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LARRY MITCHELL

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In 7 billion years, the Sun will vastly swell and brighten, threatening our planet.
CASEY REED / *S&T*

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Sometimes, when you've got a decent product to begin with, you don't need to redesign it from scratch.

The Stone Tree

PETER TYSON / S&T

YEARS AGO WHILE HIKING across a desert in the American Southwest, I stumbled upon an enormous petrified tree trunk. The trunk at one end was so fat I couldn't have wrapped my arms around it, and it retained every detail of its gnarled, mahogany-colored "bark." As I fingered the former wood, I could easily picture primeval ants scuttling up and down it, going about their obscure lives.

The trunk was so out of place in that treeless expanse that it seemed to have fallen from the sky. Yet I knew from the geologic formation it lay in that it belonged there just as unassailably as the widely spaced ocotillo and creosote plants that now claimed the semi-arid landscape around it. The stone tree was eroding out of the Aguja Formation, which is roughly 75 million years old. When the tree was alive, it stood in a bald cypress-like forest on the edge of a shallow seaway that extended from the Arctic Ocean to the Gulf of Mexico.

As I knelt there marveling at this throwback to another age, it occurred to me that, despite the almost incomprehensible dissimilarity between the landscape today and way back then, *only time* separates the fossil tree from its living counterpart. No other variables need change. If I could just wind the clock back 75 million years to the final day in the Late Cretaceous when this tree stood erect, I could lean against it (careful not to crush any ants) and behold the likes of duck-billed dinosaurs, giant crocodilians, and imposing cycads and tree ferns.

Only time separates this fossil tree from its living analogue.

The same conceit came to me while writing this month's cover story, which concerns what will happen to our solar system as the Sun swells into a red giant over 6 billion years from now (page 22). Only time — or Time, if you will — divides our beautiful blue Earth from a world that's but a burnt ember hosting no life of any sort. As with my musing on the stone tree, one need not adjust a single other factor. Simply leap forward 6 billion years — if you could — and no matter where you are on the planet, that spot, in that distant eon, will have long since been scorched to a cinder. Earth will have become a Venus.

This is not cause for gloom but for fascination — and perspective. Thought experiments like these remind us that our presence in the stream of Time, despite all the importance it holds for us humans, is but a ripple. In the grand scheme of things, we and all we pride ourselves on are, geologically or cosmologically speaking, akin to passing whims, here now and gone a moment later. Astronomy offers infinite opportunities for such chastening reflection, and I find that to be one of its great draws.

Peter

Editor in Chief

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"The Hoary Meteor Fell"

I recently had occasion to look through John Greenleaf Whittier's 1866 poem, "Snow-Bound: A Winter Idyl," which was inspired by a days-long snowstorm hitting New England. My reading came to a halt at line 46: "All day the hoary meteor fell."

Wait, what? What did meteors have to do with snowfall? Then I remembered reading a similar usage in a 1604 treatise by King James I of England titled *A Counterblaste to Tobacco*. There he denounced smoking as "hatefull to the Nose" and "dangerous to the Lungs." True enough, though his impassioned condemnation apparently had little effect. In paragraph 11, however, he referred to "Raynes, Snowes, Deawes, hoare Frostes, and such like waterie Meteors."

With my interest piqued, it was high time to visit the Library of Congress, my ever-reliable resource for such questions. The library's News & Current Periodical Reading Room has a copy of the truly massive *Webster's New International Dictionary,* 2nd edition (1937). Its definitions for *meteor* include brief flashes due to incoming space rocks, of course, but also this: "any phenomenon or appearance in the atmosphere." It went on to define *aerial meteors* as winds, *aqueous meteors* as rain and snow, and *luminous meteors* as halos and rainbows. Finally, it listed lightning and meteors from space as *igneous meteors*.

In more recent times, "meteor" has come to mean only the kind that originates in outer space. But it sure looks as if this older meaning is the root of *meteorology,* the science of weather.

I took a second look into the dictionary and found that the science of space rocks is *meteoritics*. The tongue-twisting name for its practitioners is *meteoriticists*.

John Lockwood • Washington, D.C.

Enduring Views of Capella

Fred Schaaf recently wrote (*S&T:* April 2017, p. 45), "The stars that remain above the west horizon into May and (in the case of the two Gemini luminaries) even into June are Procyon, Castor, Pollux, and Capella."

I note that for observers at mid-northern latitudes just a few degrees north of his location, including the northern tier of U.S. states, Capella is circumpolar. One of the pleasures of a warm summer evening here at latitude 49° is watching Capella wildly scintillating low in the north. I have a jagged ridge along the horizon toward the north and north-northeast. Consequently, during early evening twilight in August, I see twinkling, multicolored Capella appearing in gaps and then disappearing behind high points on the ridge. It looks rather like a slow-motion grazing occultation!

Alan Whitman
Okanagan Falls, British Columbia

The "Habitability Factor"

I'm struck by David Grinspoon's reference to "metahabitable" worlds (*S&T:* July 2017, p. 14). He paints a picture where the only constant is change. Inhabitable planets become habitable and vice versa. We happen to live in a relatively short, 420-million-year portion of our planet's history during which conditions have remained right for advanced life forms to flourish on land. Presuming that planets exist around stars that are 10+ billion years old, intelligent life might have evolved elsewhere billions of years ago — and perhaps many times.

Tom Kellogg
San Francisco, California

Now that the Cassini mission is coming to an end (*S&T:* Sept. 2017, p. 16), isn't it time to update the Drake Equation? Frank Drake's famous 1961 formulation refers to "habitable planets," and at the time Saturn and its moons were considered to be far outside the "Goldilocks zone." Yet, with the discovery that even remote Enceladus might be life-friendly, surely "moons of planets" should also be factored into the equation. After all, there might be more habitable moons than habitable planets in any given solar system — even in our own!

Peter Gibbons
Cork, Ireland

What Stars Leave Behind

I've just read Bob King's interesting, well-crafted blog on skyandtelescope.com about what happens to stars — celestial ones, not Hollywood ones! — after death (**https://is.gd/star_death**). It built up such colorful pictures in my imagination that I simply couldn't set it aside till I'd finished it. To have such excellent language skills as well as such great knowledge and expertise on this immense topic is indeed an envy-provoking gift.

Carole F. Mackintosh
Fort Frances, Ontario

PATRICIA GILLIS-COPPOLA / S&T; BIGSTOCK / MOOLTFILM

Whither "Tabby's Star"?

Why isn't "Tabby's Star" (*S&T:* June 2017, p. 16) called "copernicus123's star"? The article seems to give credit to the latter, a citizen scientist, for being the first to note the unusual dip in light emanating from KIC 8462852. I ask this in light of the article in the same issue about assigning credit for the discovery of M57. There the authors put a lot of work into studying the available sources to decide whether Charles Messier or Antoine Darquier should be credited with being the first to observe and describe the Ring Nebula.

Bob Rosenstein
Ellicott City, Maryland

Monica Young replies: *Most stars don't have common names, at least not official ones recognized by the IAU, but instead are referred to by catalog numbers. In this case, "Tabby's Star" is officially designated KIC 8462852 (for Kepler Input Catalog), and that's how astronomers refer to it. That said, well-studied objects do lend themselves to common names, and those are often the names of their discoverers. It's true that copernicus123 first noted that this star's light curve displayed a "bizarre peak — a giant transit." However, numerous scientists as well as citizen scientists had already examined the Kepler observations, even if only as part of a larger dataset. As important as the comment from copernicus123 was in pointing out the star's unusual nature, it can't be said that he discovered the star itself.*

Moreover, what was essential to understanding the star's unusual nature was not just the single dip spotted by copernicus123 but rather all of its dips and weird behavior. It wasn't until Tabetha Boyajian and her colleagues published their "Where's the Flux?" paper that this all came together. (It's worth noting that she did not name the star after herself.)

A New Maunder Minimum?

Thanks for the update on the Maunder Minimum (*S&T:* June 2017, p. 9). Since science has not been able to affirm that the abnormally cold temperatures recorded in Europe during that 70-year period were related to the corresponding lull in solar activity, I wonder what researchers will conclude if temperatures once again recede during Cycle 25. Perhaps they'll debate whether solar inactivity is merely temporarily masking the underlying global-warming data.

Bill Zuna
Tallahassee, Florida

FOR THE RECORD

● In the diagram listing elementary particles found in physics' Standard Model (*S&T:* Aug. 2017, p. 30), the particle labeled "t" is the Top (not Tau) quark.

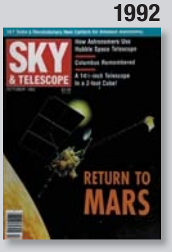
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1942

1967

1992



◖ October 1942

Crab Nebula "The rate of expansion of the Crab nebula is so great that, within an astronomically brief interval, perhaps by 3000 A.D., the material of which it is composed must become so tenuous that it cannot perceptibly shine. It is very likely that the entire episode of the Chinese nova [the supernova of A.D. 1054] and its sequel, so far as it can be perceived from the earth, has taken place in an interval shorter than the 4,000 years required by its light to reach us. The story of the Crab nebula, therefore, may well have ended centuries before it seemed to begin, and in the interim was carried secretly by the light waves spreading in ever-increasing spheres from the place of the outburst."

This lavish summation by John C. Duncan (Wellesley College) still holds, though the Crab is now thought to be about 6,500 light-years away.

◖ October 1967

Lopsided Moon "Despite the enormous labor and care that generations of mathematical astronomers have devoted to the moon's orbital motion, small but puzzling discrepancies between observation and theory continue to arise. . . .

"Recently, at the Royal Greenwich Observatory in England, an analysis of occultations observed in 1958 and 1959 revealed a cyclic discrepancy [in the Moon's orbital latitude, up to] a large fraction of a second of arc, even after corrections for lunar limb irregularities have been applied. . . . The cause of the fluctuations is uncertain. [Perhaps] the lunar center of mass deviates from its center of figure."

Indeed it does, a finding that has led to adjustments in solar-eclipse predictions and the way lunar elevations are defined.

◖ October 1992

CCD Era Begins "On one of my first nights using the [Santa Barbara Instrument Group] ST-6, I had it mounted on an 11-inch Celestron telescope and ready to go less than an hour after sunset. [Aided by] setting circles, I swung the telescope in the direction of the open star cluster M67 deep in the western twilight. Nothing was visible through an 8 × 50 finder, [but nevertheless] I took a 10-second exposure.

As the ST-6 image swept down the computer screen, my jaw dropped. Hundreds of sparkling suns splashed across the field, the three faintest ones being an incredible magnitude 15.7. All this from an image made in a sky too bright to show the cluster visually! . . .

"The ST-6 should blow open the door to deep-sky CCD imaging by amateurs. Nothing else in its price range can offer the same level of performance."

Not long after Dennis di Cicco's glowing review, Sky Publishing launched a separate magazine, CCD Astronomy, *to explore the ways amateurs could benefit from electronic imaging. It came out quarterly from early 1994 through early 1997.*

EXOPLANETS

Kepler Team Releases Final Catalog

THAT'S A WRAP for the Kepler space telescope's primary mission. On June 19th, astronomers released the eighth and final mission catalog, with data gathered from the spacecraft's first four years of life. The final analysis adds 219 new planet candidates to the mission's total of 4,034; of these, astronomers have confirmed that 2,335 are bona fide exoplanets.

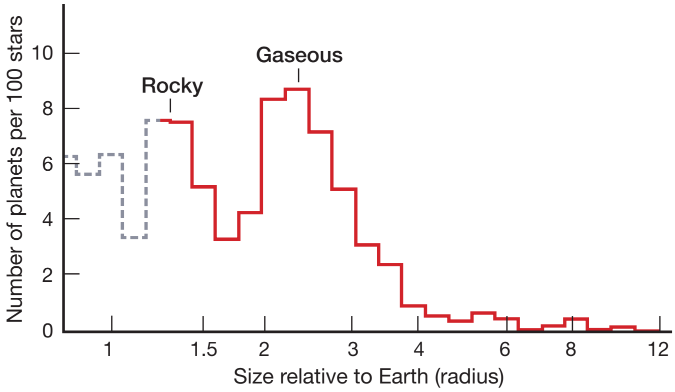
Among the new candidates, 10 are near Earth-size and orbit in their star's habitable zone. This brings the total for near-Earth-size, habitable-zone candidates to roughly 50, more than 30 of which astronomers have verified are real.

To create the final catalog, Susan Thompson (SETI Institute) and colleagues reprocessed the entire set of data from Kepler's primary mission, introducing their own false signals into the data set to determine which types of planets had been overcounted and which were undercounted.

"The reason why I'm so excited about [Thompson's] results is that this catalog — because it was done in such a sophisticated, methodical way — really enables studies of habitable-zone-planet occurrence for Sun-like stars in a way previous catalogs did not," says Courtney Dressing (Caltech). "It's laying fundamental groundwork."

Taking advantage of the latest data set, Benjamin Fulton (University of Hawai'i, Manoa) and colleagues investigated worlds that form with diameters between those of Earth and Neptune. They sought a dividing line between planets that are super-Earths — rocky worlds a little larger than Earth — or gaseous mini-Neptunes (*S&T:* Mar. 2017, p. 22).

Fulton's team found that few planets form with sizes between 1.75 and 2 times Earth's diameter (see plot above). The team interprets this gap as a split: Any planet smaller than 1.75 Earth diameters is likely a super-Earth, while planets larger than 2 Earth diameters are likely mini-Neptunes.



▲ Most exoplanets discovered during Kepler's primary mission fall into two distinct size classes, with a gap between 1.75 and 2 Earth diameters. Astronomers think this gap divides rocky (smaller) and gaseous (larger) worlds. Incomplete data at smaller sizes (dashed line) hint at a second gap between smaller, Earth-size planets and rocky super-Earths, but it's unclear whether that second gap is real.

"This is a major new division in the family tree of exoplanets, somewhat analogous to the discovery that mammals and lizards are separate branches on the tree of life," says Fulton.

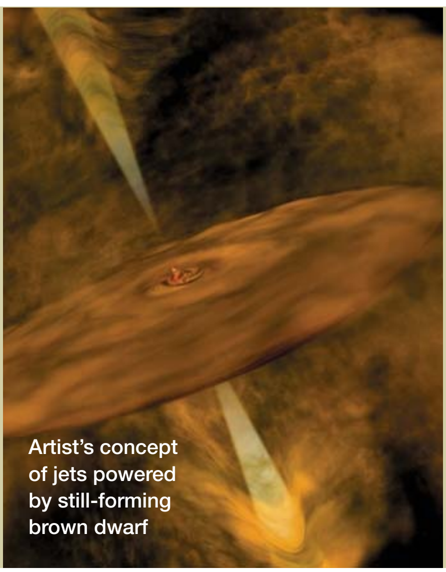
Fulton suggests the split comes down to whether a planet contains the two lightest elements. "A very small amount of light hydrogen and helium gases goes a long way to inflate the size of planets," he says. "Adding a tiny amount of hydrogen to one of these rocky planets, say about 2% by mass, would cause the planet to jump the gap and move into the group of larger planets."

By implication, astronomers searching for habitable worlds can probably discount any exoplanet that is more than twice as wide as Earth.

The release of the final Kepler catalog marks the end of an era. But it's also a new beginning for scientists eager to mine the full Kepler data set to understand exoplanet populations.

■ SHANNON HALL

EXOPLANETS: BILL SAXTON / NRAO / AUI / NSF: STARS: LEAH TISCIONE / S&T, SOURCE: NASA / AMES RESEARCH CENTER / CALTECH / UNIVERSITY OF HAWAI'I / B. J. FULTON



Artist's concept of jets powered by still-forming brown dwarf

STARS

Brown Dwarfs Mimic Stellar Siblings

BRIDGING THE GAP between the largest planets and the smallest stars, brown dwarfs don't fuse hydrogen in their cores. But two recent studies suggest that these "failed stars" are nevertheless more like stars than planets, displaying strong polar jets and accretion disks like those seen around forming stars.

Basmah Riaz (Max Planck Institute for Extraterrestrial Physics, Germany) and colleagues studied a young brown dwarf in the 3 million-year-old Sigma Orionis star cluster. The observations, to be published in the *Astrophysical Journal*, show the brown dwarf powering a jet of material 0.7 light-year long. It's the largest jet ever observed coming from a brown dwarf and displays all the hallmarks of stellar outflows.

Amelia Bayo (University of Valparaíso, Chile) led another study, published in the May 18th *Astrophysical Journal Letters,* of a planetary-mass object in the Chameleon star-forming region OST44. It isn't a brown dwarf exactly —

SOLAR SYSTEM

Observers Track New Horizons' Next Target

DURING JUNE AND JULY, two dozen teams of observers in South America and South Africa learned crucial new details about distant 2014 MU_{69}, the Kuiper Belt object that New Horizons will fly past on January 1, 2019. Knowing its diameter in advance would be a huge help in planning the flyby.

Based solely on its apparent brightness in Hubble Space Telescope images, where it appears exceedingly faint at 27th magnitude, astronomers guessed that this object is between 25 and 45 km (16 to 28 miles) across. But the exact size depends on the reflectivity of its surface — and that's still unknown. The object orbits some 6½ billion km (43.3 astronomical units) from the Sun, a third farther out than Pluto is. "This object has so far proven to be impossible to detect from the ground," laments Marc Buie (Southwest Research Institute).

To learn more and guess less, Buie and the New Horizons team have turned to an observing technique that can be even more powerful than Hubble: stellar occultations. It turns out that 2014 MU_{69}, currently drifting among the rich star fields of Sagittarius about 5° northeast of the Teapot, passed directly in front of three stars this year, on June 3rd, July 10th, and July 17th. Unfortunately, those stars are themselves faint, and traveling to the predicted occultation tracks presented plenty of challenges.

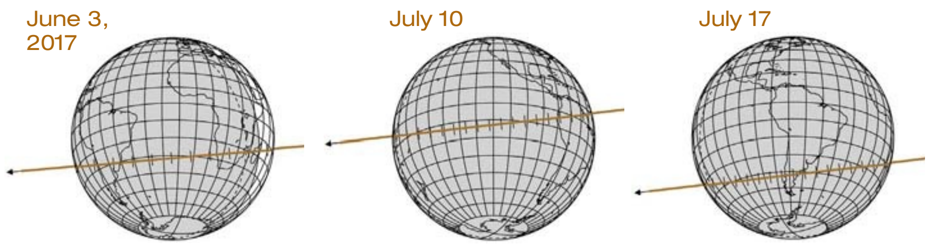
In South America, the predicted track for the June 3rd event came very near Santiago, Chile, missing all the world-class observatories perched in the Andes farther north. In South Africa, the track skirted very close to the South African Astronomical Observatory site in Sutherland. So the New Horizons team funded a massive occultation campaign. Led by Buie, the effort dispatched 22 two-person mobile observing teams to Argentina and South Africa. Each team observed through a Sky-Watcher 16-inch truss-tube Dobsonian reflector paired with a QHY174M-GPS CCD camera.

Buie deployed his teams in Argentina 10 to 25 km apart to create a "fence" of observers perpendicular to the path. Across the Atlantic, Anne Verbiscer (University of Virginia) coordinated the teams in South Africa.

June 3rd's effort couldn't have gone better. Buie says that every team collected usable data, though some might have been partially impacted by clouds. "That is quite remarkable," he says, "and it took some heroics on the part of the South African teams" to avoid bad weather. However, none of the observing teams recorded an occultation. This suggests that 2014 MU_{69} is more reflective and thus smaller than had been assumed — or perhaps it's a binary object.

The effort fared better during the occultation on July 17th, which 24 teams tracked from remote locations in Argentia's Chubut and Santa Cruz provinces. According to Buie, five teams recorded brief coverups of the dim star. Once fully analyzed, these data should yield a much-improved diameter for 2014 MU_{69}.

■ J. KELLY BEATTY



NEW HORIZONS

▲ During mid-2017, the small Kuiper Belt object 2014 MU_{69} briefly hid three faint stars as seen from Earth. Here are the predicted tracks, each only about 50 km wide, from which those disappearances would have been visible.

with a mass 12 times Jupiter's, OST44 lies right on the planet-brown dwarf boundary. Yet the 2 million-year-old object is growing from an accretion disk, as stars do.

Bayo's team used the Atacama Large Millimeter/submillimeter Array in Chile to examine OST44's disk, finding that its dust matches what's expected based on observations of disks around other stars and more massive brown dwarfs. The question remains, though, how such a low-mass object manages to form like a star.

■ JOHN BOCHANSKI

IN BRIEF

Asteroid Mission to Shut Down

Program director Michele Gates announced on June 13th that NASA's plan to retrieve a boulder from an asteroid and place it in lunar orbit, known as the Asteroid Redirect Mission (ARM), will be shut down due to lack of Congressional support in the proposed FY 2018 budget. The focus will now turn to closing out the program while salvaging key technologies and lessons learned for future applications.

ARM was an ambitious plan. First proposed in 2013, the project called for an automated rendezvous with a near-Earth asteroid, where robotic devices would pick up a boulder from its surface (*S&T:* July 2015, p. 14). The spacecraft would then return the boulder, placing it in orbit around the Moon. Astronauts would rendezvous with the boulder in lunar orbit for further study.

Politically, the mission failed to find support in Congress from the start, even though it was touted as a stepping-stone between leaving low-Earth orbit and heading to Mars.

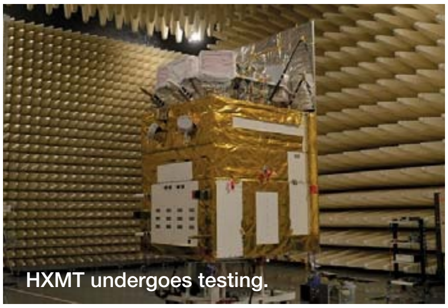
But even as the ARM mission closes out, research and development will continue in key areas, including solar electric propulsion and searches for near-Earth asteroids.

■ DAVID DICKINSON

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

MISSIONS

China Launches X-ray Observatory



HXMT undergoes testing.

CHINA ENTERED the X-ray astronomy game on June 15th with the launch of its Hard X-ray Modulation Telescope (HXMT). Renamed Huiyan (Chinese for “insight”) after launch, this is the country’s second astronomical satellite. (China’s Dark Matter Particle Explorer launched in December 2015; *S&T:* April 2016, p. 10.)

HXMT joins a cohort of X-ray observatories circling Earth, including NASA’s Chandra and NuSTAR and the European Space Agency’s XMM-Newton. The new observatory will study known X-ray sources, hunt for new ones, and map the cosmic X-ray background. The mission could also work with China’s new FAST radio observatory (*S&T:* Feb. 2017, p. 26) to study the properties of millisecond pulsars, in hopes of using these sources as navigational beacons for deep-space missions.

HXMT has three detectors, together spanning an incredible range of energy coverage, from 1 to 250 kiloelectron volts (keV). (For comparison, Chandra covers 0.1 to 10 keV.) The high-energy detector is the main science instrument and has the greatest sensitivity. Another instrument, designed to help calibrate the high-energy detector, can also detect gamma rays between 300 keV and 3,000 keV in energy.

Rather than using complex, nested mirrors to focus a source’s X-rays, HXMT employs an innovative technique, filtering out all X-rays except those that are coming in parallel to a specified direction. Thanks to this method, the telescope doesn’t have to narrow its field of view, making it an ideal instrument for large sky surveys. The trade-off is in sensitivity: The new observatory is more sensitive than ESA’s Integral spacecraft at the same energies but generally has poorer sensitivity than NuSTAR, putting it on par with the now-retired Rossi Timing X-ray Explorer.

■ DAVID DICKINSON

COSMIC STRUCTURE

Is the Milky Way in a Void?

MEASUREMENTS OF how fast today’s universe is expanding depend on what in the universe you measure: Observations of the cosmic microwave background, photons emitted 370,000 years after the Big Bang (three leftmost points in graph below), point to a significantly slower current expansion rate than that gleaned from measurements of relatively local objects, such as variable Cepheid stars or Type Ia supernovae in nearby galaxies (three middle points in graph).

At June’s meeting of the American Astronomical Society, Benjamin Hoscheit and Amy Barger (both at University of Wisconsin, Madison) showed that these observations could be reconciled if the Milky Way lives in a void.

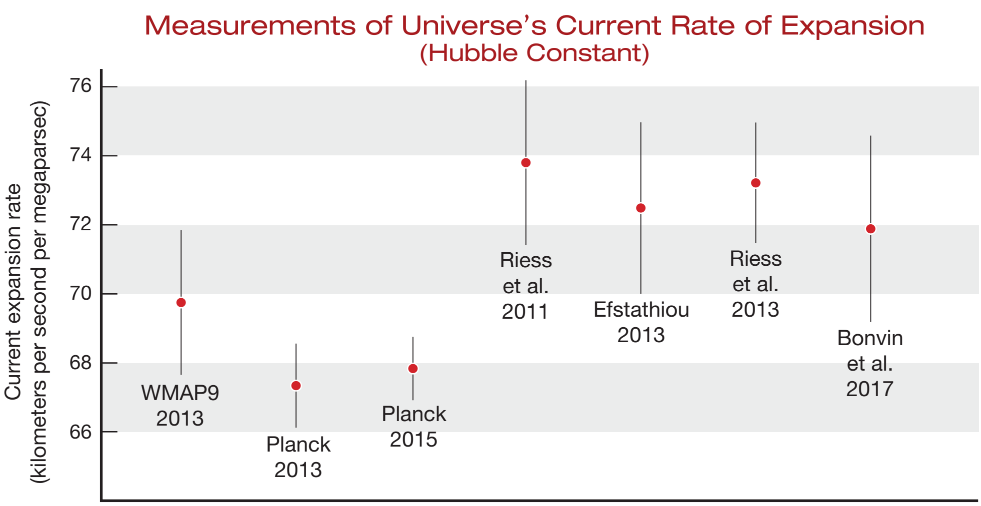
In 2013 Barger and colleagues counted some 35,000 galaxies from multiple sky surveys. They determined that, per unit volume, there’s half again as much light reaching us from galaxies 1½ billion light-years away as there is from galaxies right around us. It’s as if we were living in the suburbs, and the sky-glow in our backyard came more from distant cities than from our neighbors.

If this sparse region that we live in is a true cosmic void, then at 1½ billion light-years in radius, it’s gigantic: “It would be the largest void known to science,” Hoscheit says. Such an immense void would skew local measurements of the universe’s current rate of expansion, bringing them in line with measurements of the faraway CMB. However, a local void wouldn’t affect other measurements, such as those of lensed quasars (rightmost point in graph), which could still pose a problem.

That’s if this region is a void at all. Radek Wojtak (University of Copenhagen, Denmark) isn’t convinced. Typically, cosmic voids have less than 20% of the universe’s average density, he says, but this void is much denser, 70% of the average.

A larger problem, he adds, is that the galaxy surveys used to define the potential void don’t cover the whole sky — for example, they don’t encompass the Laniakea Supercluster. Surveying galaxies to greater distances and across the whole sky could help determine whether this void is real.

■ MONICA YOUNG



MISSIONS: INSTITUTE OF HIGH ENERGY PHYSICS (CHINESE ACADEMY OF SCIENCES); COSMIC: ANA ACEVES / MONICA YOUNG / S&T

BLACK HOLES

Supermassive Black Holes in Close Dance

▲ This artist's concept shows two black holes at the center of a nearby galaxy.

MOST LARGE GALAXIES host central black holes, and those galaxies frequently collide, so supermassive duos should abound in the universe. Yet, despite observing thousands of galaxies, astronomers have only found one close pair of supermassive black holes, separated by 24 light-years in elliptical galaxy 0402+379. Now, a team has measured the plane-of-sky motions of this pair for the first time, making it the first visual black hole binary.

Karishma Bansal and Gregory Taylor (both at University of New Mexico) and colleagues used radio observations spanning 12 years to create sharp images of the galaxy's core at multiple frequencies, publishing the results in the July 1st *Astrophysical Journal*.

The set of images shows the motion across the sky of two bright spots of radio emission coming from each black hole's jets. Bansal and colleagues measured the black holes' relative motion to be 1,500 km/s, or 0.5% the speed of light. The duo will take some 30,000 years to complete a single orbit and, the authors suggest, millions of years to merge. (The team plans additional radio observations in 2019 or later to pin down precise orbital parameters.)

But black hole mergers aren't guaranteed. Just as Earth has circled the Sun for about 4.5 billion years, two black holes will continue to orbit unless something siphons away their angular momentum. Initially, gravitational interactions between the black holes and surrounding material do the trick; eventually, when the black holes are within spitting distance, they'll emit gravitational waves that drive their inward spiral. But in between there's a "final parsec" problem: When the black holes are a few light-years apart, simulations show that they'll already have slingshotted away all the surrounding stars and other material, yet the gravitational waves they emit won't be strong enough to change their orbits.

Even so, coauthor Taylor speculates, the pair in 0402+379 will probably merge if enough material continues to fall into the center. Although we'll never see it happen, this pair nevertheless presents a tantalizing target for understanding how black hole mergers work.

■ MONICA YOUNG

BLACK HOLES: JOSH VALENZUELA / UNIV. OF NEW MEXICO; GALAXIES: STEPHANIE JUNEAU ET AL.

IN BRIEF

Titan's Geologic History

A topographic analysis suggests something has erased part of Titan's geologic past. Benjamin Black (City University of New York) and colleagues used global drainage patterns to determine the likelihood of recent tectonic activity. Drainage patterns will align with ancient topographic gradients, unless tectonism disrupts them. By blurring out small-scale features, the team determined how often fluvial features "conformed" to the underlying topography. In general, surface material on Titan seems to migrate poleward — hydrocarbons in the atmosphere travel from mid-latitudes to the pole, and five out of six rivers drain to the poles. Reporting in the May 19th *Science*, the team finds that Titan's drainage networks follow the prevailing slopes in mid-latitude and equatorial regions, but not near the north pole.

■ **JANINE MYSZKA**

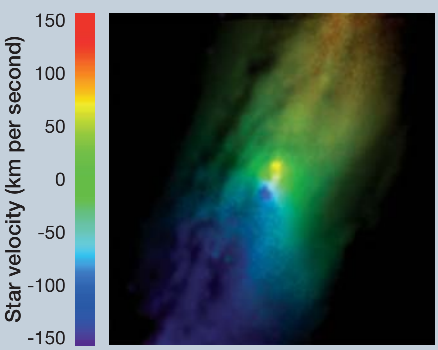
Mass Makes the Star

Trent Dupuy (University of Texas, Austin) and Michael Liu (University of Hawai'i) defined stardom in a study appearing in the *Astrophysical Journal Supplement Series*. The team used the Hubble Space Telescope, Keck Observatory, and Canada-France-Hawaii Telescope to monitor 31 binary systems, consisting of brown dwarfs and low-mass stars, for almost a decade. The period and size of each pair's orbit determines each object's mass. Based on their sample, Dupuy and Liu confirmed that an object must have at least 70 times Jupiter's mass to ignite fusion; anything less is fated to brown dwarf status.

■ SUMMER ASH

GALAXIES

Ring Around a Black Hole



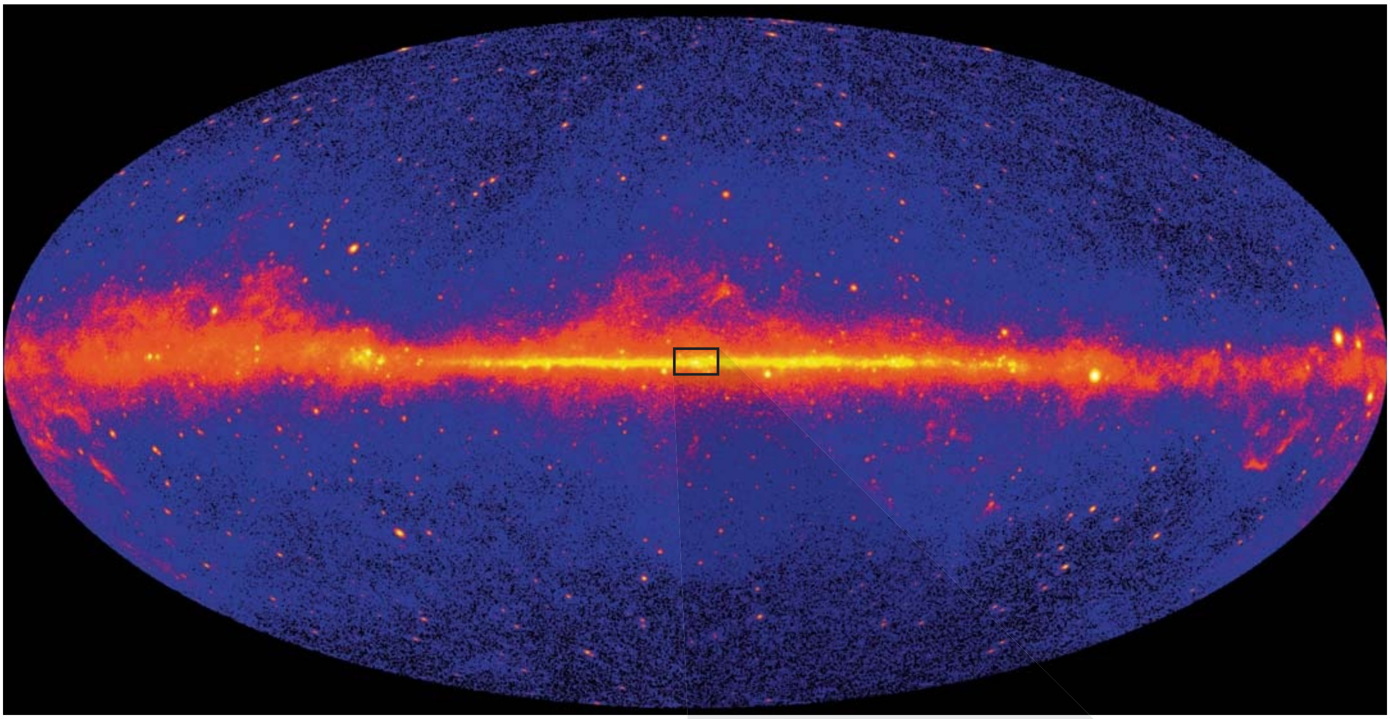
◀ **A TEAM OF ASTRONOMERS** has taken a close look at nearby spiral galaxy NGC 7582 and discovered an unusual structure circling its supermassive black hole: a ring of dust, gas, and stars spanning 2,000 light-years. Stephanie Juneau (NOAO) presented new data from the MUSE instrument on the Very Large Telescope in Chile at June's meeting of the American Astronomical Society.

Each of the image's 90,000 pixels includes a spectrum, its Dopper shift revealing how that part of the galaxy is moving. Red indicates stars moving away along our line of sight, while blue indicates stars moving toward us. Juneau's team separated the overall rotation of stars around the galactic center (red-to-blue gradient) from the even faster rotation of an inner ring, seen edge-on (blue and yellow dots in the galaxy's core).

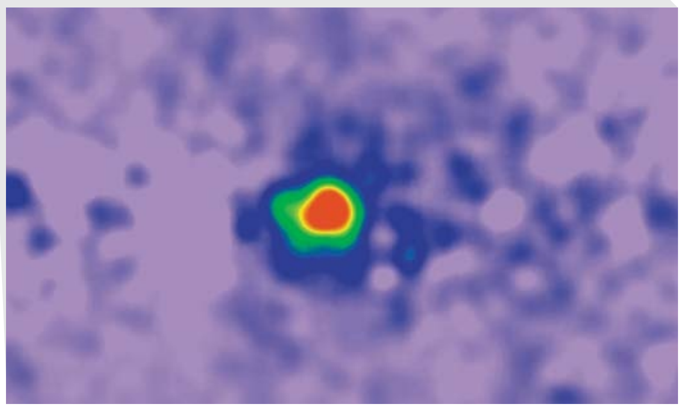
The ring spans a thousand times the width of the gaseous accretion disk that's feeding the black hole. In addition to blocking some of the disk's intense radiation, the ring shapes the wind emanating from the disk and protects the galaxy from its destructive power. The authors speculate that the ring might have formed during a recent merger with a dwarf galaxy once in orbit around NGC 7582.

■ MONICA YOUNG

• **Learn more about the study at https://is.gd/ringaroundbh.**



The Origin of the Milky Way's Mysterious Gamma Rays



When NASA's Fermi Gamma-ray Space Telescope first painted a picture of the high-energy sky, it revealed a view outside our ordinary experience. Instead of the dust lanes and star-filled patches of the visible-light Milky Way, Fermi's whole-sky map features a thin, bright stripe of gamma rays emanating from the galactic plane, most of it coming from interstellar gas, pulsars, and stellar-mass black holes.

But when several teams of scientists subtracted all of the known sources of gamma rays from the sky map, a bright central glow remained. The inner part of the Andromeda Galaxy emits a similar, mysterious gleam. Seven years after its discovery, astronomers still don't understand what's producing this high-energy radiation.

One tantalizing explanation is dark matter. So-called weakly interacting massive particles (WIMPs) ought to act as their own antimatter (*S&T:* Aug. 2017, p. 28), annihilating each other and in the process producing gamma rays and energetic particles, such as positrons and antiprotons (the antimatter equivalents of electrons and protons, respectively).

▲ **EXCESSIVE BEHAVIOR** The Fermi Gamma-ray Space Telescope has imaged the whole high-energy sky, pictured here in the background. The Milky Way's galactic plane is visible as a thin bright strip. Even after astronomers remove all known sources of gamma rays, an unexplained glow remains (inset).

