shrinking from 41″ to 37″ across its equator.

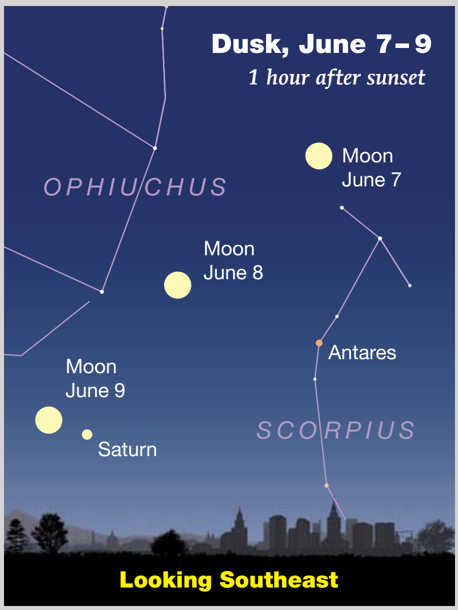
Jupiter remains about 11° west (right) of Spica in Virgo all month, halting its slight retrograde (westward) motion against the stars on June 9th and slowly resuming direct (eastward) motion. Jupiter will spend the summer heading back toward Spica, passing it low in twilight on September 11th.

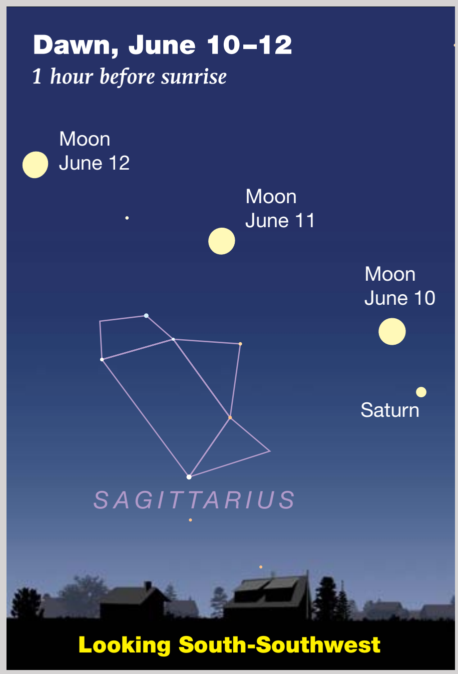
DUSK TO DAWN

Saturn comes to opposition with the Sun on the night of June 14th, so it rises around sunset and shines almost all night throughout the month. Saturn is at its closest to us for the year and therefore at its largest and brightest in telescopes. All month, it remains at or very close to magnitude +0.0. This brightness is amazing because next year Saturn will be at the aphelion (farthest from the Sun) of its nearly 30-year orbit. The wide-open rings are what make Saturn so resplendent even at one of its most distant oppositions. At 26.5°, they're very close to their maximum possible tilt from our line of sight. All year the rings are open enough to add almost a full magnitude to the planet's brightness.

On the other hand, for the next several years observers at mid-northern







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

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

latitudes must continue to deal with Saturn at essentially its most southerly, and therefore lowest, in the sky. Try for your best observations between midnight and 2 a.m. (daylight-saving time), when Saturn crosses the meridian at its highest. This is also a good time to check out the fascinating Milky Way background, as the planet creeps westward in southeastern Ophiuchus away from Sagittarius.

Neptune, in Aquarius, rises in the middle of the night and by June 30th stands about 40° high in the southeast at the approach of morning twilight.

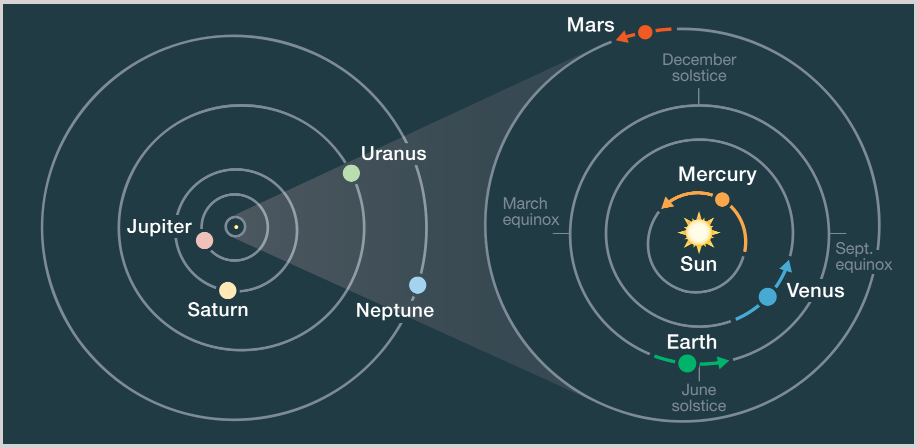
DAWN

Venus gleams in the east on June mornings, arriving at greatest elongation (46° west of the Sun) on June 3rd. Its visibility before sunrise isn't extremely impressive, but viewers around latitude 40° north can watch Venus's altitude a half hour before sunrise increase from about 18° to 24° as the planet increases its lead on the Sun from about 1 hour and 45 minutes to a little more than 2 hours over the course of the month. An improving angle of the ecliptic to the dawn horizon will keep Venus's altitude growing until early August, two full months after greatest elongation.

Venus dims from magnitude –4.5 to –4.2 during June as its disk shrinks from about 24″ to 18″ wide. Its phase thickens past 50% sunlit around the time of greatest elongation.

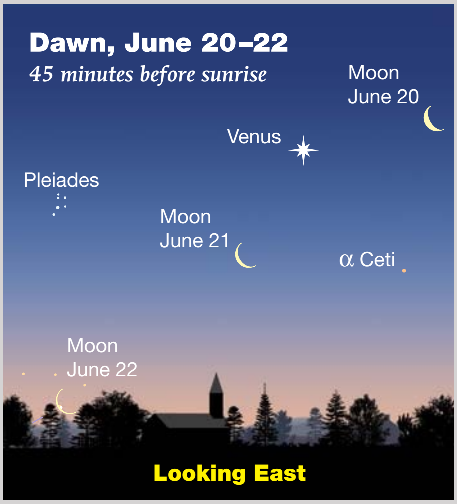
A challenge for planet watchers at the start of the month is **Uranus**. Shining about 10 magnitudes or 10,000 times fainter than Venus, it can be found with a telescope less than 2° north or northwest (upper left) of Venus on the American mornings of June 2nd and 3rd. The 3.5″ disk of Uranus would normally be easy to distinguish from a star at moderately high magnification. But in early dawn when the sky is still dark enough, you'll be looking *very* low where everything is blurry.

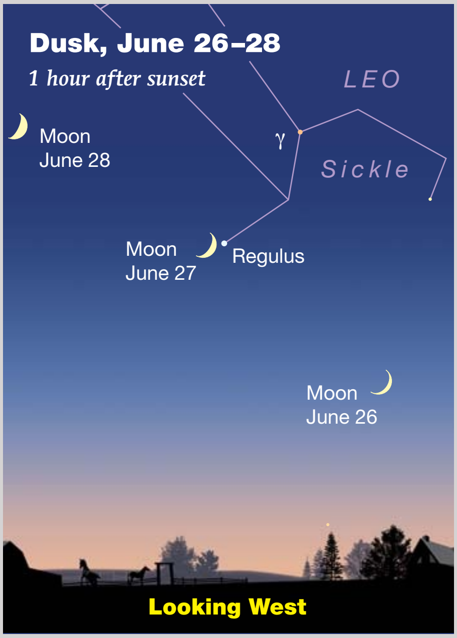
Mercury remains lost in glare of the Sun. It will have a low, modest evening apparition in July. Try for it on the last day of June with binoculars.



ORBITS OF THE PLANETS

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





SUN AND MOON

The **Sun** arrives at the June solstice at 12:24 a.m. EDT on June 21st (11:24 p.m. CDT on the 20th), marking the shortest night of the year and the start of summer in the Northern Hemisphere.

The waxing gibbous **Moon** poses about 2° upper left of Jupiter at nightfall on June 3rd and 6° upper left of Spica on June 4th. As evening twilight deepens on June 7th, look for Beta (β) Scorpii about 3° below the Moon.

The full Moon pairs with Saturn as they rise in the southeast on the evening of June 9th. At dawn of the next morning, June 10th, the Moon is 4° upper left of the Ringed Planet.

On June 20th, the waning lunar crescent cuts the morning twilight about 7° right of Venus; it's 8° lower left of Venus the next morning.

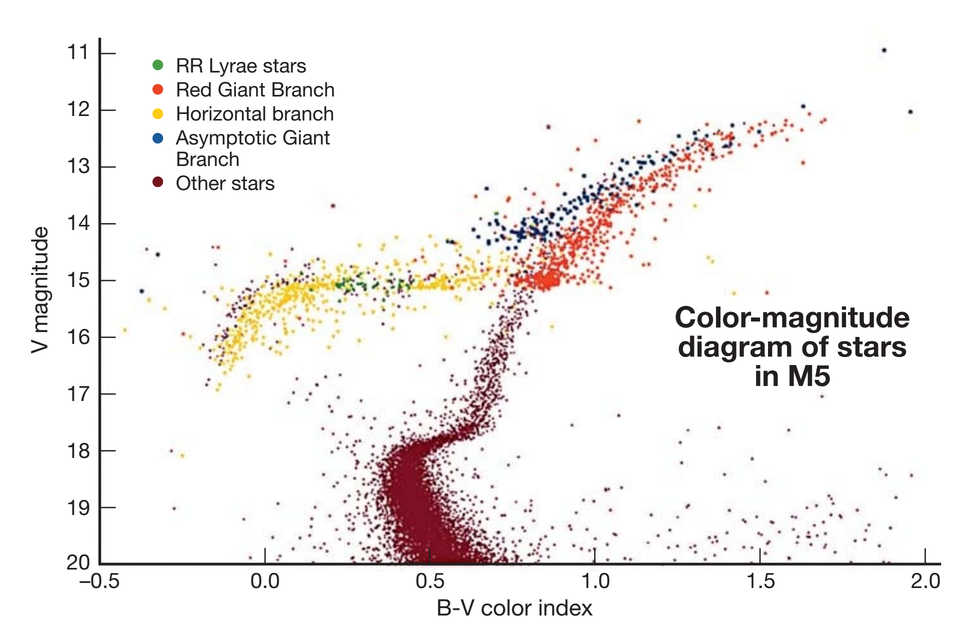
A waxing lunar crescent hangs about 1° from Regulus for North America on the American evening of June 27th; it occults Regulus for Hawai'i, Micronesia, and parts of South America. The first-quarter Moon beams about 4° right of Jupiter on June 30th.

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

The Fast Pulse of the RR Lyraes

An amateur program tracks the quirks of the oldest standard-candle stars in the universe.

Above: The globular cluster M5, located 25,000 light-years away in Serpens, is nearly 13 billion years old — plenty old enough for stars a little less massive than the Sun to have become fast-pulsing RR Lyrae variables. These are the green dots in the color-magnitude diagram of 15,000 of the cluster's stars. Some free-floating RR Lyraes are much closer to us and in easy reach of amateur scopes.



ADAM BLOCK / MT. LEMMON SKY CENTER, LITHOPSIAN / WIKIMEDIA COMMONS

If you ever took an astronomy course, you probably learned about the role of the pulsing RR Lyrae stars in astronomers' long and heroic construction of the cosmic distance scale. A few amateurs know these stars in another context: as a pleasant way to pass a summer's night.

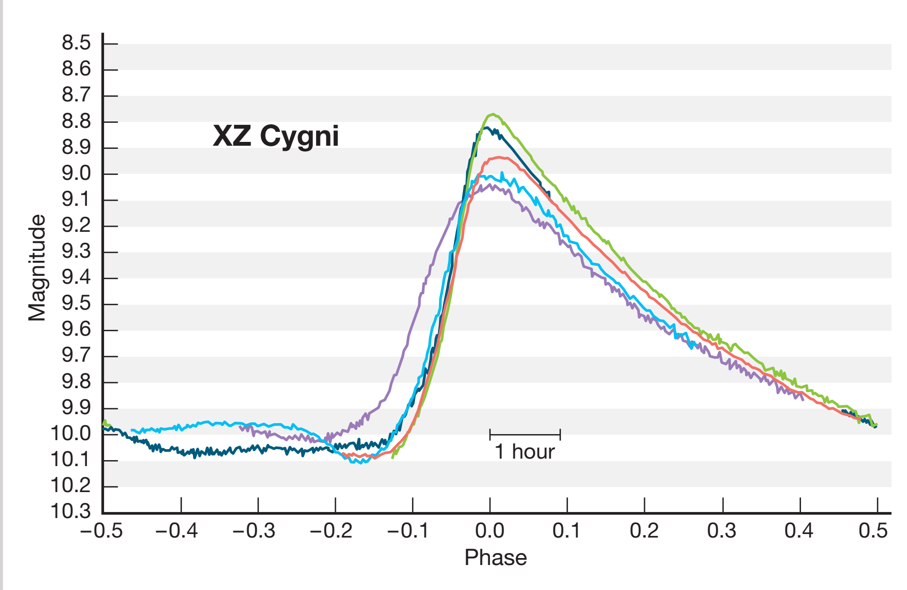
All RR Lyrae variables of the type considered here have nearly the same absolute visual magnitude, +0.75. That means they're 40 to 50 times as luminous as the Sun — not nearly as bright as the giant Cepheid variables, those more famous standard distance markers that can be seen much farther away.

RR Lyraes are extremely old, however, so they mark ancient populations of stars that lack any Cepheids — such as globular clusters and the Milky Way's outer halo. A star becomes an RR Lyrae very late in its life if it began as a yellow dwarf with only about 80% the mass of the Sun. After such a star finally ages off the main sequence, completes its red-giant phase, and evolves onto the horizontal branch in the Hertzsprung-Russell diagram (shown at left), it spends a while pulsing rapidly before advancing to its final death throes.

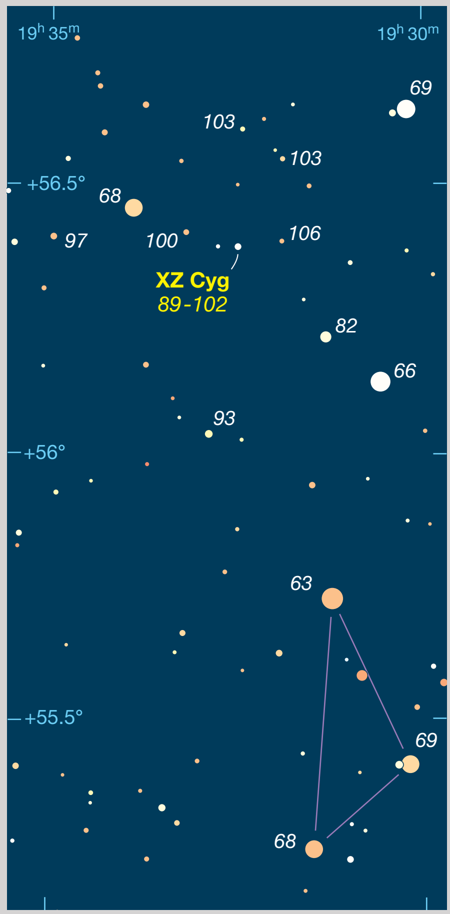
The pulses amount to about one magnitude, easy enough to measure by eye at the eyepiece. The stars have periods of about half a day, and their rise from minimum to maximum light can take an hour or less as you watch.

For the last half century, a small, select group of amateur variable-star observers have kept nearby RR Lyraes — visitors from the galaxy's halo that are just passing through — under regular scrutiny. The idea is to time when their maxima occur, in particular to follow strange irregularities that many RR Lyraes display known as *Blazhko cycles*. These oddly periodic changes in the strength and timing of maximum light were discovered 110 years ago by the Russian astronomer Sergei Blazhko and remain pretty much unexplained.

All such star-timing work is done now by CCD photometry, says Gerry Samolyk, who runs the Short Period Pulsator Section of the American Association of Variable Star Observers



▲ *Above:* Light curves of five of XZ Cygni's pulses, recorded by amateurs using CCD-image photometry. XZ Cygni's pulsation period is very stable, but *individual* pulses wander around in amplitude and shape. This graph covers the star's entire pulsation period of 11 hours 11 minutes 43 seconds.



S&T: LEAH TISCIONE. DATA: AAVSO / GERRY SAMOLYK

(AAVSO). An automated camera on a telescope, clicking away tirelessly while you observe something else (or snooze indoors), results in far more accurate brightness measurements, and therefore timings, than eyeball estimates used to do. And an automated camera can record a high-quality light curve of a star's entire pulse, which may be rather different than the previous pulse just hours earlier.

