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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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RON BRECHER

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OBSERVING

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COLUMNS / DEPARTMENTS

ON THE COVER

Matter's flow outlines several voids in our cosmic neighborhood.

JOHAN HIDDING / UNIV. OF GRONINGEN / KAPTEYN INST.

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The Big Empty

YOU MIGHT ASK WHY we would do a cover story on cosmic voids — those stupendously vast, largely galaxy-free Saharas of space. After all, astronomy is all about observing *things*, not nothings, right? Even if you wanted to look there, as a zealous coterie of professional astronomers does, it's not a walk in the park. As one of these folks wryly notes in our article on page 12, "Observing empty space is very hard."

Well, it turns out that cosmic voids play a key role in shaping the large-scale structure of the universe. As gravity draws galaxies together, so it lures them away from voids. Take the example of our Local Void, as it's prosaically known. This fantastically empty zone steepens the gravitational "hill" that our Milky Way Galaxy slides down at a dizzying 630 km/s (1.4 million mph).

Voids are captivating to researchers, because they might help us better probe those invisible presences, dark energy and dark matter. They may also aid us in testing general relativity: Any tiny effects that might sit uncomfortably with Einstein's theory may be easier to detect in those desolate hollows than amid the hustle and bustle of galaxies. In the end, to gain a robust understanding of our place in the universe, we can't ignore voids. It'd be like learning all we can about island chains while paying no mind to the boundless oceans around them.

Barnard's Galaxy, a lonely outpost between the Milky Way and the Local Void

ESO

And there *are* things to see in voids, just not many of them. Astronomers have identified a few lone galaxies in our Local Void, for example. Each of them is beating a hasty retreat towards clumps of galaxies, like a lost hiker gravitating toward far-off sounds of people. The center of the Local Void happens to lie on the opposite side of our galactic core, which makes it a beast to observe. But radio telescopes can penetrate the intervening dust, gas, and starlight. And because the Local Void juts above and below the core, amateur astronomers might be able to help discover faint galaxies within the void using CCD cameras under ink-dark skies.

Even armchair astronomers can get something out of voids, which offer much to work the brain. The Local Void might be 250 million light-years across. *Whoa*. One light-year equals 63,240 astronomical units, with 1 a.u. being the distance from Earth to the Sun. Multiply that 63,240 by 250,000,000. I'm out of breath just thinking about it. Or try this on for size: Space expands faster in voids than in galaxies. Who knew? Nothingness grows bigger faster than somethingness does!

Perhaps now — if you didn't already — you can see why we devoted the cover to something unseeable.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Image courtesy of Tom O Donoghue.

Solo Artist

It took me a few glances over a couple of days at the "new, pancake-shaped artist's concept of `Oumuamua" (*S&T:* July 2018, p. 8) to finally see it: `Oumuamua is the *Millennium Falcon*, albeit rusty.

Coincidence? I think the new, pancaked-shaped artist has a sneaky sense of humor. (What was wrong with the old pancaked-shaped artist, anyway?)

I'll definitely be keeping a closer eye on all your content.

Jeff Martin • San Diego, California

▶ Perhaps this strange visitor from another solar system isn't such a stranger after all.

Another Approach to LPCs

Thank you for giving due mention to long-period comets in your feature article about the impact threat (*S&T:* June 2018, p. 12). Too often these days planetary defense is equated with defense against rogue asteroids exclusively.

One feature of the acknowledgment of the cometary threat remains puzzling, however, and indeed disturbing. Alan Harris is quoted as saying that, because of the short warning time for an LPC heading our way, "The best you can do is evacuate and things like that."

However, a typical LPC is larger than the minimum size of an object that scientists have agreed presents "the risk of civilization-ending catastrophe." So unless the evacuation Harris has in mind is to another habitable planet, a different approach is called for.

The obvious alternative, which has been advocated by other scientists in this area such as Brent Barbee and Joseph Nuth, is to design, test, and build a deflection infrastructure prior to the discovery of any such object . . . in other words, beginning right now.

Joel Marks
Milford, Connecticut

Astronomer Seeks Companion

The mention in "Messier 27: The First Planetary Nebula" by Howard Banich (*S&T:* July 2018, p. 66) of an unseen stellar companion definitely piqued my curiosity, since I seemed to recall that there was already a suspected main-sequence star companion near the central star of this nebula.

I fired up the CDS's *Aladin* software and overlaid proper motions from the Gaia DR2 database onto Pan-STARRS imagery of M27 to try to find this previously suspected companion. I was surprised to see not one but two other stars within 8 arcseconds of the central star with proper motions and parallax measurements essentially identical to that of the central star, within Gaia's measurement error. One is an early *K*-type dwarf that I believe was already a suspected companion, and the other is a 19th-magnitude probable red dwarf that might be a companion as well, which I think would be a new find.

However, radial-velocity measurements are necessary in order to determine the probability that these other stars are indeed companions. If they are, then it means that the progenitor system to M27 could have been somewhat analogous to the Alpha Centauri triple-star system.

Does anyone have a big telescope with a high-resolution spectrograph to follow up?

Jeffrey Neubauer
Tucson, Arizona

Howard Banich replies: *I'm impressed that you took the time to dig into the Gaia DR2 release to look for companions to the Dumbbell's central star and came up with two possibilities. It would be really cool if they are true companion stars, and I hope someone does point a big scope with a high-resolution spectrograph at M27's central star to find out one way or another. It would be awesome if it turns out to be a multiple star!*

Martian Greenwich

Your special issue on Mars prompts me to ask something I've always wondered: Who established the 0° point for longitude on Mars, and when? In the article on "canals" (*S&T:* July 2018, p. 28), both Schiaparelli's and Flammarion's maps have it in the same place, just where it is on modern maps. Does this location predate them? What's more, the point doesn't seem to focus on any prominent Martian feature, and there's no "Greenwich," so what was the basis for placing it where it is?