In this scenario dwarf galaxies, which are rich in dark matter, should emit gamma rays, too. So far, it's unclear if they do: The Fermi Collaboration has reported zero gamma-ray detections from 25 nearby dwarfs, but other studies using Fermi data have reported tentative detections from two dwarf galaxies, Reticulum II and Tucana III. If the Milky Way's excess gamma rays really come from dark matter, then the WIMP theory of dark matter will finally find solid footing.

Still, given that dark matter particles have yet to be detected in the lab — where they would be spotted not by collisions

MILKY WAY: NASA / DOE / FERMI-LAT COLLABORATION; INSET: T. LINDEN (UNIV. OF CHICAGO) with each other but by rare interactions with ordinary matter — some scientists have been hesitant to accept this exotic explanation for the high-energy glow. The alternative, they suggest, is more prosaic: gamma ray–emitting pulsars. Until recently, attempts to detect galactic center pulsars in large enough numbers to explain the extra gamma rays have failed. Now, though, studies are beginning to reverse that conclusion.

Gamma-Ray Pulsars

The Fermi-LAT Collaboration is publishing a new study that picks out gamma-ray pulsar candidates from 7½ years of Fermi observations. The results point to a pulsar population in hiding.

Looking within a box 40° on a side centered on the galaxy's center, the team picked out about 100 point sources likely to be pulsars based on the shape of their gamma-ray spectra. These candidates represent the tip of an iceberg, as there are probably many more point sources that Fermi can't resolve. The team concludes that a total population of 1,000 or so pulsars, most of them unseen by Fermi, could explain the excess gamma rays.

That said, the 100 point sources are still *candidates* — the team hasn't yet detected pulsations in the radio or gamma rays that would confirm their pulsar status. The team is planning follow-up radio studies.

Tansu Daylan (Harvard University), who had proposed a dark matter explanation for the gamma-ray excess, agrees this new analysis is important. "However," he adds, "until we have a smoking gun signature for pulsars, I think both hypotheses should be considered viable."

Dark Matter: Still on the Table?

The study leaves a limited playing field for dark matter, which can't explain the properties of the pulsar candidates that the Fermi team observes. Still, the data also don't entirely rule out the dark matter scenario. And another study, published by Ming-Yang Cui (Chinese Academy of Sciences and Nanjing University, China) and colleagues in *Physical Review Letters*, argues that the gamma-ray excess might be due to dark matter after all.

Cui's team looked at data collected by the Alpha Magnetic Spectrometer (AMS), which collects particle (and antiparticle) data from aboard the International Space Station. Among other things, AMS measures incoming positrons and antiprotons. There are surprising amounts of both positrons and antiprotons at high energies.

While the positron signature — like the gamma-ray excess — could be explained equally well by pulsars or by dark matter, pulsar processes can't easily produce an excess of antiprotons. Instead, Cui's team calculates that dark matter particles with masses between 20 and 80 gigaelectron volts could be responsible. This mass is in turn consistent with a dark matter explanation for the extra positrons and gamma rays.

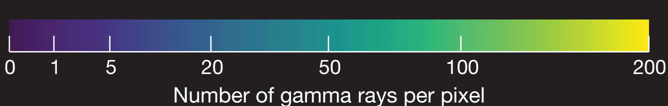
"We want to emphasize that consistency does not mean correct," cautions study coauthor Qiang Yuan (Chinese Academy of Sciences and University of Science and Technology of China), adding that much work must still be done to test whether dark matter is the provenance of our galaxy's high-energy emissions.

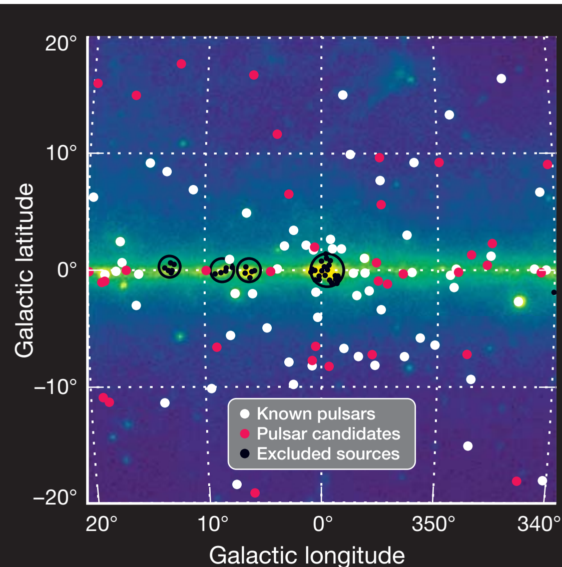
It's important to remember, though, that the debate on the origin of the Milky Way's gamma-ray excess doesn't serve as a proxy war on the reality of dark matter. Multiple lines of cosmic evidence support dark matter's existence, including galaxy rotation curves, whirling galaxy clusters, and weak gravitational-lensing observations. Theorists would rejoice if our galaxy's high-energy emission expanded our understanding of dark matter. But if the extra gamma rays turn out to come from pulsars rather than WIMPs, it only means that scientists will have to look elsewhere to pin down dark matter's nature.

■ **MONICA YOUNG** is *Sky & Telescope*'s News Editor.

WHERE ARE THE PULSARS?

◗ Pulsars have proven difficult to find in the crowded galactic center, but based on 7½ years of gamma-ray data, the Fermi-LAT Collaboration has picked out about 100 new candidates based on their gamma-ray spectra (red dots), in addition to the pulsars already known in this region (white dots). (Black dots mark gamma-ray sources excluded from analysis due to their crowded locations.) The new pulsar candidates may be the brightest of a larger population, which would produce enough gamma rays to explain the Milky Way's excess.





PULSARS: NASA / DOE / FERMI-LAT COLLABORATION

The Hunt for Planet X

Evidence is building that a large world lurks far beyond Pluto and the Kuiper Belt. The race to find it is on.

We were going cross-eyed searching for faint, slow-moving points of light among the steady state of background stars and galaxies. When Chad Trujillo (Northern Arizona University) and I started the search over a decade ago, we had in mind a simple question: What lies beyond the known observable solar system? In the survey that ensued we detected a few comets, thousands of asteroids and Kuiper Belt objects, and even some of the first known Trojan asteroids shadowing Neptune — but nothing that was way, way out there, far beyond Pluto and the Kuiper Belt.

In late 2012 the game changed with the new Dark Energy Camera on the Blanco 4-meter telescope in Chile. Astronomers use this camera to search for signs of dark energy, by mapping the locations of hundreds of millions of galaxies to study patterns in cosmic structure. To do so, the camera takes huge images, each of which is large enough to fit about 14 full Moons. These images cover some 10 times the sky area possible with the telescope's previous camera. Compared to the new camera's view, it was like we had previously been looking through a straw.

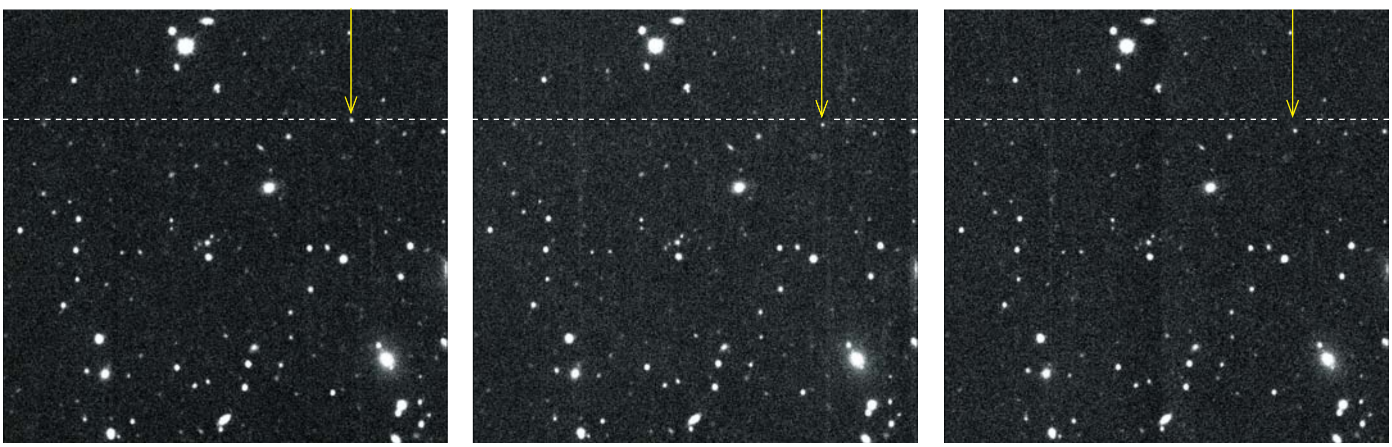
Time on the Blanco was also available for other projects — so why not ours? We realized one night's observations with DECam would cover as much sky as we had searched in all the previous years. "We don't know what we will find," we wrote in our proposal for telescope time. Nobody had searched to the faint depths and across the large sky area that we envisioned doing.

Taking the images themselves posed a challenge, however. During commissioning, the revitalized telescope had trouble pointing and tracking with the camera. To prevent smearing we had to take several short, 90-second exposures, then shift their positions by the bad tracking rate before adding them together to get our required deep, 6-minute exposure time.

The pointing of the telescope was so far off in 2012 that the automated computer algorithm we normally used to flag possible moving objects didn't work yet on the misaligned images. In order to find and re-observe new objects before we lost them, I looked through the data by eye, without the help of any algorithm. It was similar to how Clyde Tombaugh manually blinked photographic plates to find Pluto.

I was looking at one of our worst-aligned images, my eyes glossing over, when I came across the slowest object I had ever seen. Based on its slow motion the object appeared to be about 80 astronomical units (a.u.) from the Sun, almost 2½ times farther than Pluto is currently. But we didn't know much else. A couple of months had passed since the images had been taken, and the new object was in danger of being lost.

In early 2013 we re-observed the object at the Magellan Baade 6.5-m telescope (not far away at Las Campanas Observatory) and found it near the image edge, almost lost to oblivion. The orbit we derived showed the object never comes closer to the Sun than it currently is. It was then we knew we'd found something special that could shed light on the fringes of our solar system.



SCOTT S. SHEPPARD / CARNEGIE INSTITUTION FOR SCIENCE

▲ **PLANETARY HERALD** These discovery images show the distant object 2012 VP_{113} (arrows), taken about 2 hours apart on November 5, 2012, with the Dark Energy Camera. The author found the object thanks to 2012 VP_{113}'s motion against the background of stars and galaxies.

SUBARU Two teams hunting for Planet X are using the 8.2-meter Subaru telescope, shown here on Mauna Kea in Hawai'i.

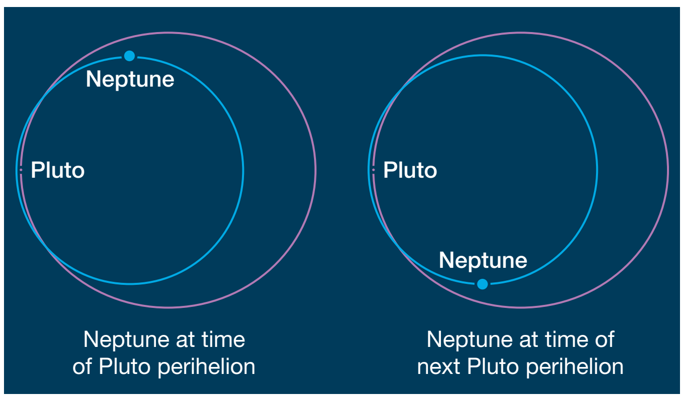
Signpost for an Unknown Planet?

The object, now called 2012 VP_{113}, has the most distant *perihelion* (its closest approach to the Sun) of any object known in the solar system. It's one of a handful of bodies found with very distant orbits and large perihelia — extreme objects that spend most of their time well beyond the known mass in the solar system and thus should be minimally perturbed by the known planets (*S&T:* Mar. 2015, p. 26).

When we started to look at the orbits of these extreme objects, we noticed a strange resemblance: Although they have orbits wildly tilted out of the ecliptic plane, all their perihelia lie near where their orbits cross the ecliptic moving from south to north. The technical way to describe this situation is to say they all have similar *arguments of perihelion*. The argument of perihelion is an angle that defines the orientation of an orbit's perihelion with respect to the ecliptic plane (see figure, page 19), somewhat like a latitude angle on Earth defines an orientation with respect to the equator. The arguments of perihelion for these objects should have been random, yet they clearly clustered around 0°.

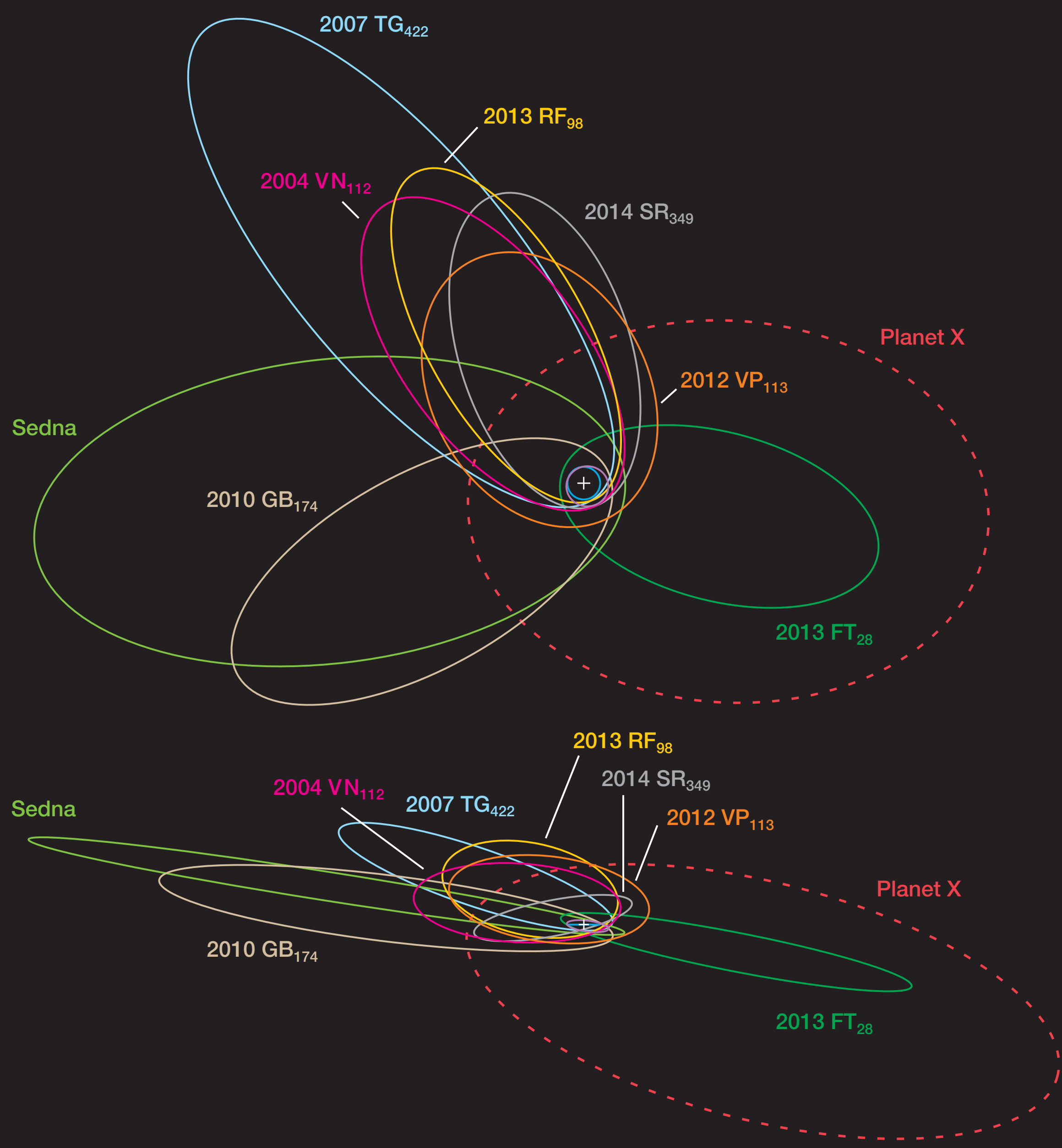
We first thought this cannot be; it must be some observational bias. Certain angles might be more easily found over others when looking at a small range of ecliptic latitudes. But most of the extreme objects were discovered through surveys that looked at a range of latitudes, making observational biases unlikely. Furthermore, our numerical simulations confirmed that, if the known planets were the only significant influences on these objects, the arguments of perihelion should have been random: Even if these extreme objects started with nearly the same orbital angles, their paths would randomize in much less than the age of the solar system. The only way to create and keep this orbital clustering stable is if whatever is causing it still exists.

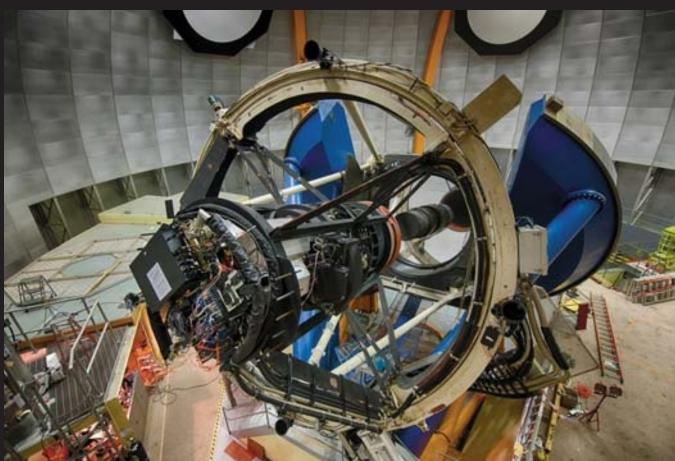
The best solution? A massive, unknown planet.



▲ **IN RESONANCE** Pluto and Neptune occupy a 2:3 orbital resonance: For every two loops Pluto completes around the Sun, Neptune completes three. Because of this synchrony, Pluto and Neptune never come close to each other, even though Pluto crosses Neptune's orbit. Similarly, an unknown planet could exist in resonance with the extreme objects.

PABLO MCLOUD / SUBARU TELESCOPE / NAOJ; DIAGRAM: LEAH TISCIONE / *S&T*; SOURCE: S. S. SHEPPARD





▲ **EXTREME ORBITS** Several objects in the solar system's far reaches follow orbits whose planes are wildly tilted with respect to those of the major planets. Two orientations are shown: as seen looking straight down from above (top) and along the plane of Neptune's orbit. Neptune's orbit is the tiny blue one at the center of each diagram, purple is Pluto's, and the cross marks the Sun. Both orientations have the March equinox pointing straight up and/or behind the Sun from our perspective. Orbits are to scale. These extreme orbits should not be clustered unless they're being shepherded into place by something very massive.

◀ **HIGH-POWERED CAMERA** The Dark Energy Camera, installed on the 4-meter Blanco telescope in Chile, includes everything from the big black box at far left down to the red ring. This gigantic camera, more than 2 meters long, contains a shutter, filter changer, and several large lenses.

ORBITS SOURCE: WORLDWIDE TELESCOPE; TELESCOPE: FERMILAB

Our basic simulations showed this planet would need to lie beyond a couple hundred a.u. and be larger than a few Earth masses to shepherd the extreme objects. Its strong gravitational influence would create some sort of dynamical resonance behavior, similar to the stable resonance between Pluto and Neptune that forces Pluto to go around the Sun twice for every three orbits Neptune completes. This 2:3 resonance also keeps Pluto and Neptune safely separated, even though their orbits cross. Even if we never saw Neptune, we would still know it exists because of the hundreds of known objects, called *plutinos*, with very similar orbits to Pluto's. This is also true with the Jupiter and Neptune Trojans, which are in a 1:1 resonance with their respective planets (*S&T:* June 2016, p. 16).

We also saw hints of a second trend, which Konstantin Batygin and Michael Brown (both at Caltech) confirmed two years later in 2016: The orbital planes of the most extreme objects are also aligned in *ecliptic longitude*. Just as locations on Earth can have the same latitude but different longitudes, orbits with similar arguments of perihelion can still have various orientations with respect to each other. But if the orbital planes have similar latitudes *and* longitudes, then they line up in physical space (see facing page).

Using this alignment, the team was able to calculate a rudimentary orbit for a distant, massive planet that would cause these two geometric clusterings. The planet needed to have a highly elongated orbit, with a perihelion that lies on the opposite side of the Sun as the extreme objects' perihelia. This arrangement allows the planet to spend most of its time well away from the other, smaller objects and thus keeps their orbits stable over the age of the solar system, somewhat analogous to how Pluto stays away from Neptune.

Although statistically it was still unclear if the longitude alignment was real, this work took me from some 70% sure in 2014 to 80% sure that a massive planet much larger than Earth exists beyond a couple hundred a.u.

Since then, Renu Malhotra (University of Arizona), Sarah Millholland and Gregory Laughlin (both at Yale), and others have shown that some of the extreme objects could be in orbit period resonances with the much larger world. An orbital period for the planet of around 17,000 years seems to work well.

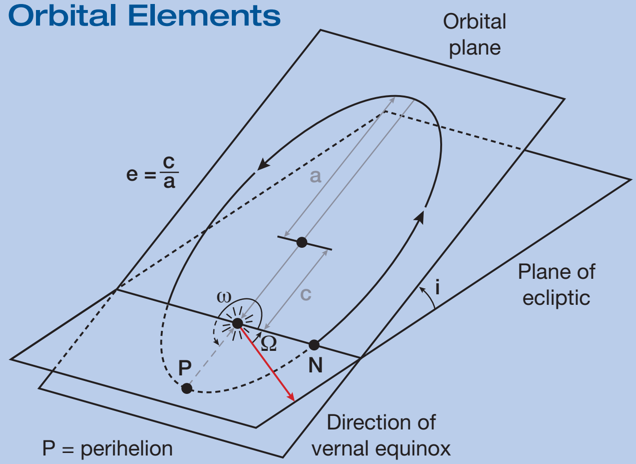
Curiouser and Curiouser

I'm now nearing the 90% level that this massive, distant planet exists. Not only does our continuing survey now cover most areas of ecliptic longitude on the sky, but we have also discovered two more extreme objects, called 2013 FT_{28} and 2014 SR_{349}. Amazingly, 2014 SR_{349} has all the same orbital characteristics as the previously known extreme objects.

But while 2013 FT_{28} has a somewhat similar argument of perihelion, its perihelion lies on the *same* side of the Sun as the mystery planet's presumed perihelion, a 180° longitude difference from the others. The existence of 2013 FT_{28} suggests that *two* clusters of objects exist, not just one, with the first group on the opposite side as the unseen, massive world and the second on the same side, aligned with the planet

LEAH TISCIONE / S&T, SOURCE: *CAMBRIDGE DICTIONARY OF ASTRONOMY*

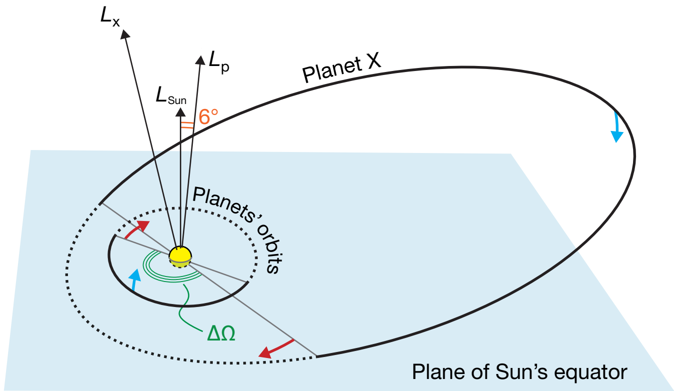
Orbital Elements



Astronomers describe the shape, orientation, and timing of orbital motion using a set of parameters called *orbital elements*. Six orbital elements — *a*, *e*, *i*, Ω, ω, and *T* — specify everything you need to know to locate an object in an elliptical orbit at any time. The ascending node, *N*, denotes where the body passes from below the ecliptic to above it. Dotted lines belong to the underlying plane.

Orbital Elements for Solar System Objects

Name	Symbol	Definition and Function
Semimajor axis	*a*	Distance from elliptical orbit's center to edge along the longest axis. Defines the mean size of the orbit.
Eccentricity	*e*	Distance between the ellipse's center and one of its foci, divided by *a*. Defines how elongated an orbit is.
Inclination	*i*	Angle between the orbital plane and the ecliptic plane.
Longitude of ascending node	Ω	Angle drawn in the ecliptic plane between the vernal equinox direction and the line where the orbit intersects the ecliptic with the object moving south to north. Defines the direction in space of the line where the orbit intersects the ecliptic plane.
Argument of perihelion	ω	The ascending node–Sun–perihelion angle, measured in the orbital plane in the object's direction of motion. Defines the orbit's orientation with respect to the ecliptic.
Time of perihelion passage	*T*	When the object reaches perihelion. Sets the reference frame for the orbital motion.



▲ **TILTED SUN?** The plane of the known planets' orbits is askew relative to the Sun's equator by 6°. A massive planet on a large, elongated, highly inclined orbit could cause most of this tilt, pulling on the planets and making everything wobble like a big top over billions of years. Here, *L* indicates orbital angular momentum (essentially, an axis perpendicular to each orbital or rotation plane), and the blue arrows show the change in the orbits' inclinations with respect to the plane of the Sun's equator. The red arrows indicate the change in the longitude of ascending node for both Planet X and the giant planets (see page 19), and the green angle is the difference between those two, which changes with time. Dotted lines denote where an orbital plane passes beneath the reference plane.

but remaining interior to its orbit at all times. Both of these arrangements would be stable.

The planet, if massive enough, could also explain another solar system quandary. For decades planetary scientists have wondered why the average plane of the planets' orbits (known as the *invariable plane*) is inclined to the Sun's equator by about 6°. A distant planet of roughly 10 Earth masses, with an orbit highly inclined to the ecliptic, could create most of the tilt.

Perhaps we're now in a situation similar to when Le Verrier predicted Neptune's location based on Uranus's peculiar motion. But astronomers are still very cautious about the planet hypothesis, and while most believe it has good merit, there could always be a better explanation we have not yet envisioned. Some still suspect that poorly understood observational biases are the cause, and we'll need to find additional extreme objects to know for sure. This is science at its finest.

The Race Is On

The best way to show the planet exists is to find it. Success will depend on this putative object appearing bright enough for our current telescopes to pick it up, which relies on three big unknowns.

First is its size. In order to create the effects we see, the planet must be more massive than Earth and perhaps even more than Neptune. Many recent analyses suggest the planet is on the more massive end.

Second is its *albedo*, or reflectivity. The object's surface could be as dark as coal or as bright as fresh snow. This factor is a complete unknown, and it depends highly on the composition and how extensive an atmosphere the planet might have.

Finally, the planet's distance is crucial. An object that shines by reflected sunlight looks 1⁄16 as bright as it would when only half as far from the Sun.

If the planet is on the faint end of all three of these unknowns — smaller, darker, and farther — it might not even be easily detectable by our largest optical telescopes. If it were on the big, bright, and close end, we probably would have found it by now. Most likely the planet is somewhere in the middle, making it between 23rd and 25th magnitude, faint but observable with possibly a medium-class professional telescope (4 m in aperture) and likely with a large-class telescope (6.5 to 10 m). Our current all-sky surveys have only used 2-m or smaller telescopes, which can efficiently cover the sky to only 22nd magnitude.

The planet could be anywhere in the basic orbit proposed in 2016, a search area that encompasses some thousands of square degrees — some 20,000 full Moons of sky. Yet time on large telescopes is limited, and an all-sky survey is impossible.

So we need to limit the playing field. Simple dynamics and basic reasoning can help. The eccentric orbit predicted for the planet means that it will spend most of its time near aphelion, its orbit's farthest point. Also, Brown and Batygin have shown that many of the past large, shallow surveys should have found the world unless it is near aphelion and thus too faint.

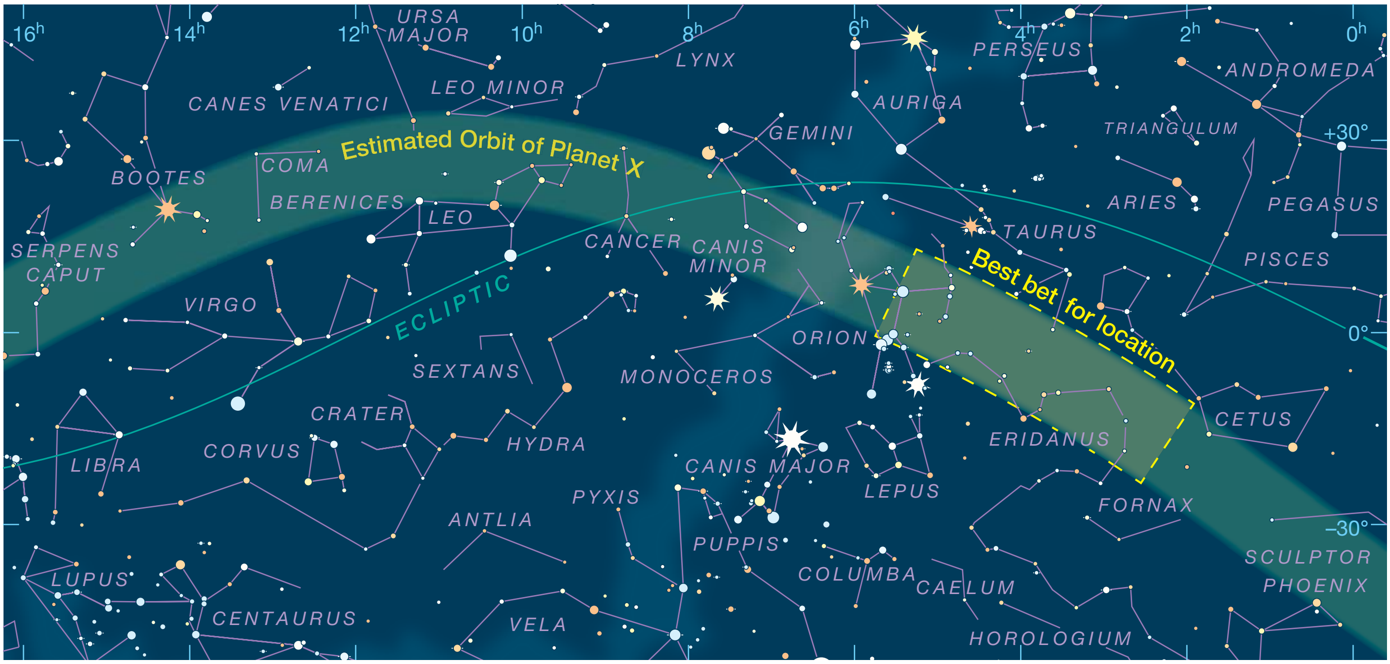
This conclusion has support from a surprising source. If the planet were larger than 10 Earth masses and situated within a few hundred a.u. of the Sun, NASA's careful tracking of the Cassini spacecraft would have likely revealed perturbations in Saturn's orbital motion — perturbations unseen during Cassini's 13-year residence around Saturn. Thus either the planet is on the less massive end or it is near aphelion, over several hundred a.u. away.

If its perihelion is indeed anti-aligned with those of the main extreme objects, then the planet's aphelion would be in the September to January sky, in or near the constellations Orion, Taurus, Eridanus, or Cetus. Most simulations of potential orbital resonances with the extreme objects also put the planet near its aphelion in the October to December sky.

Citizen Scientists Join the Hunt

If the hypothesized planet is on the very massive end, it likely has a significant atmosphere. Such an atmosphere might still be radiating heat left over from the world's formation billions of years ago. This thermal glow would make the planet bright at infrared wavelengths from about 5 to 20 microns. NASA's WISE spacecraft recently completed an all-sky survey at around these wavelengths, and although Kevin Luhman (Penn State) and others have searched these observations for giant planets in the outer solar system and found none, the planet could still be hiding in WISE's archives. Citizen scientists can search the spacecraft's data even further using the tools at **zooniverse.org** in a project called Backyard Worlds.

LEAH TISCIONE / *S&T*, SOURCE: E. BAILEY ET AL. / *ASTRONOMICAL JOURNAL* 2016 (152:126)



▲ **THE PLAYING FIELD** Based on an approximate estimate for its orbit (yellow shaded region), astronomers think that a massive but unseen planet might be lurking in the September to January sky. They have narrowed in on the boxed region for the 2017 campaign. Unfortunately, this race is beyond amateurs' equipment abilities: Telescopes with apertures less than 4 meters need not apply.

LEAH TISCIONE / *S&T*; SOURCE: S. S. SHEPPARD

To conduct the hunt, we need both a medium to large aperture and a wide field of view. Most large telescopes (including the Hubble Space Telescope) have small fields of view. They're good for looking at known objects but are not adept at searching for *new* ones. One of the few exceptions is Japan's 8.2-meter Subaru telescope in Hawai'i, arguably the most powerful survey telescope in the world. Subaru's Hyper Suprime-Camera, commissioned in 2014, can cover some 9 full Moons in one image. Both our group, which includes Chad Trujillo and David Tholen (University of Hawai'i), and the Caltech group working with the Japanese, are using Subaru to hunt for the hypothesized planet. With this telescope we're focusing on the Eridanus and Orion region; the other group is looking in or near Taurus and Orion.

The next most powerful survey telescope is the 4-meter Blanco and its Dark Energy Camera. The DECam's field of view is bigger than Subaru's, but the telescope's mirror has only a fourth as much collecting area, meaning it's less sensitive to faint objects. Our group is also using this telescope to survey regions farther south, in Cetus and Eridanus. Images from the Dark Energy Survey consortium's work, though not optimized for planet hunting, might also serendipitously find the planet, as their field locations include predicted aphelion locations for the planet.

Uranus, Neptune, and Pluto were all seen or imaged before astronomers realized what they were. This distant, massive planet could likewise already be in some archived data, whether in optical wavelengths or infrared (see sidebar, facing page). To actually detect the planet will require at least two very deep images separated in time long enough to see it shift against the background stars. These two criteria are hard to satisfy, because so little of the sky has been imaged to the depths required and with the time-base of days necessary to see movement.

Back in the Saddle

With the arrival of September, the prime search areas are now up. If the weather behaves, some 30% to 70% of this real estate will be covered in the next few months. We could be in for the first planet discovery in our solar system in about a century or two, depending on how you're counting.

It's this potential revelation that powers our breakneck pace. At almost every new Moon, when the sky is dark, our survey continues searching for any objects at the fringe of our known solar system. Just as I get back on a normal sleep cycle, I'm usually off again to Chile or Hawai'i to start the sleepless nights all over again. We can capture almost a terabyte of data per night, but we must find the objects within a few weeks in order to re-observe them before they are lost. I start looking at the images while on the plane home from the telescope run. I always wonder what the person sitting next to me thinks I'm doing. Blinking through the new images, marked up with a bunch of green circles our algorithm has drawn around moving dots, might just look like the latest video game craze. It's no game, but it *is* just as fun. In each new image you never know what you are going to get. Game on.

■ **SCOTT S. SHEPPARD** is an astronomer in the Department of Terrestrial Magnetism, Carnegie Institution for Science in Washington, D.C. If Guinness World Records had a category for moon discoveries, Sheppard would hold it.

 by Peter Tyson

Written *in the* Star

The future of our solar system largely hangs on how the Sun ages. Regardless of the outcome, it doesn't look good for Earth.

Illustration by Casey Reed

On human timescales, it's easy to think of the solar system as stable and unchanging. But over the next 6.5 billion years, as the Sun swells into a red giant and goes on to become a white dwarf, the invisible plane in which all the major planets orbit will undergo radical alterations. Mercury will evaporate into the Sun, and Pluto will develop lakes on its surface. There's a chance life could arise in liquid seas on distant moons, that two or more of the inner planets could collide, or that planets could be flung right out of the solar system. For Earth in particular, all hell will break loose, with our beloved planet becoming a cinder devoid of all life, and possibly destroyed altogether.

Only time separates us from this destiny. Fortunately, there's lots of it.

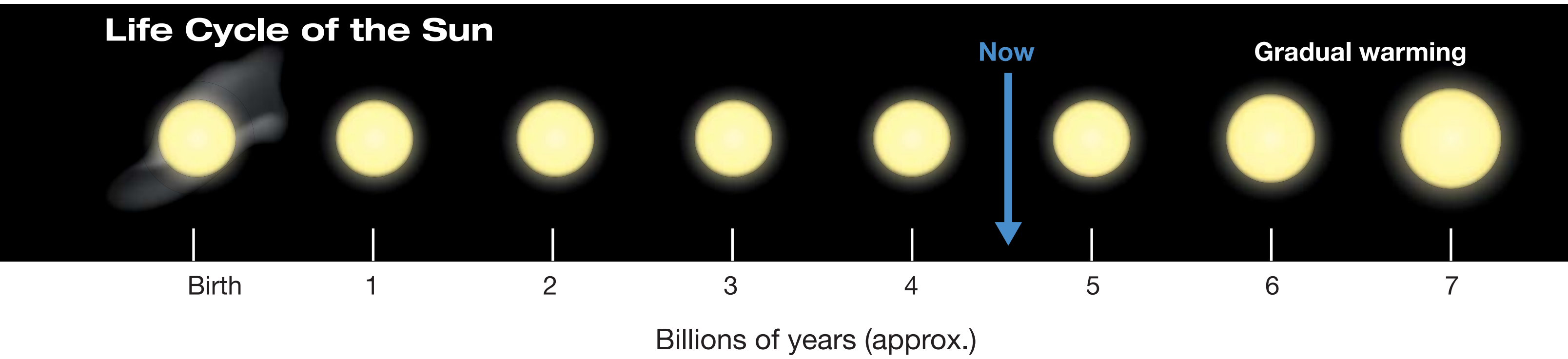
Our Star

The solar system's future depends in large measure on what the Sun does as it ages. In its broadest brushstrokes, the fate of our star is well understood. That's because astrophysicists have the luxury of studying other Sun-size stars in various stages of their lifetimes, from brand-new stars to red giants and beyond. (A star's mass prefigures its endgame, whether that's becoming a white dwarf as our Sun will or going supernova as stars much larger than the Sun do — see page 29.) In a widely cited 1993 *Astrophysical Journal* paper, Juliana Sackmann (Caltech) and colleagues estimate our star's lifespan — from the time it began fusing hydrogen in its core about 4.5 billion years ago to when it will have exhausted its fuel — at about 12.5 billion years. Thus, it's roughly a third of the way through its entire lifetime.