To get a taste for these stars, on these pages are comparison-star charts for three RR Lyraes in easy reach of amateur telescopes.

Set up at least an hour before a predicted maximum. About every 10 minutes, make a very careful estimate of the variable's exact brightness with respect to comparison stars around it, labeled on the charts with their visual magnitudes to the nearest tenth with the decimal points omitted. Do not let yourself be influenced by what you saw a few minutes ago; each estimate must be unbiased and independent. You'll likely see faster action than amateurs usually observe anywhere else beyond the solar system.

Watch out; this project could get you hooked enough to buy an astrocamera, learn how to do automated photometry, and change your nights forevermore. If you'd like to dive in, read the AAVSO's CCD Photometry Guide at **aavso.org/ccd-photometry-guide** and then write to Samolyk care of **aavso@aavso.org**.

Listed below are Universal dates (bold) and times (in hours) for maxima predicted to happen well within dark hours for at least part of the continental United States and southern Canada. Times are rounded to the nearest 0.5 hour to avoid biasing what you see.

Maxima of VX Herculis

Period = 0.4553595 day

May 1, 4.5; **4,** 9.0; **5,** 7.0; **6,** 5.0; **9,** 9.5; **10,** 7.0; **11,** 5.0; **12,** 3.0; **14,** 9.5; **15,** 7.5; **16,** 5.0; **17,** 3.0; **19,** 9.5; **20,** 7.5; **21,** 5.5; **22,** 3.5; **25,** 8.0; **26,** 5.5; **27,** 3.5; **30,** 8.0; **31,** 6.0.

June 1, 3.5; **4,** 8.0; **5,** 6.0; **6,** 4.0; **9,** 8.5; **10,** 6.5; **11,** 4.0; **14,** 8.5; **15,** 6.5; **16,** 4.5; **20,** 6.5; **21,** 4.5; **25,** 7.0; **26,** 5.0; **30,** 7.0.

July 1, 5.0; **2,** 3.0; **5,** 7.5; **6,** 5.0; **10,** 7.5; **11,** 5.5; **12,** 3.5; **15,** 8.0; **16,** 5.5; **17,** 3.5; **20,** 8.0; **21,** 6.0; **22,** 3.5; **25,** 8.0; **26,** 6.0; **27,** 4.0; **30,** 8.5; **31,** 6.5.

Maxima of XZ Draconis

Period = 0.467497 day

May 1, 4.5; **2,** 3.5; **7,** 9.0; **8,** 8.0; **9,** 7.0; **10,** 6.0, **11,** 4.5; **12,** 3.5; **17,** 9.5; **18,** 8.0; **19,** 7.0; **20,** 6.0; **21,** 5.0; **22,** 3.5; **27,** 9.5; **28,** 8.5; **29,** 7.0; **30,** 6.0; **31,** 5.0.

June 1, 4.0; **7,** 8.5; **8,** 7.5; **9,** 6.0; **10,** 5.0; **11,** 4.0; **12,** 3.0; **17,** 8.5; **18,** 7.5; **19,** 6.5; **20,** 5.5; **21,** 4.0; **27,** 9.0; **28,** 7.5; **29,** 6.5; **30,** 5.5.

July 1, 4.5; **7,** 9.0; **8,** 8.0; **9,** 6.5; **10,** 5.5; **11,** 4.5; **12,** 3.5; **17,** 9.0; **18,** 8.0; **19,** 7.0; **20,** 5.5; **21,** 4.5; **22,** 3.5; **27,** 9.0; **28,** 8.0; **29,** 7.0; **30,** 6.0; **31,** 4.5.

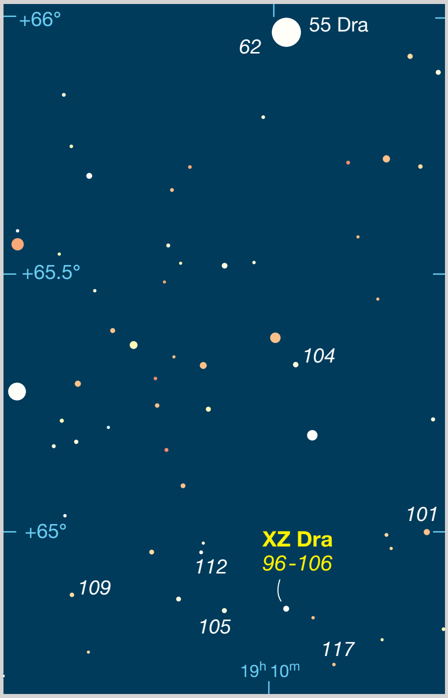
Maxima of XZ Cygni

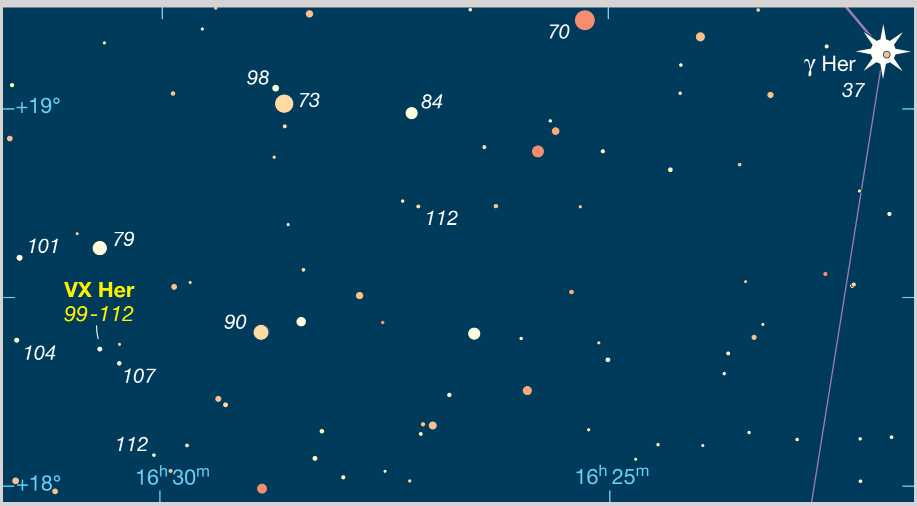
Period = 0.466473 day

May 3, 9.5; **4,** 8.0; **5,** 6.5; **6,** 4.5; **10,** 9.5; **11,** 8.0; **12,** 6.0; **13,** 4.5; **17,** 9.5; **18,** 8.0; **19,** 6.0; **20,** 4.5; **24,** 9.5; **25,** 8.0; **26,** 6.0; **27,** 4.5; **31,** 9.5.

June 1, 8.0; **2,** 6.0; **3,** 4.5; **4,** 3.0; **8,** 7.5; **9,** 6.0; **10,** 4.5; **11,** 3.0; **15,** 7.5; **16,** 6.0; **17,** 4.5; **22,** 7.5; **23,** 6.0; **24,** 4.5; **28,** 9.5; **29,** 7.5; **30,** 6.0.

July 1, 4.5; **6,** 7.5; **7,** 6.0; **8,** 4.5; **13,** 7.5; **14,** 6.0; **15,** 4.5; **20,** 7.5; **21,** 6.0; **22,** 4.5; **26,** 9.0; **27,** 7.5; **28,** 6.0; **29,** 4.5.





Lunar Occultation

Late on the night of May 31 – June 1, telescope users in most of the U.S. and Canada can watch the dark limb of the first-quarter Moon occult Rho Leonis, magnitude 3.8. Times for hundreds of cities and towns are at **lunar-occultations.com/iota/bstar/0601zc1547.htm**. The star is binary, magnitudes 4.3 and 5.4, but with its separation of only 0.1″, the two steps will happen only about 0.2 second apart or less at most locations.

Jupiter's Red Spot

The Great Red Spot continues to be unusually colorful and visible. Here are the dates and times (UT) when it should cross Jupiter's central meridian:

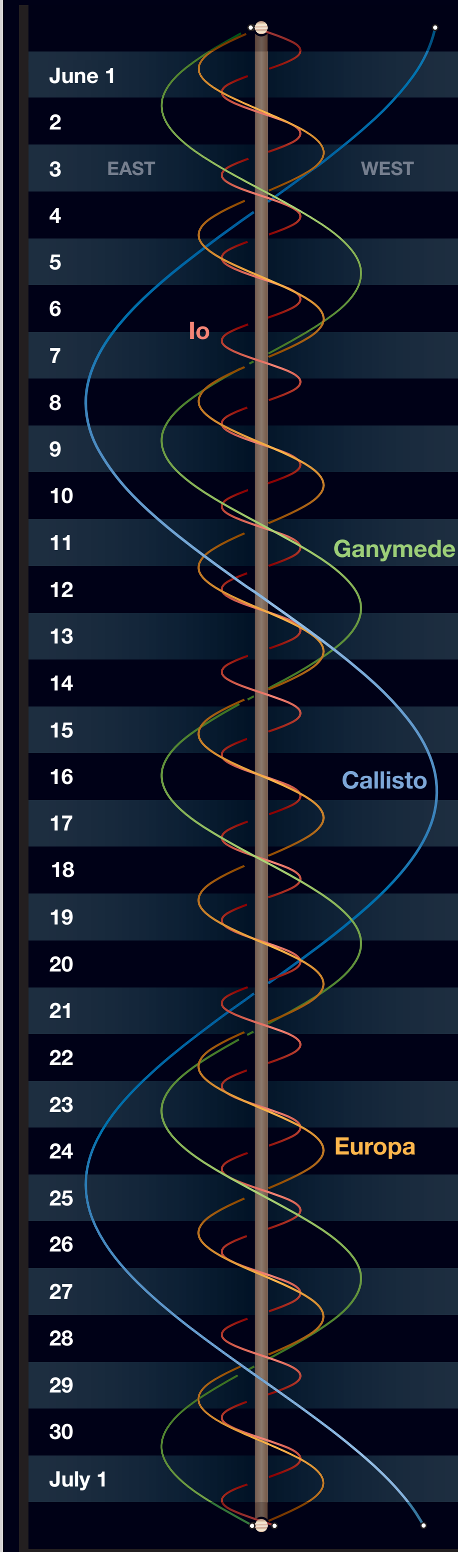
June 1, 7:25, 17:21; **2,** 3:16, 13:12, 23:08; **3,** 9:04, 18:59; **4,** 4:55, 14:51; **5,** 0:46, 10:42, 20:38; **6,** 6:34, 16:29; **7,** 2:25, 12:21, 22:16; **8,** 8:12, 18:08; **9,** 4:04, 13:59, 23:55; **10,** 9:51, 19:46; **11,** 5:42, 15:38; **12,** 1:34, 11:29, 21:25; **13,** 7:21, 17:17; **14,** 3:12, 13:08, 23:04; **15,** 9:00, 18:55; **16,** 4:51, 14:47; **17,** 0:43, 10:38, 20:34; **18,** 6:30, 16:25; **19,** 2:21, 12:17, 22:13; **20,** 8:08, 18:04; **21,** 4:00, 13:56, 23:51; **22,** 9:47, 19:43; **23,** 5:39, 15:35; **24,** 1:30, 11:26, 21:22; **25,** 7:18, 17:13; **26,** 3:09, 13:05, 23:01; **27,** 8:56, 18:52; **28,** 4:48, 14:44; **29,** 0:39, 10:35, 20:31; **30,** 6:27, 16:23.

Phenomena of Jupiter's Moons, June 2017

June 1	9:22	I.Oc.D
	12:39	I.Ec.R
June 2	5:18	II.Tr.I
	6:38	I.Tr.I
	7:31	II.Sh.I
	7:42	I.Sh.I
	7:46	II.Tr.E
	8:49	I.Tr.E
	9:52	I.Sh.E
	9:56	II.Sh.E
June 3	3:50	I.Oc.D
	7:08	I.Ec.R
	21:51	III.Tr.I
	23:59	II.Oc.D
June 4	0:18	III.Tr.E
	1:06	I.Tr.I
	2:11	I.Sh.I
	2:21	III.Sh.I
	3:16	I.Tr.E
	4:21	I.Sh.E
	4:35	II.Ec.R
	4:37	III.Sh.E
	22:17	I.Oc.D
June 5	1:37	I.Ec.R
	18:31	II.Tr.I
	19:33	I.Tr.I
	20:39	I.Sh.I
	20:49	II.Sh.I
	21:00	II.Tr.E
	21:44	I.Tr.E
	22:49	I.Sh.E
	23:14	II.Sh.E
June 6	16:45	I.Oc.D
	20:05	I.Ec.R
June 7	11:49	III.Oc.D
	13:12	II.Oc.D
	14:01	I.Tr.I
	14:19	III.Oc.R
	15:08	I.Sh.I
	16:12	I.Tr.E
	16:32	III.Ec.D
	17:18	I.Sh.E
	17:52	II.Ec.R
	18:49	III.Ec.R
June 8	11:13	I.Oc.D
	14:34	I.Ec.R
June 9	7:46	II.Tr.I
	8:29	I.Tr.I
	9:36	I.Sh.I
	10:09	II.Sh.I
	10:15	II.Tr.E
	10:39	I.Tr.E
	11:47	I.Sh.E
	12:33	II.Sh.E
June 10	5:40	I.Oc.D
	9:03	I.Ec.R
June 11	1:32	III.Tr.I
	2:25	II.Oc.D
	2:56	I.Tr.I
	4:00	III.Tr.E
	4:05	I.Sh.I
	5:07	I.Tr.E
	6:15	I.Sh.E
	6:20	III.Sh.I
	7:10	II.Ec.R
	8:35	III.Sh.E
June 12	0:08	I.Oc.D
	3:32	I.Ec.R
	21:01	II.Tr.I
	21:24	I.Tr.I
	22:34	I.Sh.I
	23:27	II.Sh.I
	23:29	II.Tr.E
	23:35	I.Tr.E
June 13	0:44	I.Sh.E
	1:51	II.Sh.E
	18:36	I.Oc.D
	22:01	I.Ec.R
June 14	15:33	III.Oc.D
	15:39	II.Oc.D
	15:52	I.Tr.I
	17:02	I.Sh.I
	18:03	I.Tr.E
	18:05	III.Oc.R
	19:12	I.Sh.E
	20:27	II.Ec.R
	20:32	III.Ec.D
	22:48	III.Ec.R
June 15	13:04	I.Oc.D
	16:29	I.Ec.R
June 16	10:17	II.Tr.I
	10:20	I.Tr.I
	11:31	I.Sh.I
	12:31	I.Tr.E
	12:46	II.Tr.E
	12:46	II.Sh.I
	13:41	I.Sh.E
	15:10	II.Sh.E
June 17	7:32	I.Oc.D
	10:58	I.Ec.R
June 18	4:48	I.Tr.I
	4:53	II.Oc.D
	5:17	III.Tr.I
	6:00	I.Sh.I
	6:59	I.Tr.E
	7:48	III.Tr.E
	8:10	I.Sh.E
	9:44	II.Ec.R
	10:19	III.Sh.I
	12:33	III.Sh.E
June 19	2:01	I.Oc.D
	5:27	I.Ec.R
	23:16	I.Tr.I
	23:32	II.Tr.I
June 20	0:28	I.Sh.I
	1:27	I.Tr.E
	2:01	II.Tr.E
	2:04	II.Sh.I
	2:38	I.Sh.E
	4:28	II.Sh.E
	20:29	I.Oc.D
	23:56	I.Ec.R
June 21	17:44	I.Tr.I
	18:08	II.Oc.D
	18:57	I.Sh.I
	19:21	III.Oc.D
	19:55	I.Tr.E
	20:37	II.Ec.D
	20:37	II.Oc.R
	21:07	I.Sh.E
	21:54	III.Oc.R
	23:01	II.Ec.R
June 22	0:31	III.Ec.D
	2:47	III.Ec.R
	14:57	I.Oc.D
	18:25	I.Ec.R
June 23	12:12	I.Tr.I
	12:49	II.Tr.I
	13:26	I.Sh.I
	14:23	I.Tr.E
	15:19	II.Tr.E
	15:24	II.Sh.I
	15:36	I.Sh.E
	17:47	II.Sh.E
June 24	9:26	I.Oc.D
	12:53	I.Ec.R
June 25	6:40	I.Tr.I
	7:24	II.Oc.D
	7:54	I.Sh.I
	8:51	I.Tr.E
	9:08	III.Tr.I
	9:53	II.Oc.R
	9:54	II.Ec.D
	10:04	I.Sh.E
	11:40	III.Tr.E
	12:18	II.Ec.R
	14:19	III.Sh.I
	16:32	III.Sh.E
June 26	3:54	I.Oc.D
	7:22	I.Ec.R
June 27	1:09	I.Tr.I
	2:06	II.Tr.I
	2:23	I.Sh.I
	3:20	I.Tr.E
	4:33	I.Sh.E
	4:36	II.Tr.E
	4:42	II.Sh.I
	7:05	II.Sh.E
	22:22	I.Oc.D
June 28	1:51	I.Ec.R
	19:37	I.Tr.I
	20:40	II.Oc.D
	20:52	I.Sh.I
	21:48	I.Tr.E
	23:01	I.Sh.E
	23:09	II.Oc.R
	23:12	II.Ec.D
	23:13	III.Oc.D
June 29	1:35	II.Ec.R
	1:48	III.Oc.R
	4:30	III.Ec.D
	6:45	III.Ec.R
	16:51	I.Oc.D
	20:20	I.Ec.R
June 30	14:06	I.Tr.I
	15:20	I.Sh.I
	15:24	II.Tr.I
	16:16	I.Tr.E
	17:30	I.Sh.E
	17:54	II.Tr.E
	18:01	II.Sh.I
	20:24	II.Sh.E

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.