Jan A. Maas
Alexandria, Virginia

Contributing Editor Bill Sheehan replies: *In 1830, while making the observations that led to the first map of Mars, German astronomers Wilhelm Beer and Johann Heinrich von Mädler used the 3.75-inch Fraunhofer refractor in Beer's private observatory in the Berlin Tiergarten. They were struck by the appearance of a small round patch "hanging from an undulating ribbon," which because of its small size and conspicuous form they regarded as a convenient reference point for determining the rotation period of Mars. It was designated with the letter "a" and served as the prime meridian on their map. (Curiously, later, in 1840, when Mädler was in Dorpat and had the use of its 9.6-inch Fraunhofer refractor, he was unable to recover the feature and doubted the permanency of the Martian markings of which he had been sure in earlier years. Was the area covered by a dust storm as it is now?)*

As astronomers with better telescopes studied the planet, they discovered the round spot was actually more complex in structure. Rev. William Rutter Dawes in the

`OUMUAMUA: © WILLIAM K. HARTMANN; MILLENNIUM FALCON: MANFRED SCHMID / GETTY IMAGES

1860s found that it appeared forked — thus the feature is sometimes referred to as Dawes' Forked Bay. Later mappers, including Richard A. Proctor (and Flammarion and Schiaparelli) continued to follow Beer and Mädler's convention in using this as the Martian prime meridian. Since then, the IAU has designated Airy, a 43-km-wide crater, as the location of the "Martian Greenwich."

Funding SETI

David Grinspoon attributes the 1990s cut in funding for the search for extraterrestrial intelligence to "anti-intellectual budget cutters" (*S&T:* July 2018, p. 12). But there are other, more legitimate reasons why SETI funding was not a high priority in the 1990s.

First, radio-based SETI is a huge signal-processing problem, and it would have been reasonable to expect that hardware costs would decrease dramatically in the future (as they in fact have).

Second, high-power radio-frequency transmissions (with effective radiated power exceeding 1 megawatt) might be an infrequent or short-lived aspect of technologically advanced civilizations. Note that much of the UHF band, a frequency space once dedicated to TV transmissions, has been switched to use by mobile phones.

Third, there hasn't been any irrefutable evidence of extraterrestrial life, though Mars provides some tantalizing hints. We also might be on the verge of detecting the signature of life in the atmospheres of planets outside our solar system. Finding that life of any kind exists elsewhere would be a huge boost in the incentives for SETI funding.

Erik Magnuson
Cardiff, California

A Wish for Wedel

We wish upon a star that somehow Mathew Wedel can find a way to continue the amazing articles explaining Earth's events when the light that we now see departed the celestial objects he names (*S&T:* June 2018, "Fifteen Steps to Forever," p. 64; December 2016, "Twelve Steps to Infinity," p. 24). These space-and-time journeys with light underscore the fascinating, incomprehensible size of the universe.

Frederick J. Summers
Ferndale, California

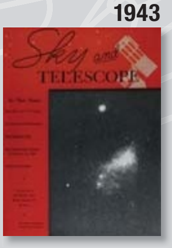
FOR THE RECORD

- "Hunting Phobos and Deimos" (*S&T:* July 2018, p. 53) should note that Phobos can appear as much as 22 arcseconds (not 16) from the limb of Mars.
- The Gallery caption for NGC 1514 (*S&T:* July 2018, p. 75) should have stated that new findings show the companion star's orbital period to be 3,306 days, or a little over 9 years.

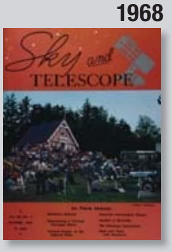
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

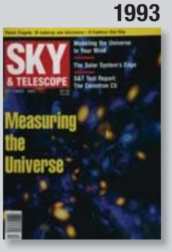
1943



1968



1993



October 1943

Mira's Maximum "A recent publication from Stockholm reports on the discovery of old record books kept by the 18th-century Swedish astronomer, Peter Wargentin. They contain valuable observations of Mira Ceti in the years 1751–1782. . . . Happily they cover the brightest maximum ever observed for that much-examined variable star.

"Mira has a period of over 330 days. Individual cycles differ considerably in amplitude. . . . The newly discovered old observations show that Mira attained magnitude 1.2 on November 11–12, 1799 — about twice the brightness of its more recent maxima."

October 1968

Mascons "Mass concentrations of dense material lie beneath the surface of the moon, report Paul M. Muller and William L. Sjogren of the Jet Propulsion Laboratory. Their evidence for . . . these 'mascons' comes from small changes noted in the motion of Lunar Orbiter 5, when very precise radio Doppler tracking was continued for 80 consecutive circuits of the moon. . . .

"Five conspicuous mascons, each about 50 to 200 kilometers in extent and perhaps 50 kilometers below the surface, were detected under . . . Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Nectaris, and Mare Humorum. . . .

"The JPL investigators comment in *Science* for August 16, 1968: . . . 'Does each of these mascons represent an asteroidal-sized body which caused its associated mare by impact?' "

NASA's 2012 GRAIL mission gave new insight into mascons. A Purdue University study concluded that large asteroid impacts carved huge craters, liquified the interiors, and drew in surrounding material that melted and congealed there.