For the next 6.5 billion years, the Sun will gradually brighten, eventually becoming twice as luminous as it is today. But that will be just the start of its transformation, and the most straightforward. Once it leaves the so-called main sequence and enters the *red giant branch* phase, it will begin a frightful growth in both luminosity and size, becoming, over the course of just 600 million years, 2,300 times as bright as today and 170 times its current diameter.

It will get even more climactic. There's a second red giant phase, called the *asymptotic giant branch* (AGB), and during that stretch of about 20 million years, the Sun will attain its greatest luminosity (5,200 times today's) and its largest radial extent of more than 200 times its present width.

◀ **A SEARING FUTURE** Late in its life, the Sun will swell to such a size that it might swallow the Earth. Long before that, it will have incinerated our planet.

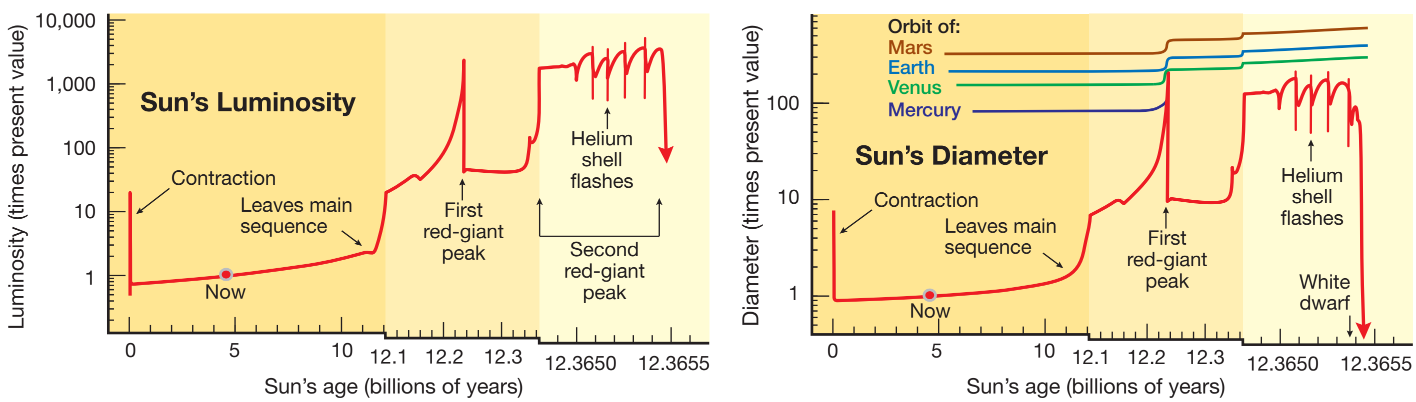


Even as it bloats during these red giant phases, the Sun paradoxically will lose much of its mass in a ballooning solar wind. By the end of the AGB phase, it will have sloughed off so much of its erstwhile self that it might well form an expanding planetary nebula. Eventually it will end up as a white dwarf, a stellar remnant that has used up all its possible sources of fuel for thermonuclear fusion. At this stage, 12.5 billion years after it first ignited, our once-massive star will have a mass about half of today's and a size not much larger than Earth's. The Sun will remain bright — about 35 times as luminous as today — and its surface temperature will be a ferociously hot 120,000°C. It will also be extremely compact, and the leftover heat from fusion will take billions of years to leak to the surface.

Eventually, perhaps 100 billion years from now, it will have cooled to the point where it becomes a *black dwarf*, too cold to emit any optical radiation at all. The light will have gone out in our solar system.

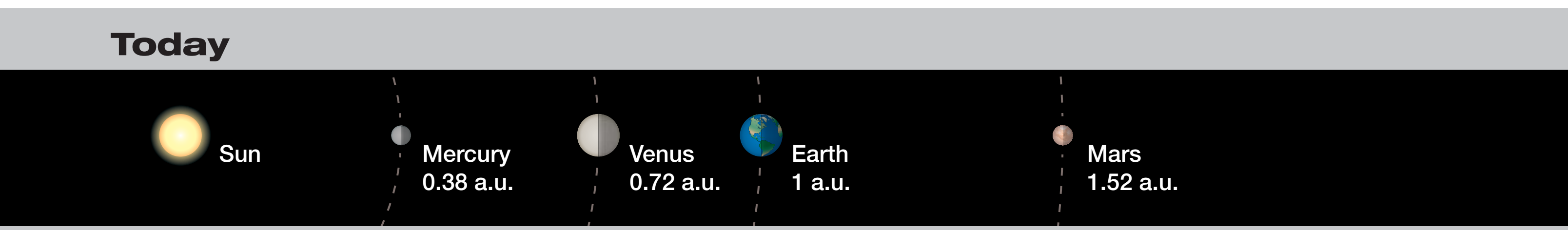
Uncertainties about the Sun's future remain. One concerns mass loss. It's hard for astrophysicists to know just how much of its bulk the Sun will throw off after it exits the main sequence. To improve their understanding, they need to collect loads more data on other solar-size stars undergoing mass loss. Rates of such dissipation depend on a star's mass, age, metallicity (the fraction of its mass that's not hydrogen or helium), and perhaps even angular momentum. "That's 3 or 4 variables, and to survey some function that has 3 or 4 variables is an enormous amount of data," says Fred Adams (University of Michigan). "So it's going to take awhile."

Another ambiguity is convection, or precisely how heat circulates in the outer layers of the Sun. "It's sort of the elephant in the room," says Robert Smith (University of Sussex, UK).

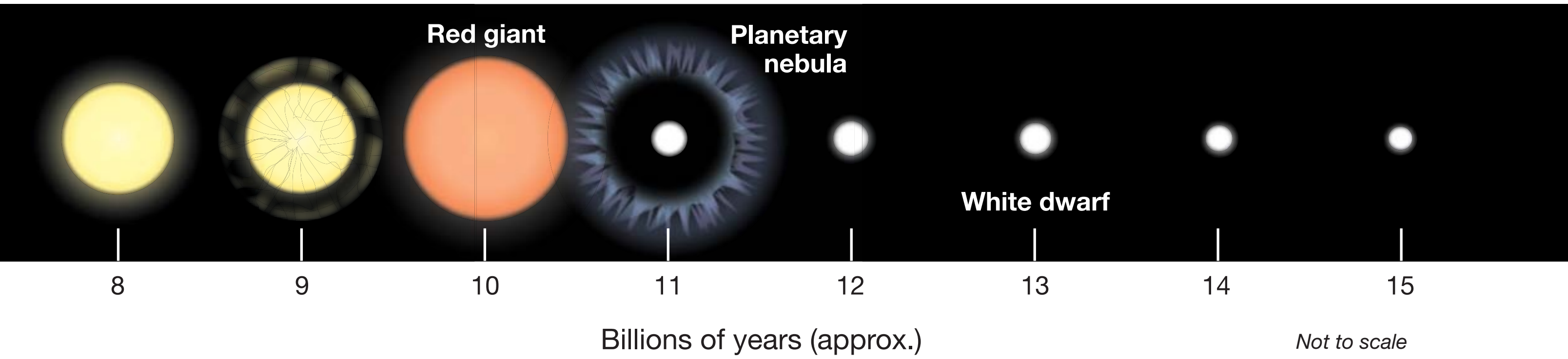


▲ **FUTURE SHOCK** The Sun is already growing in both brightness and size — slowly for the next 7 billion years, then enormously as it enters its red giant phase. Note the three different time scales; they're expanded greatly near the end of the Sun's life to show comparatively rapid changes. The orbits of the planets enlarge when the Sun loses mass. In this particular model, by I.-Juliana Sackmann, Arnold Boothroyd, and Kathleen Kraemer, the Sun swells large enough to engulf Mercury but not quite Venus or Earth.

TIMELINE: WIKIMEDIA COMMONS / OLIVERBEATSON; CHARTS: C. REED / *S&T*, SOURCE: SACKMANN ET AL / *ASTROPHYSICAL JOURNAL* 1993; EXPANDING SUN: G. DINDERMAN / *S&T*, SOURCE: K.-P. SCHRÖDER (UNIV. OF GUANAJUATO) & R.C. SMITH (UNIV. OF SUSSEX) / *MNRAS*, 2008



According to solar-evolution models by K.-P. Schröder (U. of Guanajuato, Mexico) and Robert C. Smith (U. of Sussex, U.K.), our Sun, as it expands . . .



"Everybody knows it's there, but nobody talks about it." Properly treating three-dimensional turbulent convection in the Sun's outer layers is critical to creating viable models of stellar evolution, but it's almost impossible at the moment, Smith says. "Even fluid dynamicists can't fully describe convection in the laboratory. So to be able to get a good model of it in stars is asking a very great deal. Nobody has yet managed it."

Mercury, Venus & Mars

For the inner planets, how much mass the Sun loses — and how fast it does so — is crucial, for it determines their fate. As our star's bulk decreases, its gravitational tug on the planets eases, causing them to drift outward in their orbits.

Mercury won't move away fast enough, and it will be caught by the Sun, like a moth that lingers too close to flame. As our star inflates large enough to engulf the innermost planet, Mercury's iron-dominated density will ultimately count for nothing. Over many orbits within the Sun's outer layers, Mercury's orbit will decay due to gas drag. "As it spirals into the atmosphere, it will be under intense ablation from the radiation field inside the Sun," says Gregory Laughlin (Yale). "Mercury will basically be in a radiation bath." Eventually the planet will dissolve in the unfathomable heat.

Venus, the next planet whose orbit the swelling Sun will overtake, will share the same fate, most models suggest (though not the Sackmann model illustrated on the previous page). Again because of gas drag, Venus will sink farther and farther into the Sun's embrace, eventually becoming so hot that it, too, will dissolve. As Mercury before it, Venus will have reached its *virial temperature*. This is the tipping point beyond which the energy of motion in an object's molecules exceeds its gravitational binding energy, and the body disintegrates. For Earth, Kacper Rybicki (Polish Academy of Sciences) and Carlos Denis (University of Liège, Belgium) calculated the virial temperature to be about 300,000 kelvin. At that temperature, all molecules comprising the planet begin moving faster than its escape velocity, or, in Earth's case, faster than 11 km/sec. "If everything's moving faster than 11 kilometers per second, that thing won't hold together by its gravity, and then you no longer have a planet," says Adams. "You just have a bunch of particles."

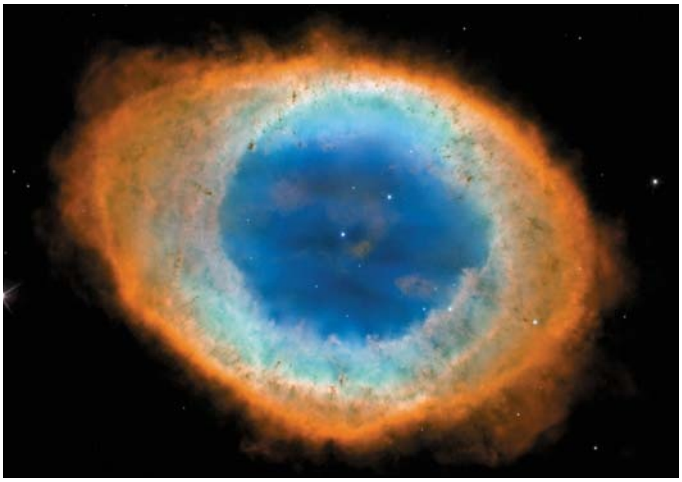
What about Mars? Most models agree that it will escape the Sun's clutches. But while, about 6 billion years from now, it will receive as much warmth as Earth does today, the Red Planet will remain a lifeless world. It's so dessicated already, it has no magnetic field, and its gravity is too low to hold a substantial warm atmosphere, Laughlin says. In 6 billion years, its internal geology will be even more inactive than it is today. "Mars just isn't a very alive world right now, and it will be even more dead," he says.

The Blue Planet

Earth is the wild card: No one knows whether it will survive physically or not (*S&T:* June 2007, p. 32). Our planet may be sucked into the Sun's atmosphere late in the AGB phase, or it may survive the encounter. It depends, again, on exactly how much mass the Sun will shed in these late stages.

Whether or not Earth pulls through in one piece, it's kind of a moot point: Our planet will be toast long before that. Alas, the choice is between no Earth or Earth as "a charred ember of its former self," as Adams puts it. Over the next billion years, the Sun's luminosity will increase by about 10%. Although modest compared to what's coming during the red giant phases, this jump is a death knell for life on Earth.

That much extra energy pouring out from the Sun will melt the polar ice caps and begin to evaporate the oceans. Water vapor is a powerful greenhouse gas, and with so much



▲ **GREAT EYE IN THE SKY** The Ring Nebula, also known as Messier 57, might resemble the planetary nebula the Sun could spawn late in its existence as it shrinks to a white dwarf.

NASA / ESA / C. ROBERT O'DELL (VANDERBILT UNIVERSITY)

SCORCHED EARTH About 3 billion years from now, our planet will enter the *dry greenhouse*, with temperatures approaching those on the surface of Venus today. No life will be possible.

of it now in the atmosphere, our broiling, humid planet will enter a *moist greenhouse* stage. Over the next billion years, Earth's surface will become so seared that not even heat-loving bacteria will survive. By about 3 billion years from today, according to cloud-free climate models run by James Kasting (Penn State University), the planet will have entered a *dry greenhouse* phase. Eventually Earth become essentially another Venus, with surface temperatures reaching 400°C (750°F), hot enough to melt lead.

"You know the *Kansas* song, 'Dust in the Wind'?" Konstantin Batygin (Caltech) asked me rhetorically. "You know, 'Nothing lasts forever but the Earth and sky'? It's clear those guys had not carefully considered the red giant branch of the Sun's evolution." Batygin for one finds the notion that our planet has an expiration date philosophically satisfying: "We tend to think of our cosmic environment as a constant, but it's actually ever-changing. It's just changing on timescales much larger than ones we're used to." That seems like a more orderly model for how the universe works, he says, than one in which our celestial neighborhood remains static.

The Gas Giants

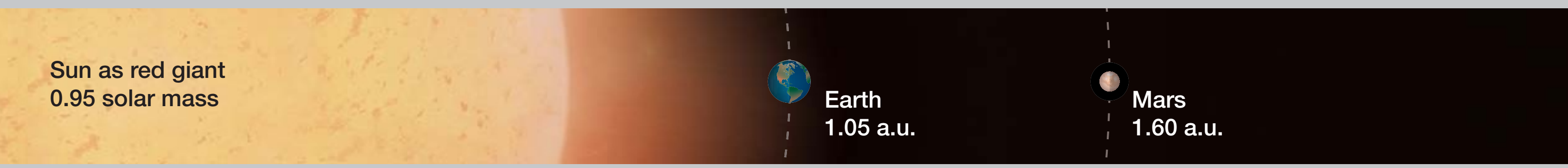
As the Sun matures, Jupiter, Saturn, Neptune, and Uranus will also lose mass, and at rates faster than today. But effects will be minor relative to the gas giants' sizes. Any perturbation of their orbits will likely be small as well, says Jack Lissauer (NASA Ames Research Center). In fact, working with Martin Duncan (Queen's University, Ontario, Canada), Lissauer determined through detailed simulations that the orbits of the giant planets will likely remain stable for more than 10 billion years, and possibly far longer than that.

What most interests astronomers is what will happen to some of their moons. As the red giant Sun mushrooms in size and our solar system's habitable zone — defined as where liquid water can exist on a body's surface — moves outward, currently frozen worlds like Jupiter's Europa or Saturn's Titan will warm up. The question is: Will they warm up long enough to perhaps evolve life (if they haven't already)?

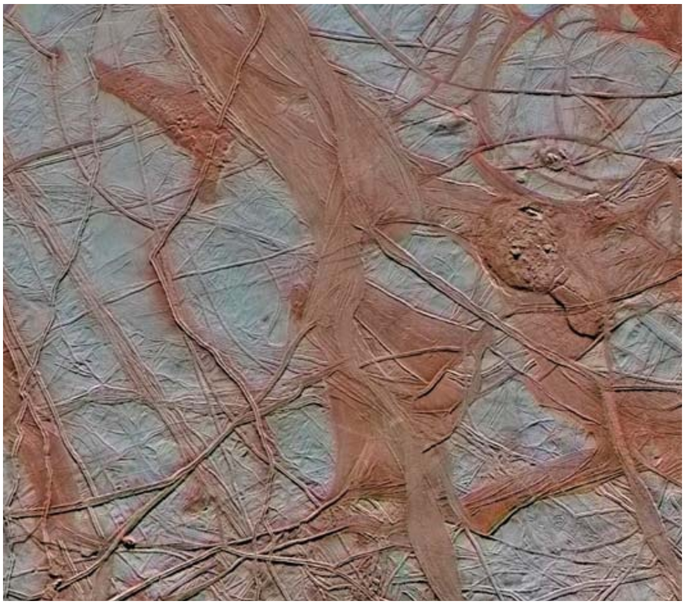
These distant moons will certainly heat up sufficiently to partly melt. On Titan, for instance, Ralph Lorenz (University of Arizona) and colleagues envision that, about 6 billion years from now, a window of several hundred million years will open when liquid water-ammonia could form oceans on Titan's surface and react with the abundant organic compounds there. While water-ammonia would be toxic to Earth's organisms, it might provide a viable solvent for prebiotic and possibly biotic chemistry on Titan and elsewhere. (They dub it a "primordial gazpacho.") Such conditions on Titan might last 500 million years, which is longer than it took life to develop on Earth, they note.

ILLUSTRATION: DETLEV VAN RAVENSWAAY / GETTY IMAGES; EXPANDING SUN: G. DINDERMAN / *S&T*, SOURCE: K.-P. SCHRÖDER (UNIV. OF GUANAJUATO) & R.C. SMITH (UNIV. OF SUSSEX) / *MNRAS*, 2008

7.588 billion years from now



. . . into a red giant over the next 7.5 billion years, will first engulf Mercury and Venus . . .



▲ **NURSERY MYSTERY** Will the inevitable warming of Jupiter's satellite Europa (seen here in close-up, fractures webbing its ice-covered surface) spur the evolution of life on the moon — if it hasn't already evolved there?

But the *possibility* that life could develop and life actually developing are two different things. We only have one example of life arising, and we just don't know how things will transpire elsewhere. "I think the idea that Europa will warm up and turn into this clement, habitable water world — that's wrong," Laughlin says. "It will be even more interesting than that, in the sense that there are all sorts of weird chemical pathways." The same holds for Titan. Laughlin feels that it's naïve of us to speculate on what would happen when Saturn's largest moon warms up (except to say that, as he told me, "it's gonna smell really bad"). We just don't know.

Eventually, we may get an idea by studying exoplanets. Laughlin considers Titan probably the best proxy in our solar system for certain short-period "super-Earths" that have similar compositions to Titan's but are balmy. Yet he stresses that any biosignatures would not necessarily look like ours. "I think the prospects for giving hints of weird, crazy chemical disequilibria that have nothing to do with our own biology but are hinting toward truly alien biologies — that might pan out," he says. "It's important that we keep our expectations completely open. Seeing blank-slate what's there is going to be a really exciting adventure."

Pluto and Other Kuiper Belt Objects

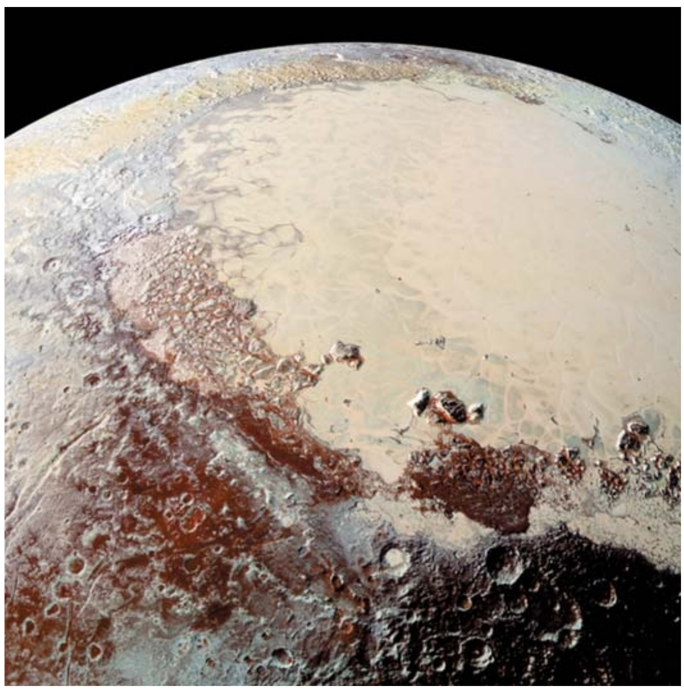
The drifting habitable zone will not stop at Saturn, of course. During the hottest stages of the Sun's red giant phases, the zone will push right out into the Kuiper Belt, as much as 50 astronomical units (a.u.) from the Sun. Alan Stern (Southwest Research Institute) calls these "delayed gratification habitable zones." Triton, Neptune's largest moon, Pluto and its largest moon Charon, and large Kuiper Belt objects are all rich in both water and organic compounds, and thus may become possible sites of biochemical, if not biological, evolution.

The window of time for *complex* life to potentially develop in that distant realm is comparatively short, on the order of 300,000 to 100 million years, versus the roughly 3 billion years Earth had for such life to arise, Stern says. But at their enormous distance from the Sun, these bodies will be safe from wholesale evaporation, they enjoy less harmful stellar radiation, and they suffer fewer collisions from errant asteroids and other smaller objects. So maybe they'll have a chance at life, even the sophisticated variety.

For our solar system, this is way off in the future, of course. But the Milky Way has an estimated 1 billion red giant stars. If icy organics are common 20 to 50 a.u. out from these stars, as they are from ours, then such zones, Stern says, "may form a niche type of habitable zone that is likely to be numerically common in the galaxy." Thus they might enable us to test the hypothesis that simple life can evolve on short timescales, or that the slow evolution of complex life is not necessarily the norm. They might even allow the potential for intelligent, space-traveling civilizations to escape the destruction of their home habitable zones during red giant stretches. Perhaps the locations of advanced civilizations are even biased toward such late-term habitable zones, Stern says.

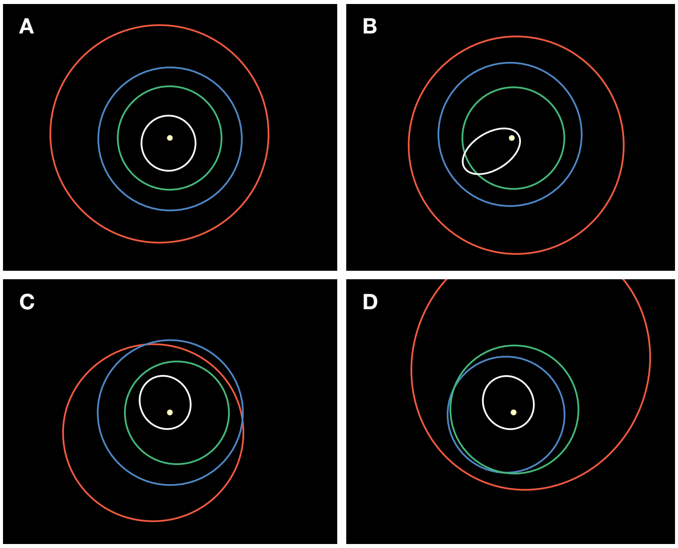
Other Scenarios

Earth, meanwhile, might face other destinies as lethal as burning to a crisp. Simulations by Jacques Laskar and Mickaël Gastineau (both at Paris Observatory) have shown that collisions or ejections from the solar system are possible for the inner planets long before the Sun becomes a red giant.



▲ **LAKES ON PLUTO?** As the Sun matures, all that nitrogen, carbon monoxide, and methane ice in Sputnik Planum may become liquid.

EUROPA: NASA / JPL-CALTECH / SETI INSTITUTE; PLUTO: NASA / JHUAPL / SWRI



▲ **COLLISION COURSES** These four examples of the long-term evolution of the inner-planets' orbits show Mercury (white), Venus (green), Earth (blue), and Mars (red). In (a), roughly our current time, all is well. But in 1% of cases, Mercury's orbit can deform enough for it to collide with either the Sun or Venus (b). One simulation had the eccentricity of Mars' orbit increase enough to allow a close encounter or collision with Earth (c). This eccentricity leads to a destabilization of the inner planets such that Venus and Earth could collide (d).

Altogether, Laskar and Gastineau simulated 2,501 different solutions to the movement of the solar system's planets over the next 5 billion years.

Most of these calculations showed little change, which is consistent with our basic understanding that the solar system hasn't evolved much in 4.5 billion years. But in 1% of cases, Mercury's eccentricity increases considerably. This causes trouble in more than 200 of the French team's simulations. In 29 cases, Earth and Mars collide, for instance, and in 18 others Earth and Venus do so. Batygin, in a separate study with Laughlin, turned up similar probabilities for errant behavior. Their experiments yielded one evolution in which Mercury falls onto the Sun about 1.2 billion years from now, and another in which Mercury and Venus collide about 862 million years forward.

Laskar found two aspects of his findings surprising. The first is that the likelihood that such catastrophic events could occur was relatively high and not just a mathematical curiosity with a vanishingly low probability. The second was that if he relied only on Newtonian mechanics in his simulations, and not on general relativity, the probability of such collisions within 5 billion years rose to 60%. "So the odds go from a 1% chance of having a big problem for the terrestrial planets to about a 60% chance," Laughlin says, referring to Laskar's calculation. "It's kind of ironic that the failure of Newton's law through general relativity is what actually stabilizes the solar system and allows the Earth to be here."

The chance that Mercury will enter the kind of *secular resonance* that would result in a radically altered orbit is low, however. "It has to be relatively low, because we're still here," Batygin says. If it were high, the solar system likely would have rearranged itself already in the 4.5 billion years since the planets assumed their current orbits. But his and Laskar's findings do provide food for thought. Understanding how that instability gets turned on — *if* it ever does — is essential to understanding how planets evolve.

Earth might also get banished from the solar system or even kidnapped. In a study that investigated the likelihood within the next 3.5 billion years of our solar system's planets scattering due to the perturbing influence of passing stars, Laughlin and Adams put the chance of Earth being expelled from the solar system at 1 in 400,000 or captured by a passing star at 1 in 2 million. While our solar system may seem isolated, in the immensity of time stars do drift nearby.

A Billion Threads

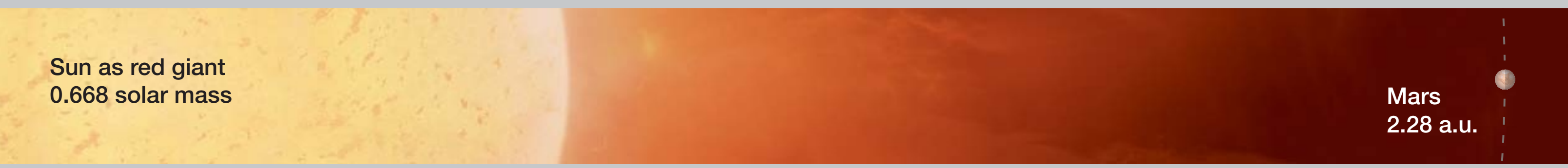
In the end, all we know is that the solar system has been stable for a long time and may remain so for a long time yet, but if and when it becomes unstable, anything could happen. "You might find planets scattering all over the place," says Smith. "Which planets would do what is anybody's guess."

Batygin, again, takes a philosophical stance. "The solar system, despite its seeming regularity and immutability, is actually an unpredictable beast." He likens it to a double pendulum, an ostensibly simple dynamical system that can exhibit unpredictable behavior. Change an initial condition even slightly, and the long-term evolution of the double pendulum — or the solar system — can change incalculably. "We have to stop thinking of the evolution of the solar system as one thread that will take us somewhere," he says. "We have to start thinking about it as a statistical ensemble of a *billion* threads, all of which are pinched together by today. The solar system could take any one of them, and we can't predict exactly which."

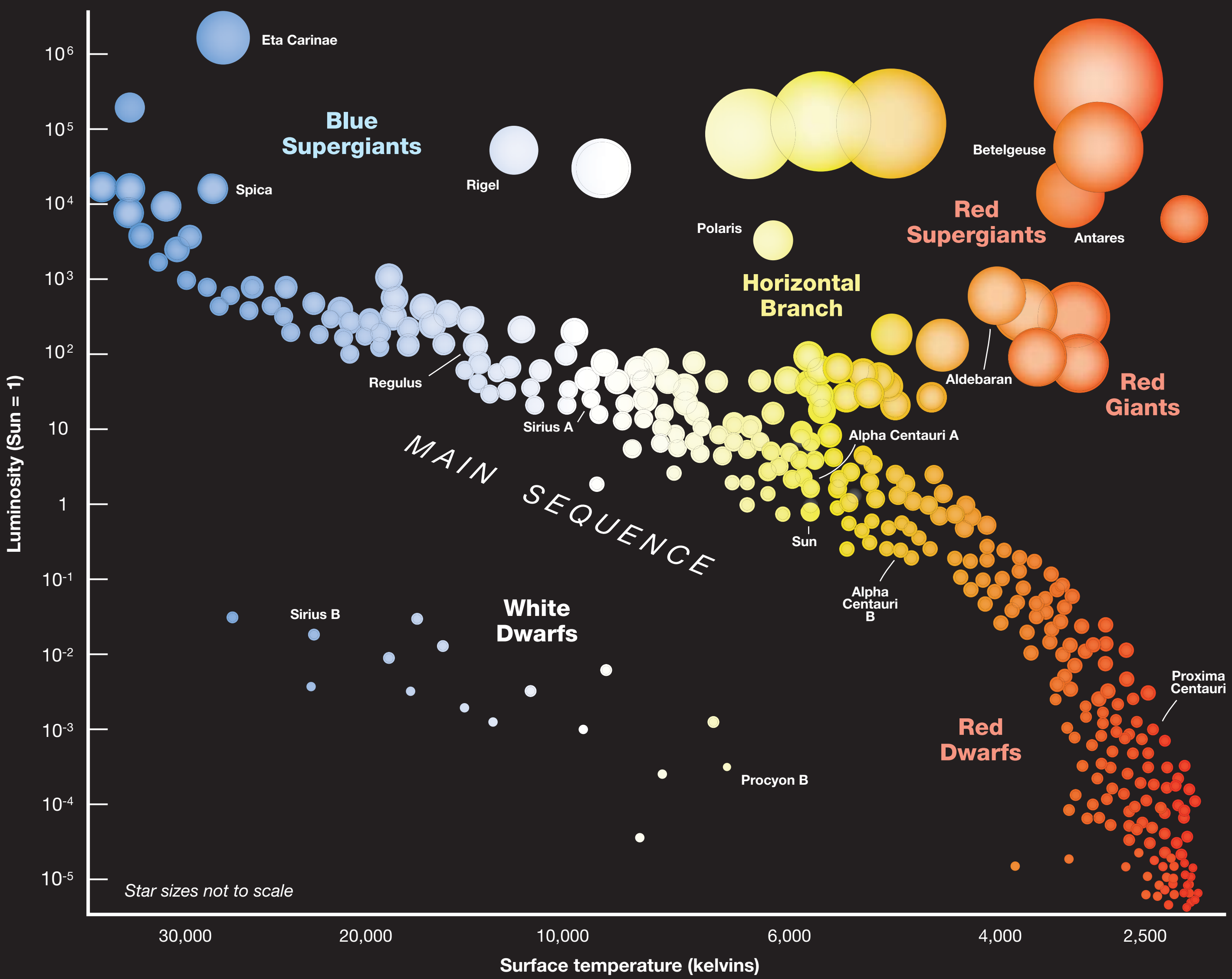
■ **PETER TYSON** is *S&T*'s editor in chief. He'd like to ride the habitable zone to Pluto, but he doubts he'll live long enough.

ORBITS: G. DINDERMAN / *S&T*, SOURCE: J. LASKAR / *PROGRESS IN MATHEMATICAL PHYSICS* 2013; EXPANDING SUN: G. DINDERMAN / *S&T*, SOURCE: K.-P. SCHRÖDER (UNIV. OF GUANAJUATO) & R.C. SMITH (UNIV. OF SUSSEX) / *MNRAS*, 2008

7.59 billion years from now



. . . and, finally, Earth. Mars will have drifted out far enough to escape the Sun's grasp, but it will remain a dead world, the last of the inner planets.



The Lives of Stars

OUR SUN IS an average star about a third of the way through its lifetime. For most of a star's existence, its color and brightness depend almost entirely on how much hydrogen it was born with. Stars much more massive than our Sun are hot, bright, and blue-tinted; stars less massive than ours are comparatively cooler, fainter, and red-hued.

As seen above, a scatter plot of color (temperature) versus absolute brightness (luminosity) shows that most stars lie along a broad swath called the *main sequence*. (Our Sun is about midway along this arc.) Main-sequence stars are busy burning hydrogen in their cores. Red giants and supergiants, for their part, have stopped hydrogen core-burning. Instead, they host vast envelopes of gas that surround nuclear shell-burning layers around an inert, compact core.

Plots like that seen here are called Hertzsprung-Russell diagrams after the two astronomers — one Danish and one American — who independently developed them in the early part of the last century. Mainstays of modern astronomy, H-R diagrams have greatly aided astronomers in teasing out the secrets of stellar evolution.

Despite in many cases truly astronomical longevity, all stars must die, and their initial mass largely determines their fate. Late in their lifetimes, stars that end up with cores of about 1.4 times the mass of our Sun or less will, after burning up the last of their thermonuclear fuel, become white dwarfs. That's our own star's destiny, far off in the future. By then it will have shrunk to not much larger than the Earth, but it will bear an incredible density: One teaspoon of its matter would weigh about a metric ton.

Those stars whose late-life cores weigh between roughly 1.4 and 3 times the Sun's mass will, at some sudden moment, cataclysmically explode in a supernova and wind up as neutron stars. The size and density of these objects make white dwarfs seem huge and practically porous in comparison: A teaspoon of neutron star, which is only 10 or 20 kilometers across, would weigh a *billion* metric tons.

Finally, those stars with cores over 3 times our star's mass will, after going supernova, condense into black holes.

LEAH TISCIONE / S&T

ALL PHOTOS PROVIDED BY THE AUTHOR

A Gentleman's Observatory

This backyard structure recalls classic tastes of the Victorian age.

I've always had an affinity for 19th-century telescopes, because they were so beautifully made, with every bit as much attention given to the aesthetics as to the engineering. The idea of beautifying scientific equipment may seem strange these days, but as an amateur astronomer, my priorities are rather different than those of a professional scientist. I observe purely for enjoyment, and using handsome equipment greatly enhances that experience, in much the same way that lovely decor in a restaurant enhances the dining experience.

The Inspiration

Having made a Victorian-style telescope and mount several years ago (*S&T:* May 2011, p. 64), I had the idea of creating a permanent home for a similar instrument that matched its style and that would optimize its usefulness in the British weather. In the United Kingdom you can often spend an hour setting up a telescope only to have the clouds to roll in. Conversely, even on cloudy nights there are often periods of clarity that a rapidly deployed telescope can take advantage of. Our winter nights also tend to be cold, damp, and windy! So having the telescope permanently mounted in an observatory offers significantly more opportunities to observe and to do so in far greater comfort.

Constructing observatories in the Victorian style in its heyday was the sport of English Lords and American industrialists. Since I'm neither of the above, it was quite a challenge to work out how to make something that would have a similar feel yet still fit into the corner of my modest English garden while adhering to a sensible budget.

My starting point was to study as many 19th-century observatories as possible. Some, such as Yerkes Observatory in Wisconsin, are masterpieces of classical architecture, but their scale is far too Olympian for the aesthetics to work in a domestic garden. Others, such as Ladd Observatory at Brown University in Rhode Island, are more modest in size but still very beautiful. At the small end of the scale, the Aldershot Observatory in the UK manages to elegantly capture the essence of Victorian design in a relatively tiny building.

I concluded that a small circular structure with brick walls and a copper dome would best encapsulate the look I was after. I began my design by making sketches before moving on to scale models constructed of cardboard and glue. Even after being an artist for many years, it still surprises me how different a design can look on paper compared to when it's transformed into three dimensions.