Peaks of "Eternal" Light

If we ever try to live on the Moon, the best locations will be polar mountains bathed in nearly continuous sunlight.

This is the time of year when we become keenly aware that Earth's equator is inclined 23½° to the plane defined by its orbit around the Sun. The solstice falls on June 21st at 4:24 Universal Time (12:24 a.m. Eastern Daylight Time), and that's when the northern pole of our planet's spin axis is maximally tilted toward the Sun.

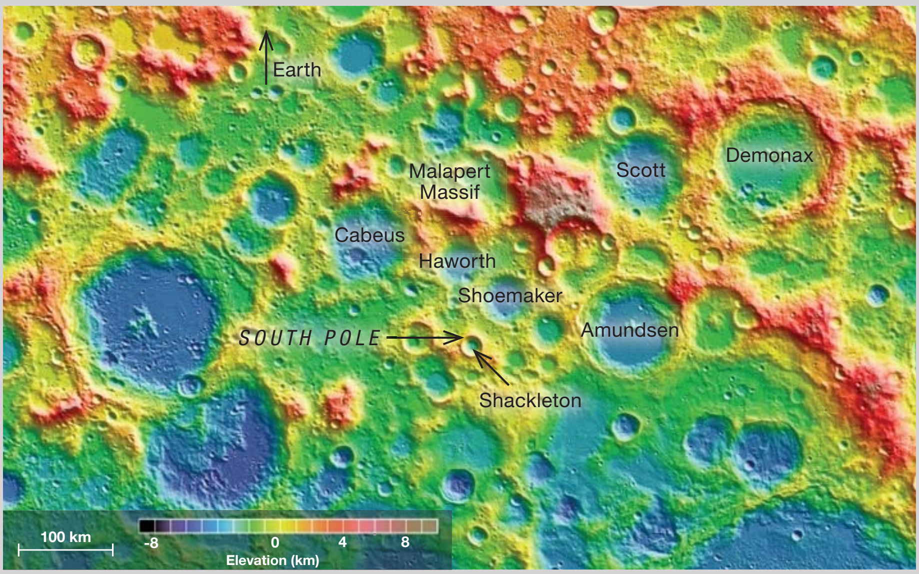
In addition to causing seasons, this axial tilt (known as *obliquity*) allows sunlight to fully illuminate the poles — periodically even at midnight — so that over a year, remote-sensing satellites can image the entire surface of our planet.

The Moon, however, is tilted only 1½° with respect to the ecliptic, and hence the Sun is always near or just below the horizon as seen from its poles. In fact, the Sun never rises above the rims of some deep polar craters, and so their floors receive very little direct sunlight, if any at all. Thermal maps created by the Diviner instrument on NASA's Lunar Reconnaissance Orbiter (LRO) show that the always-dark floors of these craters are some of the coldest locations in the solar system.

Offsetting this absence of light are some nearby polar mountains that nearly always bask in sunlight. The pioneering German lunar mapper Johann Heinrich von Mädler was the first to realize this, but it was French astronomer and author Camille Flammarion who, about 40 years later in 1879, romanticized the idea by calling these always-sunlit places *pics de lumière éternelle* – peaks of eternal light.

Actually, no lunar real estate is 100% illuminated, though a few peaks are lit by the Sun more than 90% of the time. In any case, these locations are always difficult to observe and identify. Even when seen with favorable lunar libration, the extreme foreshortening created by looking sideways at the lunar poles compresses circular crater rims into apparently straight ridges.

However, using images from the lunar-orbiting Clementine, Kaguya, and LRO spacecraft, which have been able to look straight down on the poles, scientists have disentangled these distortions and mapped lunar locations that are nearly permanently shadowed and, conversely, rarely so.



▲ Spacecraft-borne laser altimeters have mapped the topography near the Moon's south pole. High points on the rims of Malapert and Shackleton receive sunlight about 90% of the time.

NASA / GODDARD SPACE FLIGHT CENTER

Take the Polar Challenge

For a telescopic observer, identifying the *"pics"* near the lunar south pole is especially difficult because the area is heavily cratered. The most continuously sunlit peaks typically occur as small pieces of rim crests and ridges around Shackleton, a 21-km-wide crater located right at the pole. But I have yet to come across an Earth-based image of Shackleton.

Instead, peaks on the rims of the craters **Cabeus** and **Malapert** are the most southerly named features that can usually be identified telescopically when librations tip the south pole toward Earth. They're both in view in the image at the top of the facing page.

Most conspicuous are informally named **Malapert Massif** (a 5-km-high crest along that crater's southwestern rim) and other isolated high points that are parts of the rim of the enormous farside basin called South Pole-Aitken.

Cabeus is a little easier to spot. In 2009, NASA's LCROSS probe crashed onto its permanently shadowed floor, discovering near-surface deposits of water and other volatiles (*S&T:* Feb. 2010, p. 28).

Your best near-term chance to spot some of these far-southern features comes on June 5th to 7th, when the south pole of a waxing gibbous Moon is tipped a little less than 6° toward Earth.

Observing *pics* near the north pole is far easier because the topography is much flatter and appears less cluttered with craters and mountains. The view at lower right shows the longest and easiest-to-see peak of eternal light. The bright ray crater at far left is Anaxagoras — ignore it. Instead, look toward the right at **Scoresby**, a fresh, somewhat larger (56-km-wide) but not-as-bright crater at 78° north. A distinguishing feature is the small bright crater on its inner rim.

Immediately poleward are the overlapping, flat-floored twins **Challis** and **Main**. Continuing north, look for another flat-floored crater **Gioja** (42 km wide, 83°N). Beyond that are prizes not often seen: **Byrd** (94 km, 85°N) and **Peary** (70 km, 89°N). The actual north pole is on the brightly illuminated far wall of Peary — it is nearly constantly draped with sunlight.

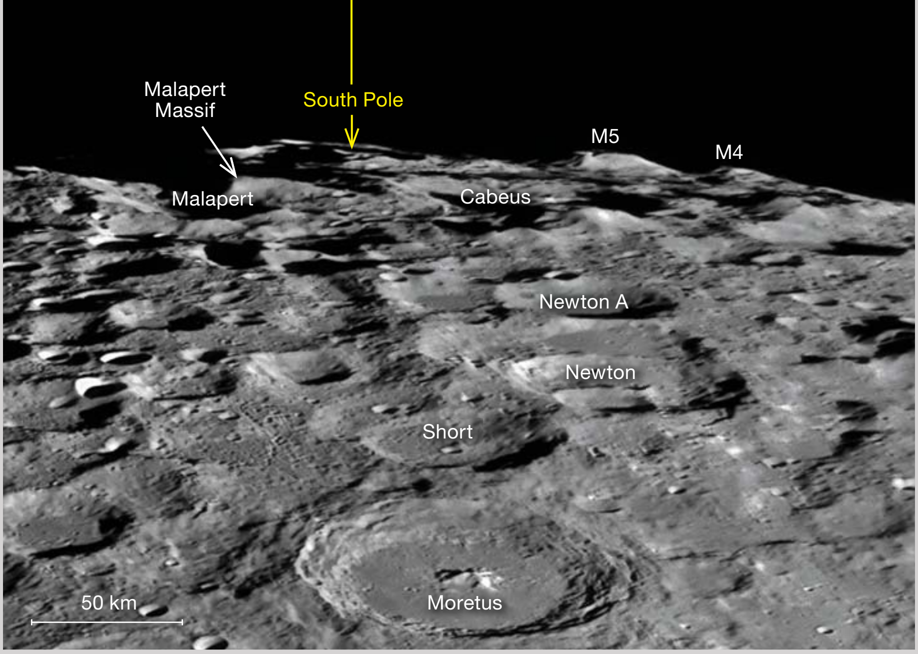
A very favorable north-polar libration — just under 7° — occurs on May 24th. Unfortunately, the Moon is then a hair-thin waning crescent only 1.3 days from new. You might try one day earlier, May 23rd, when the libration is closer to 6°.

In Flammarion's day, the *pics de lumière éternelle* were romantic oddities, but they could soon become valuable real estate. Their summits are washed with nearly constant grazing sunlight that solar-cell arrays could use to generate electricity for lunar bases. The temperature would stay nearly constant at roughly –50°C (–60°F), which is a brutally frigid winter day in Alaska but rather temperate for a lunar location. The deep, permanently shadowed craters nearby likely contain enough water to drink, irrigate crops, and break down into hydrogen and oxygen for use as rocket fuel. They could be the oases in an otherwise completely arid land.

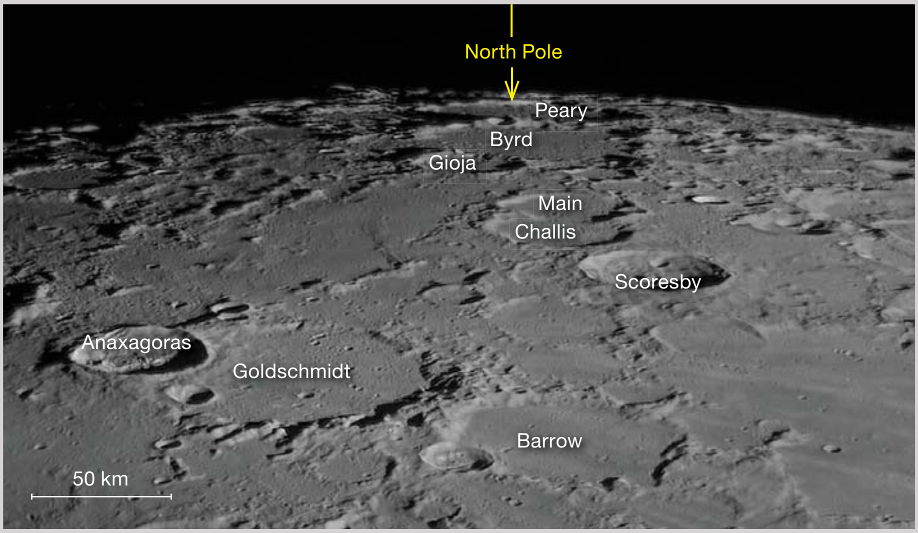
A recent investigation by Martin Elvis (Harvard-Smithsonian Center for Astrophysics) and two colleagues suggests that the uniqueness of these *pics* might lead to a rush to claim them. The Outer Space Treaty of 1967 states that the Moon is the "province of all mankind" and prohibits nations and corporations from claiming ownership of lunar land.

But 50 years ago we had no detailed knowledge of these polar peaks. Elvis and his co-authors speculate that their value as both energy and water resources could lead to creative interpretations of the Treaty. For example, one provision states that any lunar station's "delicate scientific experiment" would require others to keep away so as not to interfere. So you might want to get out your telescope and take a look at this polar property before the "no trespassing" signs go up.

■ No matter where he ventures on the Moon, Contributing Editor **CHUCK WOOD** always prefers to explore locations where the Sun is up.



▲ South is up in this view of the south-polar terrain seen during an extremely favorable libration. Malapert Massif and other high-standing peaks in this region receive nearly constant sunlight.



▲ Thanks to smoother terrain overall, you'll have an easier time "crater-hopping" to the Moon's north pole when favorable libration permits. The far rim of Peary enjoys nearly constant sunlight.

• **Visit www2.lpod.org for more insights on viewing the Moon telescopically.**

TOP: AVANI SOARES, BOTTOM: GEORGE TARSOUDIS

Doodles in the Sky

From sharks to dogs, hats to rings, these night-sky patterns will have you seeking more.

Our brains are wired to seek patterns. We see castles in the clouds, butterflies in inkblots, and faces or even rabbits on the Moon. Amateur astronomers experience this *pareidolia* when gazing at the vast dot-to-dot tableau of the night sky. We imaginatively sketch figures among the stars, spawning a wealth of cosmic doodles that we call *asterisms*.

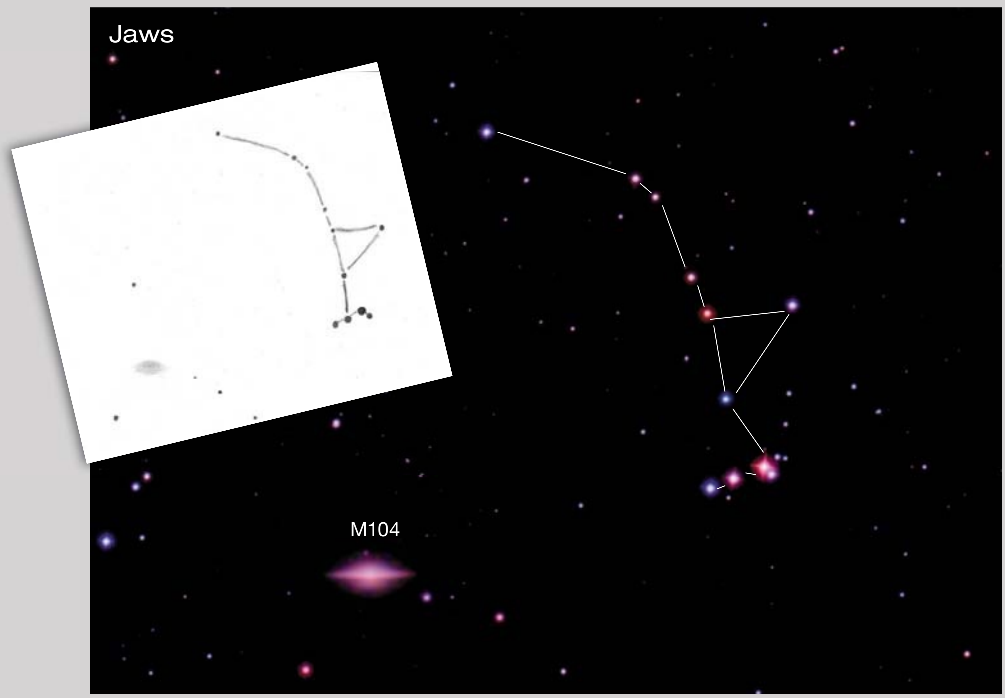
Let's take a look at some of the asterisms that populate the sky at this time of the year, sticking to those that are noteworthy for the images they've evoked.

From April through June, the star-figure known as **Jaws** is best caught early in the night. You'll find it in the constellation Virgo, near the border it shares with Corvus. Jaws is one of my favorite asterisms. It's just beautiful in the field of view with the Sombrero Galaxy (M104) through my 130-mm refractor at 48×. My pencil sketch shows the two as seen through the scope and also outlines the asterism. Jaws represents a skeletal shark whose most prominent feature is a toothy mouth of four stars, the brightest one gold. Its six-star spine curves northeast and is all you can see of the shark's body, while a solitary star to the west marks the tip of its dorsal fin. Mouth to tail, our finny friend spans 27′. Well-known author Phil Harrington gave Jaws its popular name in his book *The Deep Sky: An Introduction*.

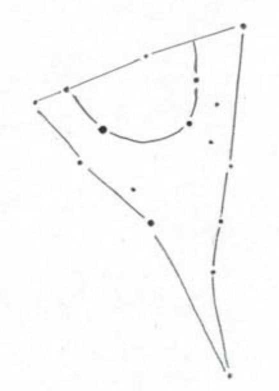
French amateur Laurent Ferrero keeps an internet list of interesting star groups that he's noticed during more than 20 years of deep-sky observing (**https://is.gd/laurentferrero**). His catalog currently consists of 53 objects, some of which proved to be true open clusters. Among his asterisms, the **Eiffel Tower** (Ferrero 6) is thus named because its tapered form is reminiscent of this famous cultural icon. In the 130-mm scope at 37×, it's composed of 16 stars, magnitude 8.2 and fainter, the brightest one deep yellow. The tower is 28′ tall, with its tip pointing south-southwest. The Eiffel Tower is easy to locate by picturing the right triangle that it makes with Zeta (ζ) and Epsilon (ε) Ursae Majoris in the Big Dipper's handle. Our asterism's discoverer is also the author of a French-language, five-volume observing guide called *Splendeurs du Ciel Profond*.