October 1993

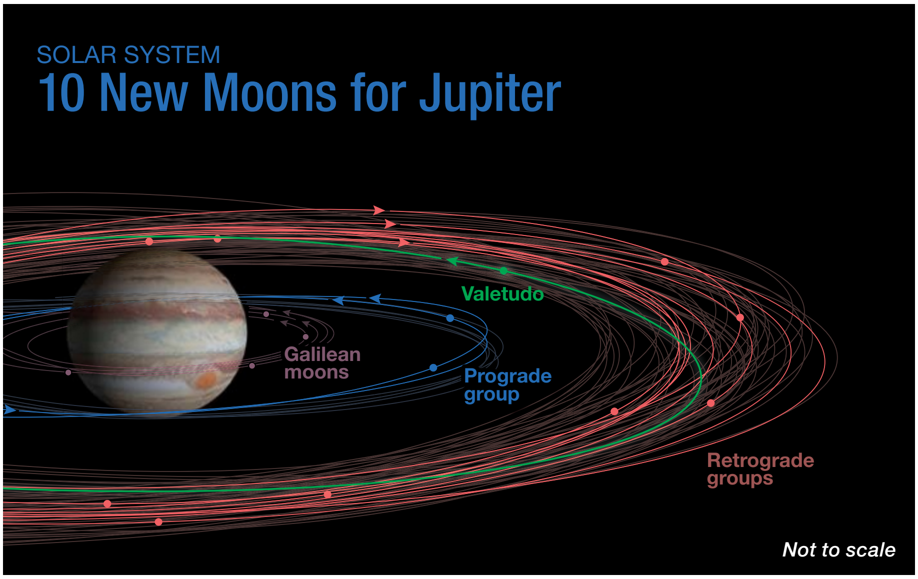
M31's Double Nucleus "Over the last three years astronomers using the Hubble Space Telescope have become accustomed to finding curious structures at the centers of active galaxies or galaxies undergoing collisions. But now they've found something odd in the core of a seemingly normal, quiet spiral. New Hubble images show that neighboring M31 in Andromeda has a double nucleus.

"Tod R. Lauer (National Optical Astronomy Observatories), Sandra M. Faber (University of California, Santa Cruz), and their colleagues made the announcement at the Space Telescope Science Institute on July 20th. Their observations with Hubble's Planetary Camera reveal that the bright spot identified as the nucleus in ground-based images is actually offset from the true dynamical center of the galaxy, marked by a fainter spot 5 light-years (½ arc second) to the southwest."

Further study, using HST's corrected optics, showed the nucleus to be a lopsided disk of stars orbiting M31's central black hole.

SOLAR SYSTEM

10 New Moons for Jupiter



▲ In this plot showing the orbits of Jupiter's 79 satellites, brighter colors indicate the 10 new finds and two others from last year (*S&T:* Sept. 2017, p. 13). The prograde moons (purple, blue) orbit relatively close to Jupiter, while its retrograde moons (red) are farther out. Valetudo (green) is the exception: a far-out prograde body.

ON JULY 17TH, the IAU's Minor Planet Center announced that a search team led by Scott Sheppard (Carnegie Institution for Science) has identified 10 new moons of Jupiter, bringing the known total to 79 — the most of any planet in our solar system. Of that total, Sheppard has led the searches that discovered 51 of them.

Dozens of Jupiter's moons circle the planet in a *retrograde* direction, that is, opposite that of the planet's spin, in a swarm of distant orbits. They cluster in three groups of 15 to 20 objects, named for members Ananke (discovered in 1951), Carme (1938), and Pasiphae (1908). Most likely each of these moonlet "families" represents fragments of larger precursors that were shattered by collisions early in Jupiter's history.

Of the 10 new finds, seven of them are among these retrograde objects. Two more of them orbit Jupiter in *prograde* directions (in the same sense as Jupiter's rotation) and appear to be members of a smaller group anchored by Himalia (discovered in 1904).

"Our other discovery is a real oddball and has an orbit like no other known Jovian moon," Sheppard notes. Designated S/2016 J2, it's far enough from Jupiter to be in the midst of the retrograde swarm. But this new find, provisionally named Valetudo, has a prograde orbit.

With the exception of Valetudo, all of the new finds were swept up in early 2017, when Sheppard was on solo observing runs in Chile using the 6.5-meter Magellan-Baade reflector at Las Campanas and the 4.0-meter Blanco reflector on Cerro Tololo.

"Jupiter just happened to be in the sky near the search fields where we were looking for extremely distant solar system objects," he says. Sheppard leads one of the teams searching for a putative massive planet thought to lie far beyond Pluto (*S&T:* Oct. 2017, p. 16).

Follow-up observations earlier this year allowed Sheppard to establish firm orbits for each object. Valetudo, in particular, becomes eligible for naming because it has now been observed during three oppositions of Jupiter. Valetudo is the Roman goddess of health and hygiene; she's a descendant of Jupiter and known as Hygieia in Greek mythology.

Sheppard's searches also swept up many of the 11 "lost" satellites of Jupiter, bodies whose orbits are so poorly known that they essentially have to be discovered all over again.

■ **J. KELLY BEATTY**

● **For more on this discovery, visit https://is.gd/10newmoons.**

SOLAR SYSTEM

Organics Inside Enceladus: Complex Enough for Life?

An artist's impression shows Cassini flying through the plumes of Enceladus.