One thing that came to light during the modelling process was that the building looked much better if it had windows, especially if the tops were rounded. Of course, from a practical perspective, windows in an observatory are not necessarily a desirable thing, but this was one of several cases in which aesthetics won out over practicality.

Inside the model observatory, I also made a moving model of the telescope and mount to ensure it wouldn't hit the roof and walls as it went through the complex gyrations of slewing a long refractor on a German equatorial mount. This also enabled me to experiment with various shutter designs.

◀ **STELLAR SHRINE** British amateur Tim Wetherell's observatory is designed to complement the Victorian aesthetics of his home, garden, and even the telescope it houses.

▶ **WINDOW TO THE UNIVERSE** The aluminum panels on the interior of the dome were custom-printed with mirror-reversed images from Vincenzo Coronelli's celestial globe.

▲ **STEEL SKELETON** The walls of the observatory were constructed of welded galvanized steel surrounded by perforated mesh used to secure the adhesive to affix the brick facade.

Dome shutters have always presented a headache for observatory designers. Geometrically, a hemisphere really doesn't want to open into a slot that will give wide access to both horizon and zenith. There are several solutions to this problem, none of which are entirely perfect. My preference was for a shutter that rolled back over the dome because it best preserved the classic look of the roof. However, such a shutter wouldn't have been able to slide back far enough to give me a good view of the zenith, so my shutter has two parts. Rolling back just the main shutter allows access to the sky from 30° to 110°, providing excellent access to the zenith. With both parts rolled back, the sky window is –10° to 70° offering a good horizon view. Having a working model enabled me to refine this double-shutter design and choose the optimal point at which to split it.

The final revelation that came from playing with the model was that the roof would look much better with a little dome or cupola on the top. I guess that's something the great Renaissance architects of Italy discovered centuries ago, and many domes since have incorporated such a finishing touch. Once again, aesthetics triumph over practicality, because adding a cupola does nothing to improve the running of a shutter. It did, however, offer the opportunity to incorporate a weatherproof vent fitted with a solar-powered fan to suck out hot air from the roof in summer.

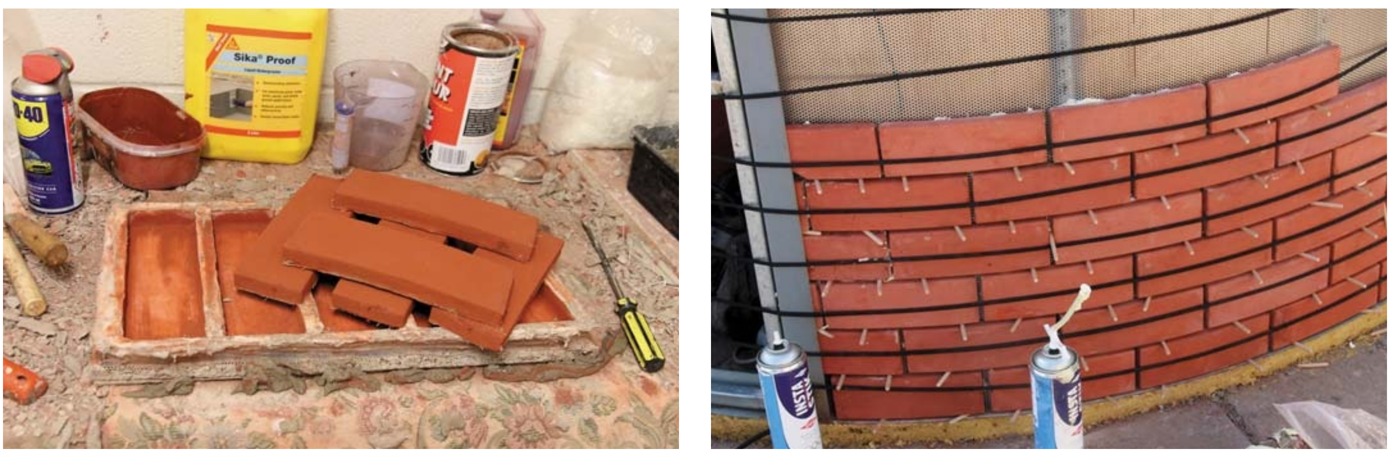
Upscaling the Model

Having established the aesthetics of the building, it was time to consider the engineering that would translate this into a real brick-and-mortar structure. I imagine the observatory will have a useful life of perhaps 100 years, significantly exceeding my own!

Regular bricks retain a lot of heat, which isn't ideal for an observatory. Bricks also generally come in rectangular shapes that don't lend themselves to creating tight radius-curved walls. I have no doubt that the Victorians would have solved the latter problem by creating special curved bricks, so I decided to do the same. Since I don't have access to a brick factory, I used colored concrete impregnated with fiberglass reinforcement instead. With the mixture just right, the end result is very brick-like indeed. Making my own bricks also made it possible to reduce the thickness to about ½-inch, reducing thermal mass.

The bricks were made in a special silicone mold that accommodates five bricks at a time, with a day of setting in between each batch. A total of 450 bricks were required for the observatory walls, making this the longest and most tedious parts of the entire build. Brick-making spanned almost four months, each day taking out a set batch of bricks and mixing another five to go.

Such thin bricks are incapable of supporting any real load, so the observatory required an internal structural frame. This was made from welded galvanized steel covered with thin perforated mesh. The frame provides a very strong and rigid structure to support the roof, and the perforations in the



▲ **BRICK MOLD** To reduce thermal issues from traditional bricks, the author fabricated custom "bricks" from a concrete and fiberglass mixture in a custom mold designed to match the radius of the walls. **Right:** Each brick was then mounted using a foam adhesive and strapped into place using bungee lines while the adhesive set. The final structure is 2½ meters (8.2 feet) in diameter by 3 meters tall, with a 60-centimeter-wide (24-inch) slit.

▲ **SHAPING THE ROOF** Each section of the dome roof was bent into shape using a large slip roller.

mesh offer an excellent gripping surface for the foam adhesive that holds the bricks on.

The roof, an aluminum skeleton with riveted metal sheet cladding, is very similar in design. I didn't use real copper for the exterior because it's heavy, expensive, and difficult to shape into the decorative parts required by the aesthetics of my design. So instead, I used aluminum sheet for the panels and fiberglass castings for the cupola and decorative corbels. After much experimentation, I developed a paint effect that gives any surface a very similar look to verdigris on copper.

When it came to the interior, my wife Asia and I wanted the observatory to be a fun place to hang out. It needed to feel cozy in spite of being essentially an unheated outdoor shed. As artists, we were also very keen that it should be a beautiful celebration of the night sky. Since the internal ceiling is a dome, we thought it would be great to have stars on it — even better if they were set amongst mythological figures.

In the library of my alma mater there's a celestial globe that a colleague had created from engravings by the great 17th-century cartographer Vincenzo Coronelli. Seeing this magnificent globe made me determined to use the same artwork on the inside of our dome so that, in effect, you'd be standing in the middle of Coronelli's universe.

One problem was that, like most early globe makers, Coronelli imagined that the stars existed in a fixed crystal sphere around the Earth. So what he drew was a view of the constellations as seen from outside of that sphere, looking down on the stars and the Earth below. The trouble with translating such a globe onto the internal roof of an observatory is that an observer looks outwards from *within* the sphere, not in from outside. As a result, everything, including the order of the constellations around the sky, is left-right reversed compared to the globe. Of course, the star patterns and the illustrations around them can easily be flipped over, but Coronelli also included thousands of star and constellation names, inscriptions, notes, and markings — each one had to be manually reversed in *Photoshop* so they weren't backward when the main artwork was reversed. I'm sure my wife recalls my complaints once or twice about this tedious job.

The final artwork was printed out onto aluminum panels using a big industrial sign printer and UV setting inks — which are 100% weatherproof and in theory should last a lifetime. The panels were then bent into the proper contour using rollers and then riveted onto the interior frame of the roof.

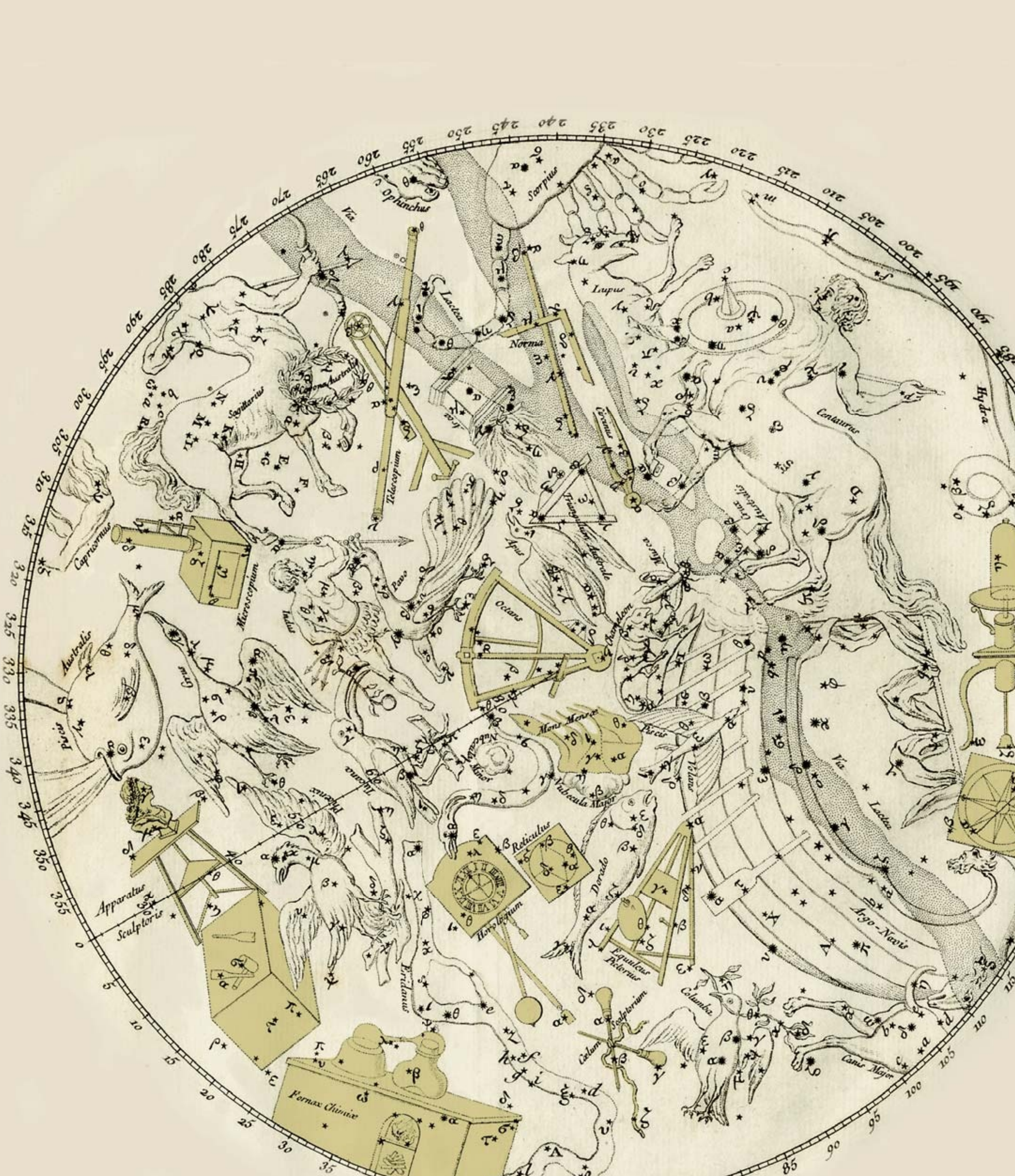
The finished observatory is a lovely space to sit and enjoy the magnificence of the night sky. We're lucky to live on the edge of the Exmoor National Park Dark Sky Reserve (**https://is.gd/dark_sky**), so the skies are particularly dark and stunning here. With the observatory's interior red lights dimmed, the real stars shining through the shutter sit beautifully alongside Coronelli's fantastic creatures progressing around the ceiling. Even on a windy night observers stay reasonably warm and the telescope remains steady. The interior is far from roomy, but it's big enough for two people.

Setting up for an observing session simply involves unlocking and opening the shutter, then removing the lens caps from the telescope, all of which takes less than a minute. Perhaps most importantly, there's no heavy lifting or straining involved. Having once owned a very large "portable" telescope that was a real workout to move, I really appreciate that avoidance of physical exertion. The prospect of heavy lifting is especially daunting at the end of an observing session when I'm often cold and tired. It's not something I miss at all.

Not everyone is lucky enough to have the ability to build an observatory, but if it's feasible for you to do so, I would highly recommend it. Having a permanent home for your telescope will significantly increase your observing time.

■ **TIM WETHERELL** is an accomplished artist and amateur astronomer. Visit his website at **timwetherell.com**.

BEAUTY WITHIN The author with his wife Asia and the premier instrument of the observatory, an attractive, Victorian-style 7-inch f/7 apochromatic refractor.



ALL CONSTELLATION DRAWINGS: IAN RIDPATH
WWW.IANRIDPATH.COM/STARTALES/LACAILLE.HTM

The Father of Southern Astronomy

Introverted and unassuming, the French astronomer Nicolas-Louis de Lacaille created more of today's constellations than anyone before or since.

When 15th-century European navigators first sailed south of the equator, they watched nervously as the North Star sank below the horizon. What new dangers would the southern seas hold? And how would they navigate under unfamiliar stars?

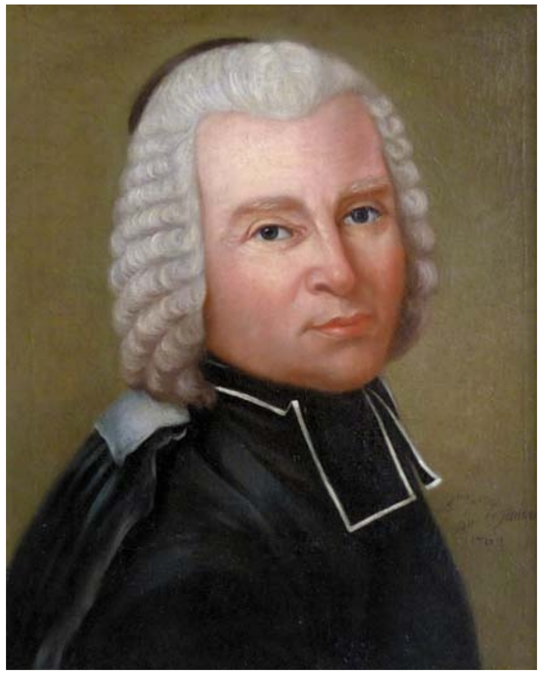
The dangers of the southern seas were real enough. But the Southern Cross served as a good omen to Christian navigators, and it was practical, too: its long shaft points to within a few degrees of the south celestial pole. And in time navigators learned to find their way using many other bright southern stars.

By the late 1500s, the Dutch navigators Pieter Keyser and Frederick de Houtman and the astronomer Petrus Plancius had invented new constellations for the leading southern stars. Many of these were based on exotic austral creatures: Tucana, the Toucan; Pavo, the Peacock; Dorado, the Golden Fish; Volans, the Flying Fish; Apus, the supposedly footless Bird of Paradise — as well as creatures mythical (Phoenix) and annoying (Musca, the Fly). Johann Bayer included many of these newly invented constellations in his epic star atlas *Uranometria* in 1603, and many, including all of the above, remain in use today.

But large patches of the far southern sky remained uncharted and their patterns unnamed until the mid-18th century, when the industrious French astronomer Nicolas-Louis de Lacaille, during a scientific expedition to South Africa of astounding range and productivity, carried out the best southern sky survey that would exist for the next hundred years.

Smitten by Astronomy

The son of a prosperous and respected family, Lacaille (pronounced "la-KAI") was born on March 15, 1713, in Rumigny, France, near the Belgian border. His father invented a number of industrial machines and supported his family through positions appointed by the Duke of Bourbon. Nicolas-Louis studied classics, philosophy, and theology. When his father died suddenly, Nicolas-Louis, then near age 20, was left without means to continue his studies. But the Duke recognized the young man's abil-



▲ **WORKAHOLIC** Nicolas-Louis de Lacaille (1713–1762) was said to have made more observations and calculations that all other astronomers of his time combined. Today he is best known for inventing 17 southern constellations that are still in use, more than anyone in history. This portrait was painted by Anne-Louise Le Jeuneux in the year of his death.

◀ **JUMBLED ATTIC** Lacaille's map of the sky below the Tropic of Capricorn mixes classical constellations around the edges, birds and beasts added by previous Southern Hemisphere explorers, and devices Lacaille revered from the arts and sciences — from the Artist's Easel and Palette to the Chemist's Furnace to the Air Pump. This second edition gives constellation names in Latin; for Lacaille's original French, see page 37.

PARIS OBSERVATORY

CŒLUM AUSTRALE STELLIFERUM;

SEU

OBSERVATIONES AD CONSTRUENDUM

STELLARUM AUSTRALIUM

CATALOGUM

INSTITUTÆ,

IN AFRICA AD CAPUT BONÆ-SPEI,

A NICOLAO-LUDOVICO DE LA CAILLE, *in alma Studiorum Universitate Parisiensi Matheseon Professore, Regiæ Scientiarum Academiæ Astronomo, & earum quæ Petropoli, Berolini, Holmiæ & Bononiæ florent, Academiarum Socio.*

Laudate Dominum . . . . qui numerat multitudinem Stellarum, & omnibus eis nomina vocat.

Psal. 146. ℣. 4.

PARISIIS,

Sumptibus HIPP. LUD. GUERIN & LUD. FR. DELATOUR, viâ Jacobeâ, sub signo Sancti Thomæ Aquinatis.

M. DCC. LXIII.

CUM PRIVILEGIO REGIS.

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ity and seriousness of purpose, and he continued to provide him with support.

Lacaille expected to become a priest. But he was smitten with mathematics and astronomy, which he began to study privately. He finished his theology degree but had no taste for further religious study. Instead, as a self-taught astronomer, in 1737 he obtained a recommendation for a position at the Paris Observatory, which was then under the directorship of Jacques Cassini, son of Jean-Dominique Cassini (the discoverer of the Cassini Division in Saturn's rings).

Here Lacaille honed his skills and applied them to the science of geodesy. He helped map the French coast from Nantes to Bayonne and took a leading role in remeasuring the great meridian of France: the line of longitude from the North Pole through Paris to the equator. The precision surveying for this project verified earlier work showing that Earth is an oblate spheroid — slightly wider across the equator than from pole to pole — rather than a prolate spheroid as some had argued.

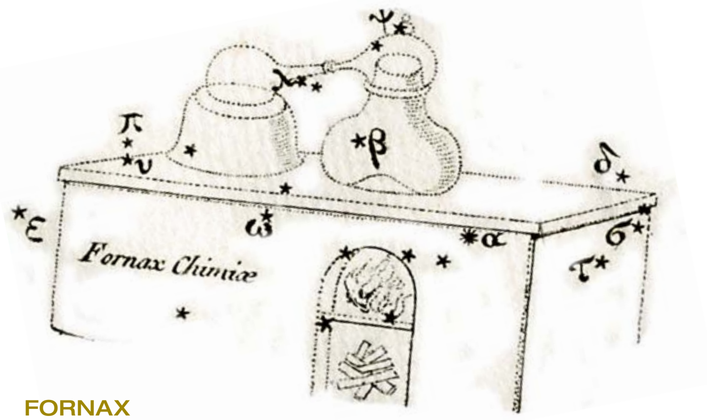
Lacaille's work gained him election to the Royal Academy of Sciences in Paris and a post at the Collège Mazarin. There he established a small observatory, made systematic observations of star positions and parallaxes, and wrote widely read texts on mathematics, astronomy, and optics. By the late 1730s he had established a solid reputation and a comfortable future as an academic.

But he sought new challenge, and he found it in the southern heavens. He proposed to the Academy that he make an expedition to the Cape of Good Hope to catalog the southern sky and to make geographical measurements of the region. On November 21, 1750, Lacaille embarked on the ship *Glorieux,* heading first to Rio de Janeiro, then tacking east to South Africa.

On April 19, 1751, Lacaille landed at Cape Town, then a small way station of the Dutch East India Company. Carrying a letter of introduction from the Dutch Prince of Orange, he was received warmly by the Dutch governor and obtained lodging at the home of Jan Bestbier on what is now Strand Street.

The Dutch found the French astronomer somewhat reserved but amiable, and they gave him what help and materials they could. In the backyard of Bestbier's home, Lacaille oversaw the construction of a 12-foot-square observatory for his instruments and telescopes, which included a 14-foot-long refractor for timing the phenomena of Jupiter's moons: their eclipses and their entries and exits across the planet's face. The local times of these events, carefully determined, could be compared against the local times predicted for the events at the longitude of Paris or London, yielding a means to determine one's longitude anywhere in the world — ingenious, though fairly crude in practice.

◀ **REPORTING BACK** *The Starry Southern Sky* was Lacaille's initial report to the astronomical world after he returned to a hero's welcome in France. It included measures of only the brightest southern stars.



FORNAX

Lacaille's Constellations

Born into the Age of Reason, the industrious and serious-minded Lacaille mostly shunned fanciful names for his new constellations. Instead, he filled his sky with tools of the arts and sciences. Most of the bright southern stars had already been assigned to constellations by Petrus Plancius and Johann Bayer in the late 16th and early 17th centuries, so Lacaille's 14 new constellations are quite dim. They were the final ones created that are still in use.

Here they are with their current, often shortened, names, and their meanings and the original French names on Lacaille's first edition of his southern sky map.

Antlia, the Air Pump *(la Machine Pneumatique)*
Caelum, the Engraver's Tools *(les Burins)*
Circinus, the Geometer's Compass *(le Compas)*
Fornax, the Chemist's Furnace *(le Fourneau)*
Horologium, the Pendulum Clock *(l'Horloge)*
Mensa, Table Mountain *(Montagne de la Table)*
Microscopium, the Microscope *(le Microscope)*
Norma, the Carpenter's Square *(l'Équerre et la Règle)*
Octans, the Octant *(l'Octans de Réflexion)*
Sculptor, the Sculptor's Workshop *(l'Atelier du Sculpteur)*
Pictor, the Painter's Easel *(le Chevalet et la Palette)*
Pyxis, the Mariner's Compass *(la Boussole)*
Reticulum, the Eyepiece Reticle *(le Réticule Rhomboïde)*
Telescopium, the Telescope *(le Télescope)*

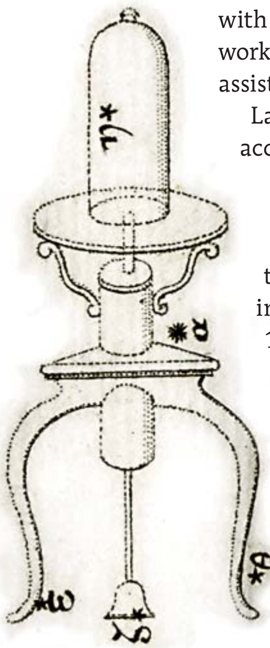
In addition, Lacaille divided huge Argo Navis, a survival from classical times, into three:

Puppis, the Stern
Carina, the Keel
Vela, the Sails

It's no wonder that astronomer Heber Curtis of Lick Observatory remarked that, when he first saw a map of the far-southern sky, "It looked like somebody's attic."

Southern Survey

On August 6, 1751, Lacaille set to work on his major project of charting the stars of the far south with high precision. Constant southeast winds made for shaky observing with large instruments. Lacaille found that he obtained the most accurate star positions using a tiny ½-inch refractor, 26 inches long, affixed to a very solidly mounted meridian quadrant with a 3-foot radius. With this small telescope, he measured the sidereal times when stars near the meridian drifted across V-shaped pairs of lines on a glass reticle in the little telescope's focal plane. The average of the times when a star crossed the two lines could yield its right ascension. The difference between the two times gave its declination with respect to the center of the reticle. He worked alone through the nights, with no assistant to watch the clock or make notes.



ANTLIA

Lacaille had promised the Academy an accurate survey of all southern stars brighter than 3rd or 4th magnitude, a population of several hundred. He far surpassed his own expectations. Over the next 11 months, during 110 observing sessions of 8 hours each and another 16 dusk-to-dawn marathons, and despite suffering headaches, rheumatism, and fevers, Lacaille mapped 9,766 stars to as faint as 8th magnitude between the Tropic of Capricorn (declination –23.4°) and the south celestial pole. It was an astonishing feat of personal industry and endurance.

In comparison, Edmond Halley, no slacker himself, had measured the positions of just 341 stars from the South Atlantic island of Saint Helena from 1676 to 1678.

During his survey, Lacaille also measured and cataloged 42 non-stellar objects, including the Jewel Box Cluster, the Eta Carinae Nebula, and the globular clusters 47 Tucanae and Omega Centauri. Lacaille's catalog of southern deep-sky objects predates even the first version of the more famous catalog by his countryman Charles Messier by some 20 years. With his tiny telescope Lacaille was unable to determine their nature, but he wrote to the French Academy that they were "so varied that their exact and detailed description can occupy astronomers for a long time and give rise to a great number of curious reflections on the part of philosophers." Lacaille himself refrained from such reflections, content to tend to his measurements.

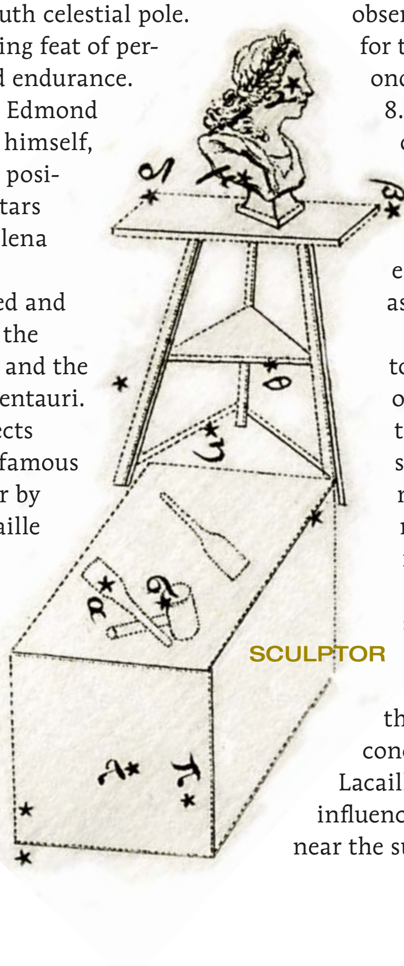
This prodigious celestial bounty created a new problem for the French astronomer: how to organize it all. Much of the far southern sky was not yet demarcated into constellations. So Lacaille invented his own.

RETICULUM

As a man of the Enlightenment and unencumbered by classical whimsy, he named most of his new constellations after, as he put it, "principal figures of the arts": The Painter's Easel; the Sculptor's Workshop; Microscopium and Telescopium; Reticulum, the celestial apotheosis of his little refractor's measuring reticle; Octans, the Octant; Fornax, the Chemist's Furnace; and so on.

His one exception was the constellation Mons Mensa (Table Mountain), now simply Mensa, which he named for the famous landmark near Cape Town. He placed it so the Large Magellanic Cloud would rest upon the mountain's top. Mensa remains the only constellation, of the 88 now officially recognized, named after a geographical feature.

While at the Cape, Lacaille also precisely measured positions of the Moon, Venus, and Mars with respect to stars. Upon his return to France, he compared these measures to ones made on the same dates by his colleague Joseph Jérôme de Lalande in Germany. The two collaborators found slight differences in the angular positions of these objects: parallaxes caused by the thousands of miles between their observing stations. The value that they determined for the Sun's topocentric parallax (10.2 arcseconds) compares well with the currently accepted 8.8 arcseconds; the distance to the Sun that they obtained thereby was just 16% too short.



SCULPTOR

Lacaille and Lalande also compared positions of stars low on the horizon in France and high overhead in South Africa to estimate the effects of atmospheric refraction as a function of temperature and pressure.

His celestial survey complete, Lacaille turned to his next major goal: measuring a long arc of a longitude meridian near the Cape. With the help of the governor and a translator, he surveyed a highly precise north-south arc 84 miles long, a punishing task in unfamiliar, mountainous countryside and without a working knowledge of Dutch.

Lacaille found a surprising result, and it survived a quick second survey to check it: Degrees of latitude in the Southern Hemisphere seemed to be 0.2% closer together than their northern equivalents. In essence, he concluded that Earth was slightly pear-shaped. But Lacaille had failed to account for the gravitational influences of Table Mountain and other mountains near the surveyed line. These caused a plumb bob to deviate enough of a trace from vertical to produce the odd result. Newton's Law of Gravitation predicted the effect, and historians have long debated why Lacaille neglected it. Some say Lacaille, a Frenchman, may have had an unconscious reluctance to apply the theory of an English scientist. Others think it was just an oversight, an easy one to make.

Before he left the Cape, Lacaille also measured Cape Town's longitude using Jupiter's moons, kept tide and weather records, and mapped the area. He collected shells, plants, rocks, and the skin of a wild donkey and shipped them back to the King's royal gardens in France. It's small wonder that Sir David Gill, the distinguished director of the Cape Observatory from 1879 to 1907, said of Lacaille's time in South Africa, "This was one of the most remarkable, successful, and useful scientific expeditions ever undertaken."

Return to France

Lacaille returned to France after a 10-month detour in which he surveyed the islands now known as Mauritius and Réunion in the Indian Ocean. In his journal he records his indifference to these tropical paradises (he was "bored to tears") and his longing to return to France to continue his work. He finally arrived in Paris on June 28, 1754, after an absence of three years, eight months.

Lacaille was greeted in France as a scientific hero, a "star returning above the horizon." This was the long-lost Age of Reason, when scientists were as celebrated as sports heroes today. But the modest Lacaille would have none of it. He refused the fanfare and trappings of fame, wishing only to return to his quiet observatory at the Collège Mazarin.

Supported by a small pension from the Academy, Lacaille resumed work. He produced and presented to the Academy an engraved star map of the heavens south of the Tropic of Capricorn, plotting naked-eye stars and his 14 odd new constellations (page 34). Although not shown on this engraving, Lacaille also split the enormous Argo Navis (the Ship of the Argonauts) into three smaller constellations: Puppis, the Stern or Poop; Vela, the Sails; and Carina, the ship's Body or Keel. A Latinized version of his planispheric map was included in his *Coelum Australe Stelliferum,* published posthumously. This map served as a basis for Jean Fortin's widely read 1776 *Atlas Celeste.*

In 1930, when the International Astronomical Union settled on today's canon of 88 constellations covering every point on the celestial sphere, Lacaille's collection of machinery made the cut.

From 1756 through 1761, Lacaille precisely measured star positions along the zodiac to provide better references points for measuring positions of the planets and Moon. He edited his textbooks, published his table of atmospheric refractive index, and issued a report on the appearance of the Comet

HAVANG / WIKIMEDIA COMMONS

▶ **STILL GAZING** A bust of Lacaille in his dress wig, above a carved telescope and palms of honor, stands in a small park today in his home village of Rumigny, Ardennes, France.

of 1759, now called Halley's Comet. He wrote an early draft of his travel memoirs, *Journal Historique*. He also managed to reduce 1,942 of his 9,766 star positions to standard, equinox-1750 right ascensions and declinations, at a time when the math was done with paper and pencil. Thomas Henderson (Royal Observatory, Edinburgh) and Francis Baily (FRAS) compiled the rest in Edinburgh in the 1840s and published the full list in 1847 as *A Catalogue of 9766 Stars in the Southern Hemisphere*.

Lacaille dreamed of returning to observe the southern heavens, but he never got the chance. Twenty-seven years of hard work and long nights at the telescope took their toll. In early 1762, symptoms he suffered in South Africa returned: headaches, nosebleeds, fever, and digestive problems. Dutch doctors at the Cape had helped Lacaille, but Parisian doctors could not. He died on March 21, 1762 at the age of 49.

Legacy

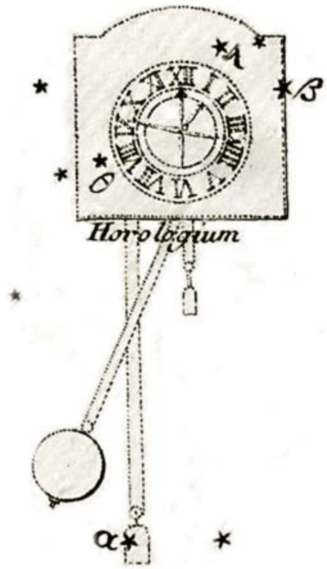
It was said of Lacaille that he made more observations and calculations than all his peers combined. That may be true. Lacaille was no innovative thinker like Isaac Newton or Pierre-Simon de Laplace, and he was not given to speculating in public about the nature of what he observed, as William Herschel did a few decades later. Instead, Lacaille was a data collector of the highest order at a time when the burgeoning sciences required exactly that. His results enhanced navigation, geodesy, and astronomy. And they set the stage for the mid-19th century astronomical work in South Africa by John Herschel and Thomas Maclear.

Lacaille could have accomplished even more. But he suffered the great regret of many northern stargazers who travel to the Southern Hemisphere: He should have brought a bigger telescope. John Herschel, who transported an 18¼-inch reflector to South Africa in 1833, discovered and cataloged some 1,700 deep-sky objects in the southern heavens. Had Lacaille been better equipped, he would surely have earned credit for many of them nearly a century earlier.

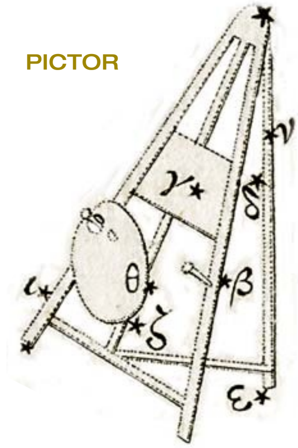
Still, Lacaille is often called the Father of Southern Astronomy, especially in South Africa, where he continues to be held in high regard. Unlike the Herschels or Charles Messier he's not well known generally, perhaps because he caused little controversy, shunned fame, kept to himself, and died relatively young. But fame was not his goal. Indeed, as his recent biographer David S. Evans said of Lacaille, he "lived for science and nothing else. In none of the accounts does he ever appear as a definite personality; he has few friends and no emotions. He seems a man without a private life who appears to pour forth the flood of his researches and disappears into an obscurity in which those researches are at once the only light and the only memorial."

BRIAN VENTRUDO is a writer, scientist, and amateur astronomer living in Maryland. He publishes the popular astronomy website **CosmicPursuits.com**, with articles for science buffs and stargazers in both the Northern and Southern Hemispheres.