Just 40′ south-southwest of Arcturus in Boötes, we find **Napoleon's Hat** (Picot 1). Fulbert Picot, the French amateur astronomer for whom the group is named, also bestowed its apt nickname. Through the 130-mm refractor at 23×, the emperor's chapeau consists of seven stars ranging from magnitude 9.4 to 10.7, distributed along a bell curve. The brim of the hat is 20′ long and runs northeast to southwest. My 18×50 image-stabilized binoculars capture six of the seven stars, missing only the one at the top of the hat. Ken Hewitt-White, a contributing editor for *Sky & Telescope*, fittingly thinks this asterism "suggests a caterpillar humped-up in mid crawl." Ken is probably referring to the caterpillars commonly called inchworms, since most other caterpillars don't have the inchworm's looping gait.

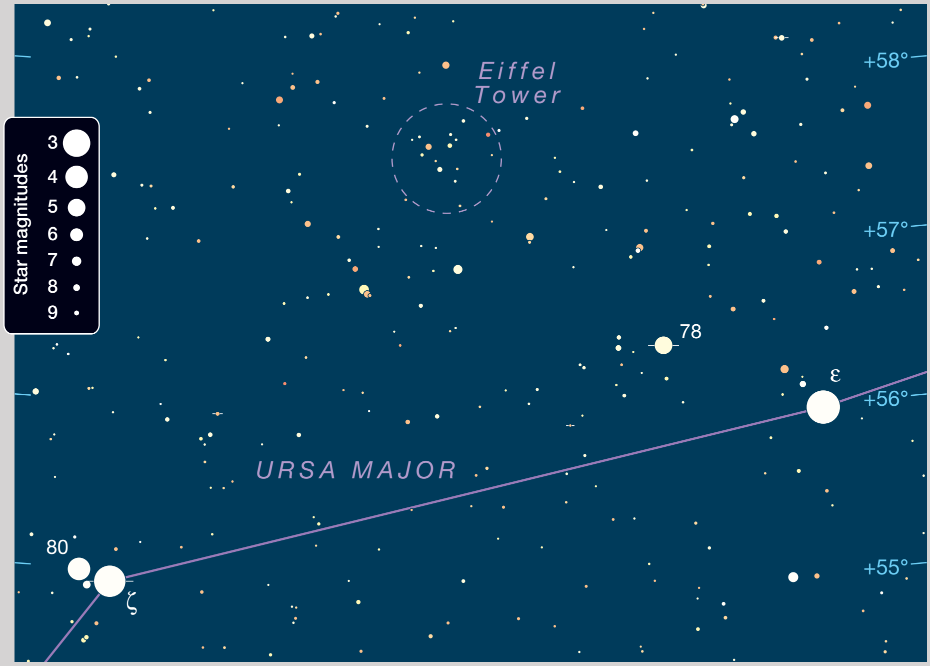
Now commonly called the **Zigzag**, our next asterism was introduced by Phil Harrington in *Touring the Universe*



DAVID RATLEDGE, SKETCH: SUE FRENCH

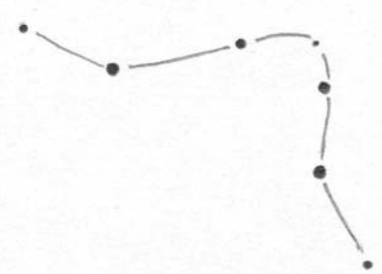


Imagine a right triangle that uses the line that runs between Mizar and Alioth in Ursa Major as the hypotenuse. The Eiffel Tower asterism occupies the 90° corner of the triangle.



through Binoculars, a book affectionately known as TUB. Look for the Zigzag about 2° west-southwest of Omega (ω) Herculis. The asterism's name describes the view through large binoculars, but it's a wonderful area for dot-to-dot games through any telescope that offers a field of view of at least 1½°. My 105-mm refractor at 28× shows a score of 8th- to 10th-magnitude stars in a switchback, 1.3° chain. It reminds me of the beautiful Chinese dragons carried in parades, its head at the south-south-eastern end. Since the tail's brightest star gleams gold, I think of this as the Golden Dragon. At a similar magnification, the 130-mm scope plucks out more stars and turns the asterism into a flower, as outlined on my pencil sketch. On one occasion, I even fashioned a balloon animal with its stars.

Webb's Wreath also resides in Hercules, 2.7° south-southwest of Omicron (ο) Herculis. The wreath was first mentioned in the fourth edition (1881) of Thomas William Webb's observing guide, *Celestial Objects for Common Telescopes*. Its brightest star, 7th-magnitude HD 164922 (SAO 85678), adorns the wreath's eastern side. My 130-mm scope at 63× discloses 16 additional stars, magnitudes 10.7 and fainter, outlining an 11′ × 7′ oval that leans northeast and is dented inward at the bright star. Although some skygazers call this asterism the Ruby Ring, I see



Napoleon's Hat lies 40 arcminutes south-southwest of Arcturus in Boötes.

A look at the Zigzag asterism through a 105-mm refractor at 28× reveals 20 or so 8th- to 10th-magnitude stars in a crooked chain about 1.3° long.

SUE FRENCH (3)

Summer Doodles

Object	Size/Sep	RA	Dec.
Jaws	27′	12^h 38.8^m	–11° 21′
Eiffel Tower	28′	13^h 09.9^m	+57° 29′
Napoleon's Hat	20′	14^h 15.0^m	+18° 33′
Zigzag (Flower)	1.3°	16^h 17.5^m	+12° 55′
Webb's Wreath	11′ × 7′	18^h 02.4^m	+26° 18′
Candle and Holder	1.1°	18^h 01.3^m	+47° 59′
Dog and Stick	1.5°	17^h 35.0^m	+68° 54′
Engagement Ring	48′	02^h 40.0^m	+88° 52′
Ring of the Nibelung	1.4′ × 0.6′	15^h 58.0^m	+62° 32′

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.

the ring's bright gem sparkling with a deep-yellow hue.

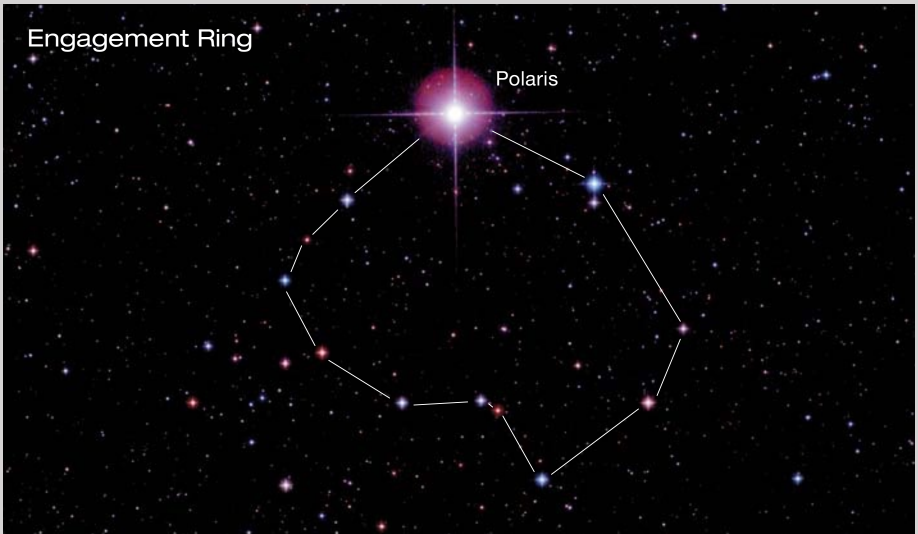
In far northeastern Hercules we find an asterism that comes from the fertile imagination of John A. Chiravalle, author of *Pattern Asterisms: A New Way to Chart the Stars*. Known as the **Candle and Holder**, Chiravalle thinks of it as the flame that lights Hercules' way though the dark. This cute asterism sits 4.2° east-northeast of Iota (ι) Herculis, and it's brightest star is 6th-magnitude HD 165358 (SAO 47173) in the base of the holder. The pattern's stars are bright enough to see in my 18×50 binoculars, with the candle dangling upside-down in the sky. The sketch shows my interpretation of the Candle and Holder as seen through these binoculars, which is slightly different than Chiravalle's. Base to flame, the asterism is 1.1° tall, and the star that marks the flame flickers with an appropriately yellow-orange hue.

We'll find another of Chiravalle's unique star patterns in Draco, the **Dog and Stick**, which Chiravalle calls "absolutely remarkable." Its brightest star is Omega Draconis, the dog's nose, and the next brightest is yellow-orange 27 Draconis on the back of his head. The asterism shows quite well in the 18×50 binoculars, displaying 24 stars within 1.5°, magnitudes 4.8 to 9.2. Once again, the interpretation on my sketch is a bit different that Chiravalle's, so feel free to let your own fancy rule.

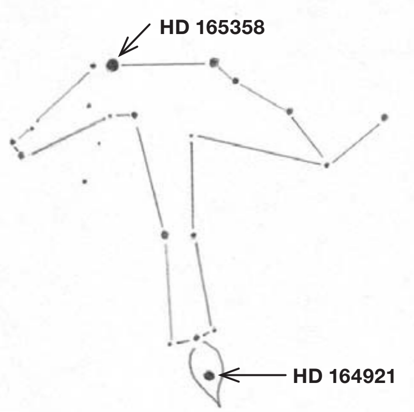
In 1961, William L. Dutton reported an asterism that he called the **Engagement Ring** (*S&T:* Jan. 1961, p. 41). Polaris, the North Star, is the ring's brilliant diamond, and through my 18×50 binoculars, nine 6th- to 9th-magnitude stars form the band. One has to wonder if the engagement was broken, because the dented band looks as if it was vehemently thrown and damaged in some lovers' spat. Even the diamond is chipped, as you'll see if you look at Polaris with a telescope at 50× or more. This little diamond chip is a 9th-magnitude companion star, separated from the diamond by 18″. Overall, the Engagement Ring is about 48′ across.

Our final target is the **Ring of the Nibelung** (Ferrero 27) in Draco. Ferrero says its name is a "reference to Norse mythology, which says that the dragon Fafnir was the guardian of the cursed ring forged by the Nibelung, the ring that brought misfortune to the knight Siegfried." Unfortunately, this compact asterism is not a good target for small telescopes. One of the stars looks very faint even in my 10-inch reflector. Nevertheless, this tiny ring is adorable. It's made up of six stars and appears to be tipped away from us so that we see it as a 1.4′ × 0.6′ oval. The ring's colorful stars make it an especially tempting target for imagers. Give it a try!

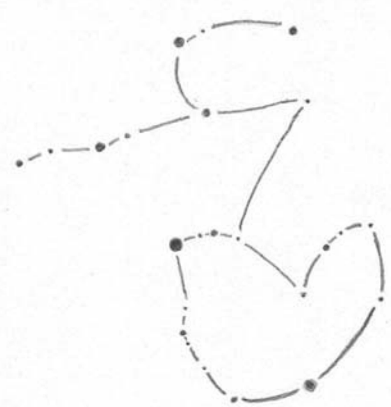
■ Contributing Editor **SUE FRENCH** welcomes your comments at **scfrench@nycap.rr.com**.



If you can find the Little Dipper, you should be able to track down the Engagement Ring asterism, which features Polaris, the North Star, as its diamond.



The author captured the Candle and Holder asterism with her 18×50 image stabilized binoculars. The white *A*-class star HD 165358 holds down the base of the holder while the yellow-orange *K*-class star HD 164921 marks the flame.



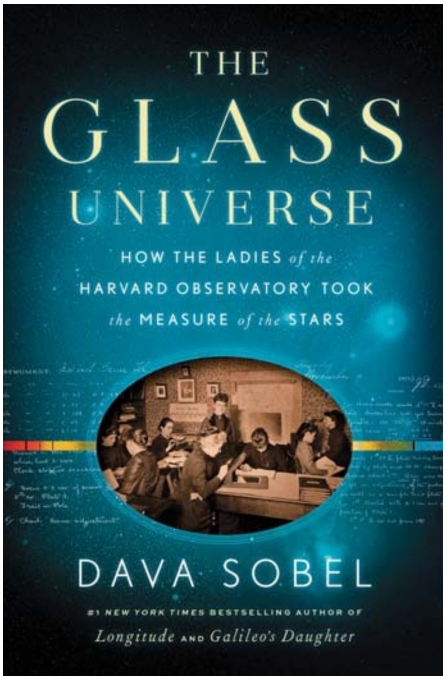
Build the Dog and Stick asterism out of the stars surrounding Omega Draconis, using the yellow-white *F*-class star as the nose.

ENGAGEMENT RING: DAVID RATLEDGE; SKETCHES: SUE FRENCH

When Computers Wore Skirts

THE GLASS UNIVERSE: *How the Ladies of the Harvard Observatory Took the Measure of the Stars*

Dava Sobel
Penguin Random House, 2016
320 pages, ISBN 978-0670016952
$30.00, hardcover.



WHEN I SAT DOWN to review *The Glass Universe* by Dava Sobel, I had a hard time finding a copy. I'd already given away my book after reading it in full — and I wasn't the only one on staff to do so. That, as much as anything, gives testament to this book's appeal, particularly for anyone interested in stellar science, astronomical history, the women's movement, or all of the above.

Sobel guides the reader through an ambitious period that began in the late 19th century, when astronomers around the world — but led primarily by the Harvard College Observatory — began to photograph and classify stars by the thousands. As in her earlier books *Longitude* and *Galileo's Daughter*, Sobel approaches history through the lens of the written letter, this time written by both patrons and employees of the observatory. Though often formal, the letters are also genial and even playful. To wit: Benefactress Catherine Wolfe Bruce wrote of telescope construction setbacks to observatory director Edward Pickering, "Accept my condolences. Here is another cause of delay — Before you see all those discs you will have discovered your first grey hair and I! I shall be in cool repose in Greenwood [Cemetery]."

The story picks up the pace in the middle chapters, delivering details on the lives and research of many of the Harvard "computers," women who studied the stars imaged on photographic plates. Williamina Fleming, Antonia Maury, Henrietta Swan Leavitt, and Annie Jump Cannon feature prominently, as does Pickering's successor, Harlow Shapley. Sobel also dedicates a later chapter to Cecilia Payne-Gaposchkin's work in the 1920s and beyond.

Sobel focuses on science more than on personal lives. You'll learn a lot about stellar spectra, classification schemes, and the incredible journey astronomers undertook to understand the stars above them.

However, social commentary is also visible, if sometimes between the lines. On the one hand, it quickly becomes clear that Pickering was more farsighted than his contemporaries in employing women for scientific tasks. As tedious as their labor must have been at times, an intimate knowledge of the data is what ultimately enabled these women to reach astronomical breakthroughs.

At the same time, though, Pickering was in a financial bind as he pushed his observatory toward grand goals, and his employment of women was ultimately practical — he knew he could pay them far less than their male counterparts. The women's writings show that they weren't unaware of this discrepancy.

Still, the women knew their place in the grander scheme of things. As Annie Jump Cannon noted after participating in the international Committee on Classification of Stellar Spectra, "They sat at a long table, these men of many nations, and I was the only woman. Since I have done almost all the world's work in this one branch, it was necessary for me to do most of the talking."

Only in the book's last 50 or so pages, which take the reader through the mid-20th century, does the writing become a bit rote. It seems fair to blame this less on the author and more on the general demise of letter writing.

I thoroughly enjoyed this new perspective on the history of stellar astronomy and women's important role in it. Whether or not you're familiar with the story of the Harvard computers, you'll learn something new from reading it as well.

"They sat at a long table, these men of many nations, and I was the only woman. Since I have done almost all the world's work in this one branch, it was necessary for me to do most of the talking."

■ News Editor **MONICA YOUNG** has glimpsed the Horsehead Nebula on the very plate from which Williamina Fleming discovered it.

The 102-mm FCD100 Triplet APO Refractor

Explore Scientific's new line of FCD apochromatic refractors promise premium optics at an affordable price.

◀ The Explore Scientific FCD 102-mm aperture apochromatic refractor features a new type of low-dispersion Hoya FCD100 glass, meant to produce apochromatic performance at significantly lower cost than competing models.