NASA'S CASSINI made Enceladus, one of Saturn's icy moons, famous for its plumes of salty, organics-laced water-ice crystals. Now, a closer analysis of data from two spectrometers aboard the spacecraft reveals that the carbon-based brew inside Enceladus must be more massive and complex than previously realized.

Scientists had used Cassini's Ion and Neutral Mass Spectrometer, which can only measure up to 100 atomic mass units, to detect relatively simple organic compounds. For example, methane (CH_4) has an atomic mass of 16 amu. But in this new study, published in the June 28th *Nature*, data from the spacecraft's Cosmic Dust Analyzer (CDA) revealed that Enceladus's organic complexity extends up to thousands of atomic mass units.

Moreover, the CDA researchers, led by Frank Postberg (Heidelberg University, Germany) detected high-mass assemblages containing a likely ratio of one hydrogen atom for every two carbons. This implies the structures are "under-

COSMOLOGY

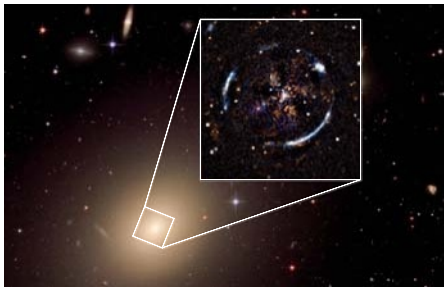
Best Long-range Test of General Relativity

ASTRONOMERS HAVE CONDUCTED the best galaxy-scale test of general relativity yet, and it rules out some (but not all) theories of modified gravity. These theories provide the main alternative to the existence of dark matter.

General relativity — which describes gravity as the curvature that mass induces on spacetime — has passed extensive tests within the confines of our solar system. But fewer tests exist on scales of thousands or millions of light-years. On larger scales, theories of modified gravity predict that gravity behaves differently than it does in our solar system. While astronomers have conducted some tests on galactic scales, none of them has put strong limits on modified gravity.

Now, a study led by Thomas Collett (University of Portsmouth, UK) in the June 22nd *Science* has provided such a test. The team investigated Hubble Space Telescope and Very Large Telescope observations of a so-called *Einstein ring*, where a nearby galaxy's gravity has bent light from a distant star-forming galaxy into a blue circle around itself.

Collett and colleagues first calculated the mass of the intervening galaxy by measuring the movements of stars within it. Then they measured the mass the intervening galaxy would have to have in order to bend the background galaxy's light into a ring. The mass inferred by spacetime curvature matches the mass as measured by the stars' motions — exactly as general relativity predicts.



▲ The nearby ESO 325-G004 (large elliptical galaxy in foreground) acts as a cosmic lens to distort the light from a more distant galaxy (inset). The so-called *Einstein ring* becomes visible after subtracting the lensing galaxy's light.

Unlike other lensing tests of relativity, Collett's team relied less on assumptions about the nature of the intervening galaxy. So this test is relatively free of systematic uncertainties that have plagued previous studies, says Lucas Lombriser (University of Geneva), who was not involved in the study. He calls the measurements "the most robust test of gravity of this type and on these length scales to date."

This study shows that gravity, as described by relativity, behaves as expected on scales less than 6,500 light-years. Additional tests will be needed to test modified gravity more generally.

■ MONICA YOUNG

COSMOLOGY

Pulsar Test Limits Existence of "Fifth Force"

SCIENTISTS RECENTLY STUDIED a pulsar binary system to constrain the existence of a hypothetical fifth fundamental force of nature.

We already know about four fundamental forces: gravity, electromagnetism, and the strong and weak nuclear forces. Some scientists attempting to explain anomalous experimental results have speculated about the existence of a fifth force of nature, one that could work on dark matter.

Relativity predicts that normal matter should fall freely toward dark matter. But a fifth force that has the ability to interact with both normal and dark matter could strengthen or diminish dark matter's gravitational pull. Lijing Shao (Max Planck Institute for Radio Astronomy, Germany) and colleagues tested for this effect using the binary system PSR J1713+0747.

Artist's concept of pulsar–white dwarf pair

This pulsar and its white dwarf companion, which are in a relatively wide 68-day orbit, lie 3,800 light-years from Earth in the direction of the galactic center. The pulsar, whose atoms have been compacted into neutrons, is so dense that its extreme gravitational field could enhance any possible interactions with dark matter. The white dwarf isn't nearly so compact. If a fifth force did exist, the Milky Way's dark matter halo, whose density peaks in the galactic center, would pull on the neutron star and the white dwarf in different ways, slightly altering their mutual orbit.

Drawing from more than 20 years of radio observations of this system, the researchers conclude that if a fifth force does exist, it must have less than 1% of gravity's strength — and gravity is already the weakest of the four known forces. The results appear in the June 15th *Physical Review Letters*.

■ ELIZABETH HOWELL

saturated" with hydrogen and rich in other atoms, such as oxygen or nitrogen.

Comets contain lots of organic material and likely contributed to Enceladus's makeup, but study coauthor Christopher Glein (Southwest Research Institute, San Antonio) says those small bodies exhibit a greater diversity and abundance of prebiotic compounds than what's seen at Enceladus. One possible explanation is that hydrothermal processes in the moon's interior drastically altered the primordial inventory, so only the most resilient molecules remain.