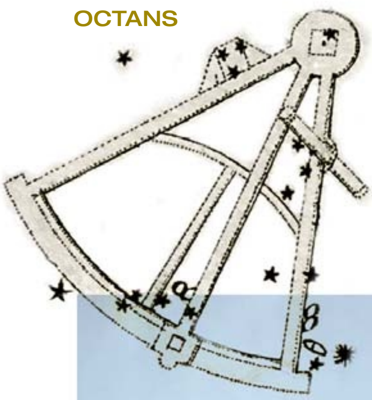
HOROLOGIUM

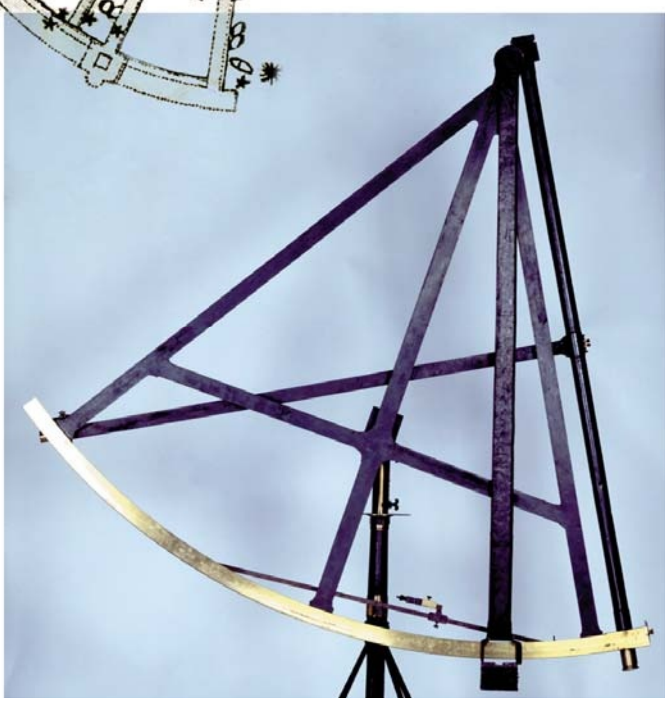


PICTOR



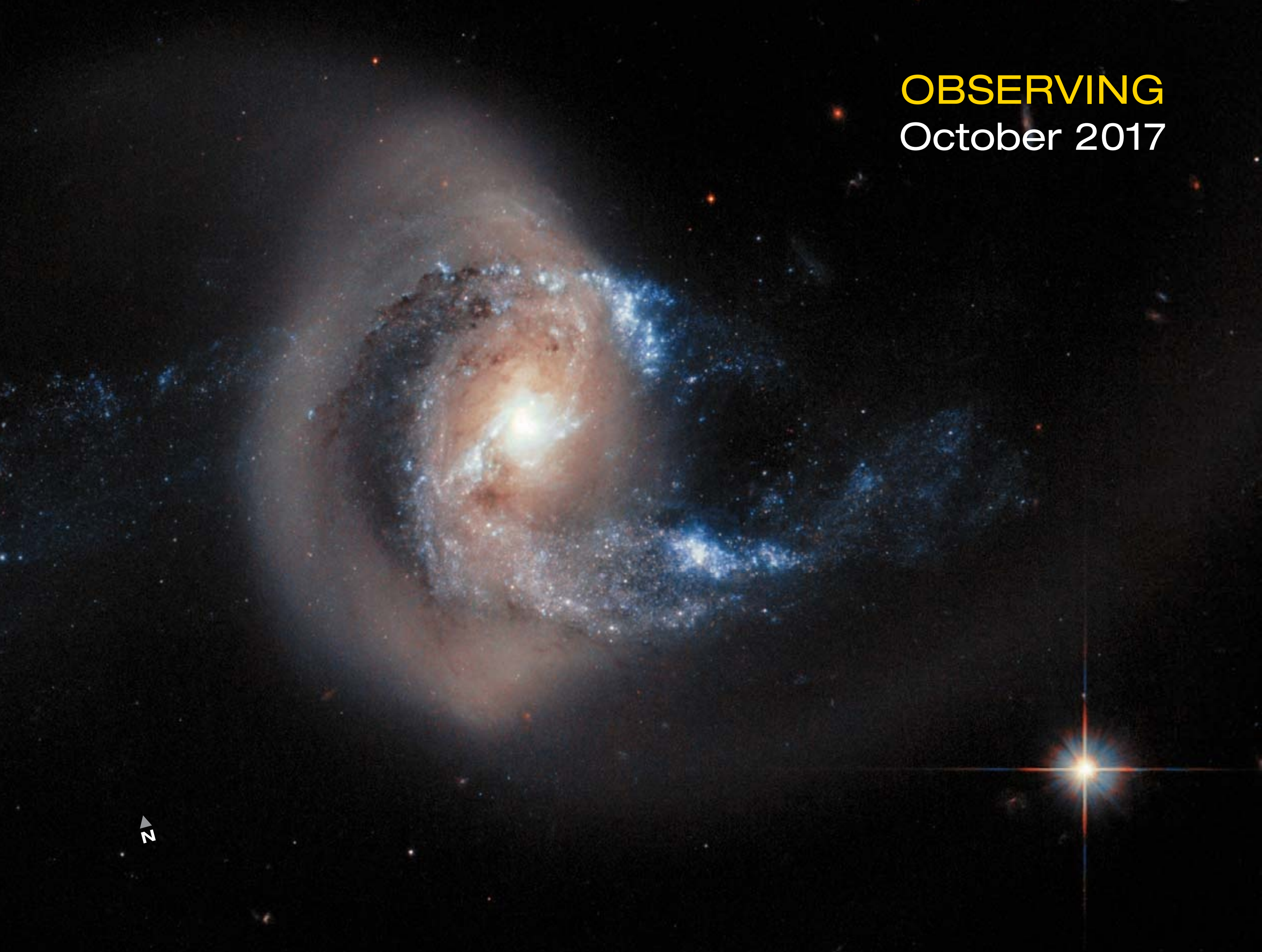
OCTANS





▼ **SURVEYING TOOLS** Lacaille used this large sextant, with a small-aperture telescope attached to its righthand side, for his geographic work. For astronomical measurements in the constant wind, he got better results from a smaller telescopic quadrant on a fixed meridional mounting.

J-M. KOLLAR / PARIS OBSERVATORY



5 **DAWN:** Venus and Mars form a tight pair low in the east early in morning twilight. Binoculars will help separate the dazzle of Venus from the dimmer lights of Mars and nearby Sigma (σ) Leonis, even fainter.

8–9 **LATE EVENING, MORNING:** The waning gibbous Moon shines with the Hyades and Aldebaran.

13 **MORNING:** Algol shines at minimum brightness for roughly two hours centered at 4:36 a.m. EDT (1:36 a.m. PDT); see page 51.

15 **MORNING:** The waning crescent Moon occults Regulus for much of the United States; see page 50.

15–30 **DAWN:** The zodiacal light is visible in the east 120 to 80 minutes before sunrise from dark locations. Look for a huge, tall, dim pyramid of light, leaning to the right, with Venus and Mars in its base.

15–16 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 10:25 p.m. PDT (1:25 a.m. EDT).

17 **DAWN:** A super-thin waning crescent Moon hangs above Venus and left or lower left of faint Mars. Look very low in the east as dawn brightens. Binoculars will help.

20–22 **Morning:** The modest Orionid meteor shower is active before dawn's first light; see page 50.

23 **DUSK:** Saturn shines fairly low in the southwest, about 6° left of the waxing crescent Moon.

24 **EVENING:** The crescent Moon, thicker now, is about 6° upper left of Saturn.

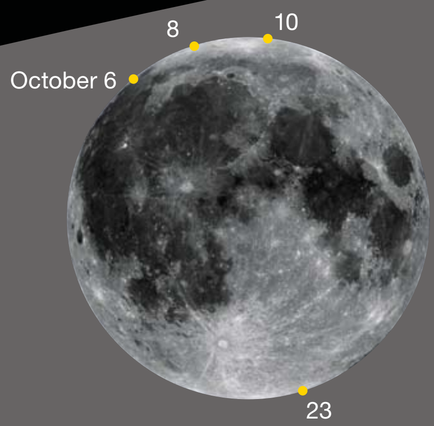
29 **NIGHT:** The asteroid 2 Pallas, magnitude 8.3 in Eridanus, reaches opposition; see page 46.

The distorted shape of spiral galaxy NGC 7714 shows the effects of its galactic entanglements; the galaxy's mangled but outstretched arms reflect an ongoing merger with NGC 7715, an edge-on spiral galaxy just outside the frame of this image. Together, the two galaxies form Arp 284; see page 62.
Photo: ESA / NASA

OCTOBER 2017 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FULL MOON
October 5
18:40 UT

LAST QUARTER
October 12
12:25 UT

NEW MOON
October 19
19:12 UT

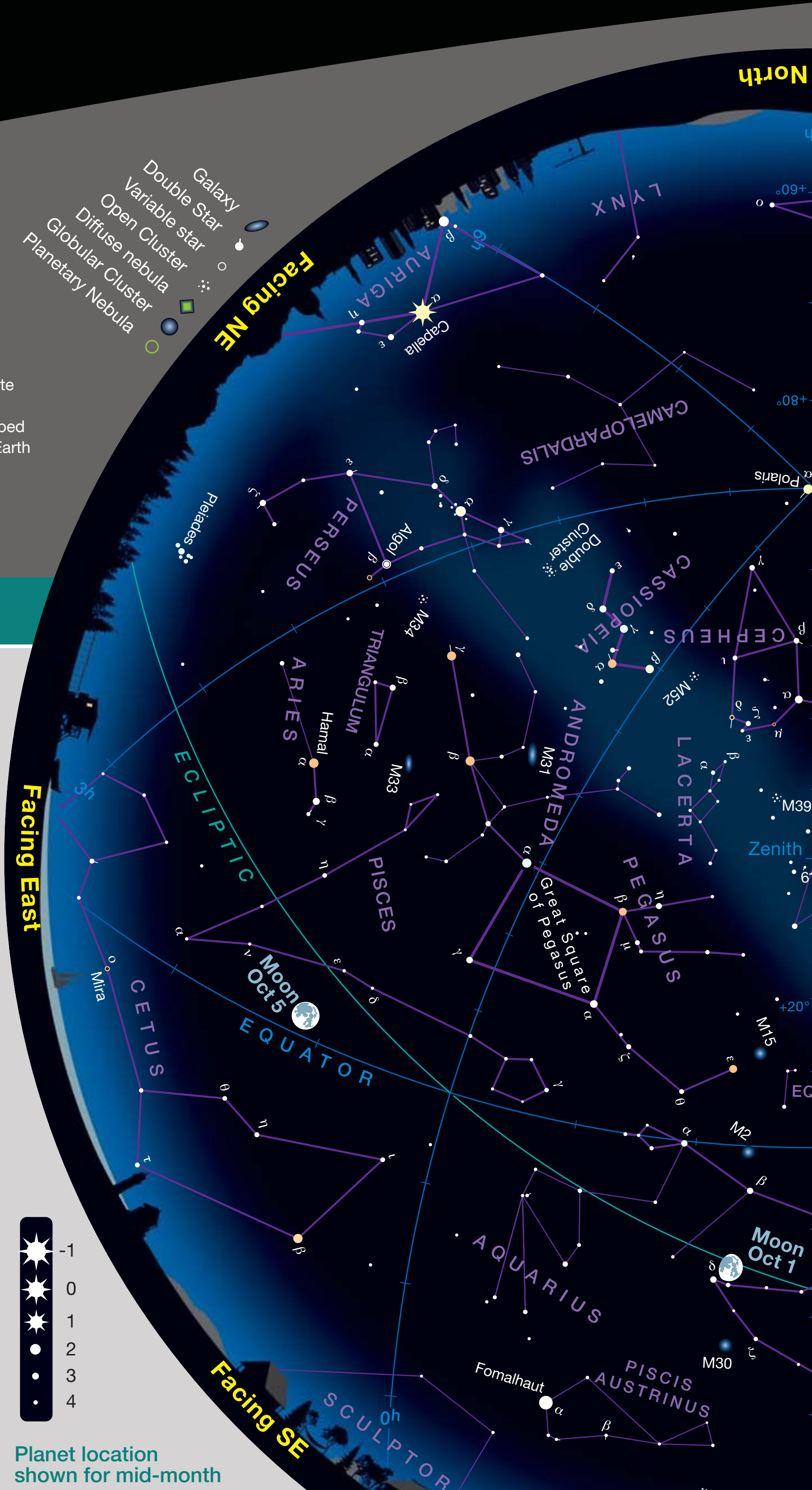
FIRST QUARTER
October 27
22:22 UT

DISTANCES

Apogee	October 25, 02^h UT
405,152 km	Diameter 29′ 29″
Perigee	October 9, 06^h UT
366,856 km	Diameter 32′ 34″

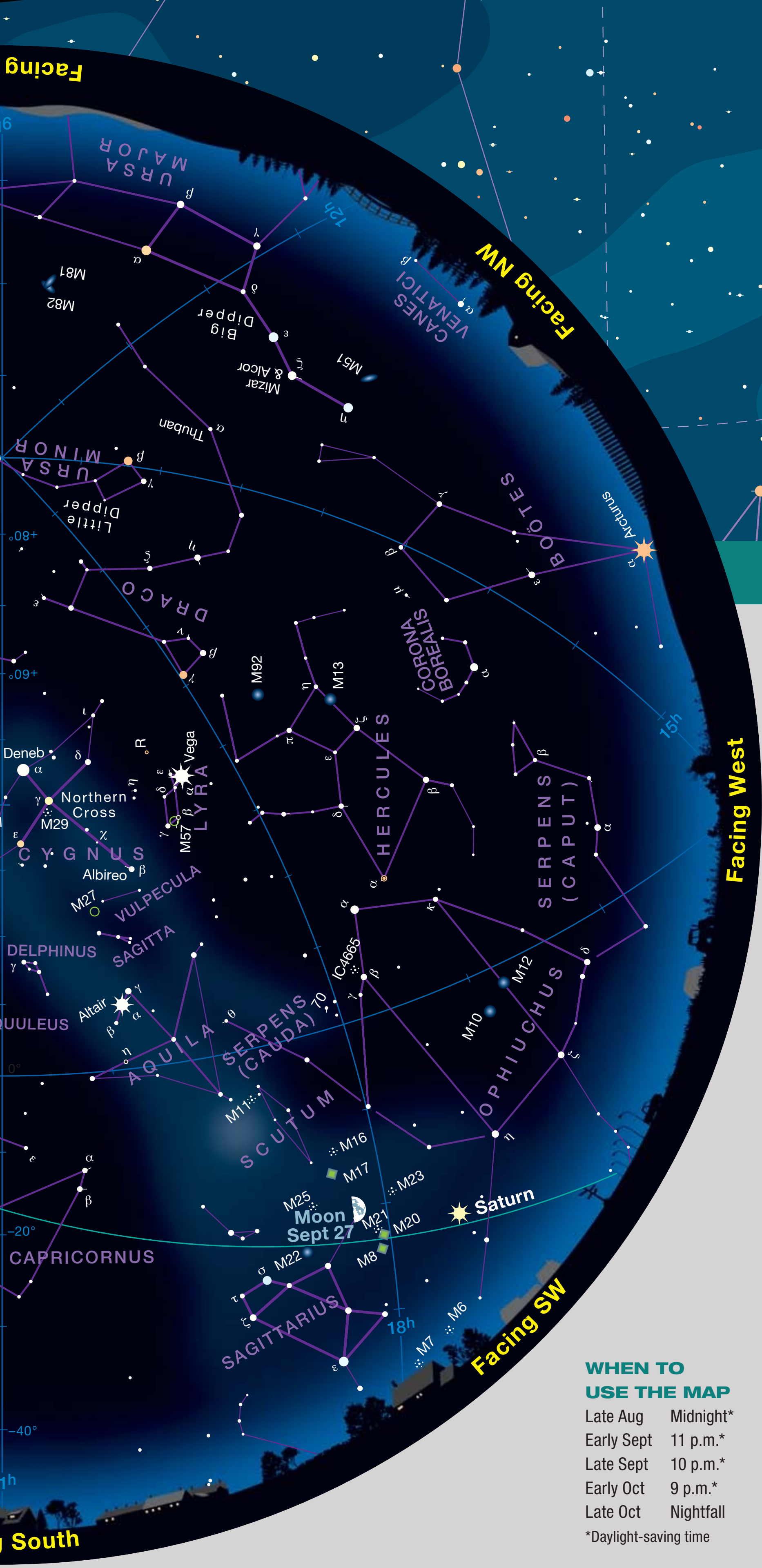
FAVORABLE LIBRATIONS

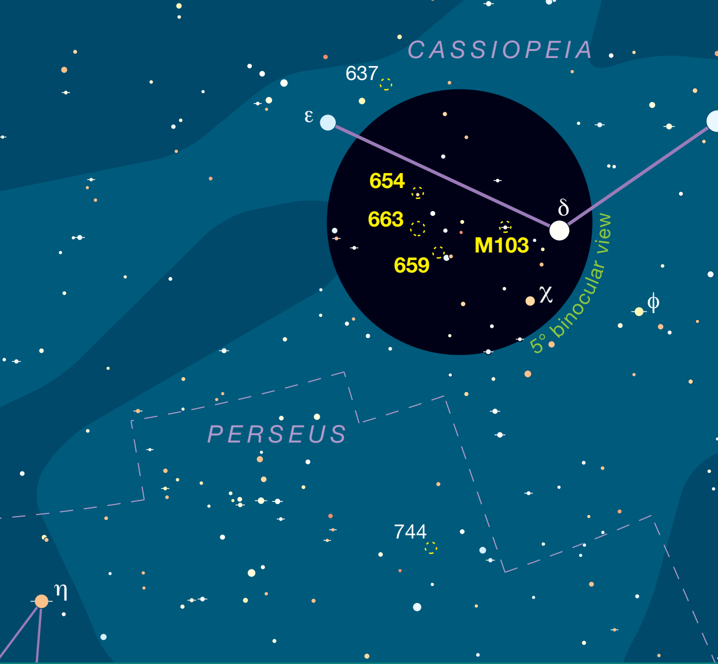
• Lavoisier Crater	October 6
• Pythagoras Crater	October 8
• Byrd Crater	October 10
• Lyot Crater	October 23



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

Four for the Road

The Romans called the Milky Way the *via lactea* or "milky road." It's a road on which I frequently find myself wandering. I want to understand the structure of our galaxy — not just where the nebulae and star clusters are located in the night sky as seen from Earth, but where they are in three-dimensional space and how they relate to each other.

A quartet of clusters in the constellation Cassiopeia is a good place to start figuring this out. From Delta (δ) Cassiopeiae, scan 1° northeast to **M103**, and then onward for an additional 1.5° to **NGC 663** (Caldwell 10). **NGC 654** lies just under 1° to the north-northwest of NGC 663, and **NGC 659** is a little closer still, to the south-southwest. All four clusters will fit comfortably in the same field of view.

NGC 663 is the brightest and easiest to pick out. On a good clear night, NGC 663 looks grainy with 8th- and 9th-magnitude stars that tremble on the threshold of resolution. Resolving stars in M103, NGC 654, and NGC 659 is more of a challenge, in part because bright foreground stars dominate each of those clusters. The clusters themselves appear as knots of slightly denser light in the galactic band.

It shouldn't be surprising that these clusters are hard to resolve with handheld binoculars. The average distance to the Messier and Caldwell open clusters is just over 3,000 light-years, but these four in Cassiopeia lie between 6,300 and 8,200 light-years away, in the Perseus Arm of the Milky Way. NGC 663 isn't any closer than the rest. It's the brightest because it's the largest: 30 light-years in diameter, compared to roughly 10 light-years for the other three. All four are signposts along the "milky road," part of the structure of the galaxy made visible.

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

WHEN TO USE THE MAP

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

*Daylight-saving time

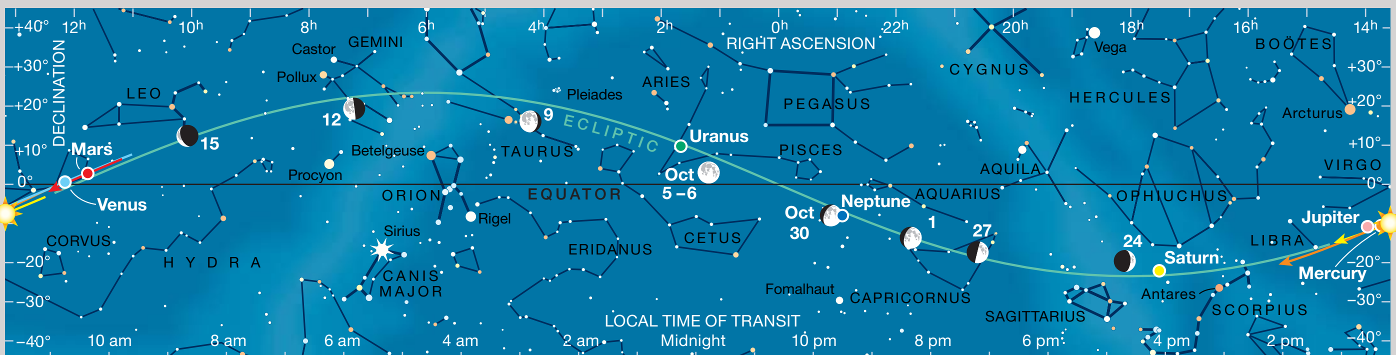
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury is out of sight all October • **Venus:** all month, dawn, low east **Mars:** All month, early dawn, low east • **Jupiter:** First few days of October, bright evening twilight, very low west • **Saturn:** All month, early evening, SW.

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h\ 28.5^m$	−3° 05′	—	−26.8	31′ 57″	—	1.001
	31	$14^h\ 20.6^m$	−14° 01′	—	−26.8	32′ 13″	—	0.993
Mercury	1	$12^h\ 08.3^m$	+0° 58′	6° Mo	−1.4	5.0″	98%	1.343
	11	$13^h\ 12.2^m$	−6° 41′	2° Ev	−1.5	4.7″	100%	1.417
	21	$14^h\ 13.2^m$	−13° 37′	8° Ev	−0.8	4.7″	98%	1.420
	31	$15^h\ 13.5^m$	−19° 19′	14° Ev	−0.4	4.9″	93%	1.367
Venus	1	$10^h\ 59.9^m$	+7° 47′	25° Mo	−3.9	11.2″	91%	1.495
	11	$11^h\ 45.9^m$	+3° 08′	22° Mo	−3.9	10.9″	93%	1.537
	21	$12^h\ 31.6^m$	−1° 44′	20° Mo	−3.9	10.6″	94%	1.574
	31	$13^h\ 17.6^m$	−6° 35′	17° Mo	−3.9	10.4″	96%	1.606
Mars	1	$11^h\ 10.3^m$	+6° 36′	22° Mo	+1.8	3.7″	99%	2.553
	16	$11^h\ 45.3^m$	+2° 52′	27° Mo	+1.8	3.8″	98%	2.490
	31	$12^h\ 20.0^m$	−0° 55′	33° Mo	+1.8	3.9″	97%	2.412
Jupiter	1	$13^h\ 44.5^m$	−9° 42′	20° Ev	−1.7	30.9″	100%	6.374
	31	$14^h\ 09.2^m$	−11° 58′	3° Mo	−1.7	30.7″	100%	6.431
Saturn	1	$17^h\ 25.4^m$	−22° 08′	74° Ev	+0.5	16.2″	100%	10.288
	31	$17^h\ 35.2^m$	−22° 19′	47° Ev	+0.5	15.5″	100%	10.717
Uranus	16	$1^h\ 38.9^m$	+9° 38′	176° Mo	+5.7	3.7″	100%	18.916
Neptune	16	$22^h\ 53.5^m$	−8° 05′	139° Ev	+7.8	2.3″	100%	29.186

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-October; 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.

Stellar Splendor

A deepest, darkest sky offers an extraordinary encounter with the stars.

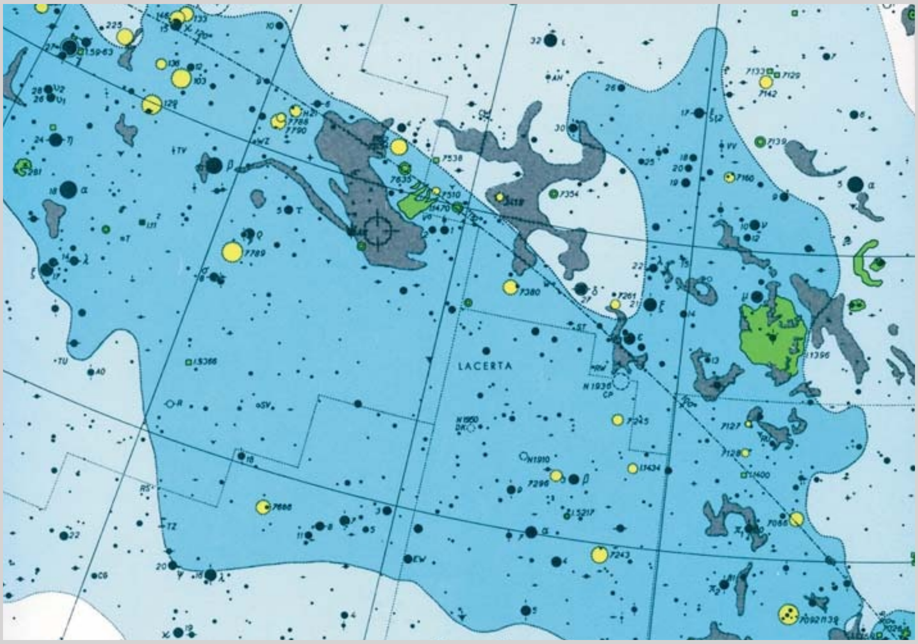
There are different experiences of awe or great wonder in astronomy. The most staggering and momentous, I believe, comes during a total eclipse of the Sun. But the most peacefully (yet still stirringly) wondrous is the sight of a clear, dark sky filled with stars.

Perhaps the best sky of this sort was one I observed 40 years ago this September.

Early autumn's limit-pushing clear nights. Across most of the contiguous United States, the least cloudy time of year runs from about late August through mid-October. Strong cold fronts move through frequently but briefly, temporarily pushing away clouds and haze. Here where I live in rural southern New Jersey, a favorably placed "omega block" weather pattern sometimes produces extremely transparent nights in late April or early May. But some of the clearest and therefore most star-crowded nights I've experienced occurred in September or early October.

Stars to 8.0? Take a look at our October all-sky map on page 42. The bright stars from northeast to southwest resemble a wave sweeping the Milky Way band across the sky. But filling the entire southeast quarter of the heavens is a flood of sky so sparse in bright stars it really does deserve to be compared to a dark ocean (and because it consists entirely of water-related constellations, it's often called "the Water" and the "Great Celestial Sea").

Fomalhaut and Beta (β) Ceti (also known as Diphda or Deneb Kaitos) are the only stars of 2nd-magnitude or brighter in this region on our map — if we consider the non-aquatic Epsilon (ε) Pegasi (Enif) and stars of the Great Square of Pegasus as merely bordering the region. But what about the interior of the Great Square? Only two stars inside its huge pattern are bright enough to be plotted on our map. What a joy it is to have a sky dark and clear enough to make this quadrant of the sky crawl with countless faint stars.



SKALNATÉ PLESO ATLAS OF THE HEAVENS

That night in September 1977 I was easily seeing stars in the magnitude 6.76 to 7.25 class of Antonin Beĉvář's *Skalnaté Pleso Atlas of the Heavens* with my 22-year-old naked eyes. I tried for a very faint but conveniently situated star from the atlas — and finally convinced myself I was seeing it. I looked up its brightness in the SAO Star Catalog — magnitude 7.9! But not many years ago I checked its brightness in a more recent database — its brightness rounds off to 8.0. And this observation was from just 40 feet above sea level. Did I really see the star? Other sights I was seeing (including M52 with the naked eye) suggest that I did.

Totality and the positive opposite of fear. Many years ago, a local newspaper ran an article about a rare southern New Jersey tornado that struck the grounds of a prison about 10 miles from my home. The tornado destroyed a huge barn (I went to inspect the ruin) and tossed one of the prison guards 50 feet through the air. But it was the words of another prison guard that struck me the most. He said seeing the tornado headed right toward him was "the kind of sight that makes strong men weak." So too is a total eclipse of the Sun — in the opposite way.

What do I mean? There are different kinds of opposites. One opposite of fear produces similar and equally strong feelings and sensations — but is positive, not negative. That emotion is, of course, awe. And if you experience a total eclipse of the Sun with even the least sensitivity to the wonders of nature, you'll be swept away by your awe of the event. In fact, I hope many of you have been swept away by the time you receive this issue — maybe around August 21st?

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

A Pretty Pair

Venus and Mars dance at dawn. Saturn sets early in the evening.

Mercury is too close to the Sun to see properly this month, and the other bright planets hang low at either dusk or dawn. Saturn remains visible in the southwest for a few hours after sunset, then the sky is devoid of bright planets until Venus and Mars rise shortly before morning twilight.

But there's one exceptionally tight conjunction of planets in October, as well as several pairings of planets and stars with the Moon.

DUSK AND EVENING

Jupiter remains detectable for just the first few days of October, very low in the bright afterglow of sunset. The giant planet goes though conjunction with the Sun on October 26th, then around November 7th returns to visibility low in the east at dawn, at least for the sharp-eyed among us.

Saturn glows low in the southwest during twilight all October, dropping lower every week. Saturn sets more than 3½ hours after the Sun on October 1st, but only 2½ on October 31st. The ringed planet's brightness lingers at magnitude +0.5 all autumn as it creeps eastward in Ophiuchus toward Sagittarius. The red supergiant Antares shines far — about 14° — to the lower right of Saturn at nightfall in early October.

Saturn's rings are at their maximum tilt of 27° this month. Too bad the planet's altitude an hour after sunset is only about 20° high for observers around latitude 40° north. From much farther south, where the planet is higher in early evening, telescope users have a better chance of steady seeing on some evenings.

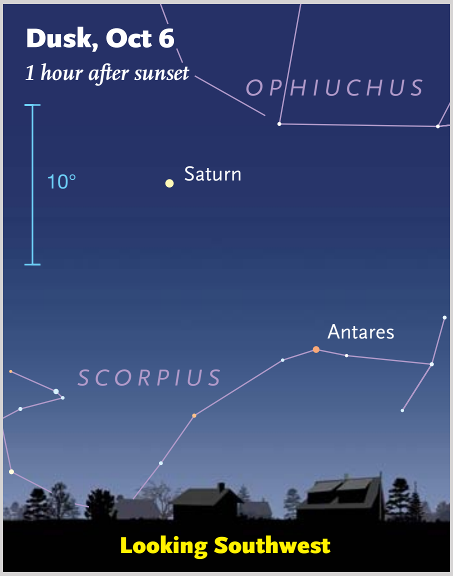
NIGHT

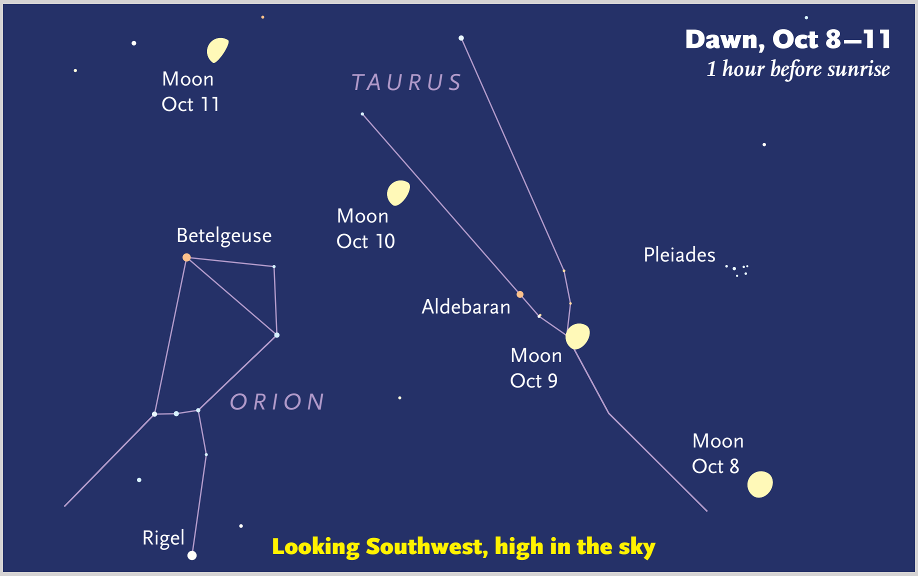
Uranus reaches opposition on October 19th and is therefore visible all night — though it's best observed when highest in the south near 1 a.m. local daylight-saving time. The blue-green world shines at magnitude 5.7 and appears 3.7″ across in telescopes.

Neptune shines only a sixth as brightly (magnitude 7.8) as Uranus because of its greater distance from both Earth and Sun. It was at opposition on September 5th, so it's now highest in mid- to late evening.

Uranus is in Pisces, about 2° from Omicron (ο) Piscium; Neptune is less than 1° southeast of Lambda (λ) Aquarii this month. See page 51 for finder charts for both planets.

Asteroid 2 Pallas, one of the largest asteroids in the solar system, is at opposition on October 29th, shining at magnitude 8.3 in Eridanus. Pallas's highly inclined orbit places it extremely far south of the ecliptic at this opposition, around declination –20° near Tau^3 (τ^3) Eridani (also known as Angetenar). A night of good transparency will help you with this observation.





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

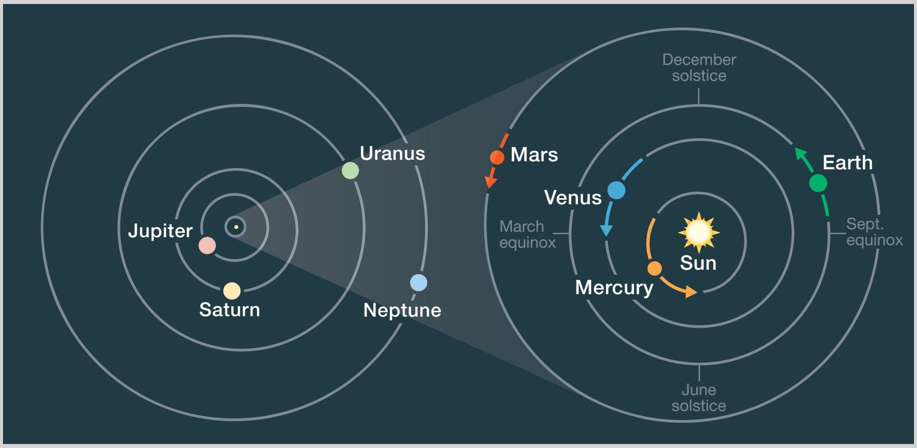
PRE-DAWN AND DAWN

Venus comes up about 2 hours before the Sun on October 1st, with much dimmer **Mars** following about 3° below it. The pair should be on best display a little more than an hour before sunrise, low in the due east, but for Mars especially, optical aid will help. Both planets are almost at their dimmest, with Venus at magnitude –3.9 and Mars at magnitude 1.8. They're also almost at their smallest, Venus appearing 11″ wide and Mars 3.7″. Coincidentally, Mars is the same apparent width as distant Uranus this month!

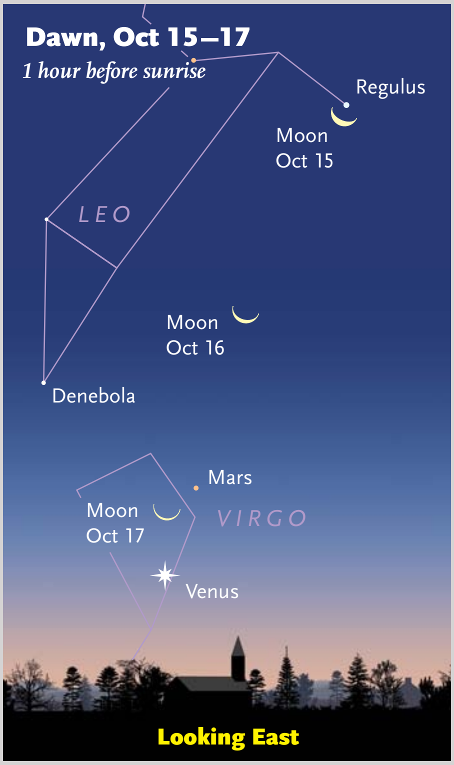
Venus and Mars pass very close to each other at dawn on October 5th. They stand only about 10° high but just ¼° apart an hour before sunrise for North Americans at mid-northern latitudes — high enough for Mars to be potentially visible to the unaided eye in the early twilight glow under very good conditions. But a better view comes with binoculars or a telescope at medium power: meager Mars is fully lit but a tiny, blurry speck, and more vibrant Venus is almost fully lit but also lacks sharpness.

Venus appears lower and Mars higher each morning thereafter; by the end of October Venus rises about 1½ hours before the Sun and Mars more than 2½ hours before the Sun. By month's end, Venus is deep in advancing dawn and Mars is 16° upper right of it.

Mercury goes through superior conjunction with the Sun on October 8th, passing from the morning to the evening sky, but it's too poorly placed for observation from mid-northern latitudes this month. Look for it to become visible at dusk once again around the 17th of next month.



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



◀ 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.

MOON PASSAGES

The fairly fat waning gibbous **Moon** rises late on the evening of October 8th and creeps closer to Aldebaran for the rest of the night and into dawn on the 9th. The Moon hangs about 5° lower right of red Aldebaran before sunrise on October 9th.

The waning crescent Moon occults Regulus just before or during dawn on October 15th for much of the United States and part of Canada. Look for the 1st-magnitude star to disappear behind the Moon's bright limb, then reappear at its dark limb about an hour later. See pages 50–51 for timing for major cities and advice on timing the occultation.

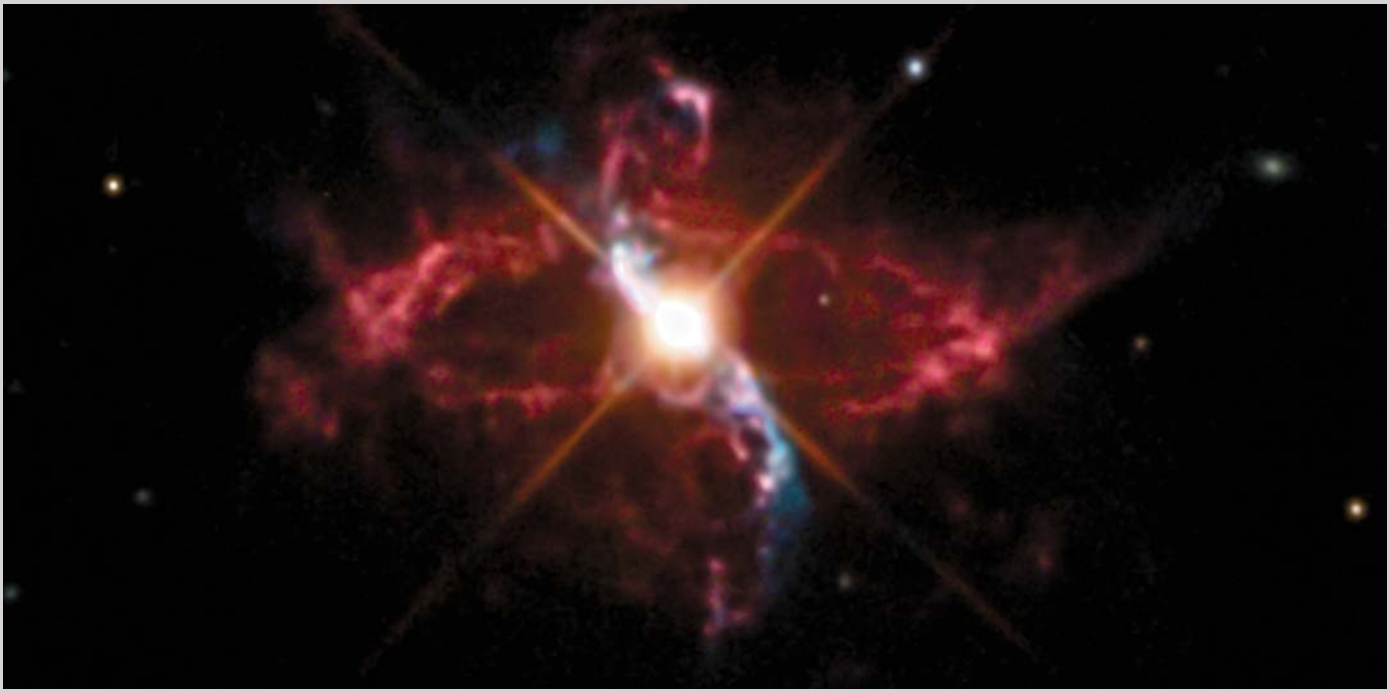
A thinner lunar sliver hangs left or lower left of dim Mars on October 17th; the pair is about 8° above vivid Venus.