102-mm FCD100 Air-Spaced Triplet ED APO Refractor

U.S. Price: $1,499.00
explorescientificusa.com

What We Like

Superb optical quality
Compact size, light weight

What We Didn't Like

Average focuser
Field flattener not fully effective

I'LL DISCLOSE AT THE OUTSET that I'm a big fan of this class of telescope. I own several 4-inch refractors and have tested many others. But this is my first experience testing an apochromatic refractor from Explore Scientific. Overall, I was impressed.

The unit in question is the 102-mm model from their new line of premium apochromatic refractors that all feature a triplet lens with an element made of the new Hoya FCD100 glass. Other telescopes in the series offer 80- and 127-mm apertures, the latter with the option of a carbon-fiber tube.

FCD100 low-dispersion glass has optical characteristics nearly identical to the Ohara FPL53 glass widely used in other top-of-the-line "apo" refractors. The difference is price. Explore Scientific's 102-mm refractor in the FCD100 series sells for $1,500, hundreds of dollars less than most competing telescopes with this grade of triplet optics.

Is this indeed a price breakthrough product? I would say yes. Its image quality was as good as any apo refractor I have used.

The Optics

Some lower-cost apo refractors I've used have sharp optics, but images are inevitably tinged with false color. With the 102-mm FCD I saw none — not a trace of false color even on demanding targets such as Vega, and on crater rims and the limb of the Moon. Even racking through focus showed no fringes of cyan or magenta in the defocused Airy disks of stars. And in focus, there

ALL PHOTOS ARE COURTESY OF THE AUTHOR

▲ The telescope weighs 5.7 kilograms (12.5 pounds) with the supplied tube rings and star diagonal in place. It measures 54.6 centimeters (21½ inches) long with the dewcap retracted, and without the 2-inch diagonal and none of the three extension tubes, one of which is on the telescope here. The optional field flattener is also shown.

were no blue halos surrounding bright objects, even at high power with a 3-mm Radian eyepiece.

Even more critical was the lack of any significant astigmatism or spherical aberration that would detract from the sharpness of the image. Diffraction patterns of stars were nearly textbook perfect both in focus and when defocused.

The tight components of Epsilon Lyrae, the Double-Double, were cleanly split with dark sky between each of the two pairs, with the component stars all exhibiting tight, well-defined Airy disks. This was true even in temperatures just below freezing when contracting lens cells can sometimes pinch or distort optics. Not here.

The tube is well blackened inside with one baffle halfway down the tube. Many other top-class refractors have two or three internal baffles, causing me some concern that the FCD scope would be subject to lens flare.

Not so. In direct comparison with another 4-inch triplet apo costing thousands more, with FPL53 glass and several tube baffles, I saw little difference in performance. Both showed a similar level of modest glare from the Moon when it was just outside the field of a 17-mm Ethos eyepiece. The FCD's tube design was working just fine.

In addition, color correction and sharpness were also on par with the premium apo. The FCD100 glass was doing its job well, providing top-of-the-line performance for a mid-range price.

Photographic Performance

Our test telescope on loan from the manufacturer came with an optional ($150) field flattener that retains the telescope's f/7 focal ratio and 714-mm focal length. Measurements of the photographic field size showed the telescope was indeed delivering just over 700 mm of focal length.

While f/7 is a little slower than I prefer for deep-sky imaging with DSLRs, it's certainly possible to get well-exposed images at modest ISO speeds in exposures of 4 minutes or more.

With the optional field flattener, images with a full-frame DSLR exhibited excellent sharpness across most of the frame, with elongation of star images increasing toward the corners. I'd judge the flattener as good, but it fell short of fully correcting a full-frame field. However, vignetting at the corners and along the bottom edge of the frame from DSLR mirror-box shadowing was minimal, as I would expect at f/7. The flattener is best-suited for APS-format or cropped-sensor cameras.

The focuser can be rotated for framing fields. I found doing so did not affect focus. It can also be locked down to prevent any focus shift from the weight of the camera.

One minor issue I found was that care was needed to ensure the field flat-

▲ **Left:** The air-spaced triplet lens is very well coated with Explore Scientific's "EMD" multi-coatings. Its internally blackened tube has one baffle to block stray light and off-axis reflections. **Right:** The Crayford-style 2½-inch rotatable focuser includes a 10:1 fine-focus control. It extends a modest 44 mm and is supplied with three screw-on tubes to extend the unit's focus range. The single short tube is shown here attached to the 2-inch adapter.

tener's 2-inch tube was squarely inserted into the focuser. Despite the focuser's 2-inch collar having a compression ring, I found I could tighten the collar's three thumbscrews and still have the flattener tilted, which would result in unevenly distorted stars across the field.

Mechanical Quality

The telescope is quite light for its aperture, weighing just 4.1 kilograms (9 pounds) without rings or other accessories. (By comparison, the premium apo I compared it to weighs 5.8 kg, even though it has a carbon fiber tube.) The FCD 102-mm will work well with a light "grab-and-go" mount, such as Explore's own Twilight alt-azimuth model, at least for visual use. I used the scope on a similar Astro-Tech Voyager mount, a combination that worked well. Of course, long-exposure photography requires a heavier equatorial mount.

The FCD100 series comes with Explore Scientific's standard HEX focuser, a Crayford-style unit with both coarse and 10:1 fine focus adjustments. It has a relatively short 44 mm of travel. So to allow for the varied back-focus demands of eyepieces and cameras, the FCD100 comes with three extension tubes, one short and two longer ones, plus a final screw-on collar that accepts 2-inch accessories.

For visual use the one short extension tube sufficed to enable all the eyepieces I tried, from low-power 2-inch to high-power 1¼-inch eyepieces, to reach focus with the excellent 2-inch mirror diagonal supplied as standard equipment. For photographic use with a DSLR, one additional longer extension tube was required. Attaching a CCD camera might require the third tube, depending on the spacing requirements of the camera.

The extension tubes screw on with fine threads that might be easy to cross-thread. Also, if they weren't on tight, I found they could loosen and turn under the weight of a star diagonal and heavy eyepiece if they were tilted towards the left side of the focuser, causing them to unscrew and flop down unnervingly. There are no lock screws to secure the extension tubes.

On the plus side, by not using any extension tubes I could get my Baader binoviewer and its own low-profile diagonal to reach focus without requiring any Barlow lens. That produced a lovely 2° field with a pair of 24-mm Tele Vue Panoptic eyepieces.

With the optional field flattener, stars appeared as pinpoints across most of the field, only exhibiting aberrations at the corners. This image of NGC 7000, the North America Nebula, is a stack of five 6-minute exposures at ISO 1600 with a modified Canon EOS 5D MkII camera.

However, the much more affordable William Optics binoviewer, typical of most units, did not reach focus, even when used with a 1¼-inch diagonal. It still needed its add-on Barlow lens. So in my judgment the extra back focus supplied by the focuser wouldn't be sufficient for most binoviewers without their accessory Barlow lenses.

At first, the focuser exhibited a fair degree of image shift, but this was largely eliminated by tightening the two tiny hex screws on the focuser barrel that serve to add tension. Even so, a slight image shift of about 15 arcseconds remained, not serious but a little annoying when trying to achieve fine focus while imaging.

More important was what I would describe as a "general mushiness" in the fine-focus adjustment. I could turn the knob and nothing would move at first, then it would grab, even with the focuser locks off. On occasion it would outright slip and not move at all, though not necessarily under a heavy load. This behavior made it more difficult to nail precise focus. When locked down, however, the focuser did stay put with a DSLR camera in place.

The HEX is a nice focuser; it just isn't top class, at odds with the scope's premium optics. I would have preferred to see a small Feather Touch focuser, the brand supplied with Explore Scientific's flagship 152-mm refractor. I would have also preferred a focuser with more travel, to reduce the need for swapping among the suite of extension tubes. Of course, all of that would add additional weight and cost to the telescope, partly negating two of the telescope's top virtues. And users can always upgrade the focuser to a third-party model at a later date.

As it is, if the 102-mm's performance is a gauge, Explore Scientific's new FCD 100 series delivers superb optical quality for affordable prices, with the 102-mm model hitting the sweet spot in cost vs. aperture vs. portability.

■ Contributing Editor **ALAN DYER**, a member of The World at Night, authored the e-book *How to Photograph & Process NightScapes and TimeLapses*.

Explore Scientific's 92° Long Eye Relief Eyepieces

SEAN WALKER / S&T

92° 12- and 17-mm Long Eye Relief Eyepieces

U.S. Price: $499.99 each
explorescientificusa.com

Since their introduction a decade ago, extremely wide-field eyepieces have become a staple among discerning observers. Every time I look through a big Dobsonian at a star party, chances are the scope is equipped with a premium ultra-wide-angle ocular with a 100° apparent field of view or more, allowing me to drink in the view for a long period before having to recenter the view. But these eyepieces come at a cost, particularly for those who wear eyeglasses. Often the eye relief is small, making a tight fit for observers who must wear their glasses when looking through a telescope.

Explore Scientific's 92° series of long eye relief eyepieces solves this issue by providing 20 mm of eye relief with both the 12- and 17-mm models, allowing any user to enjoy the entire expansive field without fussing with their glasses.

I had the opportunity to use both eyepieces on several large Dobsonians, as well as my own 12½-inch Newtonian reflector. Needless to say, the views are impressive. While not as wide as 100° models, the difference in apparent field is slight and only noticeable when directly comparing the views in the same telescopes. Stars appear as tight points of light, with some softening just before a star reached the field stop.

One particularly memorable view was with George Normandin's 20-inch Dobsonian during the Stellafane convention in Vermont last summer. Several of us lingered on the view of NGC 6520 and B86, a wonderful pairing of an open cluster next to a dark nebula. This dense region of the Milky Way in Sagittarius filled the view with myriad stars, permitting me to examine the edge quality of the eyepieces. If you observe without glasses, I suggest you use the folding rubber eye guards as a spacer to position your head to take in the entire field; otherwise, I often experienced a restricted field when my eye was too close to the field lens and my head drifted off-axis.

Perhaps the only drawback to the 92° eyepieces is their weight – the 17-mm tips the scale at 2.56 pounds, while the 12-mm weighs in at 2.26 pounds. Dobsonian owners might need some form of counterweight system when swapping these with smaller, lighter eyepieces.

The 92° long eye relief eyepieces are winners for users with or without glasses. I'm looking forward to views through additional focal lengths in the series.

What We Like
Superb star images

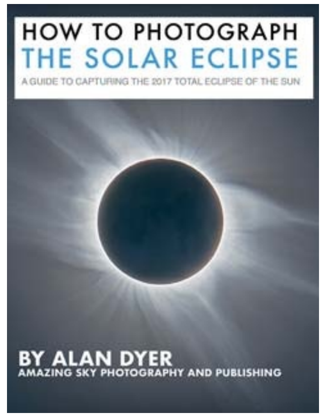
What We Didn't Like
Big and heavy

■ Equipment Editor **SEAN WALKER** enjoys observing with ultra-widefield oculars, particularly at star parties.

ECLIPSE PHOTO GUIDE ▶

Just in time for the American eclipse of August 21, *Sky & Telescope* Contributing Editor Alan Dyer announces *How to Photograph the Solar Eclipse*. This ebook ($9.99) contains 295 pages of detailed information specifically about framing and capturing the 2017 total solar eclipse. Dyer covers all the techniques and options, from grabbing simple shots and videos with cell phones to planning complex time-lapses and composites. The publication also provides detailed advice on choosing cameras, lenses, and tripods, and on using telescope mounts to track the Sun. Focal lengths, exposures, ISO settings, focusing — it's all covered in 12 chapters, including software tutorials on processing your results. Available both as a PDF file and as a multi-touch, interactive iBook for MacOS- and iOS-compatible devices from the Apple iBooks Store.

Amazing Sky Photography
amazingsky.com/eclipsebook.html



PLANETARY CAMERA ▶

Meade Instruments introduces a new planetary video camera. The LPI-G camera ($219.95) features the highly sensitive AR 130 CMOS detector with a 1,280-by-960 array of 3.75-micron pixels. This USB-2.0 camera is capable of recording up to 28 frames per second at full resolution, or 30 frames per second using a 640 × 480 region-of-interest. Additionally, the camera can function as an autoguider for deep-sky imagers, and it connects to your mount through an ST-4 autoguider port. The camera is available with color or monochrome detectors. Each purchase includes a 2-meter USB 2.0 cable, a guiding cable, a C-mount-to-1¼-inch nosepiece adapter, and a CD with ASCOM drivers and the company's *Sky Capture* control software.

Meade Instruments
27 Hubble, Irvine, CA 92618
800-626-3233; meade.com

PIXINSIGHT GUIDE ▶

Astrophotographer Warren Keller reveals the secrets of advanced image-processing in his book *Inside PixInsight* (softcover $34.99, ebook $24.99). Keller details processing workflow in the powerful software *PixInsight*, allowing readers to produce stunning astrophotos from their own data. Each chapter walks the reader through processing steps essential for producing the highest-quality deep-sky astrophotography, including calibration and integration, batch pre-processing, background modelization, and much more. Screenshots are used to help illustrate the process of navigating this essential software program. Springer, 380 pages, ISBN 978-3-319-25680-1.

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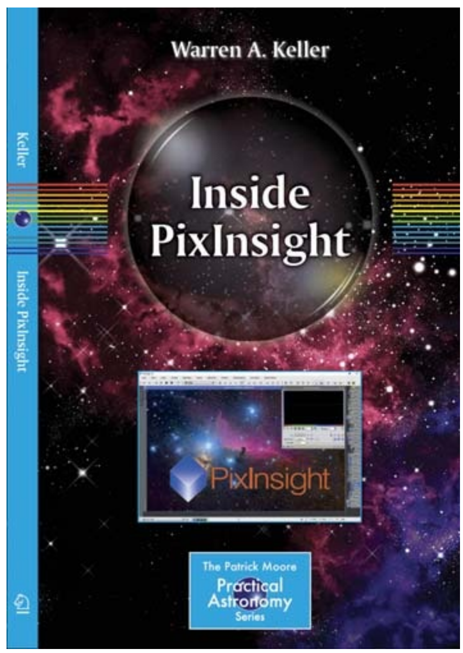


New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements.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

The Dark Wolf of Summer

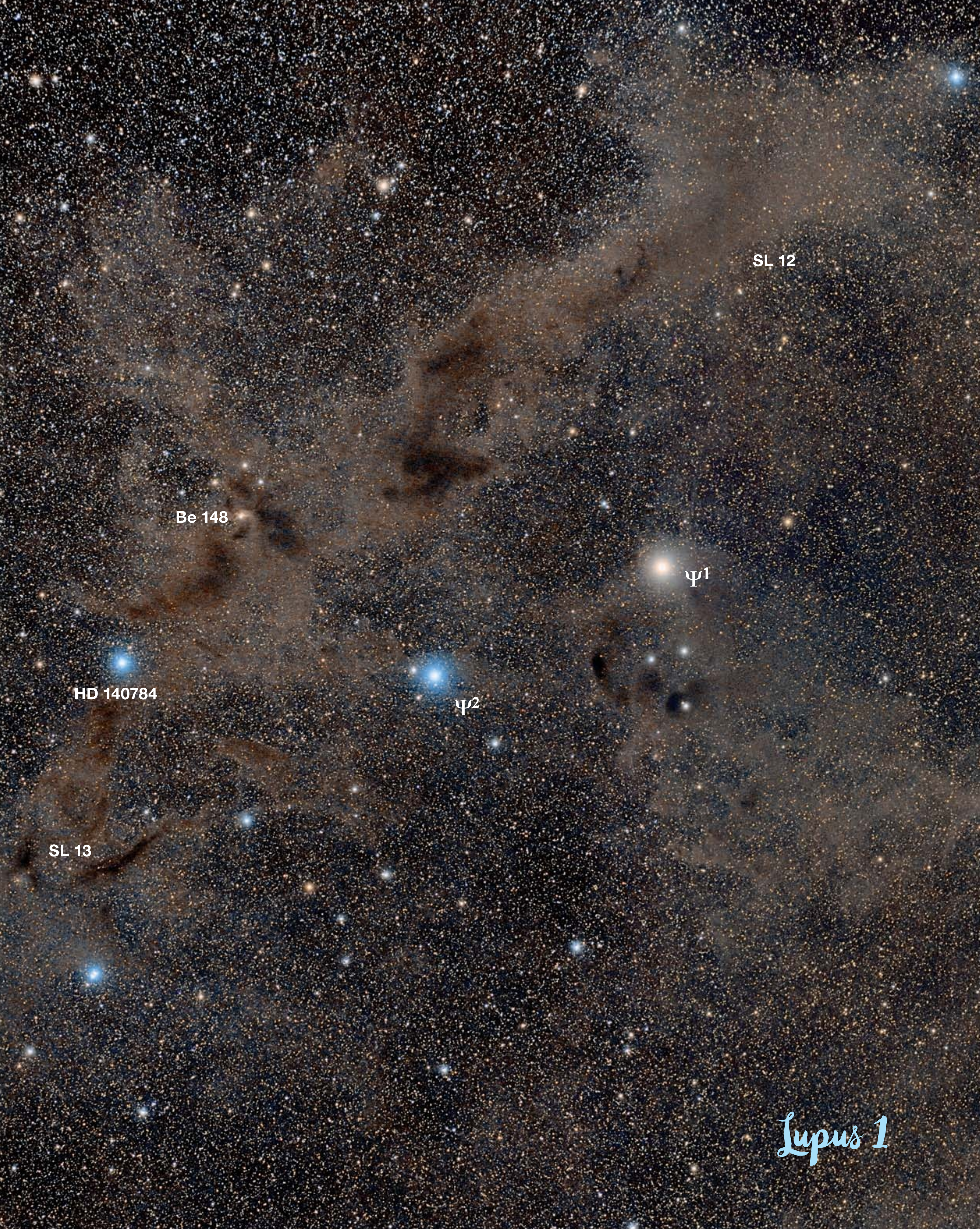
Stay up late to track down these absorption nebulae in Lupus.