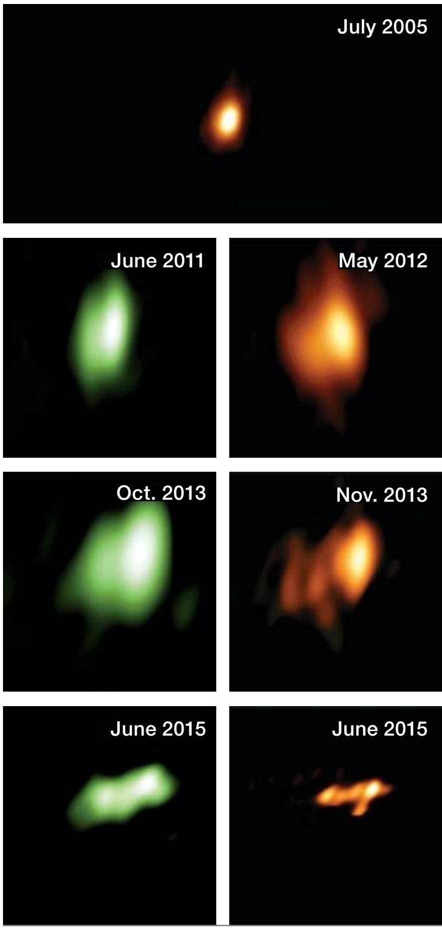
Or perhaps life arose in the ocean of Enceladus and has overwritten any organic signatures of its cometary heritage. A group led by Ruth-Sophie Taubner (University of Vienna, Austria) recently identified a strain of bacteria that can survive in Enceladus-like conditions by feasting on methane.

Still, Glein cautions that the default hypothesis is that Enceladus lacks any kind of life. With Cassini gone and no firm plans to send another spacecraft to Saturn's system, planetary scientists might wait decades to find out whether Enceladus harbors its own biology.

■ ELIZABETH HOWELL

● Visit https://is.gd/enceladusorganics for more information.

ORBITS OF JUPITER MOONS: CARNEGIE INSTITUTION FOR SCIENCE / ROBERTO MOLAR CANDANOSA; ENCELADUS: NASA / JPL; EINSTEIN RING: ESO / ESA / HUBBLE / NASA; PULSAR: ESO / L. CALÇADA



BLACK HOLES

Destroyed Star Feeds Black Hole Jet

FOR THE FIRST TIME astronomers have witnessed the birth and growth of a black hole's jet, fueled by a star shredded in the black hole's gravitational field. Such *tidal disruption events* are thought to fuel jets some 10% of the time, but until now the events have been too far away to see the resulting beams of plasma.

In January 2005 Seppo Mattila (University of Turku, Finland) and colleagues spotted an infrared flare near the active black hole of the western galaxy in the galactic pileup Arp 299. By July, a compact radio source had joined it. Over the next decade, this radio source grew and stretched into a clumpy streak. Material in the jet at first moved at almost the speed of light, then slowed down to a mere 22% of light speed as it ran into surrounding gas and dust.

◀ Over a decade, astronomers watched the radio-emitting region in Arp 299's western core stretch out into a jet, using frequencies of 5.0 GHz (orange) and 8.4 GHz (green).

The mere existence of the jet doesn't mean the flare-up comes from a disrupted star, cautions Suvi Gezari (University of Maryland), as active black holes often flare unexpectedly. But this event, called Arp 299-B AT1, has a big point in its favor: It created a jet that's angled away from the axis of the supermassive black hole. We see the big dusty donut surrounding the black hole edge-on, which means that a jet fueled by an accretion disk ought to be oriented vertically. Instead, the newly created jet points about 25° to 35° from our line of sight. That's easily done with a disrupted star, as its debris may fly out at any angle.

Mattila and colleagues calculated June 14th in *Science* that, based on their estimates of the event's radiative power, the destroyed star contained between 2 and 7 solar masses and unleashed a thousand times more radiation than a standard core-collapse supernova.

■ CAMILLE M. CARLISLE

PULSARS

A Magnifying Glass for a Pulsar

ASTRONOMERS HAVE DISCOVERED a pulsar that comes with its own magnifying glass — courtesy of its brown dwarf companion that's being torn to shreds.

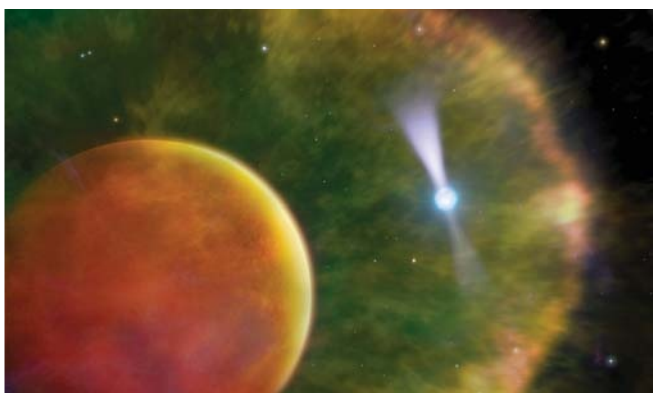
The pulsar PSR B1957+20 and the brown dwarf are dancing a cosmic dervish in an eclipsing binary system 6,500 light-years away. During every 9.2-hour orbit, the brown dwarf eclipses the pulsar for about 50 minutes.

Their dance won't last — in addition to its lighthouse-like beam of radio waves, the so-called "black widow" pulsar releases a fierce wind of energetic particles that's slowly blasting away its companion (*S&T:* Nov. 2013, p. 16). But before the brown dwarf fully disintegrates, its cocoon of plasma acts like a magnifying glass that resolves two areas of emission on the pulsar only 20 km (12 miles) apart.