Back in the evening sky, the waxing crescent Moon beams about 6° right of Saturn fairly low in the southwest on October 23rd. The next evening the Moon is about the same distance to Saturn's upper left.

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

The Drama-Ridden Couple of R Aquarii

What looks like a normal pulsing red giant has a lot more going on around it. Its next episode of weirdness may begin soon, and variable-star observers are watching.



ADAM BLOCK / MT. LEMMON SKYCENTER / UNIV. OF ARIZONA

The fuming odd couple that is R Aquarii threw off a ring of hydrogen about 250 years ago. The ring shows hints of being the neck of a larger hourglass shape. Inside it, a pair of hot jets stab up and down from the goings-on at the center. The frame above is about 4 arcminutes (0.9 light-year) wide.

Nature unfolds in utter tranquility, living out the endless trajectories of physics and all its derivative laws with minute precision — though with complete disregard for the feelings of little egos like us who find ourselves embedded within it. "Happiness is functioning the way a being is organized to function," wrote Robert A. Heinlein, and the stars are serene in their courses. But it's easy to imagine that some stars would be pretty unhappy if they were people. The long-period variable R Aquarii, a red giant that's now coming into nice telescopic view in the southeast in late evening, finds itself having to do its slow, pulsing heartbeat meditations next to the tiny, eruptive fury of a severely troubled mate who throws things. And yes, it's all the red giant's fault.

R Aquarii is, on first impression, a standard Mira-type variable, pulsing from about magnitude 6 to 11 and back every year and three weeks. In a telescope it shows the orange-red color of a late-*M* giant, especially when it's in the faint part of its cycle. Which is where it's heading now; its last maximum came in June, and minimum light is predicted for around December 11th.

But there's a lot more going on here. Distantly orbiting the giant every 44 years is a hot, very faint white dwarf contributing weak spectral features of an *O* or *B* star to the dominant *M* star's light. Stars that show such a combination-of-opposites spectrum are called *symbiotic stars.* R Aquarii is the closest of them at a distance of about 700 light-years. In a telescope the two points appear as one, but the white dwarf ventures far enough from the giant that the Very Large Array radio telescope was able to resolve the two at a separation of 0.055 arcsecond. Their orbit is thought to be highly elliptical.

Another source of light also adds to the spectrum: the faint nebula Cederblad 211. Although it dominates the photo at left, the nebula is extremely difficult or impossible to detect visually. It's expanding and changing as we watch; all or much of it was apparently thrown off violently only about 250 years ago (as seen from Earth).

There's more. The narrow, vertical S-shaped feature visible in the photo is strikingly bright in X-rays. Blobs of X-ray-hot material within it are moving outward at a tremendous 600 and 850 kilometers per second. The S results from a bipolar jet of hot material flying from the poles of an accretion disk around the white dwarf. The material that the dwarf is accreting surely comes from the giant, which like all Mira stars is shedding a thick wind.

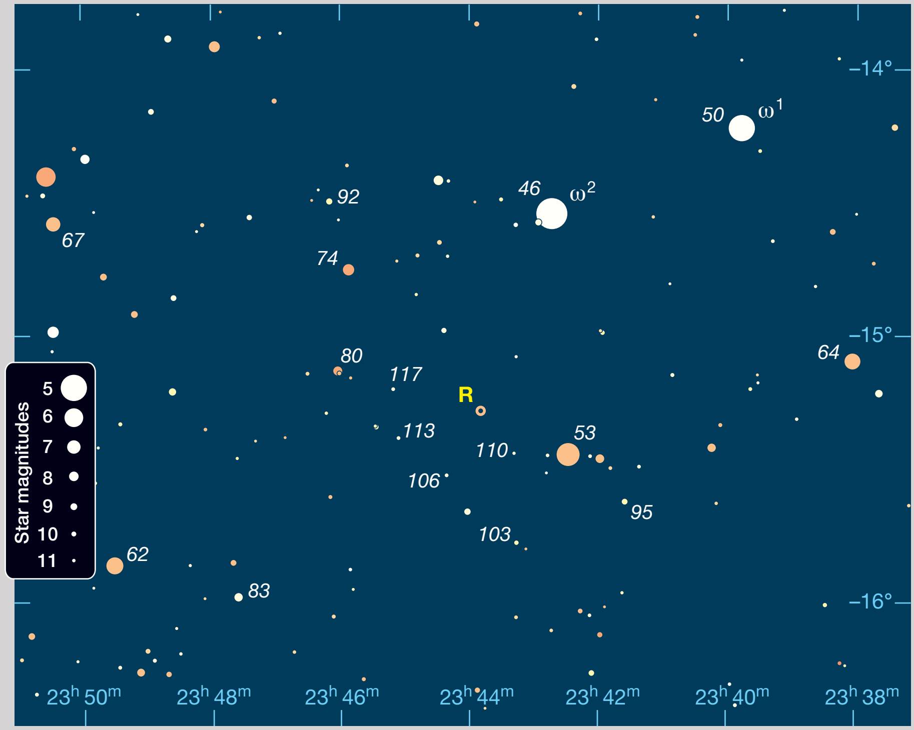
For more than a century, visual variable-star observers have tracked some very unusual behavior for a Mira giant. At roughly 44-year intervals its annual fadings become less deep, the system's overall color near minimum turns bluer — and the giant's maxima turn *fainter.* The added blue light surely comes from the white dwarf and/or its accretion disk flaring up. But how could that *suppress* the red giant's own, much greater luminosity at maximum?

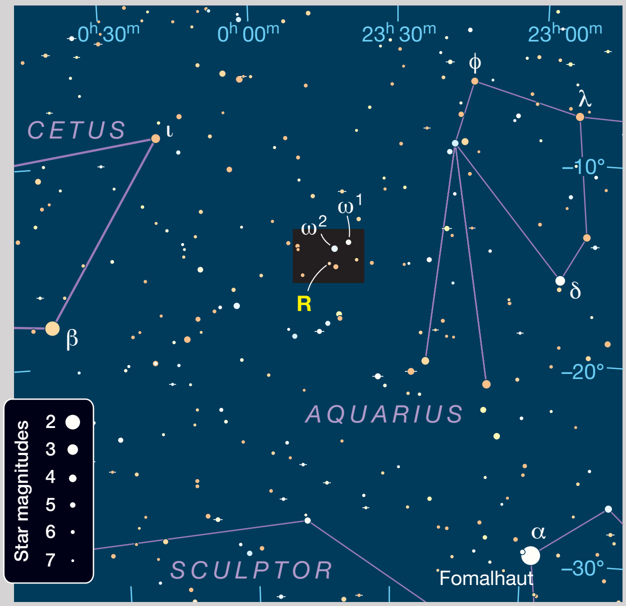
One theory is that a large, semi-transparent dark cloud surrounds the white dwarf and its accretion disk as they orbit the giant; the cloud eclipses the giant for several years. If that's the case, the next episode of giant-dimming should run from about 2018 to 2026. Variable-star observers are paying attention.

And why has the dwarf tended to brighten at around these same times? Perhaps because this is when, in its elliptical orbit, it passes closest to the giant and collects the heaviest dose of outflowing wind. That's indeed when you would expect, statistically, the cloud-eclipses to be most likely to occur.

Much more spectacular things happen at longer intervals, as the nebula attests. The fresh hydrogen building up on the dwarf's surface erupts at intervals as a nova explosion. The nebular ring, astronomers judge from its expansion rate, was blasted off by a nova outburst around 1773. A dimmer, outer nebula too faint to show on the facing page likely came from a nova explosion that Korean astronomers recorded at this location in 1073.

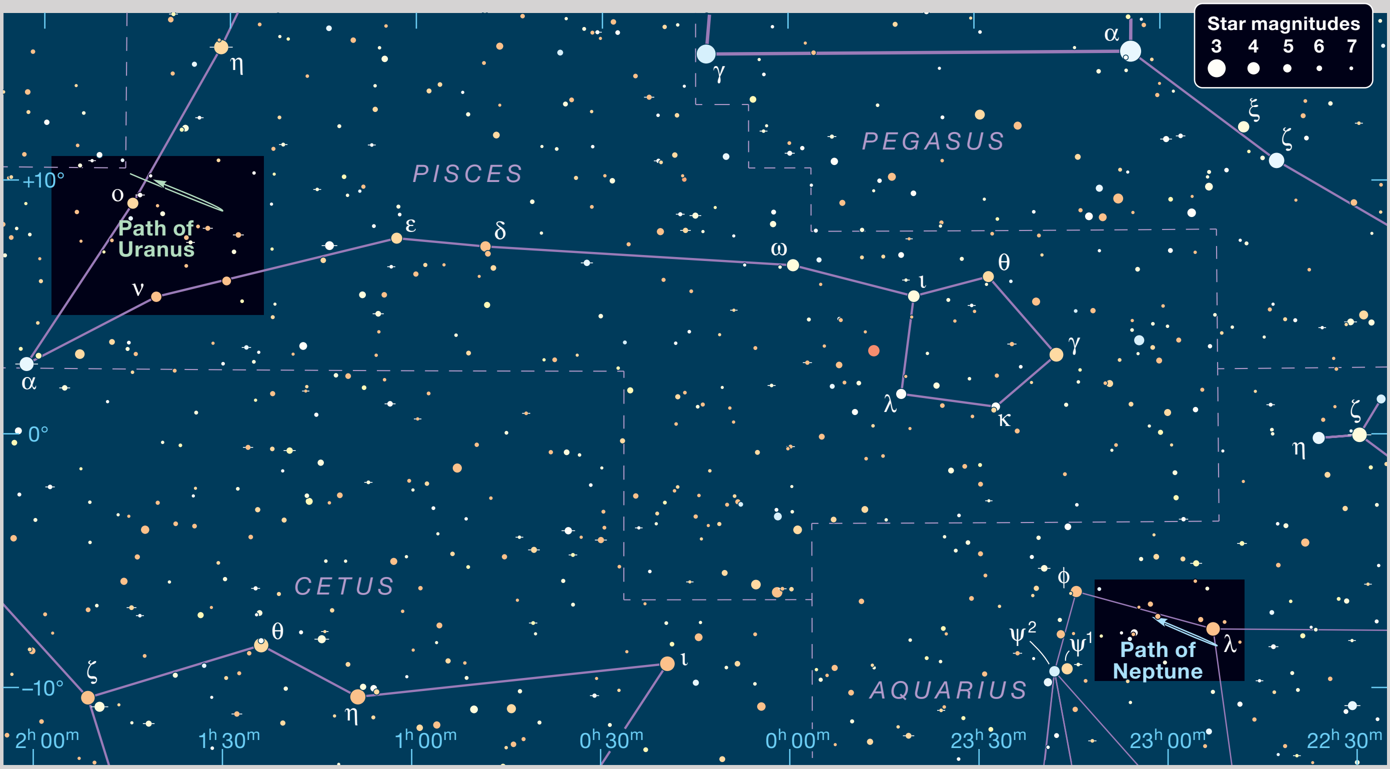
If these explosions on the white dwarf continue on schedule, R Aquarii should next go nova in the late 2400s. A system that's telescopically faint now will then shine at perhaps 2nd magnitude — as obvious to the naked eye as Beta Ceti appears now, over there to the right of it. Swing your telescope there and try to imagine the change.





▲ In the same sky area as Neptune (now near Lambda (λ) Aquarii as shown on the next page) you can look in on a very different interesting point of light. R Aquarii is close to a little triangle of 5th-magnitude stars almost halfway from Lambda Aquarii to 2nd-magnitude Beta Ceti, as seen at left. The large chart on the next page provides a wider context for this scene. The little black rectangle shows the area covered by the comparison-star chart for R Aquarii above. There, stars' visual magnitudes (courtesy AAVSO) are given to the nearest tenth with the decimal point omitted.

The Return of Uranus and Neptune



Dark Nights for the Orionid Meteors

FOR SEVERAL DAYS around October 21st every year, Earth passes through the Orionid meteoroid stream: sparse, widely scattered bits of Halley's Comet. When we cross the same stream again at a different part of our orbit in May, they're called the Eta Aquariids. Both showers last for several days running.

This year the sky will be moonless for the Orionids' best mornings: October 20th, 21st, and 22nd. The shower's radiant is next to Orion's Club, so the Orionids only become active in the hours before dawn when Orion starts wielding his club high. The later before the first light of dawn, the higher it is.

Under an excellent dark sky, you might count 10 or 15 swift Orionids per hour on those mornings. You'll need patience, a comfortable reclining chair, a wide-open sky view with no lights intruding, and plenty of bundling against the cold.

Want to try doing a scientific meteor count for reporting to the International Meteor Organization? You'll need to follow standardized procedures and plan on observing for at least an hour, preferably more, and preferably on several nights.

Halley's Comet won't be back until 2061, but on these cold mornings you can greet a few of its tiny lost children.

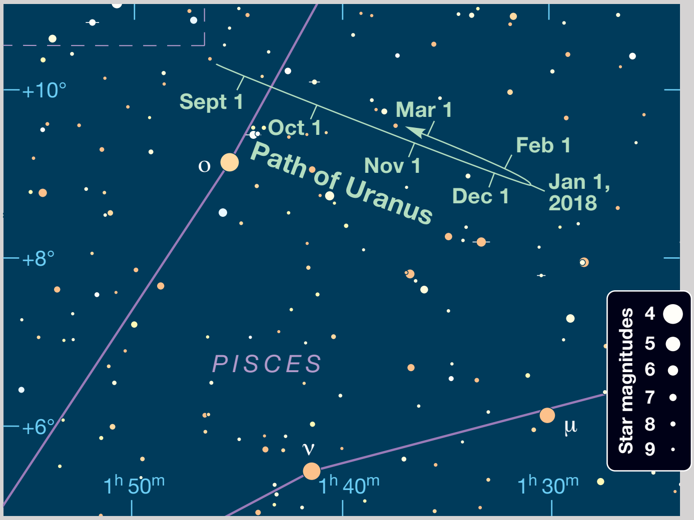
• **Learn how to do a standardized meteor count, one that can be usefully compared to those of other observers past and present — and how to report it — at www.imo.net/visual.**

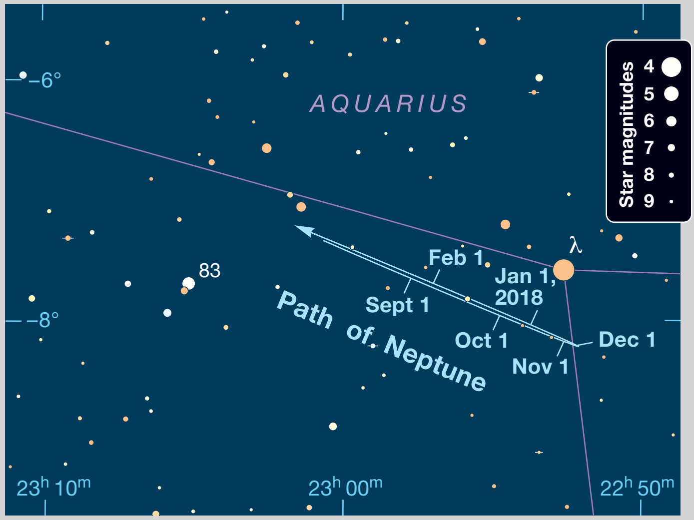
Waning Crescent Moon Occults Regulus

ON SUNDAY MORNING October 15th, the bright limb of the waning crescent Moon will occult 1st-magnitude Regulus. The star will reappear from behind the Moon's dark limb up to an hour or more later.

The events happen in dawn for North America's east, and earlier in darkness farther west. Observers near the West Coast will miss the star's disappearance — the Moon won't have risen yet — but may catch the reappearance with the Moon low in the eastern sky.

Here are some times: **Los Angeles,** *reappearance* at 3:12 a.m. PDT (Moon barely risen); **Denver,** *disap-*





A BRIGHT PLANET usually attracts attention in the very late night long before it comes to opposition. But you have to be a dedicated planet chaser to net dim Uranus and Neptune before they become conveniently placed in the evening sky. Which, for the next decade or so, will continue to mean fall and early winter.

Neptune, magnitude 7.8 in Aquarius, is at opposition on September 5th. Uranus, in Pisces, comes to opposition on October 19th. At magnitude 5.7, Uranus is detectable with the naked eye if you have a good dark sky. Both planets are in the "Great Water" region, which the Great Square of Pegasus lords over from high above.

The bottom side the Great Square just made it into the top of our wide-field chart on the facing page, which shows stars to 7th magnitude. That's more than enough for finding brighter Uranus. Use the blowup above of Uranus's immediate area to pinpoint where it will be on its path for your date.

Fainter Neptune will require using the Neptune enlargement above at your eyepiece. But Neptune this season will be easier to locate than usual; it's just a degree or so from Lambda (λ) Aquarii, magnitude 3.7.

• **Having trouble finding faint objects with a telescope? Brush up on the necessary tricks at skyandtelescope.com/charts. The key: You need to know the *scale* and the *orientation* of your finderscope view (or main-telescope eyepiece view) compared to your charts.**

pearance 3:31 a.m., *reappearance* 4:15 a.m. MDT; **Chicago,** *d.* 4:37, *r.* 5:27 a.m. CDT; **Austin,** *d.* 4:18, *r.* 5:19 a.m. CDT; **Toronto,** *d.* 5:47, *r.* 6:32 a.m. EDT (early dawn); **Atlanta,** *d.* 5:25, *r.* 6:33 a.m. EDT (early dawn); **Pittsburgh,** *d.* 5:38, *r.* 6:35 a.m. EDT (early dawn); **Washington, DC,** *d.* 5:37, *r.* 6:41 a.m. EDT (brighter dawn); **New York,** *d.* 5:44, *r.* 6:43 a.m. EDT (bright dawn); **Boston,** *d.* 5:50, *r.* 6:44 a.m. EDT (dawn to daybreak).

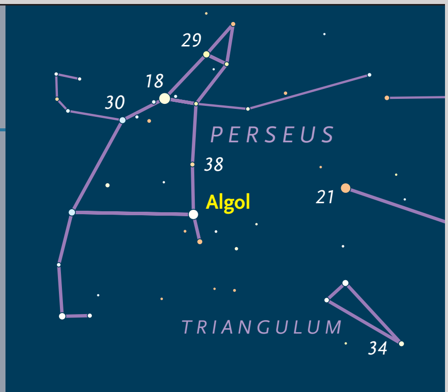
• **Detailed predictions for hundreds of locations, with the altitudes of the Sun and Moon, are at lunar-occultations.com/iota/bstar/bstar.htm.**

(The page for each star there displays three long tables with less-than-obvious divides: for the disappearance, the reappearance, and the locations of cities.)

Minima of Algol

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

These geocentric predictions are from the heliocentric elements Min. = JD 2452500.179 + 2.867335*E*, where *E* is any integer. At any *random* time you glance up at Algol, you have a 1 in 30 chance of catching it at least a magnitude fainter than normal.



◗ With autumn returning, Perseus is rising into the northeastern evening sky. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to carefully estimate its brightness with respect to the convenient comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

The Vagaries of Crater "Tweens"

Some lunar impacts have characteristics that make them neither "simple" nor "complex."

A biologist once said that God must have an inordinate fondness for beetles because he made so many of them. The Almighty must also have loved impact craters, for millions of them adorn our Moon, other moons, asteroids, solid planets, and probably the surfaces of rocky exoplanets. I like impact craters too, and the Moon's eons-old landscape is my favorite venue for admiring their variations.

Over the last 60 to 70 years, the basic facts of impact-crater formation have become well established (*S&T:* Feb. 2017, p. 52). On the Moon, crater diameters range from micron-size zap pits to 1,000-km-wide basins, and their morphologies systematically change as their sizes climb. Lunar craters smaller than about 15 km across — such as 13-km **Chladni** — are commonly flat-floored bowls with smooth walls, looking like they'd been turned on a potter's wheel.

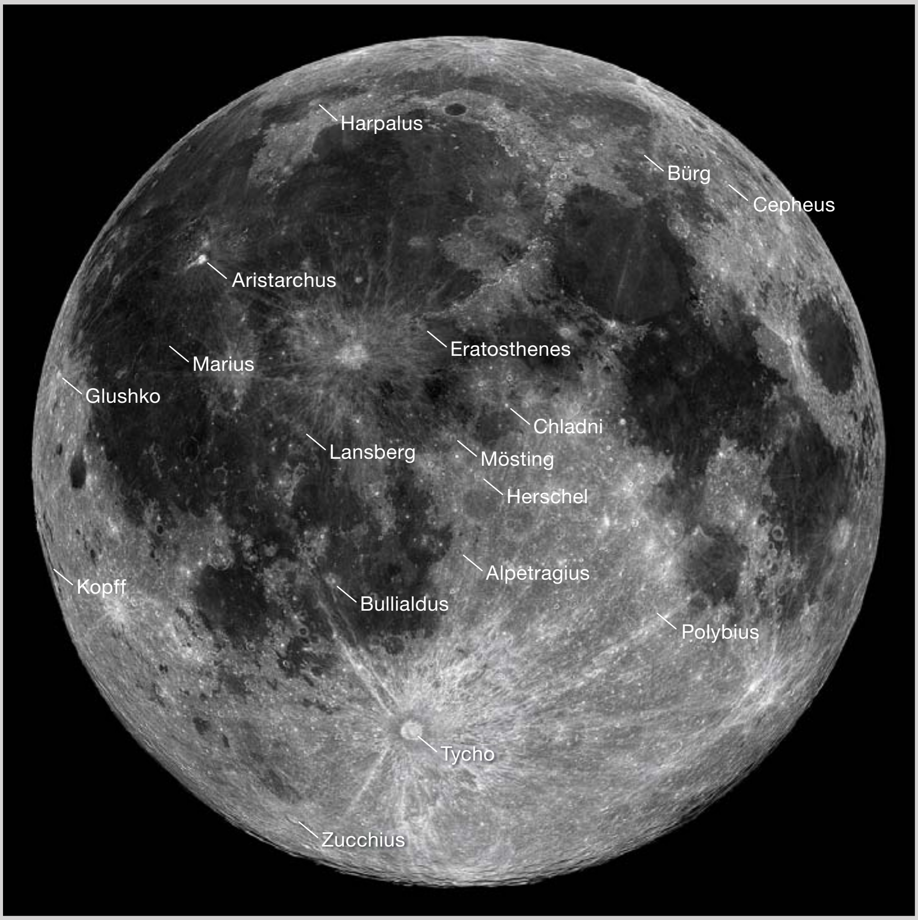
For diameters larger than 15 km, these simple characteristics start to break down, literally. Craters' outer walls begin to slump, and clumps of hills rise in their centers. Look at 25-km-wide **Mösting**, an extreme example of small-yet-complex craters. It has no flat floor, for the crater walls have collapsed nearly everywhere and sent piles of debris cascading toward the middle, inundating all but the top of its central peak. Some areas of collapse have undercut parts of the rim, creating alcoves that distort its circularity.

The walls and floors of ever-larger craters slowly become more orderly, as individual alcoves of collapses and slumps give way to stately terraces that sometimes circle the entire wall. Central hills become towering mountains. At their peak of perfection, as at **Tycho**, craters are magnificent sights.

As target rocks respond to increasing impact energy and the downward pull of lunar gravity, the resulting progression of crater morphology toward complexity is not smooth and uniform. Like children struggling to find their identities once they become "tweens," and then transition from the teen years to adulthood, these depressions exhibit many variations due to local circumstances.

Nowhere are these transitional characteristics from disorderly (Mösting) to orderly (Tycho) morphology more evident — and varied — than they are for fresh craters with diameters of about 40 km. Here are some examples that reveal key details when viewed through amateur telescopes:

Glushko, on the highlands just west of southern Oceanus Procellarum,



◀ This 30-panel mosaic, captured in red light, reveals a wealth of bright and dark markings on the full Moon of July 20, 2016. Labels identify craters mentioned in the text.

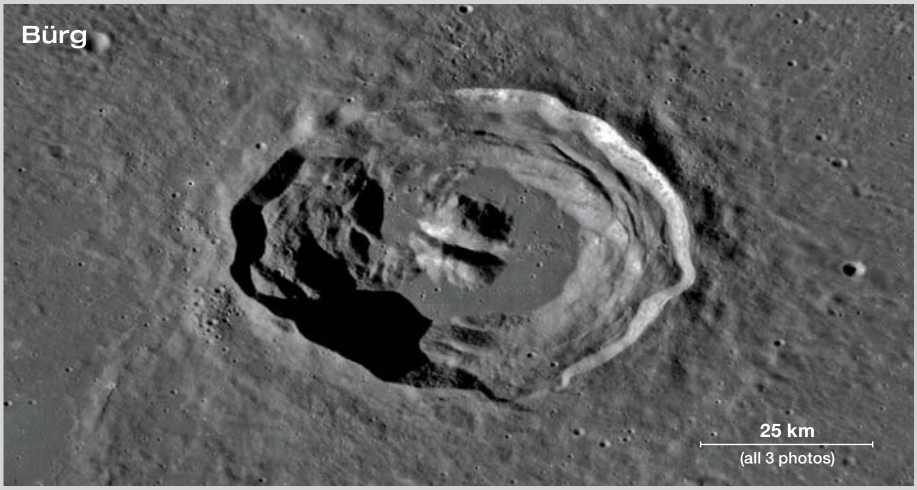
GIUSEPPE PETRICCA

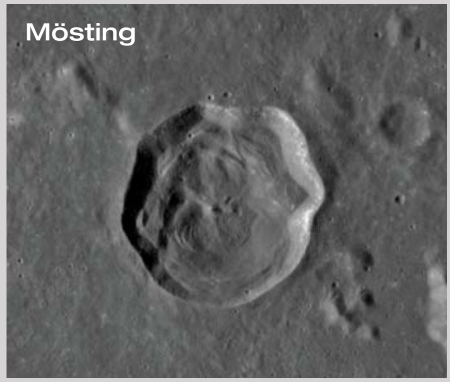
sits near the Moon's western limb and is difficult for telescopic observers to see into. But Lunar Reconnaissance Orbiter images show that this young rayed crater displays two alcoves along its northeastern side, marking where the rim gave way and material slid downslope and partway across the floor. In fact, Glushko's small central peak is totally surrounded by this cascade of debris from the slumped crater wall. Impact melt coats some of these flows, demonstrating that the wall collapsed as the crater formed, not years later.

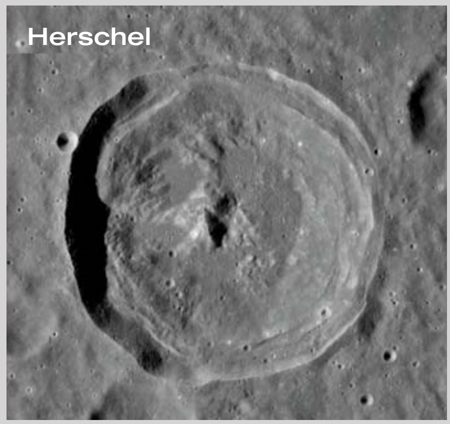
A somewhat older crater, **Herschel**, is in the middle of the nearside, just north of Ptolemaeus, and thus much easier to see. Myriads of small cratering events have smoothed the impact melt that accumulated on its floor and erased its rays, but the basic structure is still prominent. The inner wall likewise has slid downslope — not as giant mounds of debris but apparently more continuously, resulting in a smooth contour. Perhaps the inward cascades were a long-term process rather than a jumble of events in rapid succession. More massive flows from the inner wall, probably dating from the crater's formation, reached the central peak. Look about 3 km inward from the rim crest for a crisp ridge that parallels the rim all the way around; this an incipient terrace.

Bürg represents another step forward in the transition to a complex, Tycho-like crater. Its central mountain is bigger and comprises two massive peaks. Wreaths of mounded wall material step down from the rim scarp to the floor — not quite in terraces, yet more coherent than the simple slump blocks prevalent in smaller craters. Smooth material broadly covers much of the floor, which is well defined as a circle.

Aristarchus is the most famous 40-km-wide crater on the Moon. It is very young and has a bright ray system that can be traced from its floor, up its walls (seen as distinct light-hued bands), and across the surrounding mare. A pool of impact-generated melt defines a broad, relatively flat floor, with only a small central peak. Aristarchus displays the beginnings of three or four terraces around its circumference.







▲ The *morphology* (shape and characteristics) of lunar craters becomes more complex once their diameters reach 25 to 40 km. Note how the inner walls have slumped in these examples.

NASA / LUNAR RECONNAISSANCE ORBITER

You might also observe the 40-km-wide craters **Harpalus**, **Lansberg**, and **Cepheus**, all marked on the image on the facing page, to see how they compare to Herschel, Aristarchus, and Bürg.

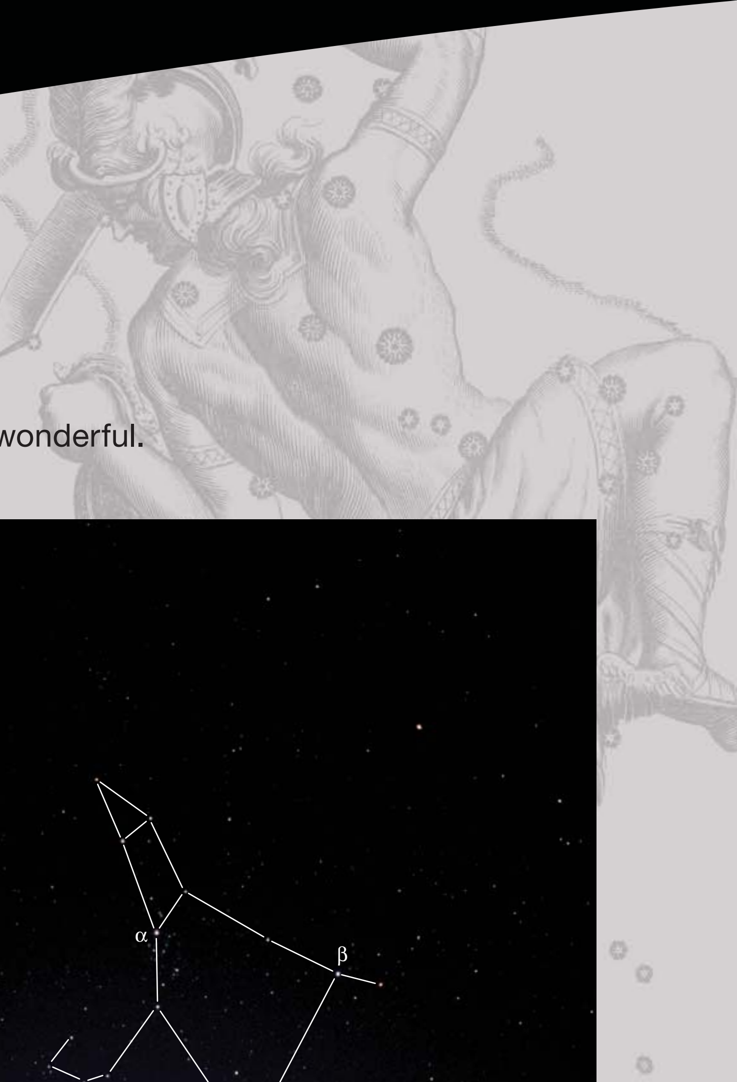
Although the examples I've cited are typical, some craters evolved differently depending on their location and the vicissitudes of time. Impact craters on maria often have lava-flooded floors that bury central peaks and debris mounds; **Marius** and **Kopff** are two good examples.

Over the course of billions of years, all craters' walls get smoothed and lose detail; their floors become shallow and widen thanks to downward cascades from the walls and by ejecta dropped in from newly formed basins and nearby craters. **Alpetragius** is a peakless, smooth-walled, 40-km-wide crater that might once have looked like Aristarchus.

More heavily modified is **Polybius**, only 2 km deep with a wide flat floor. Compare its appearance to that of Aristarchus, which is about 3.2 km deep and has a smaller floor. Like many humans, the bottoms of craters widen with age.

As you examine craters larger than these, notice how features that characterize the full "Tycho" morphology — terraced walls, large central mountains, and a broad flat floor — become more commonplace. Three 60-km-wide craters worth examining are **Erathosthenes**, **Bullialdus**, and **Zucchius**. Each has incipient terraces giving way to full terraces, with mounds of wall-hugging debris on their floors. Their flat floors are larger and better-defined, and large central mountains are more prevalent. Think of them as the "young adults" of the Moon's crater population.

■ Contributing Editor **CHARLES WOOD** has been taking a special interest of late in the craters of Saturn's moon Titan.



The Inconstant Star

The joys of observing variable stars are predictably wonderful.

There is a star that ever seems to be
A source of wonder and amazement deep;
It is an orb of changing brilliancy.
But in recurring change doth constant keep.

Algol, thou shinest with a crimson light,
Waxing and waning mid the argent throng;
On thee we gaze, mysterious star of night,
To mark the wonders that to thee belong.
—Bela Chapin, *Algol*, 1882

In ages past, mankind thought the stars were immutable and unchanging. We now know that there are many ways in which this isn't true, most plainly in the case of variable stars. Although no incontestable record supports this conjecture, some think that Algol may be the first star whose brightness variations were noticed. Its name means "the demon," perhaps indicating something about the star seemed eerie. Unassailable evidence of Algol's variability didn't come until 1667, when the Italian astronomer Geminiano Montanari noticed that the star was fainter than normal. He continued to monitor the star for ten years, submitting his results to the Royal Astronomical Society of London.

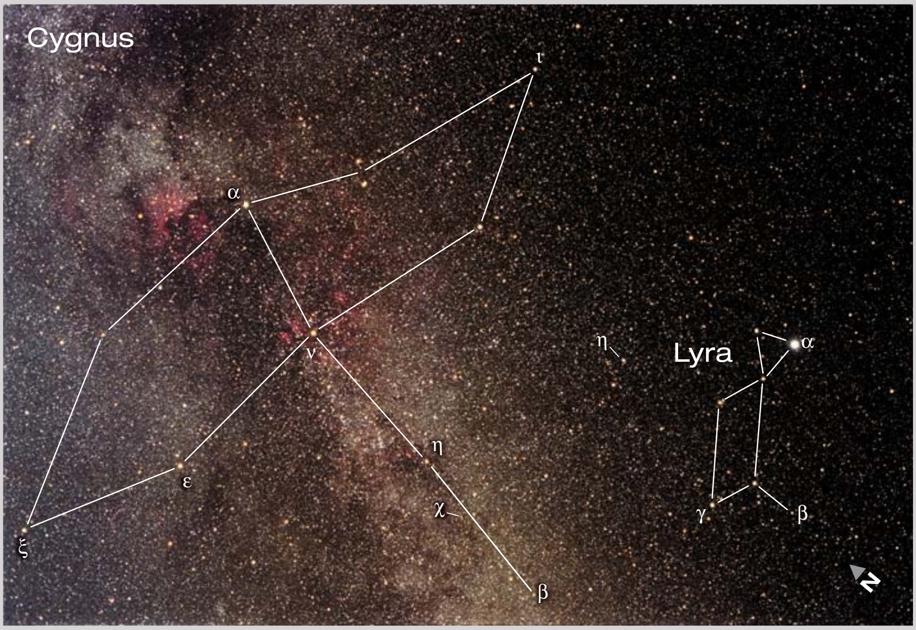
Beta (β) Persei (aka Algol) is a triple star with a tight binary orbited by a more distant star. The inner pair is made up of a blue-white dwarf and a larger but dimmer yellow-orange subgiant. The binary's orbit is nearly edge-on to our line of sight, favoring us with a

▶ The popular name for Beta Persei, Algol, comes to us from the Arabic *Ra's al-Ghul*, "the Demon's Head." Algol's drop in brightness from magnitude 2.1 to 3.3 can be observed easily with the naked eye. Use a nearby star such as Alpha or Epsilon Persei as a dependable gauge of magnitude.

TILL CREDNER

deep eclipse when the cool star passes partly in front of its bright primary every 2.867 days. The entire event can be followed with the unaided eye. Between eclipses, the stellar duo shines at magnitude 2.1, then it plunges down to magnitude 3.3 and climbs back to normal over the course of 10 hours (see page 51 for Algol's minima for September and October). For the middle two hours of the eclipse, the pair lingers fairly close to minimum light, giving you an unhurried window for catching its act. Handy comparison stars include Gamma (γ) Andromedae at magnitude 2.1, Epsilon (ε) Persei at 2.9, and Epsilon Cassiopeia at 3.4.