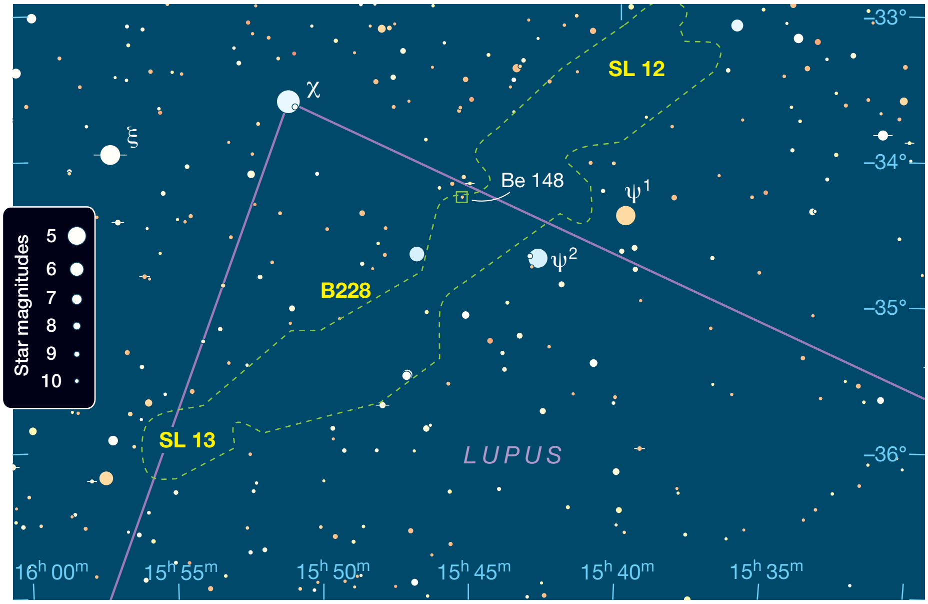
Summer is the season of the sleep out and the star party, when so many of us succumb to the temptation to stay up all night and observe. Sometimes the most overnight fun can be had in chasing down old favorites best viewed in the warm months: that brilliant line of stars in the Lagoon Nebula (M8) or the spangled shot of the Ptolemy Cluster (M7). But sometimes we're in the mood for something new, so we begin looking to the edges of our usual fields and charts. For observers in the Northern Hemisphere, this often means scanning as far south as possible, straining for targets in lower Sagittarius and Scorpius as those constellations scroll across the southern sky. Lupus, too, pops its head over the horizon in the late-night hours, encouraging us to track west for our deep-sky sights. Out of range in the winter and shoulder seasons, the Wolf offers three good options — all dark nebulae — to add to our list of summer favorites.

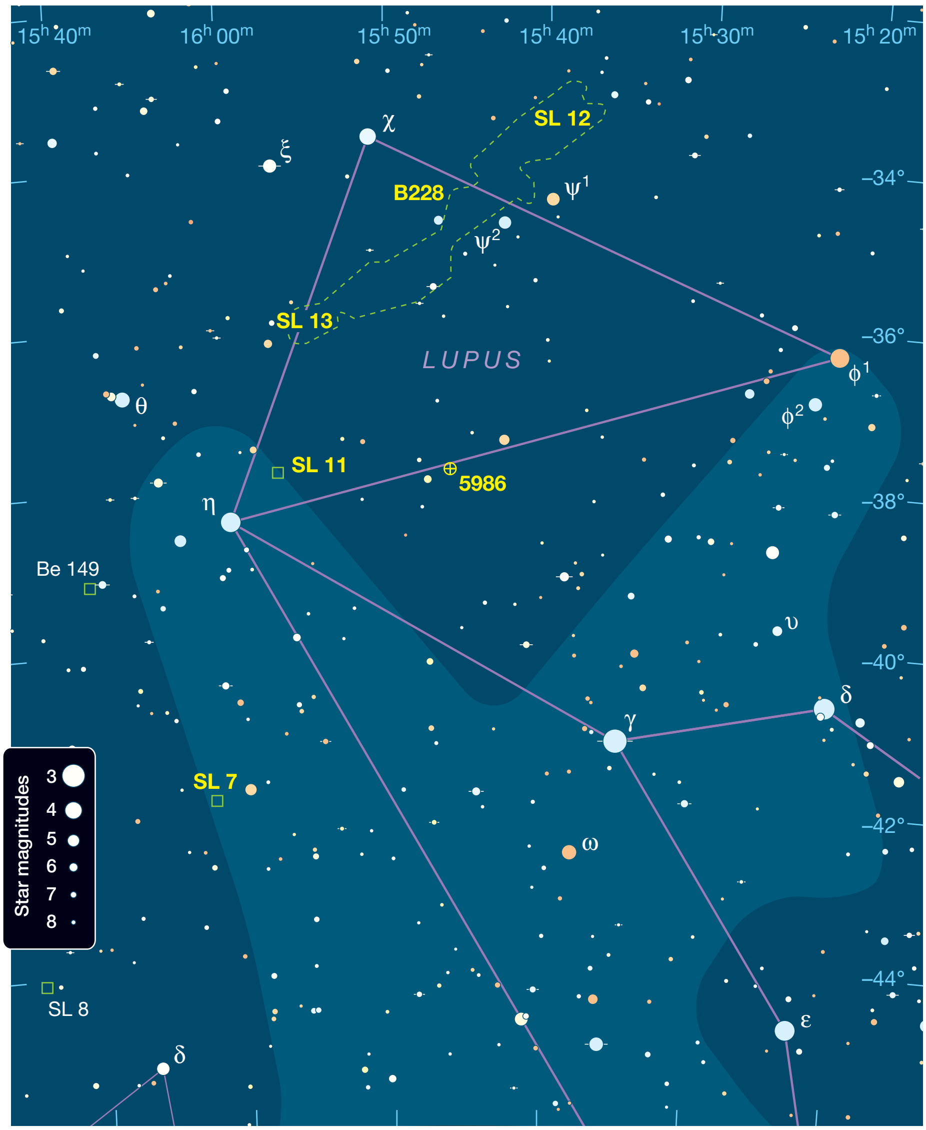
Dark, or absorption, nebulae are irregular stretches of dust and gas so dense that they block or scatter optical light, creating the appearance of dark voids in the eyepiece. These

▶ **RIDGE OF DARKNESS** Deep-sky images reveal the condensations of gas and dust in the darkest regions of the Lupus 1 molecular cloud. This three-panel mosaic covers a roughly 6° × 3⅓° field of view.

LUPUS: SCOTT ROSEN, DRAWING: JOHANNES HEVELIUS


SL 12
Be 148
Ψ1
HD 140784
Ψ2
SL 13
Lupus 1





peculiar clouds can be observed year round with binoculars, telescopes, or occasionally, the naked eye (for instance, the Great Rift stretches more than 120° from Deneb to Alpha Centauri, offering one of the largest possible naked-eye targets). To really dig in to dark nebulae you'll need binoculars or a telescope with a very wide field of view: a specially designed rich-field telescope or a scope equipped with one of the newer wide-field eyepieces. Increasing aperture increases the size of the nebula in your eyepiece and improves the contrast between the nebula and skyglow. But these "improvements" may not be much help, as some dark nebulae are so broad that they'll stretch beyond your field of view. For nebulae longer than 1°, you'll do better with a small aperture f/3 or f/4 scope with an 80° or 100° eyepiece that provides a wider field of view — the right combination can yield a field of view as wide as 3°. Low-power, high-aperture binoculars are also a good option for hunting these dust clouds.

You'll also need a dark sky and good transparency, two conditions that are sometimes difficult to obtain when observing objects close to the horizon. Move away from light pollution (star party, anyone?), meticulously protect your dark-adapted vision, and stay up until midnight when Lupus leaps to its highest between May and July.

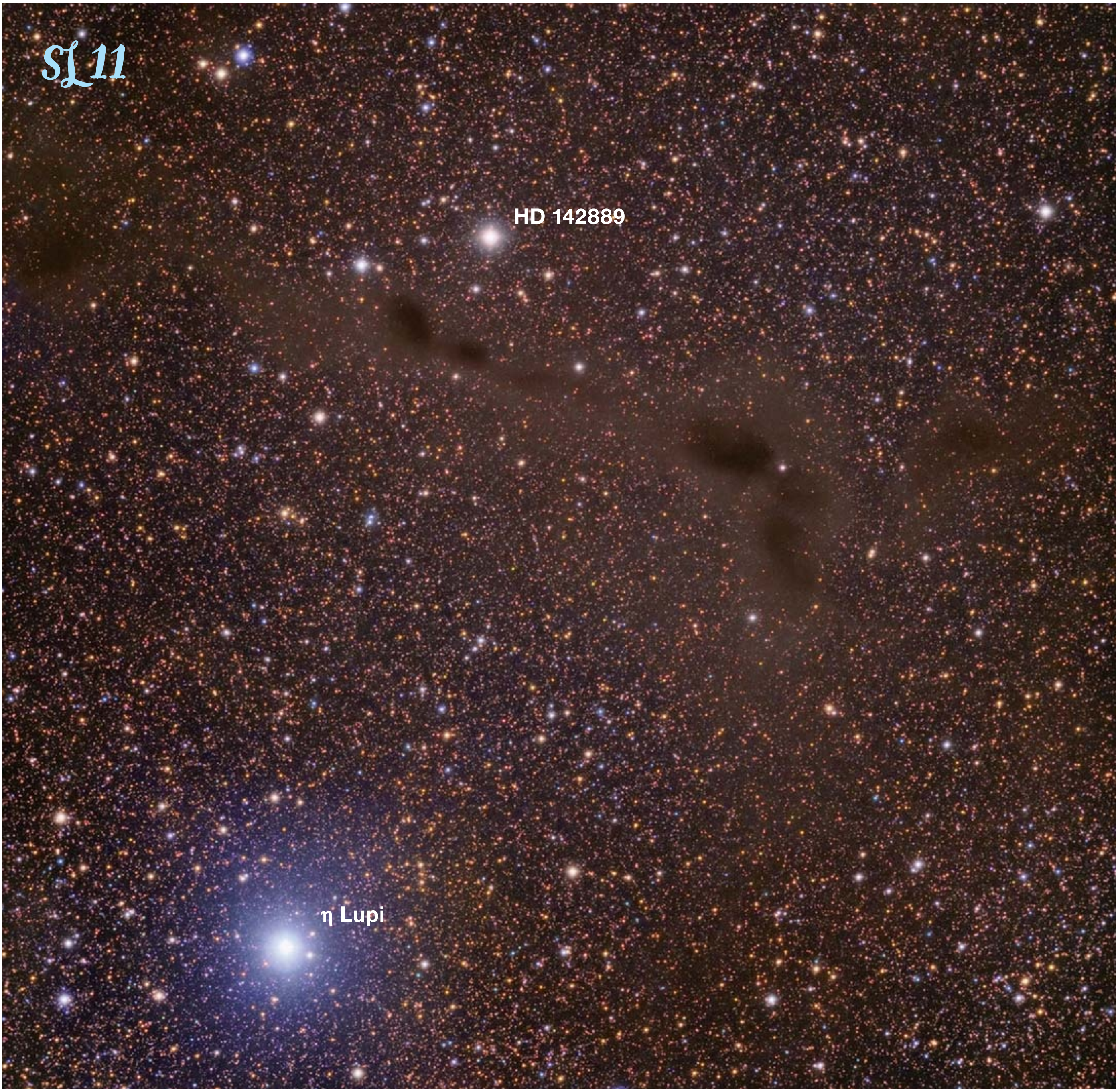
A Different Catalog

Most dark nebulae favored by amateur astronomers come from the Barnard catalog, compiled by E. E. Barnard based on photographic plates taken at Lick Observatory and Mount Wilson Observatory, or the Lynds catalog, compiled by Beverly T. Lynds from images taken during the *National Geographic Society–Palomar Observatory Sky Survey* (POSS). A few lesser-known catalogs provide coverage of dark targets at more southerly declinations. For example, the Sandqvist Lindroos (SL) catalog, compiled by Aage Sandqvist and K. P. Lindroos (Stockholm Observatory) as part of their study of formaldehyde in dark dust clouds, lists 42 absorption nebulae detected in the Whiteoak fields. (The Whiteoak fields extended POSS southward, capturing 100 fields between declination –36° and –42° with red plates taken with the 48-inch Schmidt telescope.) The SL catalog provides the equatorial coordinates of the center of each cloud (equinox 1950), the galactic coordinates, the approximate area in square degrees, and the opacity class, which numbers the opacity of each nebula from 1–6, with 1 being the least opaque, 6 being the most.

Lupus 1 Molecular Cloud

Lupus hosts a complex region of sky just west of the center of the galaxy that contains extensive dark nebulae similar to the more northerly region of the Great Rift. The greatest of the dark nebulae are molecular clouds — dense collections of hydrogen (H_2) molecules, dust, and stars. Because they're so dense — and in the process of condensing more — many of these clouds also contain active star-forming regions. The Lupus Molecular Cloud Complex, one of the nearest and largest low-mass star forming complexes, divides into four subgroups, cataloged as Lupus 1–4. We'll focus here on Lupus 1, a molecu-

▼ **BROKEN CLOUDS** The dark patches of SL 11 run approximately 30′ long, oriented roughly northeast to southwest between Eta Lupi and HD 142889. Look for the stronger pitch on the western end of the nebulosity.



SERGIO EGUIVAR

◀ **BOLD AND BEAUTIFUL** The yellow-orange *K*-type star HD 143009 marks the western edge of SL 7. Look for the triangular "bite" of stars cutting into the darkness to the southeast of the star.

Dark Targets in the Southern Wolf

Object	Alt. ID	Mag(v) / Opacity	Size	RA	Dec.
B228	SL 12, SL 13	6, 5	240′ × 20′	$15^h\ 45.0^m$	–34° 31′
Bernes 148	GN 15.42.0	9.5	3.0′	$15^h\ 45.2^m$	–34° 17′
SL 11	—	6	150′ × 40′	$15^h\ 57.0^m$	–37° 48′
NGC 5986	—	7.6	9.6′	$15^h\ 46.1^m$	–37° 47′
SL 7	—	6	60′ × 10′	$16^h\ 01.8^m$	–41° 20′
SL 14	Bernes 149	6	60′ × 70′	$16^h\ 09.4^m$	–39° 08′
B231	—	6	50′ × 40′	$16^h\ 38.4^m$	–35° 25′
B233	—	6	10′ × 40′	$16^h\ 43.7^m$	–39° 49′

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.

lar cloud 450–500 light-years from Earth and a member of our local galactic neighborhood (it's found in what's known as Loop I, next to our Local Bubble and just opposite the famous Taurus Dark Cloud).

Sometimes referred to as the Dark Wolf Nebula, Lupus 1 is dominated by a long ridge of darkness several degrees long and about 1° wide. Oriented northwest–southeast, this tangled absorption cloud was cataloged as **B228** by Barnard, who described it as a "large vacant region . . . strongest marked at the north end" in his *Catalogue of Dark Objects in the Sky*.