Although astronomers have seen plasma lensing before, it wasn't obvious that it should happen in this system. But when Robert Main (University of Toronto) and colleagues observed the system for a full orbit using the 305-meter dish at Arecibo Observatory, they saw the radio pulses brighten just before and just after every pulsar eclipse. The magnification differed by frequency, just as expected for a lensing event.

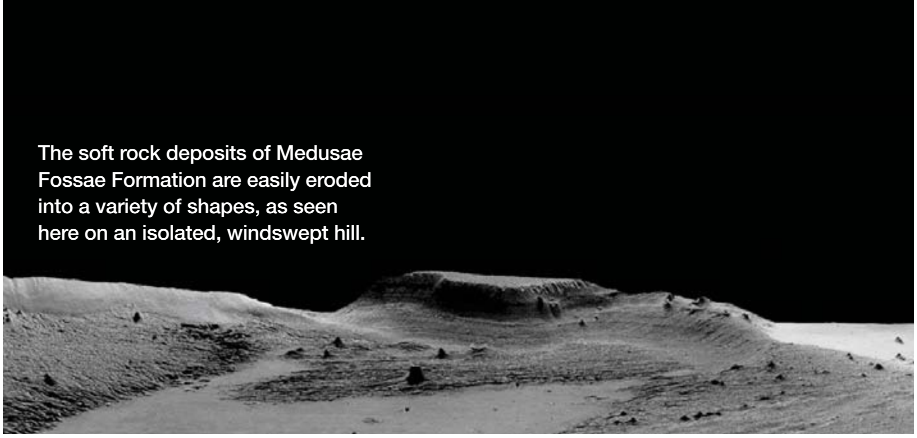
In the same way that water bends sunlight, plasma around the brown dwarf can bend and concentrate the pulsar's radio beam when the alignment is right. Moreover, it amplifies the emission from the pulsar's two poles differently, so the lens is actually resolving the emission from the top and bottom of the neutron star — that's the equivalent of resolving a flea on the surface of Pluto using Earth-based telescopes. (For reference, New Horizons flew right by Pluto and still only resolved features 80 meters, or 260 feet, wide.) The results appear in the May 24th *Nature*.

■ MONICA YOUNG



▶ In this artist's concept, the pulsar PSR B1957+20 is seen in the background through the cloud of gas enveloping its brown dwarf companion.

RADIO JET: S. MATTILA AND M. PEREZ-TORRES ET AL. / BILL SAXTON (NRAO / AUI / NSF); PULSAR: MARK A. GARLICK / DUNLAP INSTITUTE FOR ASTRONOMY & ASTROPHYSICS, UNIV. OF TORONTO



The soft rock deposits of Medusae Fossae Formation are easily eroded into a variety of shapes, as seen here on an isolated, windswept hill.

SOLAR SYSTEM

Long-ago Supervolcano Created Mars Rock Formation

SCIENTISTS HAVE ESTABLISHED that 3 billion years ago, a supervolcano created one of the largest rock deposits on Mars, the Medusae Fossae Formation (MFF), which spans an area equivalent to one-fourth of the contiguous U.S.

Scientists have been probing the nature of the massive formation since the 1960s. Using orbiter radar, they recently narrowed its composition down to two main possibilities: porous rock or kilometers-thick ice covered by ash.

Now, scientists have used gravity data from Mars orbiters to resolve the conflict, using the formation's gravitational pull on the satellites to infer its mass and density. Combining this information with the radar data enabled researchers to rule out ice as MFF's main ingredient, leaving porous rock as the viable candidate.

When a volcano explodes, explains lead author Lujendra Ojha (Johns Hopkins University), it spews gas, ash, and lava into the atmosphere. The pressure from the explosion causes lava to fragment. The highly fragmented lava then descends and starts to cool, trapping gas particles inside it to form porous rock.

This ancient supervolcano created the largest known volcanic formation in the solar system. Its eruptions would have had incredible effects on the Martian climate, spewing massive amounts of climate-altering gases into the atmosphere and ejecting enough water to cover Mars in a global ocean more than 9 cm (4 inches) thick. Ojha and JHU collaborator Kevin Lewis report this result in the June *Journal of Geophysical Research: Planets*.

■ JULIE FREYDLIN

Hayabusa 2 Arrives at Asteroid Ryugu

On June 27th, after a 3½-year journey, Japan's Hayabusa 2 (*S&T:* June 2018, p. 22) arrived at its home for the next 18 months: the kilometer-wide, die-shaped asteroid Ryugu (named after a dragon's palace in a Japanese folktale). The view shows a bifurcated pole, an as-yet unnamed large crater crossing its equatorial bulge, and plenty of boulders strewn about its surface. Hayabusa 2 is keeping pace 20 km (12 mi) from the asteroid in its orbit around the Sun and was due to approach to within 5 km by the end of July. The mission team will map the surface and analyze Ryugu's weak gravitational field before the spacecraft comes in for a series of sampling operations set to begin this fall. The sample will return to Earth by December 2020.

■ DAVID DICKINSON

▲ Hayabusa 2's view of Ryugu on June 26, 2018, one day before its official rendezvous.