Beta Lyrae is another eclipsing variable that can be enjoyed with the unaided eye. It's composed of two blue stars, one a giant and the other a dwarf, snugged so close together that tidal forces stretch the components into ellipsoidal shapes. The distended giant is losing material to the dwarf by way of a dense accretion disk that obscures the smaller star. Massive stars use their fuel at a prodigious rate, and therefore evolve into giants sooner than low-mass stars. Yet in the Algol and Beta Lyrae pairs, the giant star is less massive by a considerable margin. In each case, the more evolved giant must have started its life as the more massive star of the pair, but then transferred much of its mass to its companion as the giant's expanding outer layers overflowed into the gravitational grasp of its companion.



▲ Like Algol, Beta Lyrae is a naked-eye variable, but because of the binary system's elliptical form, Beta's brightness drops and rises gradually over a period of nearly 13 days. Chi Cygni, a low-mass red star classified as a Mira variable, exhibits a period of more than a year. It's building to maximum light, which it should reach in October, so now is a good time to start observing it.

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Beta Lyrae puts on a much different show. Beta's elliptical stars and accretion disk conspire to lend the system a continuous change in brightness rather than discrete eclipses. The cycle from magnitude 3.3 to 4.4 and back spans a leisurely 12.941 days. Lowest light comes when the smaller star and its disk pass in front of the giant. When they pass behind the giant halfway between those minima, a secondary eclipse occurs, reaching magnitude 3.8. At maximum light, Beta is as bright as Gamma (γ) Lyrae, and at the deeper minimum it dips down to the magnitude of Eta (η) Lyrae. For a star that matches the secondary minimum, look to Iota (ι) Cygni in the northern wing of Cygnus, the Swan.

The relatively low-mass red stars known as Mira variables are another fascinating type to watch. Their outer layers expand and contract, as though the stars were drawing ponderous breaths taking anywhere from 80 to 1,000 days. Many undergo dramatic changes in brightness, and they appear reddest near minimum light. A striking example is **Chi (χ) Cygni**, with a period of 408 days and magnitude extremes of 3.3 to 14.2. The last two peaks were about 4th and 5th magnitude, and they can be as low as 6th magnitude.

Chi Cygni should be at maximum in October. If it follows its usual plan of alternating higher and lower peaks, this one should be brighter than last year's 5th-magnitude peak. Look for Chi along the Swan's neck, about a quarter of the way from Eta Cygni to Albireo (see the October 2016 issue, page 49, for charts with comparison stars). Is it visible to the naked eye? If not, you can track its rise and fall with binoculars or a telescope until the Sun carries evening twilight to that part of the sky.

Consistently Delightful Variable Stars

Object	Dist. (l-y)	Mag(v)	Period (days)	RA	Dec.
Beta (β) Persei	93	2.1–3.3	2.867	03^h 08.2^m	+40° 57′
Beta (β) Lyrae	960	3.3–4.4	12.941	18^h 50.1^m	+33° 22′
Chi (χ) Cygni	600	3.3–14.2	408	19^h 50.6^m	+32° 55′
Omicron (ο) Ceti	400	2–10.1	332	02^h 19.3^m	–02° 59′
Delta (δ) Cephei	890	3.5–4.4 3.5–4.2	5.366	22^h 29.2^m	+58° 25′

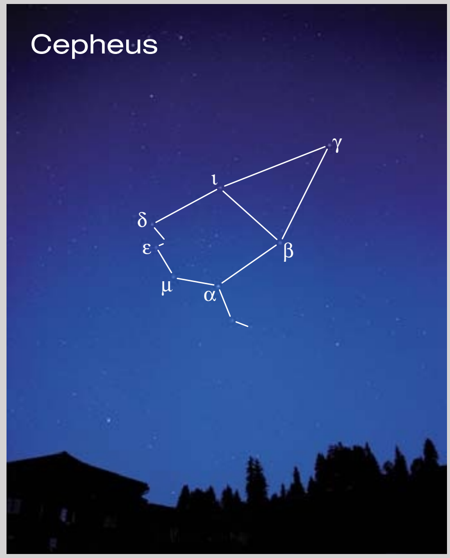
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Omicron (ο) Ceti, the prototype of the Miras, is currently making its way into our evening sky. Its common name, Mira, means "wonderful" and was bestowed by Johannes Hevelius in his 1662 *Historiola Mirae Stellae*, where he described the star's remarkable variability. As with Algol, awareness of Mira's changing intensity is rumored to have ancient origins, but solid credit goes to the German clergyman David Fabricius. While measuring Jupiter's position in 1596, Fabricius noticed a 3rd-magnitude star where none was seen before. He watched it brighten and fade to invisibility over the course of two months. He wrote several tracts about the star and sent his observations to Tycho Brahe.

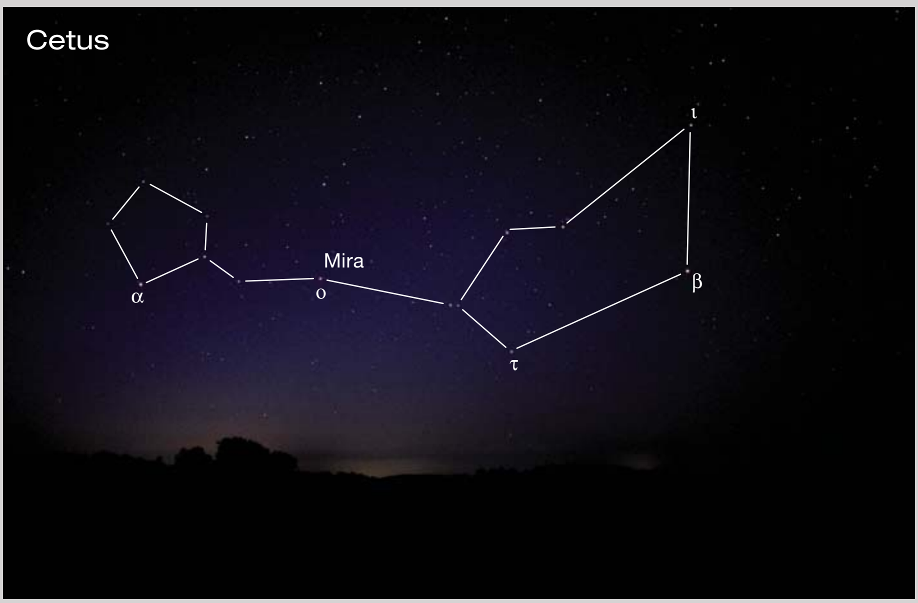
Mira should be bottoming out this September. Its climb to maximum takes only 38 percent of its 332-day cycle, so the star ought to beam at maximum light in January. Its peak can reach as high as 2nd magnitude, but typical maxima tip the scale at about 3.4. The star can be stalked with a small telescope as soon as it's high enough in the sky, since even extreme minima only dip to magnitude 10.1 (*S&T:* Oct. 2016, p. 49).

Cepheid variables hold a place among the stars most valued by professional astronomers. They're pulsating yellow giants that rhythmically expand and contract, but with breaths much shorter than those of Mira variables. A Cepheid's luminosity and period are closely tied. Once the relationship was established and calibrated with an independently determined Cepheid distance, the distances to others could be calculated by observing their periods and comparing how bright they appear to how luminous they are. Because they are highly luminous, Cepheids can be used to establish distances to galaxies as much as 100 million light-years away.

Delta (δ) Cephei is the prototype of the classical Cepheid variables. It sits near the southernmost corner of the stick-figure house often drawn on sky charts to connect the constellation's brightest stars. It varies from magnitude 3.5 to 4.4 and back over a period of 5.366 days, with the rise to maximum taking only 1.342 days (32 hours). However, if you follow the star with your unaided eye, the magnitude range is 3.4 to 4.2 because Delta's light is combined with that of a 6.3-magnitude companion 41″ to the south. The duo separates into a pretty yellow and blue-white pair at low power through any telescope. Good comparison stars for following Delta are Iota Cephei at magnitude 3.5, Alpha (α) Lacertae at 3.8, Epsilon Cephei at 4.2, and Beta Lacertae at 4.4.



▲ Delta Cepheid, the prototype star for the Cepheid variable class, has a relatively short period, cycling through its variability in just 5.366 days. Delta's apparent brightness is affected by that of its companion, whose light contributes a 0.2-magnitude bump up to the primary.



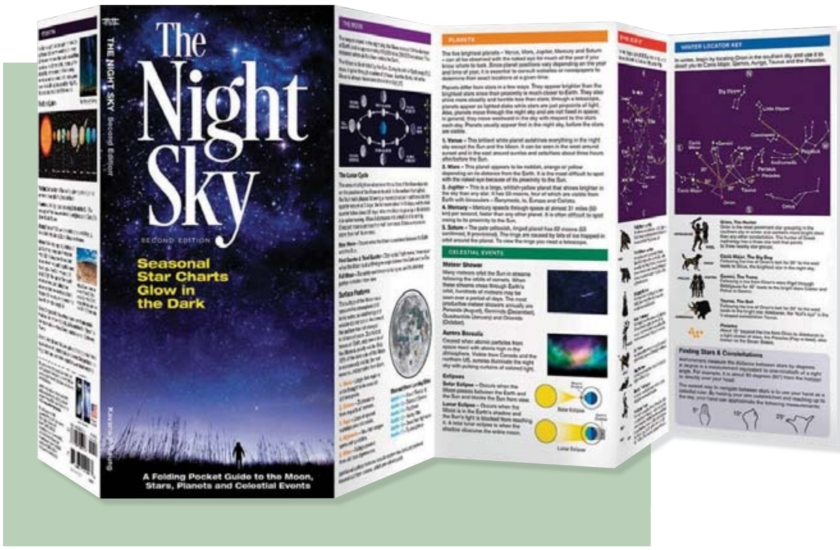
▲ Omicron Ceti, better known as Mira, is the prototype star for that class of variables. While Mira's full period is 332 days, its climb from maximum dimness to maximum brightness takes only about 126 days. Look for it to reach about magnitude 3.4 in January 2018.

The variables described above are conveniently labeled on the all-sky chart at the center of this magazine. If you find that watching variable stars strikes a chord with you, you can delve more deeply with the charts and other resources of the American Association of Variable Star Observers (AAVSO) at **aavso.org**.

At first enigmatic, these changeable stars have now yielded some of the secrets behind their inconstant light to those who studied them across the years. But variable stars their mysteries still do keep. They slowly blink at us as if to say, "Watch me. Watch me and learn."

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

TILL CREDNER (2)



◀ POCKET GUIDE

Waterford Press produces *The Night Sky* ($7.95). This laminated, folding pocket sky guide, now in its second edition, features seasonal glow-in-the-dark star charts with prominent constellations marked to help navigate the sky. The pocket guide introduces stargazing newcomers to objects visible to the unaided eye such as the Moon and bright planets, as well as special astronomical events, including meteor showers, the aurora borealis, and eclipses. A helpful section shows users how to use their fingers to “walk” between constellations to find prominent stars. A Southern Hemisphere version is also available.

Waterford Press
1123 Overcast Dr., Dunedin, FL 34698
727-812-0140; waterfordpress.com

◀ DEEP-SKY CAMERAS

SBIG announces the Aluma Series of cooled imaging cameras (starting at $3,699). These cameras have been engineered from the ground up with new sensors positioned on the central axis of the unit, including Sony’s ICX-694 and ICX-814 CCD sensors, as well as Kodak’s popular KAF-8300 CCD detector. Aluma cameras feature dual-stage cooling down to 50°C below ambient temperature to drastically reduce thermal signal in your images. Each includes USB 2.0 and WiFi 802.11 interfaces, allowing the cameras to be controlled directly by tablets and smartphones, as well as by conventional Windows, Macintosh, and Linux computers. A 110V/220V power supply, rechargeable desiccant plug, and *MaxIm DL* for Windows are included with each purchase. Software for iOS and Android control is in development.

SBIG
59 Grenfell Crescent, Unit B, Ottawa, ON, Canada K2G 0G3
613-225-2732; diffractionlimited.com

◀ HANDCRAFTED ASTROLABES

Rozendaal Astrolabes now offers a series of wood astrolabes (starting at $80). These fully functional, attractively handcrafted instruments are 15 centimeters (6 inches) in diameter and manufactured from birch wood with laser engraving. Each includes 38 stars on the rete, with different designs available. Choose your preferred latitude. Personally customized versions with personal engravings are offered at additional cost. See the manufacturer’s website for additional details.

Rozendaal Astrolabes
rozendaalastrolabes.com

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

MallinCam's SkyRaider DS2.3 Plus

This device promises to be three cameras in one convenient package.

◀ The MallinCam SkyRaider DS2.3 Plus includes an autoguiding cable, a C- to-1¼-inch nosepiece, a lens cap, a 5-meter (15-ft) USB 3.0 cable, and a flash drive containing the camera's control software and drivers. There's also an attractive ballcap.

SkyRaider DS2.3 PLUS

U.S. Price: $899.99

MallinCam.net

What We Like:

Camera versatility

Excellent quick-start guide

What We Don't Like:

Infrared-blocking filter not included

Blue LED affects images

CANADA'S MALLINCAM, best known for producing sensitive analog video-astronomy cameras, is now dipping a toe into the digital world. One of the company's recent offerings, the SkyRaider DS2.3 Plus, is promoted as a versatile camera able to handle three types of astronomical imaging tasks: long-exposure deep-sky, planetary, and video-assisted observing. That certainly piqued our interest. Could a single camera win the astrophotography trifecta? We contacted the company to borrow a unit and have a closer look.

The SkyRaider is a cylindrical camera weighing 15 ounces and is about as large as many of those 2-inch ultra-wide-field eyepieces coming out of Asia these days. It's built around a Sony 2.35-megapixel IMX302 color CMOS sensor with an array of 1,920-by-1,200 5.86-micron-square pixels. The camera employs a cooling fan to reduce thermal signal. Also included are a 5-meter USB 3.0 cable to connect the camera to a computer, a 2-meter autoguiding cable, and a threaded 1¼-inch nosepiece for inserting the camera into a standard telescope focuser.

How about software, drivers, and a manual? There was no CD, but there was a flash drive containing *MallinCam-Sky*, the program to operate the camera, as well as its required drivers and a PDF of the instruction manual. The software on the flash drive is written for Windows systems, though Macintosh and Linux versions are available for download from the company's website. At this time, however, they only provide basic functionality compared to the feature-rich PC software.

The camera's 175-page manual is a little overwhelming, but fortunately it includes a quick-start guide that leads you through the basic process of install-

ALL PHOTOS BY ROD MOLLISE

ing software and using the SkyRaider to take deep-sky and planetary images. I wish more manufacturers would do this. A folder on the memory stick is labeled "MallinCamSky Drivers" despite the fact that it also contains the camera control software and the manual. All these things are in a single compressed ZIP file that you manually extract and install using File Manager in Windows. An automated installation program is something MallinCam should consider.

When I saw the computer requirements, I got worried. The manual warns "performance is not guaranteed" if the camera is not operated with a computer having a 2.8-GHz dual-core processor, 2.0 GB of RAM, 200 MB of hard drive space, and a USB 3.0 connection. My laptop didn't meet all these specs, coming up short with a 2.2 GHz processor and USB 2.0. Would I have to round up another PC to properly test the SkyRaider? Fortunately, that didn't turn out to be the case.

My Toshiba laptop was more than powerful enough to run the *MallinCam-Sky* software and operate the camera in imaging and deep-sky video-observing modes; the USB 3.0 speed is mostly required to achieve the camera's fastest frame rates when imaging the planets.

Deep-Sky Imaging

First light for the SkyRaider went smoothly. I mounted the camera on my 80-mm f/7 William Optics refractor to provide a generous field on the camera's modest chip. In the control software, at the top left sidebar menu list, is a hyperlink, "SkyRaider DS2.3 Plus." I clicked it and was almost immediately greeted by a video stream showing the bright star the telescope was aimed at. Focusing was easy using 2-second exposures, and within minutes I was ready to begin shooting deep-sky targets.

The camera's software includes many useful features. In addition to the sidebar, which contains 15 separate menu items, there's a command menu across the top of the screen that offers a multitude of image-processing tools. While it was a lot to take in on the first night, the quick-start guide helped steer me in the right direction.

Before taking images, I changed some of the preliminary settings. I selected the camera's highest resolution mode and set its bit depth to 12 bits to ensure the camera would record images with the largest available dynamic range. I also made sure the cooling fan was running to reduce thermal signal in the images, though I still needed to record and subtract dark frames from my shots to eliminate some false "stars" caused by heat.

The SkyRaider DS2.3 Plus can make single exposures as long as 16 minutes and 45 seconds. Since my sky was relatively bright, I began by choosing

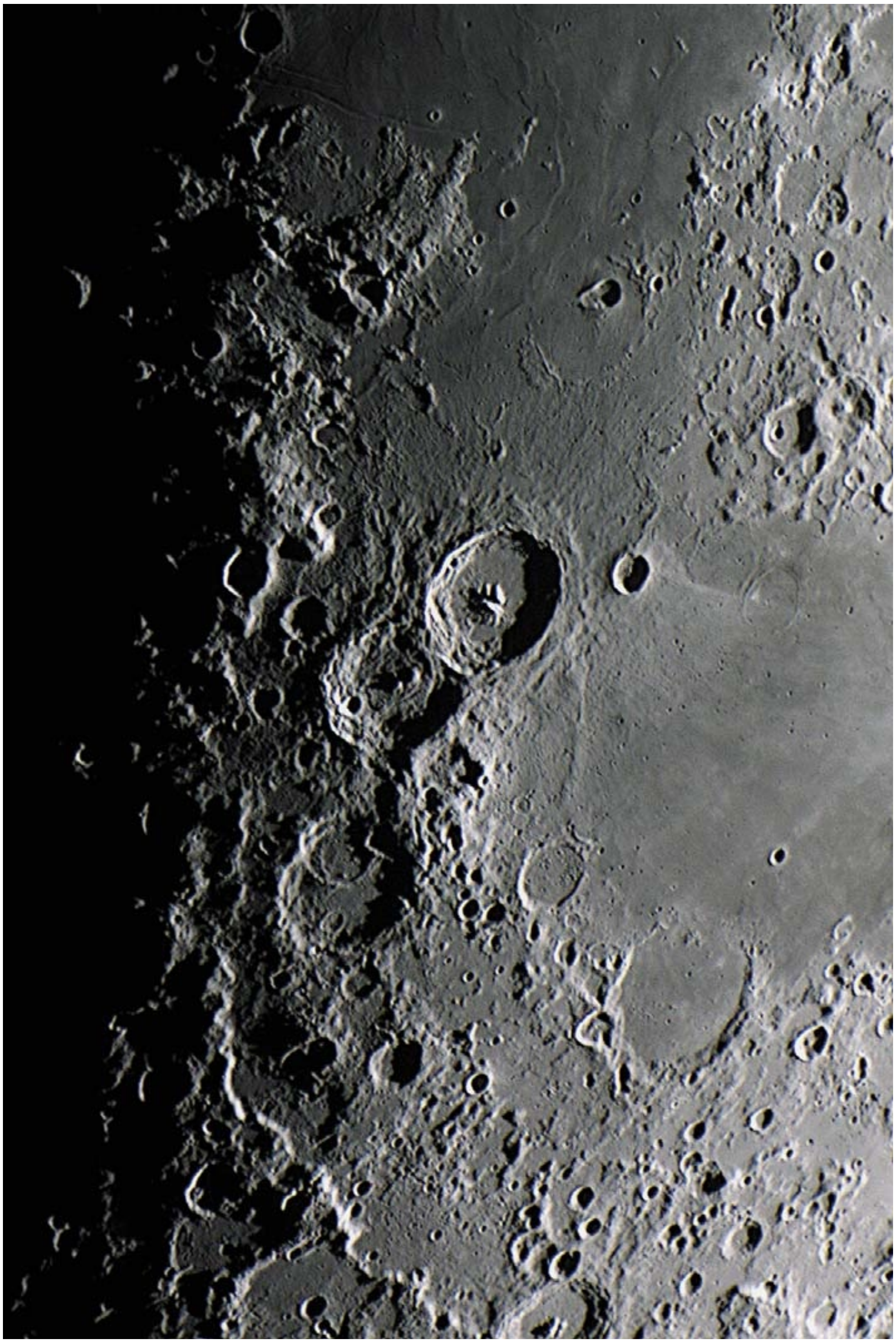
The rear panel of the camera includes a USB 3.0 port, an autoguiding port, and the cooling fan. To the left of the USB port is a blue LED power indicator. Users should cover the LED when recording deep-sky images.


▲ The camera features a 2.3-megapixel Sony IMX302 CMOS sensor, seated just behind the C-thread housing. Users may need to provide their own C-to-T-thread adapter to attach the camera to some telescopes and accessories.

2-minute exposures in the software's Trigger Mode (long-exposure) section. I then covered the telescope's aperture, and in the Dark Field Correction menu, commanded the software to take ten 2-minute dark frames. The software doesn't just take dark frames; it automatically stacks them to produce what the manual calls a "Dark Field" image. When the darks were done, I simply checked the box that would automatically apply this calibration frame to my pictures, and saved it for future use.

The rest was rather straight forward. I pointed the telescope at the galaxies M81 and M82, adjusted the histogram for a picture that wasn't too bright or too dark, and set up a sequence in the Trigger Mode window's options menu that would automatically expose and save 30 individual 2-minute frames. As the images began coming in, I could tell the camera was doing a credible job despite the light pollution. M81's delicate spiral arms were visible, if not prominent, while M82 displayed plenty of core detail.

The following night I was in the backyard again, this time with my 8-inch f/10 Schmidt Cassegrain telescope. The longer focal length of the SCT, even when equipped with an f/7 focal reducer, meant the SkyRaider's field was much smaller than with the refractor. But this works well for "close-



▲ Capturing the Moon is easy with the SkyRaider DS2.3 Plus in video mode. The author recorded and stacked 300 full-resolution frames to produce this close-up of the lunar crater Theophilus and surroundings using an 8-inch SCT at f/20.

ups" of smaller objects like galaxies and planetary nebulae.

Despite the bright backyard skies and some haze, my processed pictures were comparable to what I can do under similar conditions with a DSLR. I was particularly impressed by the absence of thermal noise with Dark Field calibration enabled. The only problem I noted was some minor background artifacts that could later be corrected using flat-field calibration frames.

When using the camera at my astronomy club's country observing site, I pushed the SkyRaider's gain setting higher than in the backyard, but despite that, the resulting pictures appeared smoother and easier to process. The background problems seen when imaging from home were gone, no doubt because pictures taken under dark skies don't require as aggressive processing.

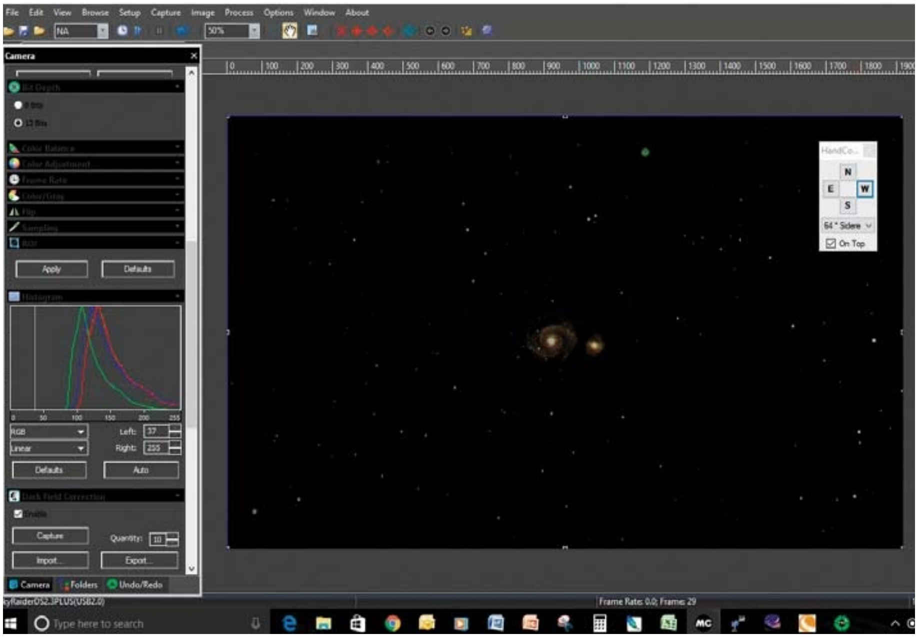
One problem I encountered was the appearance of large, blue, bloated "stars" in some frames. It appeared as if Neptune had somehow sailed into the field of the Whirlpool Galaxy! At first I was stumped as to its cause, but then it occurred to me these objects were suspiciously similar in color to the bright blue LED on the back of the camera, which comes on as soon as the USB cable is plugged in and flashes during exposures. Placing a piece of tape over the LED somehow caused the blue intruders to disappear.

Users should note that the SkyRaider DS2.3 Plus does not include infrared blocking on the CMOS detector, so an additional IR-blocking filter (not included) needs to be placed in front of the chip to ensure the best color fidelity in your images.

Planetary Performance

With the Moon and Jupiter coming into view, I tested the SkyRaider's planetary imaging performance with the 8-inch SCT with a 2× Barlow lens. Taking images of the Sun, Moon, and planets with the SkyRaider is pleasantly simple. In *MallinCamSky,* switch to video mode in the Capture menu, click the Options button, and specify the resulting video to be saved in AVI format. Adjust the exposure time to avoid over-exposing your target, and when you're focused, click the video record button near the top of the screen.

Although the image of Jupiter on screen looked good, here is where I encountered the limits of my USB 2.0 connection. While the camera's specs state it can deliver up to 30 frames per second (FPS), when I clicked the record button, the camera began capturing a measly 3 FPS! This is alright for shooting the Sun and Moon, but for planetary work, the more video frames you can record in a short amount of time, the better, thus ensuring you get



▲ Long exposures are possible with the SkyRaider DS2.3 Plus when in Trigger Mode. The controls needed for image capture are grouped at the left of the screen. The bluish-green "star" at the top of this image of M51 was due to the blue LED on the rear panel of the camera.

enough sharp frames captured during fleeting moments of steady seeing before your target rotates too much.

One of the reasons for the SkyRaider's slowness (besides my USB 2.0 connection) is the camera's large sensor as compared to the tiny chips in many dedicated planetary cameras. There was a work-around, however, involving the *MallinCamSky*'s Region of Interest (ROI) tool. I simply drew a box around the target planet with my mouse, clicked the apply button, and the program records a video of only the region within the box. This immediately increased the recorded frame rate to 10 FPS.

When I later processed my Jupiter and Moon images, I was quite pleased. Despite the relatively low frame rate, Jupiter was quite respectable given my average seeing conditions. Conclusion? The SkyRaider is capable of taking very good planetary images. Seeing will likely be the limiting factor for most imagers.

Video Observing

Finally, I put the camera to work as a video-observing tool. There are two ways to use the SkyRaider DS2.3 Plus for video-assisted observing. The first is the camera's video mode for planetary imaging. This limits its exposure to 5 seconds or shorter. But *MallinCamSky* offers a helpful live-stacking function that will align and combine deep-sky video frames on the fly, and my experience with a similar feature on one of my analog video cameras led me to believe this would help with the image brightness on popular targets.

Bright deep-sky objects were easily captured in this video mode. And while the resulting pictures weren't pretty, they were just as good as those I can get with my analog MallinCam Xtreme video camera. Even 5-second exposures revealed the spiral structure of galaxy M51 without activating the stacking feature. The images were noisy, but good enough for casual video observing and would be sufficient for near-live viewing at public outreach events.

Getting better-looking video images requires switching to trigger mode and clicking the Loop button, which exposes frames continuously (and longer) but doesn't save the results. Exposures of 15 seconds to 1 minute still gave the feeling I was observing "live" and revealed fainter details with much less noise than those taken in the camera's short-exposure video mode.

After just a few outings I grew to like this camera a lot. It performed well with all three astrophotography tasks: long-exposure imaging, planetary imaging, and video observing. The SkyRaider allowed me to do lots of things and do them easily.

■ Contributing Editor **ROD MOLLISE** pursues faint fuzzies in the sky from rural Alabama using various scopes.


▲ Another fine example of the SkyRaider's capabilities under typical urban skies is this shot of M51, the Whirlpool Galaxy, that reveals its dark dust lanes and bluish spiral arms. The result uses 30 exposures of 2 minutes each shot through an 8-inch SCT at f/7.

16 Pisces, Arp 284 & the Unexpected Quasar

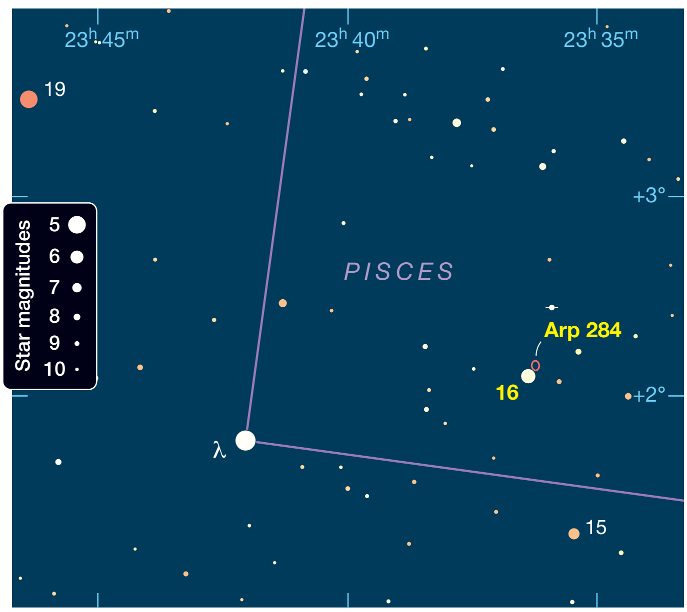
A Story of Time and Distance

Traveling to Fort Davis, Texas, to observe with Jimi Lowrey makes for a long day.

From Portland, Oregon, it takes two flight segments and six hours to get to El Paso, where Steve Gottlieb and I, whenever we go, rent a car for the three-hour drive to Fort Davis. Steve starts his journey in Oakland, California, another long trip, so by the time we arrive at Jimi's place, we're tired. But that exhaustion evaporates quickly in Jimi's observatory, with the sky darkening and his 48-inch telescope ready for action.

The 48-inch is an alt-az f/4 Newtonian reflector controlled with a laptop computer. With the scope angled nearly horizontally when the observatory roof is closed, its back end, which supports the exquisitely figured primary mirror, is almost taller than I am. Best of all, this impressively large and well-made telescope is optimized for visual observing.

We need a 14-foot-tall orchard ladder to reach the eyepiece when the scope points near the zenith. The ladder gets alarmingly narrow at the top, and it's hard not to feel how high off the floor I am up there. It's "one hand for myself and one for the scope" when I'm adjusting the focus or using the hand pad to move the scope slightly. Although I'm sure there's a slight impression of my right hand somewhere on the ladder, observing from the top isn't impossibly scary. It's difficult to see how high off the observatory floor I am in the dark, plus the view in the eyepiece is wonderfully distracting.



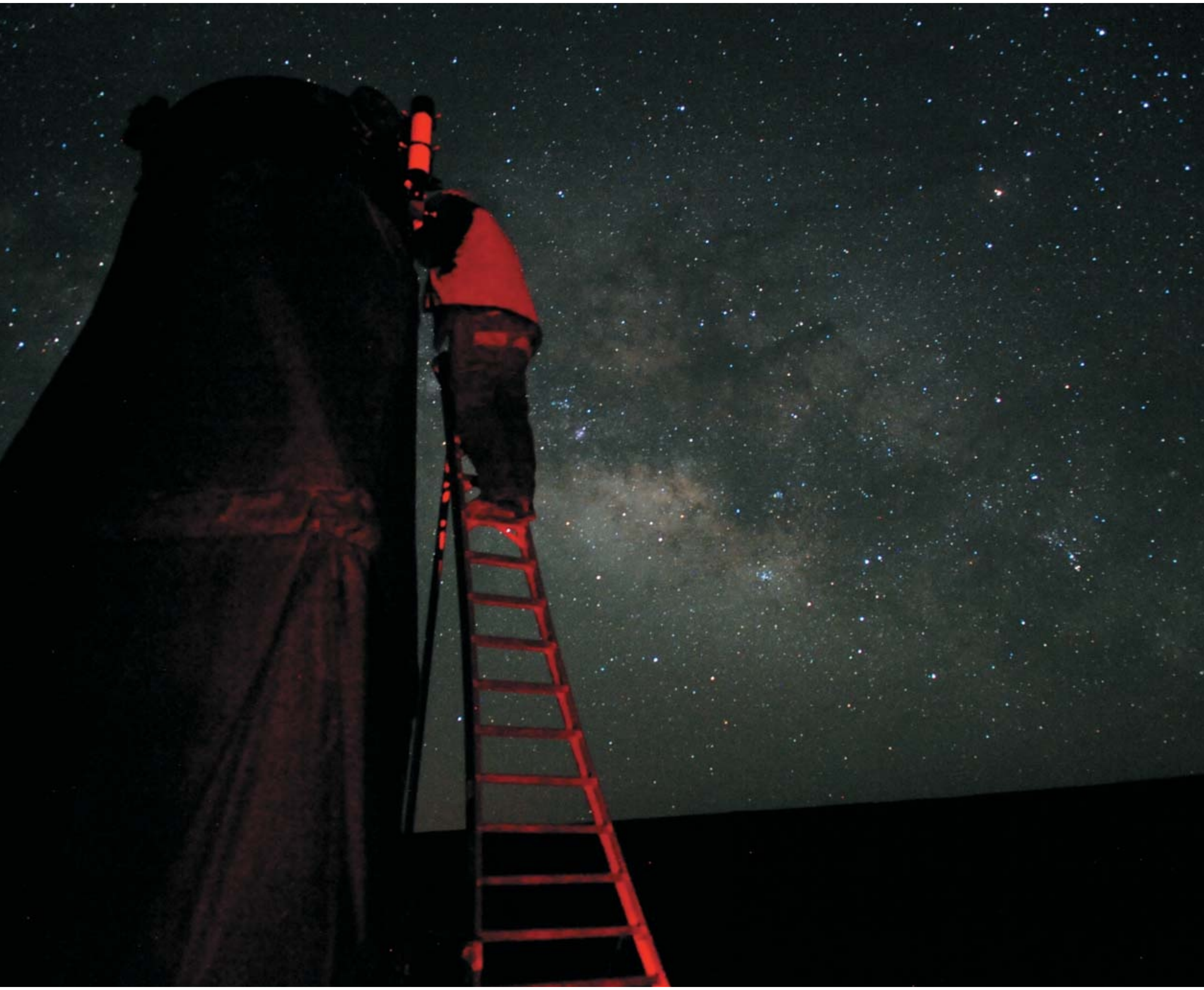
As you might guess, observing through the 48-inch under a great West Texas sky is as good as it gets for a visual observer, so there's no use being scared. Everyone climbs the ladder. Plus, the company is great.

On our most recent trip there in October 2016, Steve and I came prepared with our observing lists and had every hope of seeing things we'd never seen before. Jimi always has a list of incredible stuff he wants to show us as well. As it happens, Arp 284 was near the top of my list for that trip's observing run. I'd observed it at the Oregon Star Party a couple months earlier with my 28-inch scope but failed to discern any hint of its subtle tidal streams, even though the two galaxies themselves were easy to see. Tidal effects show the dynamism of galaxy interactions and are downright awesome to see firsthand. I thought we had a great shot at seeing them in Arp 284 through the 48-inch.

16 Pisces and Arp 284

Whatever we point the scope at on a good night will probably blow us away. Some nights are better than others, of course, and a few objects hold onto their secrets more tightly than we'd like, but when the sky cooperates we're sometimes surprised in a thrilling way. That's exactly what happened while observing the interacting galaxies of **Arp 284** (NGC 7714 and NGC 7715).

They're situated just north of magnitude-5.7 **16 Piscium**. This main-sequence F6 star resides in the Milky Way, so its apparent proximity to Arp 284 is a line-of-sight coincidence: 16 Psc is just 101 light-years away, while Arp 284 is really, *really* far in the background at 100 million light-years away.



▲ **ONE HAND FOR THE LADDER . . .** and one for the scope. It takes a bit of courage to climb a 14-foot orchard ladder to observe with a gigantic telescope, but the view through the eyepiece is always worth it.

LARRY MITCHELL

Because 16 Psc shines so brightly, it needs to be placed outside the field of view to get a good look at the galaxies. That was easy to do, given the 192-inch focal length of the scope and Jimi's favored orthoscopic eyepieces, which minimize the number of air-to-glass surfaces that can cause light scatter from a bright object just outside the field.

NGC 7714 was probably a barred spiral galaxy before it began interacting with NGC 7715, and NGC 7715 was most likely a spiral. Now they're in the process of morphing into a single, almost certainly elliptical, galaxy as their interaction pulls streams of stars between and away from each other.

These two galaxies were the eighth object(s) we observed on our first night. It was around 12:30 a.m., the sky conditions were decent, and we had settled into a good observing rhythm. When Jimi asked, "What's next?" and I replied, "How about Arp 284 in Pisces?" I heard a murmur of assent. After moving the ladder out of the way, Jimi commanded the scope to slew to the proper coordinates, then pushed the ladder back into place and climbed up to center the galaxies in the field of view. He also swapped in a higher power eyepiece.