The Sandqvist Lindroos catalog breaks Lupus 1 down into more manageable pieces in terms of your field of view: The northwest section of B228 is **SL 12**; the southeast section is **SL 13**. If you can manage a 1½ or 2° field of view, you can compare SL 12 and SL 13 more easily. Like Barnard, Sandqvist and Lindroos considered the northern condensation to be darkest, classifying SL 12 as a 6 on the opacity scale, with SL 13 coming in at a 5.

Because molecular clouds are lively star-forming regions, it's not unusual to find bright nebulosities — emission nebulae, reflection nebulae, Herbig-Haro objects — interrupting their deep reaches. Observers of Lupus 1 will find an interesting reflection nebula, **Bernes 148** (GN 15.42.0), at roughly the midway point of the dark spine of B228. An estimated 3′ across, Bernes 148 is visible at low power, and that's how you'll want to find it, hopping off the nearby brighter stars, Psi^2 (ψ^2) Lupi and HD 140784. Low power will also help you compare the brightness of Bernes 148 with the neighboring stars. In my estimation, it's brighter than the stars surrounding it.

To pull the nebula into clearer view, you'll need to change to a higher-power eyepiece, because you're going from observing an object that's many degrees

BERNHARD HUBL

in size to one only 3′ wide. Bernes 148 takes high magnification well. The nebula is well placed with an arc of four 10th-magnitude stars spread across its north side at an average of 5′ to 10′ from the nebula. The nebula is involved more tightly with the 10th-magnitude variable stars HT and HW Lupi.

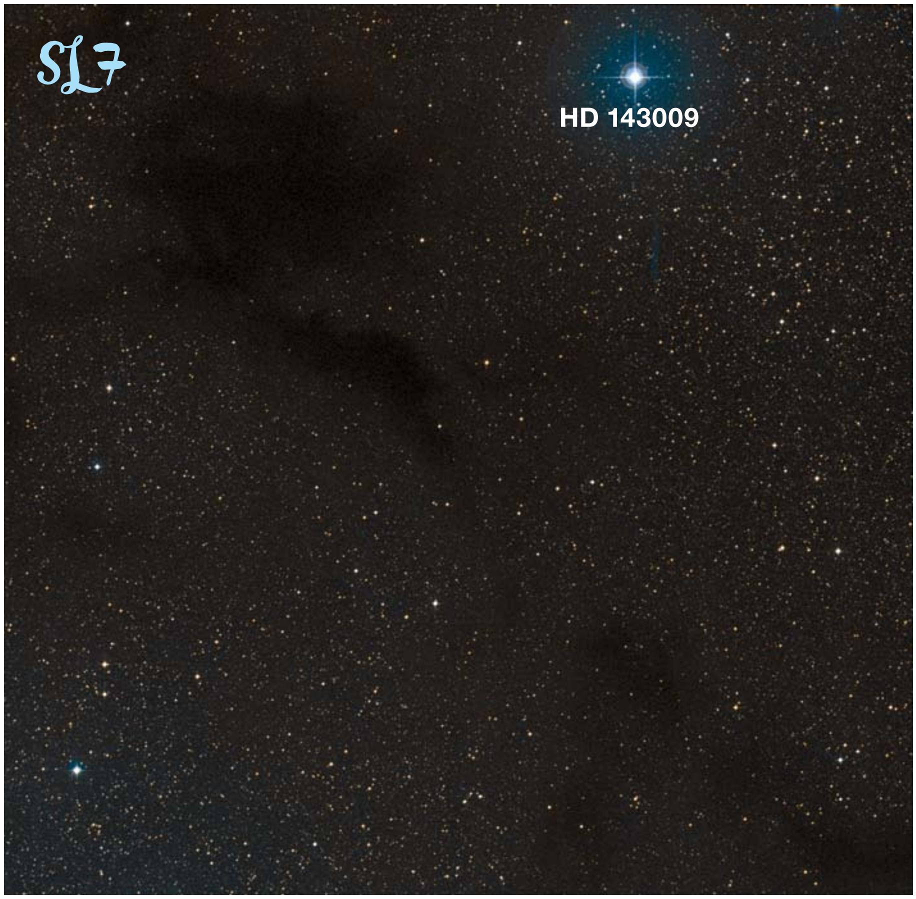
The only complication for many of us is that Bernes 148 will always be low in the south and easily affected by light pollution. But if you choose your nights well, this object, unknown to most "northerners," will soon be added to your list of favorite seasonal targets.

Of Dark Nebulae & Globular Clusters

A second dark nebula in northern Lupus can be found just 1° northwest of 3.4-magnitude Eta (η) Lupi. This is **SL 11**, a 30′ region featuring a number of smaller dark patches. Just south of the 6.4 magnitude star HD 142889 and west of HD 143473, these very dark areas measure about 10′ across. Expert observer Mel Bartels found this a very tough target, even though he caught it well above the horizon, so be patient here. It may help to edge the brighter stars out of your field of view before searching for the subtle contrast between the nebula and the background Milky Way glow.

Just 2° west of SL 11 you'll find the globular cluster **NGC 5986**. The proximity of globular clusters to many dark nebulae led early astronomers like William Herschel to the erroneous conclusion that the stars comprising globular clusters had been swept up from the dark voids to form a condensed sphere of brilliance. Today we know this isn't true; what had been thought to be empty voids in space are actually huge clouds of dust and gas that eventually are brought together by the effects of galactic encounters, supernovae, and gravity to form the protostellar regions of new planetary systems.

NGC 5986 appears grainy in a small scope, with perhaps 2–3 individual stars popping at the northeastern edge; you'll need 12 inches of aperture or more to resolve more than a few stars.



▲ **THE VOID** You won't see the twists and turns of dust and clouds shown in deep-sky images of dark nebulae. Instead, you'll see absence: a dark swath of apparently empty space, free of stars, free of skyglow. This POSS-II image offers a view closer to what you'll see in your eyepiece.

POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

Collar of Darkness

Heading farther south along the Wolf's neck, we encounter **SL 7** about 3½° south of Eta Lupi. SL 7 extends 1° in width and almost 3° in length. The POSS image above is set on the nebula's central region, just off 4.9-magnitude HD 143009, but the opaque dust cloud extends out of the field of view both to the lower right (southwest) to touch the constellation Norma and to the upper left to tag Scorpius. You'll need a rich-field telescope with a wide-angle eyepiece to get the best look at such a large cloud.

SL 7 has an overall opacity of 6, offering good contrast with the skyglow. The darkest section appears to be the inky black pool southeast of HD 143009. The cloud breaks with brightness as it extends southwest and northeast, but under the right conditions, you may be able to trace its entire length.

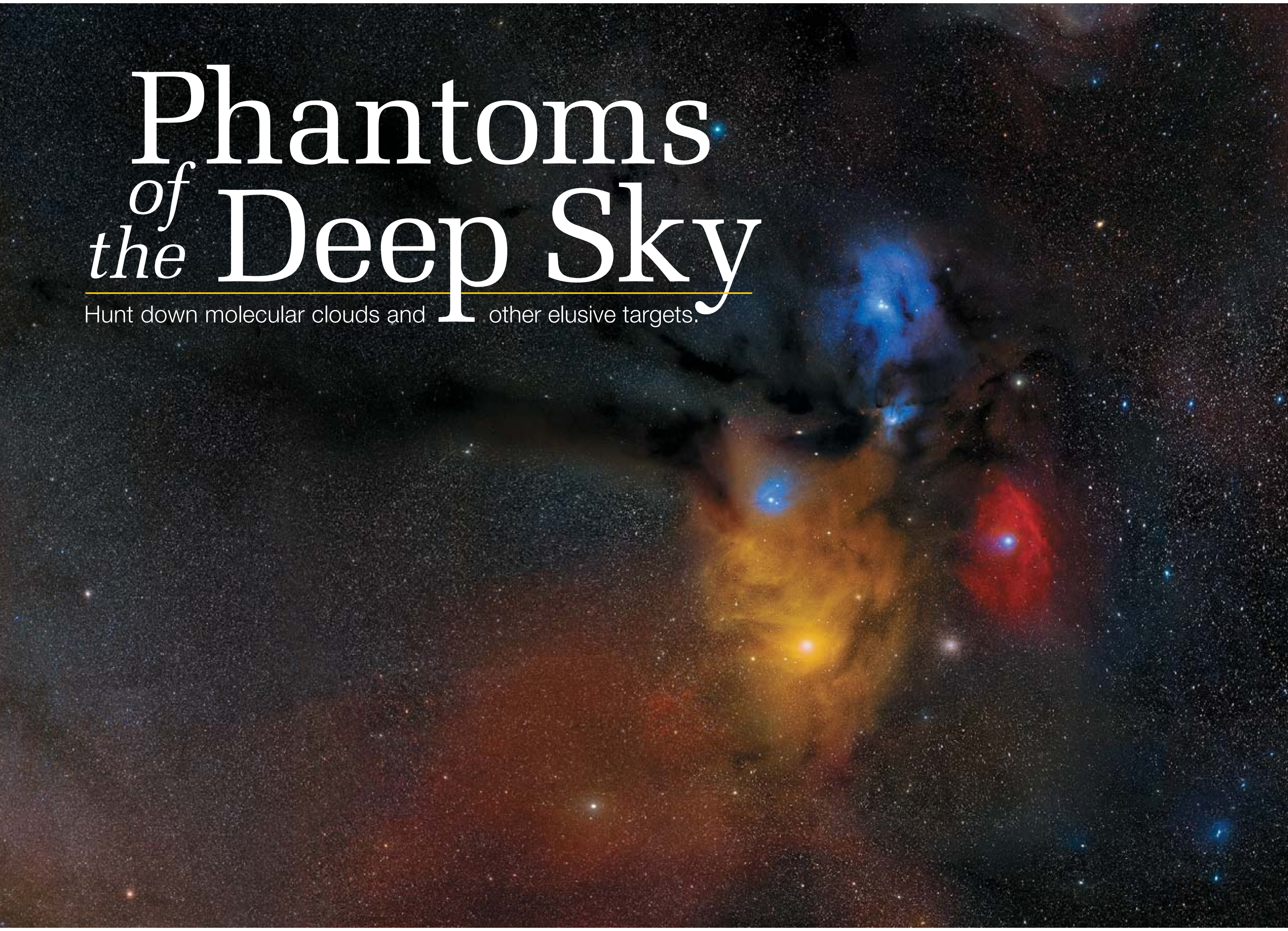
Onward and Eastward

If these fine examples of dark nebulae aren't enough, you needn't go very far for more first-class targets. Southern Scorpius lies east of Eta Lupi; here you'll find a range of large and small nebulae with various opacities. The best is **SL 14** (Bernes 149), a stretch of darkness with a collection of variable stars, including the 12.4-magnitude T Tauri star HK Lupi. HK Lupi also boasts a bright nebula just a bit dimmer than Bernes 148. While you're in the area, look for **B231** and **B233**, and for variety, finish up with HD 149447, a 4.2-magnitude *K*5 orange star.

■ **RICHARD P. WILDS** is a member of the American Astronomical Society, Division for Planetary Sciences and Historical Astronomy Division. His latest publication is *Bright and Dark Nebulae: A Pocket Field Guide* (Springer, 2016).

Phantoms of the Deep Sky

Hunt down molecular clouds and other elusive targets.



Shortly after the turn of this century, a new, highly photogenic class of deep-sky objects began to draw the attention of astrophotographers. Amateurs equipped with fast astrographs and sensitive CCD cameras noticed that many of the targets they pursued were not surrounded by inky-black skies as they have traditionally been depicted. Instead, they found that pushing the processing of their images rewarded them with mottled wisps of gas and dust often extending many degrees beyond their target's previously assumed borders.

Known as giant molecular clouds or galactic cirrus, these faint targets cover vast areas in the night sky at every season of the year, though revealing them will challenge any imager's equipment and processing skills.

These large, exceedingly low-contrast targets barely register above the sky background in long exposures, and they require a combination of very dark skies and stacking many long exposures to properly reveal their true extent. Imagers using modern CCD and DSLR cameras can try their hand at capturing these phantom nebulae. Many of these complexes span 10° or more, so a variety of optical systems can be used to hunt them down. A fast-f/ratio, high-quality telephoto lens of 100-mm focal length is a good match for many of these objects. Fast astrographs also work well with relatively wide fields of view (FOV), while larger instruments (apertures of 12 inches or more) can record the more exotic structures of these objects surrounding several well-known galaxies. Getting enough signal to noise over the sky back-

ROGELIO BERNAL ANDREO

▲ **DAZZLING COLOR** The giant molecular cloud in Ophiuchus includes the colorful region surrounding the multiple star system Rho Ophiuchi as well as the bright star Antares in Scorpius, whose reflected light produces the yellowish nebulosity in this deep photo.

ground to produce a satisfying image is the challenge — as you will soon find out, this isn't very easy to do!

Giant Molecular Clouds

The first class of these ghostly nebulae are molecular clouds consisting primarily of molecular hydrogen (H_2), helium, and smaller amounts of other gases including carbon monoxide (CO). Tiny grains of dust within these clouds aggregate into vast, dense clumps called dark nebulae. Within these giant clouds reside the major star-forming nurseries scattered along the arms of our galaxy.

The largest of these structures, fittingly known as giant molecular clouds (GMCs), range from 15 to more than 600 light-years across. They are the densest and largest gravitationally bound regions of the interstellar medium in our galaxy. But unlike giant emission nebulae such as the Orion Nebula (M42), they don't glow from the ionization of hydrogen. Instead, these objects radiate in the deep-red portion of the spectrum. This "extended red emission" or ERE is thought to come from carbon-rich molecules or polycyclic aromatic hydrocarbons in these clouds. The dense dust clouds both scatter and reflect blue starlight, and appear to have a mauve-toned glow.

Giant molecular clouds are prevalent in the night sky. Let's start by looking toward the inner regions of the Milky Way at one of the most colorful and photogenic targets: the **Rho Ophiuchi Cloud Complex**. This star-forming region is one of the closest to Earth at roughly 420 light-years away. A wonderful interplay of dark, emission, and reflection nebulae, Rho (ρ) Oph lies about 1° north of Antares. One of the most intriguing parts of this dusty nebula is the dark river that spans from Antares back toward the dense Milky Way star clouds. Yellowish dust reflecting light from the red supergiant star Antares adds to the beauty of the field.

Just as notable, but far better known to southern astroimagers, is the **R Coronae Australis** molecular complex. In its center lie the bright bluish reflection nebulae NGC 6726 and IC 4812 and an unusual variable nebula, NGC 6729. Cutting between the reflection nebulae and extending well over 10° to the east stretches an interwoven network of dust and molecular clouds. Unrelated to the cloud but completing the scene is the globular cluster NGC 6723.

Far to the north in Cepheus can be found the pretty reflection nebula **NGC 7023**, the Iris Nebula. It resides in the heart of a vast network of very dusty molecular clouds comprising the Cepheus GMC. Offsetting the stunning blue color of the Iris are eerie dark motes and dusty streamers.

This vast GMC contains many other attractive targets. Less than 2° to the east of the Iris lies **vdB 141**, the Ghost Nebula, named for the shape of its weird-looking projections made up of reflection nebulosity and brownish dust. Moving another 6° to the northeast, we find **LDN 1235**, dubbed by some the Dark Shark Nebula. Not only does it appear to have a gaping, toothy maw but also dorsal and pectoral fins! Two reflection nebulae — vdB 149 and 150 — help define the "shark" form. About 2½° to its south resides **vdB 152**, which, combined with the dark nebula Barnard 175, forms the Wolf's Cave. This part of the GMC was originally called the Cepheus Flare by Edwin Hubble. First imaged by Max Wolfe in 1908, it will certainly put your imaging and processing skills to the test.

Galactic Cirrus

Related to molecular clouds is galactic cirrus nebulosity. These large, filamentary structures were discovered in the 1960s on the red light plates of the *Palomar Observatory Sky Survey*. Unlike GMCs, these gossamer strands can project several hundred light-years beyond the equatorial plane of the Milky Way. They also cover vast areas in the night sky and can be found almost anywhere, including regions far from the ecliptic near the celestial poles (*S&T:* April 2017, p. 30).

Many galaxies also have galactic cirrus as foreground objects in the same FOV. One well-known example surrounds M81 and M82 in Ursa Major, discussed in the April issue. The field around the highly tilted barred spiral **NGC 7497** in Pegasus also contains dusty streamers, with one particularly dense filamentary band projected across the galaxy's

MASIL IMAGING TEAM

▲ **THE VULTURE** Known alternately as the Baby Eagle or Vulture Head Nebula, LBN 777 in Taurus is a dusty extension of the Taurus GMC found about 5° northeast of M45, the Pleiades.