MEDUSAE FOSSAE: HIGH RESOLUTION STEREO CAMERA / ESA; HAYABUSA: JAXA / UNIV. OF TOKYO / KOCHI UNIV. / RIKKYO UNIV. / NAGOYA UNIV. / CHIBA INSTITUTE OF TECHNOLOGY / MEIJI UNIV. / UNIV. OF AIZU / AIST

IN BRIEF

Webb Telescope To Launch in 2021

The launch of NASA's James Webb Space Telescope has been delayed to March 30, 2021. The new date is almost a year later than what NASA tentatively announced earlier this year (*S&T:* Jan. 2018, p. 12) and comes from a report released by an independent review board. The report puts a new price tag on the mission's development: $8.8 billion. This exceeds the $8 billion cap placed by Congress in 2011, which means that the mission will face Congressional reauthorization. While the astronomical instruments for Webb are ready to go, the spacecraft bus and the five-layer sunshield designed to protect the infrared instruments from the Sun's heat are still undergoing integration and testing. (To read more about specific problems, visit **https://is.gd/JWSTtesting**.) NASA has fully endorsed the review board's more than 30 suggestions, designed to address human errors as well as other factors impacting Webb's development schedule, including what board chair Thomas Young termed "excessive optimism." NASA and the independent review board both conclude that Webb's incredible science potential makes mission success critical: "Webb will be worth the wait," says Thomas Zurbuchen (NASA Science Mission Directorate).

■ MONICA YOUNG

Dawn Reaches Final Orbit Around Ceres

NASA's Dawn spacecraft has entered a new and final orbit that will take it less than 35 km (22 miles) above the surface of asteroid Ceres. Since the two first rendezvoused on March 6, 2015, the probe has come no closer than 385 kilometers to the dwarf planet's surface (*S&T:* Dec. 2016, p. 16). Attaining a lower orbit was no mean feat: NASA engineers examined more than 45,000 possible trajectories before settling on a solution. The final 27-hour, 13-minute orbit puts Dawn in a 3:1 resonant orbit with the asteroid, which rotates once every 9 hours, 4 minutes. In its last months, Dawn will map Ceres in unprecedented detail while continuing to collect neutron and gamma-ray spectra, which probe the surface's composition. Among other things, engineers are targeting the crater Occator before the mission's end later this year. To see images from Dawn's new vantage point, visit **https://is.gd/DawnsFinalOrbit**.

■ DAVID DICKINSON

AN EMPTY EXPANSE
Just beyond the Milky Way begins a vast near-emptiness of space some 250 million light-years wide. Graduate student Johan Hidding visualized this void using computational geometry, starting with galaxies cataloged in the 2MASS Redshift Survey and then recreating the filamentary cosmic web of dark matter that shapes how these galaxies are distributed.

The VO

ID
Next Door

An enormous region of near-emptiness starts on our doorstep, giving astronomers their best chance to probe one of these gigantic cosmic structures.

VISUALIZATION: JOHAN HIDDING / UNIVERSITY OF GRONINGEN / KAPTEYN INSTITUTE; BACKGROUND: KRIANTI / GETTY IMAGES

Galaxies are gregarious, most living near others. For example, our galaxy and its great spiral neighbor 2.5 million light-years away, Andromeda, rule the Local Group, which boasts more than 100 galaxies.

But on the far side of our galaxy, starting less than 4 million light-years from Earth, lurks a dark domain that bears almost no galaxies at all. Moreover, this void is gargantuan, spanning a *quarter billion* light-years. Its center hides behind the galactic plane in Aquila or Sagittarius.

At first glance, voids might seem as uninviting to astronomers as treeless meadows are to arborists. After all, you're not likely to dazzle your friends by showing them a void through your telescope.

But voids are important, because most of the space of the universe is in one void or another. Voids help sculpt the large-scale structure of the universe, as galaxies flow out of them and into the glowing sheets and filaments that crisscross the cosmos. In addition, the few galaxies that still inhabit voids may evolve differently from galaxies elsewhere.

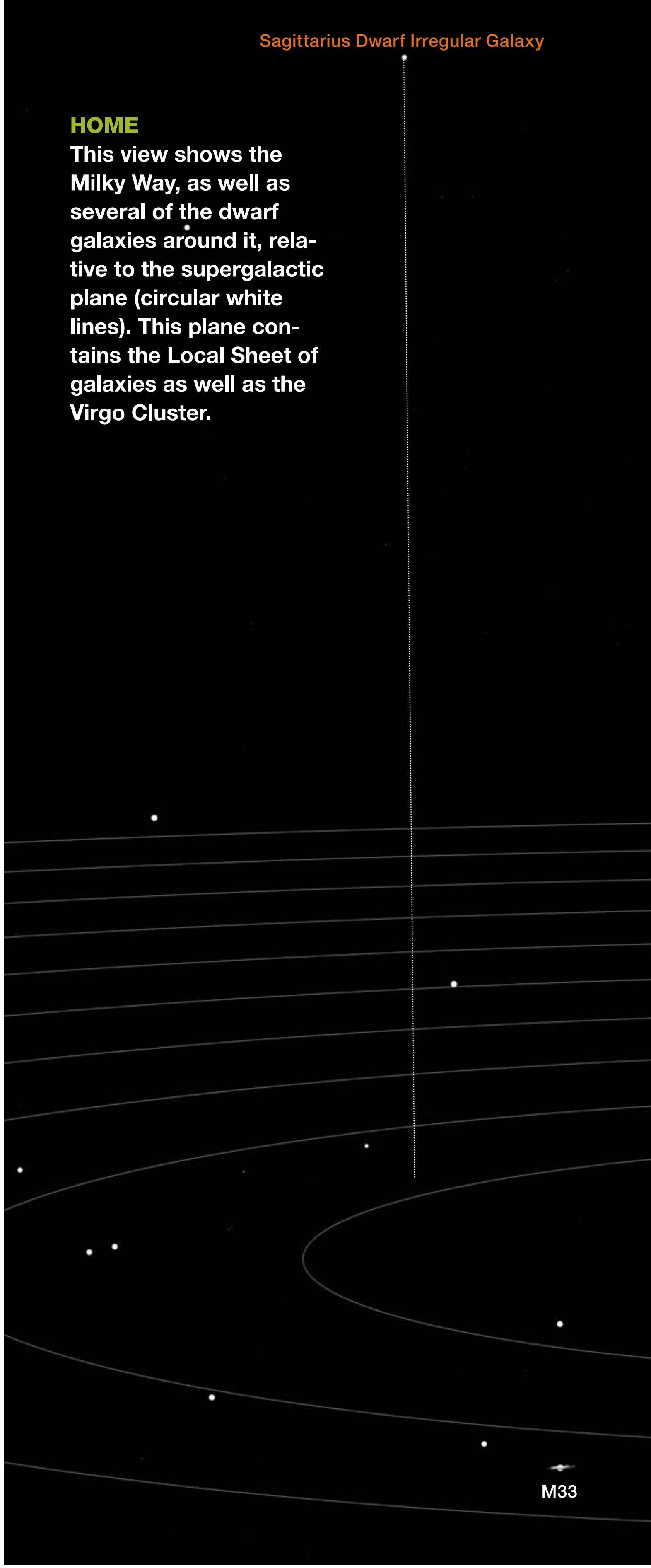
> The Local Void stretches out ahead of you for another **250 million light-years**. It's the intergalactic equivalent of driving through western Kansas.