We took turns going up the ladder and describing to the other two what each of us was seeing — when we weren't too

▲ **FINELY SPACED TRIO** Magnitude-5.7 star 16 Piscium shines at the top center of this image. Arp 284, comprised of the two interacting galaxies NGC 7714 and NGC 7715, lies north of the *F*6 star. In the unimaginably distant background shines the quasar 2333+019, seen here as a light-blue, starlike object below the west end of NGC 7715 (see arrow). Why doesn't the quasar appear red? Quasars peak in their energy output at 1000 angstroms. For a z = 1.87 quasar, this peak will shift redward to 2870 angstroms, making 2333+019 appear blue. The quasar would have to be much farther away or surrounded by dust to appear red. South is up, west is to the right.

RICK JOHNSON

distracted by the view. Steve has an impressive folder full of observing targets and writes his notes directly on its pages. I soaked in the view and then quickly returned to the guest observing table to sketch what I saw. I think it took three trips up the ladder to make my drawing.

What a sight! Even though we couldn't see the tidal tails — dang! — the view was memorable. NGC 7715 was a perfectly edge-on galaxy and appeared much brighter than it had through my 28-inch reflector, but NGC 7714 had taken on a much more detailed shape. It sported a long, curved central bar with a stubby spiral arm coming off each end. I saw both galactic arms distinctly, but the southern one was a bit brighter than the northern, with a bright spot right at its tip. The bends in both arms gave the galaxy a shape reminiscent of a seahorse. The round core was the brightest part of the galaxy overall but wasn't particularly concentrated. On the side facing NGC 7715, a faint arc of galactic fuzz connected to the central bar, almost looking like a blur of motion. Several faint stars were scattered around the field of view.

While I was working on my sketch and Steve was looking through the eyepiece, the direction of our observation suddenly changed. Jimi sat at his wonderfully shielded laptop, examining the DSS image of Arp 284 loaded into *MegaStar*, looking for anything interesting nearby we could observe next. That's when he saw a star-like object labeled **2333+019** just a few arcminutes off the northwest end of NGC 7715. With a name like that, just a right ascension and declination, it could be anything. It turned out to be a quasar.

The Unexpected Quasar, 2333+019

Jimi clicked on the image in front of him and an info box popped up to show us a redshift of 1.871. (An object's redshift, noted as z, is a measure of its distance; the larger the number, the longer it takes for the object's light to travel to us.) He excitedly told us the number, and we were suddenly reenergized. Steve was trying to figure out the light-travel time in his head while Jimi looked it up on an online cosmological calculator. Meanwhile, I was trying to remember if

$z = 1.871$ meant the quasar was really close or really far away.

Steve and Jimi instantly knew $z = 1.871$ meant that it was really far away, though, and they both came up with the same answer: its light-travel time was about 10 billion years.

That's right, 10 *billion* years.

As interesting as Arp 284 had been, our attention was suddenly riveted on the quasar. Using the DSS image on his laptop, Jimi showed us the quasar's position in comparison to two field stars off the end of NGC 7715, giving us an idea as to where to look for it in the scope. The quasar's designation, based on its 1950 coordinates, is somewhat misleading. In epoch J2000.0, it's at RA $23^h\ 36^m\ 60^s$, dec. +02° 10′ 45″.

Jimi was first up the ladder, then Steve, then me. And there it was! We all saw it easily with averted vision. Just think, 10-billion-year-old photons in real time — the back of my neck started to tingle as I felt the edges of my everyday reality start to warp. All I could do was stare at this faint point of light, letting the primordial photons stream into my left eye as my brain tried to make sense of them. Ten billion years is far too long for me to comprehend, but this unimaginable span of time was breathtaking nonetheless. Not to mention the light was coming from a supermassive black hole's relativistic jet on the other side of the visible universe, which just happened to be pointed at us.

This is what I wrote in my notebook after my sketch:

Best, most memorable view of the night. Wow, a quasar whose light has taken 10 billion years to get here — and I could hold its stellar image steady with averted vision. Holy moly . . . N7714 and 15 were astonishing, too, and much more detailed than I saw in my 28-inch at the OSP in August. 8mm (609×) and 6mm (812×), 1:07 a.m., 21.45 SQM.

We took several more turns at the eyepiece, and during my last look I thought about how photons don't experience time — at the speed of light, time stops. In our frame of reference, 10 billion years has passed since these photons were emitted by the quasar, while from the photons' frame of reference, they're just suddenly here.

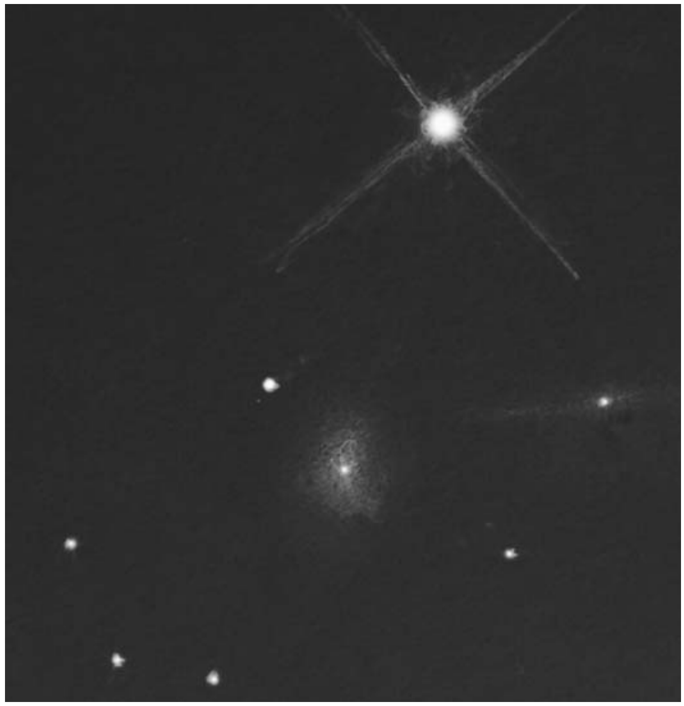
That seems impossible, but it's a part of how spacetime works on both its largest and smallest scales. Unfortunately, my comprehension is stuck somewhere in between.

Perspective

While Steve and I took a final look, Jimi did a quick search on his laptop to double-check the quasar's brightness. *MegaStar* showed it was 18th magnitude, and Steve confirmed the value the next morning by doing a more extensive search.

We eventually moved on because there's only so much to see in a faint star-like point. Even so, bumping up against the limits of my comprehension was exhilarating. We went to our next target with some reluctance.

How to compare the distances of the three objects that fit so neatly into the 48-inch scope's high-power view? To begin, 16 Psc, Arp 284, and 2333+019 represent one of the deepest



HOWARD BANICH

▲ **GALACTIC GLOW** In the author's sketch made under the dark skies (SQM reading of 21.72) of the 2016 Oregon Star Party with a 28-inch reflector at 408×, a delicate, circular smudge and an enigmatic line comprise Arp 284. The interacting galaxies lie about 3 arcminutes north of 16 Piscium. South is up.

Looking Through the Big Scope

Ever wonder what you'd look at if you got your hands on a big scope? The author added more than a dozen objects to his observing logs by the time he finished his night. If you want to follow his trail, here are the blazes:

NGC 3172 (Polarissima)
NGC 7731 & NGC 7732 (Zwicky's Pierced Galaxy)
Shakbazian 84
Arp 13 (NGC 7448)
NGC 7463, NGC 7464 & NGC 7465
Shakbazian 362
VV 84 (NGC 7433 galaxy group)
Arp 284
2333+019
M77
NGC 1048
NGC 1049
Trapezium region of M42

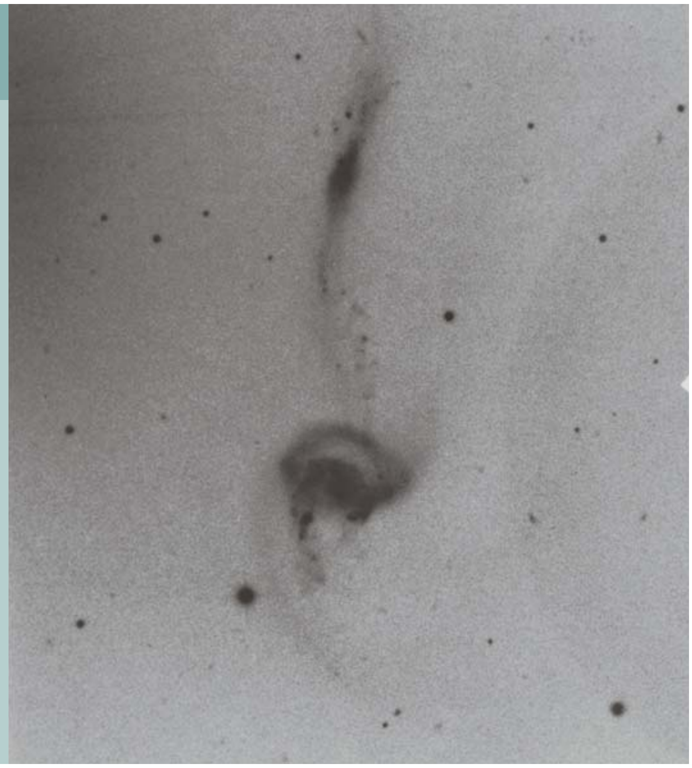
- **The Shakbazian catalog lists 377 groups of compact galaxies detected on Palomar Observatory Sky Survey (POSS) red plates (https://is.gd/Shakbazian).**
- **The Vorontsov-Vel'yaminov catalog is at http://is.gd/VVCatalog.**

Arp's *Atlas of Peculiar Galaxies*

American astronomer Halton Arp focused on both galaxy formation and quasars during his career, using his research in these areas to argue against the Big Bang theory. Although his rejection of the Big Bang remains controversial, his *Atlas of Peculiar Galaxies*, produced in part to support his ideas, remains one of the best catalogs of interacting galaxies.

Arp began gathering the photos that would serve as the basis for his atlas in 1962. Using earlier, similar lists compiled by Swiss astronomer Fritz Zwicky and Russian astronomer Boris Vorontsov-Vel'yaminov as a starting point, Arp sifted through images captured with the 48-inch Schmidt telescope and the 200-inch Hale telescope, both at Palomar Observatory. He eventually selected 338 images of galaxies with unusual, or "peculiar," shapes and sorted them into four groups based on each galaxy's deviation from a classic spiral form.

• **The *Atlas of Peculiar Galaxies* is available online at https://is.gd/ArpCatalog.**

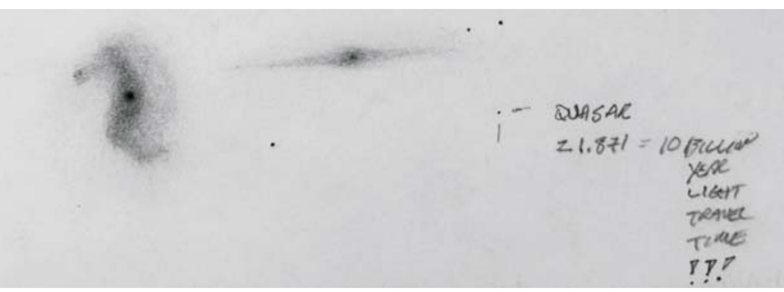


depths of field available to amateur observers. The star 16 Psc lies in our Milky Way galaxy, about 101 light-years distant. That doesn't seem so far away.

But as noted above, the two galaxies of Arp 284 are about 100 million light-years away, while the quasar's light has taken about 10 billion years to get here. These numbers are much more difficult to relate to, so looking at events on Earth when these photons started their journey helps give them some perspective.

World War I was raging 101 years ago. Albert Einstein's theory of general relativity had been published for only a year and was as yet unproven.

The Cretaceous Period was in full swing 100 million years ago; the first flowering plants made their appearance. Dinosaurs were leaving their tracks on the muddy shorelines of Earth's lakes and seas.



▲ **WOW!!!** A view of a quasar 2333+019 warrants three exclamation marks in anybody's observing log. The author's sketch of Arp 284 shows the 18th-magnitude quasar as viewed through Jimi Lowrey's 48-inch telescope at 609× and 812×. South is up.

The Earth didn't exist 10 billion years ago, and its Sun wouldn't form for another 5 billion years or so. Everything that makes up the solar system today was part of some now-extinct star, the interstellar medium, or a mixture of both.

Okay, that's incredible.

Now consider that in the photons' frame of reference, time and distance have both become something outside the human experience. At light speed, time slows to a stop and distance contracts to zero — something I didn't recall while at the eyepiece. So in the photons' frame of reference, they were emitted by the quasar at the same instant they were absorbed by the retina in my left eye. No time and no distance.

This is equally true for the photons coming from Arp 284, 16 Psc, or any light source for that matter. Goodness.

As if this isn't mind-bending enough, the universe was expanding during the 10-billion-year light-travel time. When the photons I saw left their source, the quasar was only 5.8 billion light-years from Earth. Now, redshift tells the story of the expanding space those photons have crossed: For a $z = 1.871$ object, that space has enlarged by almost a factor of three. I'm not sure if that's more or less crazy than a timeless, distance-less photon traveling for 10 billion years.

All this is as unintuitive as it gets, and although it's an accurate description of reality, I really don't understand how it works. Nonetheless, I'll never get tired thinking about it, especially when ageless photons entice me to try.

■ Contributing Editor **HOWARD BANICH**'s friends Jimi Lowrey and Steve Gottlieb were every bit as excited as he was by these observations. Howard can be reached at hbanich@gmail.com.

SKETCH: HOWARD BANICH: *ATLAS OF PECULIAR GALAXIES*: HALTON ARP/ NASA / IPAC EXTRAGALACTIC DATABASE (NED) / CALTECH / CARNEGIE OBSERVATORIES

Epic Effort to Save the Night

SKYGLOW: *A book and video disk that showcase night skies free from light pollution.*

Harun Mehmedinović
& Gavin Heffernan
2016 (self-published); 192 pages
$49.99, hardcover;
$84.99 with Blu-ray disk & calendar
Available from skyglowproject.com

FEW OF US are old enough to remember backyard views of a pristine night sky. That sad reality is due, of course, to the spread of light pollution. David L. Crawford, the professional astronomer who co-founded the International Dark-Sky Association (IDA), reminds us that light pollution has taken decades to get this bad — and it will likewise take decades to get under control.

But how, exactly, do we halt and reverse the spread of this assault on the stars? Some have sounded the alarm through their writings. Timothy Ferris led the way with *Seeing in the Dark* (2002). Paul Bogard followed with two powerful literary statements — the 2008 anthology *Let There Be Night: Testimony on Behalf of the Dark* (which he edited) and, five years later, his personal declaration *The End of Night: Searching for Natural Darkness in an Age of Artificial Light*.

Words have their value, but nothing conveys the plight of night better and more viscerally than imagery. In *Skyglow*, Harun Mehmedinovic´ and Gavin Heffernan have finally given defenders of the night a way to show everyone what we've lost. The book's nearly 200 nightscapes allow you to become immersed in superdark settings scattered across North America. Most of the scenes are

This expansive view, taken from Lodgepole Tipi Village on the Blackfeet Indian Reservation in Montana, reminds us that North America's indigenous tribes not only witnessed pristinely dark skies each night but also used the stars to develop rich mythologies.

COVER: GAVIN HEFFERNAN; TIPI VILLAGE: HARUN MEHMEDINOVIĆ a single frame from hours-long time-lapse sequences, which you can enjoy via the optional Blu-ray disk.

These two young filmmakers didn't start out as dark-sky warriors. But they soon abandoned the urban scene in Los Angeles to capture the stars that were missing from their nights. Then they launched (and topped) a $70,000 Kickstarter campaign that allowed them to travel more than 150,000 miles and log more than 500,000 photos over three years. Bucking conformity, they packaged and published *Skyglow* themselves.

> *Skyglow* has finally given defenders of the night sky a way to show everyone what we've lost.

I got a bit worried when the introduction described how parts of Southern California were plunged into darkness following the Northridge Earthquake on January 17, 1994 — and how, with all the lights extinguished, the Milky Way "shone brightly from horizon to horizon." But that would have been impossible in mid-January.

Still, I found much to love in this book. The images transport you first to prehistoric time, when only volcanoes and lightning competed with the stars, then to the sky that Native Americans and early white settlers would have experienced, and they end with scenes from today's lumen-saturated existence.

You'll find short essays by Phil Plait, Tyler Nordgren, and others. One section shows the views enjoyed from various professional observatories. And the book ends with a heartfelt pitch for the IDA. Bonus: The index details who shot what and the camera-lens combinations that Mehmedinović and Heffernan used.

I've long maintained that amateur astronomers — who arguably stand to lose (or gain) most in the light-pollution battle — don't do enough to support those of us engaged in this long-running fight. You can help change that by purchasing this excellent book.

■ *S&T* Senior Editor **J. KELLY BEATTY** serves on IDA's Board of Directors.

◀ **Clockwise:** Momument Valley Navajo Tribal Park straddles the Utah-Arizona border. In Navajo legend, First Woman and Coyote clashed over how the stars should be arranged in the sky.
HARUN MEHMEDINOVIĆ

With a population of 7.3 million, Hong Kong now ranks as the brightest city on the planet. This view is from Lion Rock Country Park.
GAVIN HEFFERNAN

A passing car and the resulting lens flare disturb the tranquility of wildflowers carpeting Death Valley National Park.
HARUN MEHMEDINOVIĆ

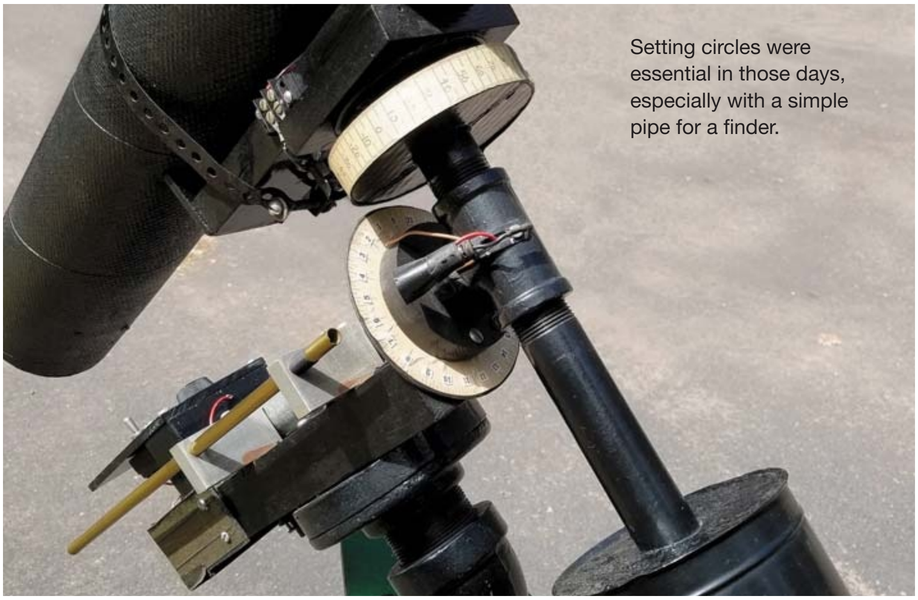
Having survived more than 4,000 years in what is now California's Inyo National Forest, ancient bristlecone pines remind us how our distant ancestors must have seen the stars every night.
GAVIN HEFFERNAN

State of the Art — 63 Years Ago

How amateur telescope making was done in the early days.

RIGHT FROM THE START, amateur astronomers have faced a dilemma: buy or build? Johannes Kepler famously asked Galileo to construct a telescope for him, but Galileo declined, forcing Kepler to design and manufacture his own. Unavailability, frugality, or simple curiosity has led people to make their own telescopes ever since.

The heyday of amateur telescope making arguably occurred in the 1950s, when professional astronomy was enjoying the success of grand telescopes like the 200-inch Hale telescope on Mount Palomar and new discoveries were being announced almost daily. Amateurs wanted to get in on the fun, but commercial telescopes were few and expensive, so many people, if not most, built their own.



Setting circles were essential in those days, especially with a simple pipe for a finder.

Wisconsin amateur Jeff Johnson recently acquired a telescope built in 1954 and had the pleasure of discussing its origin with the builder, Bruce Peterson, who sold it to him for a princely sum of $45. The telescope is still in great shape 63 years later, and it serves as an excellent example of telescope design from the mid-20th century.

Jeff Johnson poses with his "new" scope . . . built in 1954.

As Jeff says, "What stands out for me is that the young man who built this telescope had an excellent understanding of what he had to build. He accomplished it using common materials. Everything but the tube, mirrors and focuser are built of parts from the scrap yard and local hardware store."

The first thing you notice is the focal ratio. F/5 was unheard of back then; this scope was relatively average for the time at f/10. The primary mirror was 4 inches in diameter when the scope was first built, upgraded to 4½ inches sometime after. The two-part tube looks to be resin-impregnated fiberboard.

The primary mirror is mounted on a wooden base with holes drilled in it for cooling. Three perimeter screws and a central lock bolt allow for collimation.

The secondary mirror is only ¾ inches wide, presenting a 17% obstruction on the 4½-inch primary. (With such a minor obstruction, this scope is a planet killer!) It's mounted on a single rod that's held in place by a thumbscrew on the focuser casting. Secondary mirror collimation is limited to side swing and sliding in and out. Any other adjustments require bending the rod or shimming the focuser.

The scope is equatorially mounted, of course. Before John Dobson came along, almost all amateur scopes were. The mount is constructed with iron plumbing pipe, also a mainstay of ATMs of the time. In lieu of bearings, the pipe threads were lapped with fine grit and then lubricated to glide smoothly for the half-turn necessary for horizon-to-horizon slewing. Other construction materials were equally simple: wooden blocks and galvanized iron strap of the type we still use today.

Aiming was done by setting circles, also common in those days. The numbers were hand drawn in pencil on a strip of ruled material pasted to a wooden disk. The finder is almost an afterthought: just a section of narrow pipe mounted to the

JEFF JOHNSON (2)

side of the main tube. The polar alignment "scope" is also just a pipe, and an even narrower one at that.

The wiring you see in the photos is not for a motor drive, but to provide illumination for the vital setting circles. An extra bulb lights the eyepiece tray, and all bulbs are controlled by a switch and rheostat for brightness.

The counterweight is as expedient as it is necessary: The polar axis pipe was placed in a coffee can and filled with cement. No adjusting the weight up and down the shaft; it was designed for the scope as-built, and that was that.

Its pedestal is a drinking fountain base and weighs about 45 pounds. No surprise Jeff wheels it around on a dolly.

How does the telescope perform? Jeff reports, "As grimy as the mirror is, it's surprising how great the view is." The image is sharp even in a 10-mm eyepiece, but Jeff prefers to use a 25-mm. At high power, without tracking, mounted equatorially, and with a pipe for a finder, Jeff states, "It's a pain finding anything and staying on it."

In the 1950s, though, this was state of the art among amateur telescope makers, and people did a lot of great observing with scopes like this one.

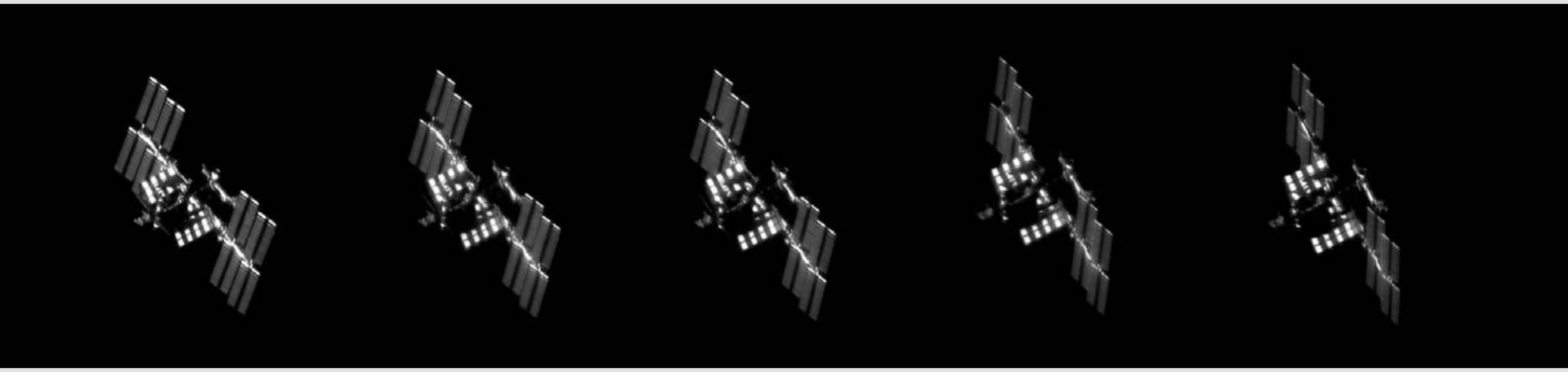
Next month: the cutting edge today.

■ Contributing Editor **JERRY OLTION** wasn't even born yet when this scope was showing its builder the wonders of the night sky.

JEFF JOHNSON

The secondary mirror is mounted on a single arm that allows it to swing sideways and move in and out. Note the pipe used as a finder.

LEAPING EMU IN
THE FAR-SOUTHERN SKY
Howard L. Ritter Jr.
This stretch of the Milky Way starts at the tail of Scorpius (far left) and glides up through Crux and the Coal Sack (center) to the Carina Nebula and beyond. Aboriginal Australians imagined this region's dark nebulae as an emu, with the Coal Sack as its head. The Magellanic Clouds are at lower right. The camera sat on a picnic table for this untracked celestial snapshot.
DETAILS: *Nikon D810A DSLR camera at ISO 3200 with a 14-to-24-mm lens set to 14 mm. Exposure: 30 seconds.*



◁◁ NORTHERN GIANT

Ron Brecher

Curiously, the immense (3°-wide) emission nebula IC 1396 has no common name. But it's a favorite imaging target, and this view isolates the object's appearance in hydrogen-alpha light. Herschel's Garnet Star (4th-magnitude Mu Cephei) is at top.

DETAILS: *Takahashi FSQ-106 ED IV astrograph with Moravian Instruments G3-16200 EC CCD camera and Hα filter. Total exposure: 3.3 hours.*

◁ IC 1396 IN "HUBBLE COLOR"

César Blanco González

Here's the same object recorded in the "Hubble palette" — narrowband emissions from hydrogen, oxygen, and sulfur atoms.

DETAILS: *Takahashi FSQ-106 ED astrograph and QSI 583ws CCD camera with Astronomik Hα, O III, and S II filters. Total exposure: 20 hours.*

◁ ELEPHANT'S TRUNK

Jerry Gardner

Nested inside IC 1396 is the dark, dense globule vdB 142, the Elephant's Trunk Nebula. It's some 20 light-years long and nearly 3,000 light-years away.

DETAILS: *Sky-Watcher Esprit 80mm ED Triplet APO refractor, Starlight Express Trius-SX694 CCD camera, and Hα and O III filters. Total exposure: 16.8 hours.*

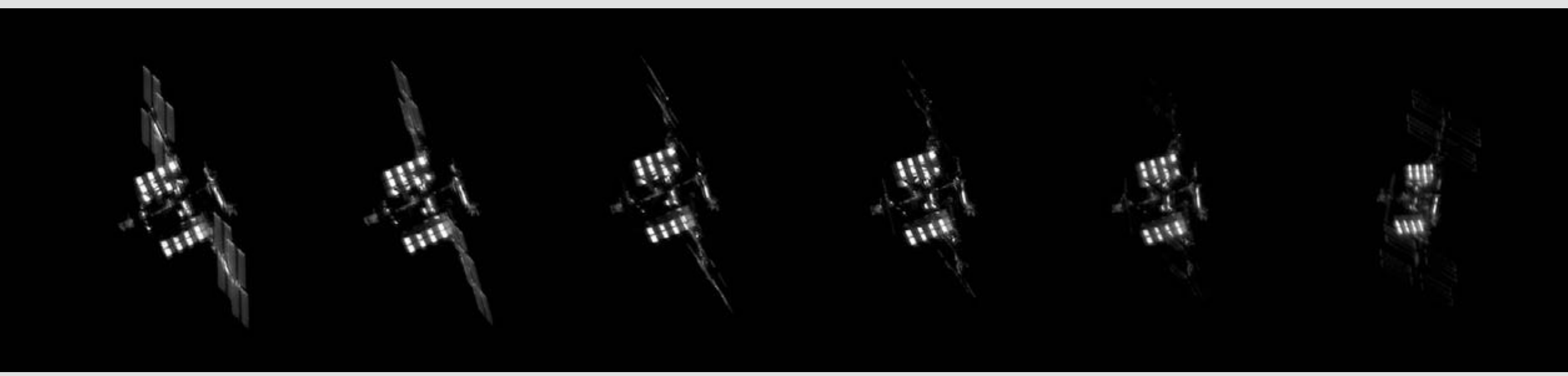
▽ "HELLO" AND "GOODBYE"

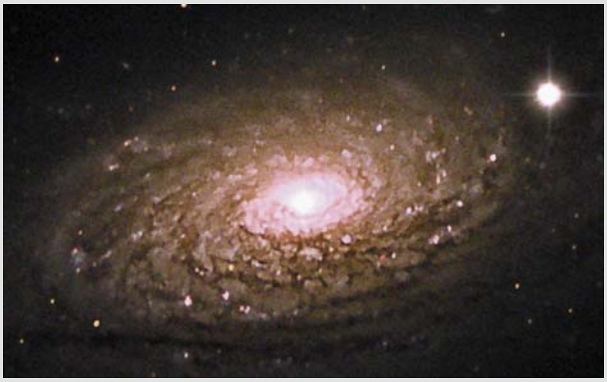
Alessandro Bianconi

The International Space Station soars above Sardinia on June 12, 2017, and a camera down below captured the flyby with exquisite detail.

DETAILS: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope and ZWO ASI 290MM CMOS video camera. Exposures: 1/100 second.*

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





◁ SUNFLOWER GALAXY

David Collings

Messier 63, in Canes Venatici, is a 9th-magnitude spiral galaxy with many short spiral arm segments. It's about 27 million light-years away.

DETAILS: *Celestron EdgeHD 11 Schmidt-Cassegrain telescope and Starlight Express Trius-SX814C color CCD camera. Total exposure: 140 minutes.*

◁ COMET JOHNSON MAKES A PASS

Chris Schur

With a total brightness of about 7th magnitude, Comet Johnson (C/2015 V2) was a pretty sight as it coasted through Virgo on June 15, 2017.

DETAILS: *Orion 10-inch Newtonian astrograph with SBIG ST-10XME CCD camera and LRGB filters. Total exposure: 62 minutes.*

▽ STARS & MOONLIGHT

Amirreza Kamkar

Light from a soon-to-set waxing gibbous Moon illuminates the shoreline of Soha Lake near Ardabil, Iran, in a seven-frame panorama taken June 4, 2017.

DETAILS: *Modified Canon EOS 5D Mark II used at ISO 1600 and 24-mm lens. Exposures: 15 seconds each.*

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

New Male Potency Formula Makes "The Little Blue Pill" Obsolete

Soaring demand expected for new scientific advance made just for older men. Works on both men's physical ability and their desire in bed.

New men's pill overwhelms your senses with sexual desire as well as firmer, long-lasting erections. There's never been anything like it before.

By Harlan S. Waxman
Health News Syndicate

New York – If you're like the rest of us guys over 50; you probably already know the truth… Prescription ED pills don't work! "Simply getting an erection doesn't fix the problem," says Dr. Bassam Damaj, chief scientific officer at the world famous Innovus Pharma Laboratories.

As we get older, we need more help in bed. Not only does our desire fade; but erections can be soft or feeble, one of the main complaints with prescription pills. Besides, they're expensive… costing as much as $50.00 each

Plus, it does nothing to stimulate your brain to want sex. "I don't care what you take, if you aren't interested in sex, you can't get or keep an erection. It's physiologically impossible," said Dr. Damaj.

MADE JUST FOR MEN OVER 50

But now, for the first time ever, there's a pill made just for older men. It's called Vesele®. A new pill that helps you get an erection by stimulating your body and your brainwaves. So Vesele® can work even when nothing else worked before.

The new men's pill is not a drug. It's something completely different

Because you don't need a prescription for Vesele®, sales are exploding. The maker just can't produce enough of it to keep up with demand. Even doctors are having a tough time getting their hands on it. So what's all the fuss about?

WORKS ON YOUR HEAD AND YOUR BODY

The new formula takes on erectile problems with a whole new twist. It doesn't just address the physical problems of getting older; it works on the mental part of sex too. Unlike the expensive prescriptions, the new pill stimulates your sexual brain chemistry as well. Actually helping you regain the passion and burning desire you had for your partner again. So you will want sex with the hunger and stamina of a 25-year-old.

THE BRAIN/ERECTION CONNECTION

Vesele® takes off where Viagra® only begins. Thanks to a discovery made by 3 Nobel-Prize winning scientists; Vesele® has become the first ever patented supplement to harden you and your libido. So you regain your desire as well as the ability to act on it.

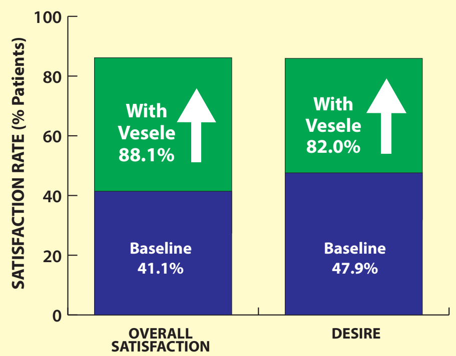
In a 16-week clinical study; scientists from the U.S.A. joined forces to prove Nitric Oxide's effects on the cardio vascular system. They showed that Nitric Oxide could not only increase your ability to get an erection, it would also work on your brainwaves to stimulate your desire for sex. The results were remarkable and published in the world's most respected medical journals.

THE SCIENCE OF SEX

The study asked men, 45 to 65 years old to take the main ingredient in Vesele® once a day. Then they were instructed not to change the way they eat or exercise but to take Vesele® twice a day. What happened next was remarkable. Virtually every man in the study who took Vesele® twice a day reported a huge difference in their desire for sex. In layman's terms, they were horny again. They also experienced harder erections that lasted for almost 20 minutes. The placebo controlled group (who received sugar pills) mostly saw no difference.

AN UNEXPECTED BONUS: The study results even showed an impressive increase in the energy, brain-power and memory of the participants.

JAW-DROPPING CLINICAL PROOF



	Vesele	Baseline
Overall Satisfaction	88.1%	41.4%
Frequency of sex	79.5%	44.9%
Desire for sex	82%	47.9%
Hardness during sex	85.7%	36.2%
Duration of erection	79.5%	35%
Ability to satisfy	83.3%	44.1%

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- **An increased intensity in orgasms.**
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- **Amazing orgasms!**
- **I feel more confident in bed**

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AD INDEX

The Name Game

Have a go at this celestial sport. You might just win gold.

WHEN AMATEUR ASTRONOMERS daydream, we often think about our next purchase. But I'll bet many also muse about a prize that can't be bought. Typically it requires loads of time at the eyepiece — or at the computer examining digital files — and a whopping dose of luck. I'm referring to the discovery of a new comet, asteroid, supernova, or nebula. Most of us will live out our astronomical lives without ever fulfilling such a fantasy.

But I've got an easier way, albeit less thrilling, to ensure one's astronomical legacy: name an object!

If a target visible through the average amateur eyepiece readily takes the shape of something or someone most people would recognize, it probably has a name already. Cross such objects off your list. Sure, you might think that NGC 6992 looks like Richard Nixon in profile. But you may have a hard time convincing other amateurs to begin calling the Eastern Veil Nebula after a disgraced former U.S. president.

Digital astrophotography has given us thousands of other possibilities, however: vast numbers of unnamed NGC or IC objects, not to mention those in lesser known catalogs. Amateurs routinely image many of these with magnificent results. Although photographs of some of these entities will show up in the pages of *S&T* or other publications, they may remain obscure because they lack a catchy appellation. Here's your chance.

> Find yourself an unnamed object and bestow a grabby moniker on it.

It's not difficult. After you complete your image processing, stare at the object on your monitor. Zoom in and out, rotate clockwise, then counterclockwise.

▲ NGC 3576, now the Statue of Liberty Nebula

Relax your mind and drift downstream, all the while watching for some compelling, previously unseen form to emerge and trigger a "eureka" moment.

I didn't always have this obsession. Just finishing a picture used to be enough, given the plethora of gremlins trying to strike me down during data acquisition or image processing. But there I was about eight years ago, assembling an image of NGC 3576, when suddenly, staring back at me from my screen, was that famous lady in New York Harbor who has welcomed millions of immigrants from abroad. Yes — a semi-abstract, spooky likeness of the Statue of Liberty looms out of a minor nebula in Carina (*S&T:* Aug. 2010, p. 79).

Excited about my "discovery," I googled to see if anyone else had noted the similarity. I found nothing. So I posted the image to my website — this was before astrophotographers routinely used Facebook to notify the world of a new picture — and I, well, took the liberty to "officially" nickname NGC 3576.

Today, I'm happy to report that most imagers have adopted the designation "Statue of Liberty Nebula," which is on its way to becoming the default sobriquet for this beautiful nimbus.

A memorable name helps to popularize astronomy. Would the Horsehead Nebula have entranced the public for generations if astronomers had only called it B33? I think not. So find yourself an unnamed object and bestow a grabby moniker on it. Then spread the word. The astronomy outreach gods will thank you, and you might just write yourself into the history books.

■ **STEVEN MAZLIN, M.D.**, a neurologist by day, images the cosmos from his backyard outside Philadelphia as well as remotely in Chile.

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