▲ **EXPANSIVE DUST** The reflection nebulosity surrounding the variable star R Coronae Australis at right is a popular target for southern imagers, though deep, wide-field images reveal the brownish dusty molecular cloud extending several degrees to its east.

GERALD RHEMANN

Phantom Nebulae Targets

Object	Size	RA	Dec.
Rho Oph Cloud Complex	11° × 6.5°	16^h 28^m	–24° 32′
R Coronae Australis	6.8° × 3.7°	19^h 13.1^m	37° 28′
NGC 7023	16′ × 16′	21^h 2.1^m	+68° 16′
vdB 141	20′ × 20′	20^h 44.4^m	+67° 44′
LDN 1235	9′ × 4′	22^h 28.1^m	+73° 28′
vdB 152	12′ × 6′	22^h 14^m	+70° 24′
NGC 7497	4.3′ × 1.5′	23^h 9.1^m	+18° 11′
Orion A	10° × 5°	5^h 37.5^m	–6° 58′
Orion B	12° × 8°	2^h 49.5^m	+2° 46′
Monoceros R2	5.8° × 3.6°	16^h 33.3^m	–6° 24′
TMC-1	14° × 9.5°	4^h 41^m	+25° 52′
LBN 777	20′ × 18′	4^h 25^m	+26° 25′

Angular sizes are based on the author's measurements on deep astrophotos. Right ascension and declination are for equinox 2000.0.

disk. Even areas in the vicinity of the nearby spiral galaxies M31 and M33, in Andromeda and Triangulum, respectively, feature faint wisps of cirrus not often captured in images.

Looking Out

Heading into the northern fall and winter months when we face the outer Milky Way resides the Orion giant molecular clouds that span more than 1,000 light-years and lie about 1,600 light-years from Earth. These complexes, designated **Orion A** and **Orion B**, cover much of Orion and Monoceros and include a number of well-known objects, including M42, IC 434, NGC 2024, M78, and all of Barnard's Loop. Some of the brightest (and easiest-to-see) portions of the Orion GMC can be found near M42 and adjacent M43, making for good targets for honing your imaging skills. With only a moderately deep accumulated exposure of a few hours, the area surrounding the emission nebulae will start to reveal both the deep ERE and brownish hues of dense molecular cloud.

Much deeper images composed of numerous long-exposures will reveal a complex interplay of dark motes, bluish reflection nebulae, and the intricate structure of the mauve-colored dusty filaments that cover the region. And you don't have to shoot the region around M42 to pick up a beautiful FOV, as just about anywhere in the central and eastern portion of Orion contains this amazing GMC.

Not far from the Orion GMC lies the more distant and compact **Monoceros R2** GMC complex. The small, bright reflection nebula NGC 2170 sits near the center of a spectacularly colorful area described by the Astronomy Picture of

▶ **SHARKS AND WOLVES** Cepheus is home to many dark nebulae, including LDN 1235, the Dark Shark (top), which really resembles its informal name. Roughly 3° to its southeast lies vdB 152 and Barnard 175, known together as the Wolf's Cave. Both objects extend much farther than implied on most star charts.

▶ **COLORFUL BOUNDARY** The giant molecular clouds within Orion are home to a variety of challenging targets, including dark nebula LBN 1622 at top left and reflection nebula M78 at bottom right, separated by a brighter portion of Barnard's Loop.

the Day website as a "celestial still life." Indeed, the region is awash with bluish reflection nebulae, patches of pinkish hydrogen-alpha emission, jagged dark rifts of dark nebulae, and broad swaths of dust. Moderate-to-large-aperture instruments work well to capture the delicate details, while even telephoto lenses can record these GMCs in their entirety.

A far more challenging target toward the northwest, the **Taurus Molecular Cloud 1** (TMC-1) can be found just north of the Hyades and extends westward past the California Nebula (NGC 1499) and the Pleiades (M45). It lies at a distance of only about 450 light-years, though in roughly the opposite direction as the Rho Ophiuchi GMC. Unlike the Orion GMCs, this complex is much more rarefied and has relatively few bright nebulae embedded within. Deep in the heart of the GMC and about 1¼° west of 44 Tauri is the very faint nebula **LBN 777**, sometimes referred to as the Vulture Head or Baby Eagle Nebula. The 15′-by-10′ "head" features a dark brownish patch of opaque dust (B207) located above the clearing that forms the "eye."

Additional Targets

Very few references have been written on imaging these challenging deep-sky objects. Edward Emerson Barnard's 1913 classic *A Photographic Atlas of Selected Areas of the Milky Way* is a good place to start your research. Even better are Beverly Lynds' catalogs of bright and dark nebulae (LDN and LBN, respectively), both published in the 1960s and based on examination of the red and blue plates of the *Palomar Sky Survey*. They give not only positional and size data but also present relative opacity of dust and the nebula's brightness on a 1-to-6 scale. Other resources include Sidney van den Bergh's (vdB) 1966 catalog of 159 reflection nebulae. For galactic cirrus, the online resources are much more limited. The best place to start is with Steve Mandel's page (**galaxyimages.com**) and perhaps searching online for images others have recently produced.

The good news is that all of these references have been scanned and are readily available online. Powerful applications such as *The SkyX* or *SkySafari Pro* include many of these objects, as well as a number of the giant molecular cloud complexes. So if you spend some time exploring these and other resources, you might become the first person to image a portion of dusty GMC or lacy galactic cirrus in color.

■ **RICHARD JAKIEL** hunts galactic molecular clouds from his backyard in rural Georgia.

TOP: JOHN DAVIS; BOTTOM: DAVID MITTELMAN

▷ CLUSTERS IN CONTRAST

Ron Brecher

Messier 12

Charles Messier discovered this globular cluster and, ironically, described it as a "nebula without stars." Also called NGC 6218, it lies in Ophiuchus some 16,000 light-years away and has an estimated age of 12.7 billion years.

DETAILS: *ASA 10N astrograph with SBIG STL-11000M CCD camera and Baader LRGB filters. Total exposure: 8.7 hours.*

Messier 67

Much less crowded, M67 (NC 2682) is a quite old open cluster in Cancer whose 500 stars are roughly the Sun's age.

DETAILS: *ASA 10N astrograph with SBIG STL-11000M CCD camera and Baader LRGB filters. Total exposure: 72 minutes.*

▽ TAKE A SWIM IN THE LAGOON

Chuck Manges

One of the showpiece objects of the northern summer sky, the Lagoon Nebula (Messier 8) is an immense star-forming complex in western Sagittarius. Embedded within are numerous dark Bok globules and the open star cluster NGC 6530.

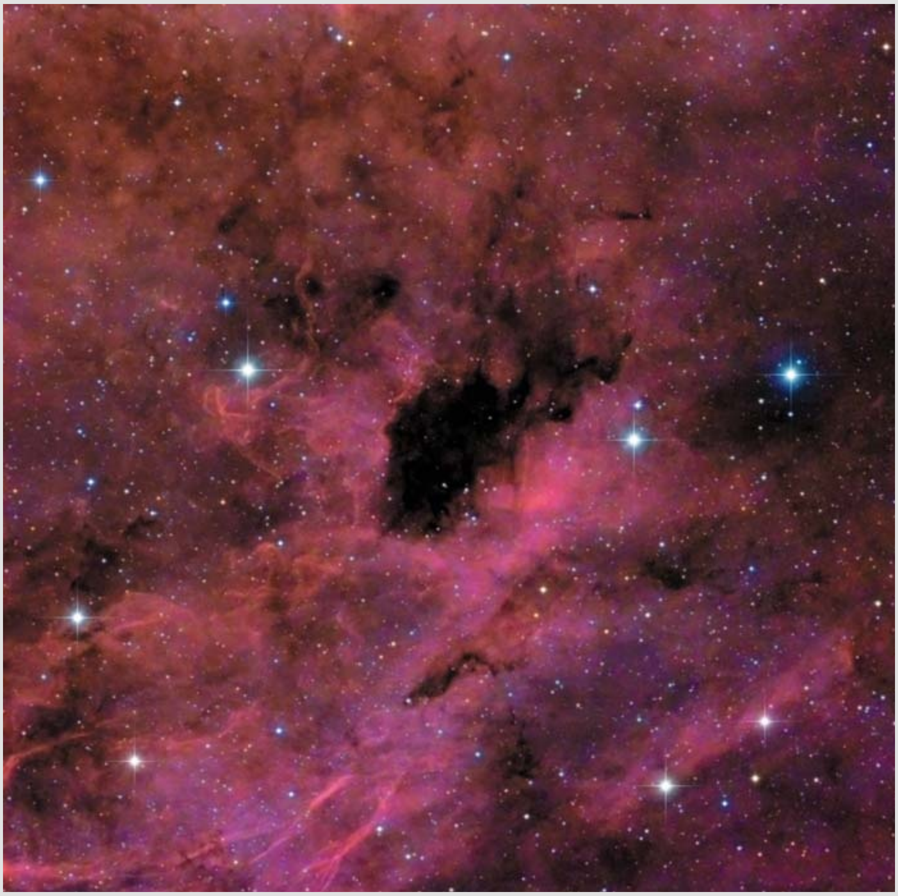
DETAILS: *Celestron EdgeHD 11 Schmidt-Cassegrain telescope with QHY23M CCD camera and LRGB filters. Total exposure: 100 minutes.*

MILKY WAY MEGAMOSAIC

Tom O'Donoghue

A full page doesn't begin to show all the detail in this 36-panel, 2-gigabyte mosaic that took 4 years to record and 9 months to process. A panoply of deep-sky objects ranges from the Eagle Nebula (M16) near the top to the Lagoon (M8) at bottom. The area shown spans 12° by 9½°.

DETAILS: *Takahashi FSQ-106N and FSQ-106ED astrographs, TEC APO 140 refractor, Atik 11000 and Starlight Xpress H36 CCD cameras, and Baader LRGB and Hα filters. Total exposure: 110 hours.*



△ BARELY THERE ECLIPSE
Gianluca Masi

Seen high in the sky from Italy, the full Moon skirted deeply into Earth's penumbra on the night of February 10–11, 2017. Compare the disk's aspect 6 hours earlier *(left image)* and at mid-eclipse.

DETAILS: *Canon EOS 7D Mark II DSLR camera at ISO 100 and a 100-to-400-mm zoom lens used at 400 mm. Exposures: 1⁄800 and 1⁄400 second.*

◁ MYSTERY SPOT
Jeffrey O. Johnson

Barnard 343 is a dark nebula that lies about 2° west of Sadr (Gamma (γ) Cygni) amid a broad expanse of brighter emission. Its distance is uncertain but likely a few thousand light-years away.

DETAILS: *Takahashi TOA-130F apochromatic refractor and QSI 540wsg CCD camera with Astrodon Hα and RGB filters. Total exposure: 2.8 hours.*

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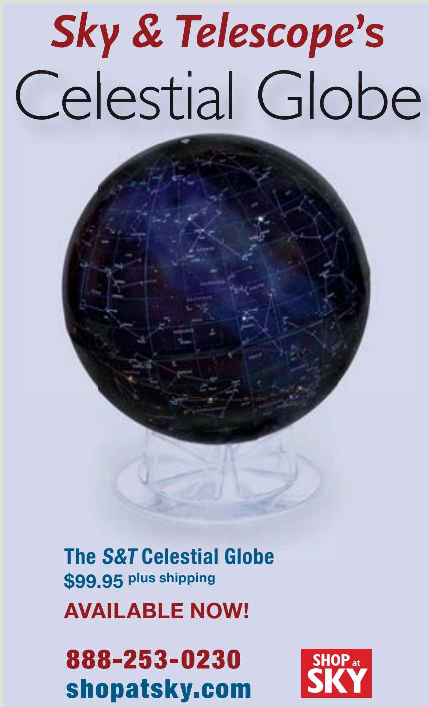

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AD INDEX

Two Routes to the Truth

Science and faith offer different but kindred paths to grasping reality.

MANY READERS ARE familiar by now with my fondness for black holes. For me, black holes are the Labrador puppies of the cosmos — so cute, so delighted by existence that in their merriment they're unintentionally destructive.

But there's something I love more than black holes. That something is a Someone.

God.

Astronomy is, in many ways, the bone and marrow of my life. But God's presence is the heartbeat. Like a heartbeat, He's often almost imperceptible. But I sense Him like a pulse, just beneath the surface of reality.

It's something too many of us forget, that reality has layers. Occasionally people ask me how I can be Catholic and a science journalist. The answer is simple: Truth does not contradict truth. Both science and religion are a pursuit of truth. They're after different aspects of truth, different layers of reality, but they're still both fundamentally about truth.

Science itself is based on the assumption that truth exists. Science wouldn't work without it. We assume that there's a right and a wrong way to describe the universe. Dark matter exists or it doesn't. Quantum mechanics is right or it's wrong. It isn't right for some folks and wrong for others. Truth is truth whether we know the truth or not; Earth revolved around the Sun even when people thought it was the other way around.

Science teaches us, in other words, that absolute truth exists. It doesn't tell us why, or Who that Truth is. Science is a marvelous tool, but in our marveling we must not forget that science is our interaction with and understanding of *physical* reality. It's immensely powerful, but it's not metaphysical; it can't grasp God. Trying to prove or disprove God with science is like trying to screw in a flat-head nail with a screwdriver. The handyman, discovering that he can't find grooves in the head of the "screw," concludes that the nail doesn't exist. But that's ridiculous. The nail is there, he just didn't use the right tool. And any handyman worth his toolbox doesn't use a screwdriver on every job.

So, too, trying to "catch" God with science, or concluding that He can't be real because His beautiful universe is too much about drama and too little about perfect engineering ("It's not how *I* would design it!" we complain) is using the wrong tool for the job.

So what is the right tool? Reason is one of them. God gave us our reason, and He wants us to use it. St. Augustine

of Hippo, one of the greatest minds of his time, came to know God better by asking hard questions. In my life I, too, have found that God can stand up to any question I throw at Him. It might take years to find the answer, but it exists.

> Trying to prove or disprove God with science is like trying to screw in a flat-head nail with a screwdriver.

Prayer is another tool. If you want to know someone, you have to spend time with that person. My faith is not merely a head faith, founded on careful research and principles. I have heard, felt, and seen God — transcendent peace while reading Scripture, a Eucharist that at one moment is just a wafer and the next is a Presence radiating love so real I can almost see it shimmer, so powerful that I cry. God is real, and He loves us tenderly and passionately. This also is truth. It's not a truth I'll find in my astronomy textbooks, but it's one I know in my core.

■ **CAMILLE M. CARLISLE** is *Sky & Telescope*'s science editor.

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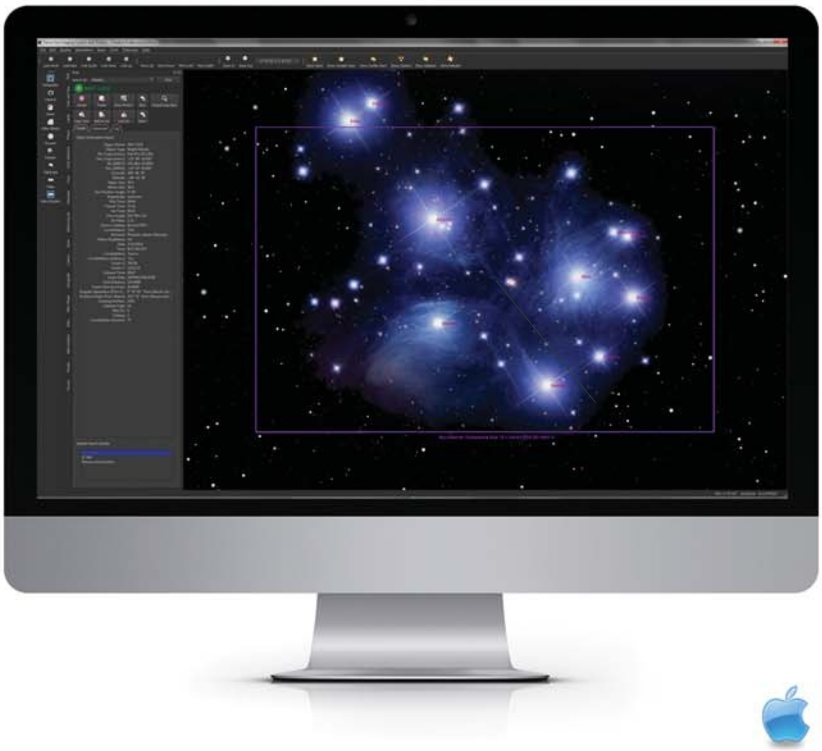

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