Because of its proximity to us, the Local Void provides our best chance to study all of these effects in action. Here, astronomers can search for galaxies so feeble they would be undetectable in more distant voids. And because the few galaxies in the Local Void are nearby, we can scrutinize them to see whether they differ from galaxies that grew up in more urban locations.

Discovering the Local Void

Two decades before R. Brent Tully (University of Hawai'i) and J. Richard Fisher (National Radio Astronomy Observatory) discovered the Local Void, the pair had met in graduate school. "I was the data guy," Fisher says, "and Brent was the interpreter." Following the completion of their PhD theses, Fisher set out to observe more than 1,000 galaxies and measure their redshifts, a sign of their distances from the Milky Way. Tully then plotted the three-dimensional positions of these and other galaxies.

"There was a whole sector of sky that was really, really empty of galaxies," Tully says. Unfortunately, the dusty galactic plane cuts right through this empty sector, obscuring any galaxies it might possess. "But it pokes out on each side, well above and below the plane of the galaxy," he adds. In their 1987 *Nearby Galaxies Atlas*, which contains information on 2,367 nearby galaxies, Tully and Fisher called this barren region the Local Void.

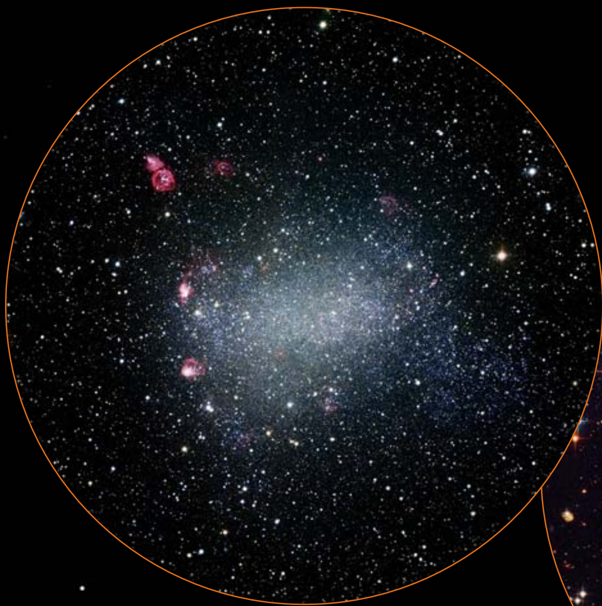


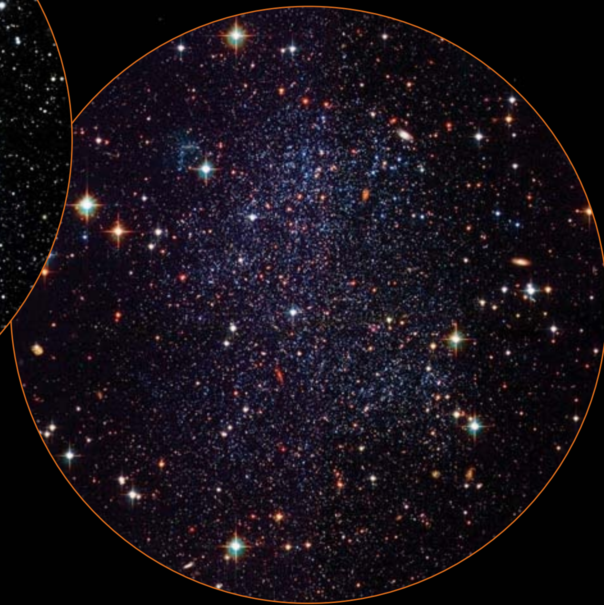
HOME
This view shows the Milky Way, as well as several of the dwarf galaxies around it, relative to the supergalactic plane (circular white lines). This plane contains the Local Sheet of galaxies as well as the Virgo Cluster.

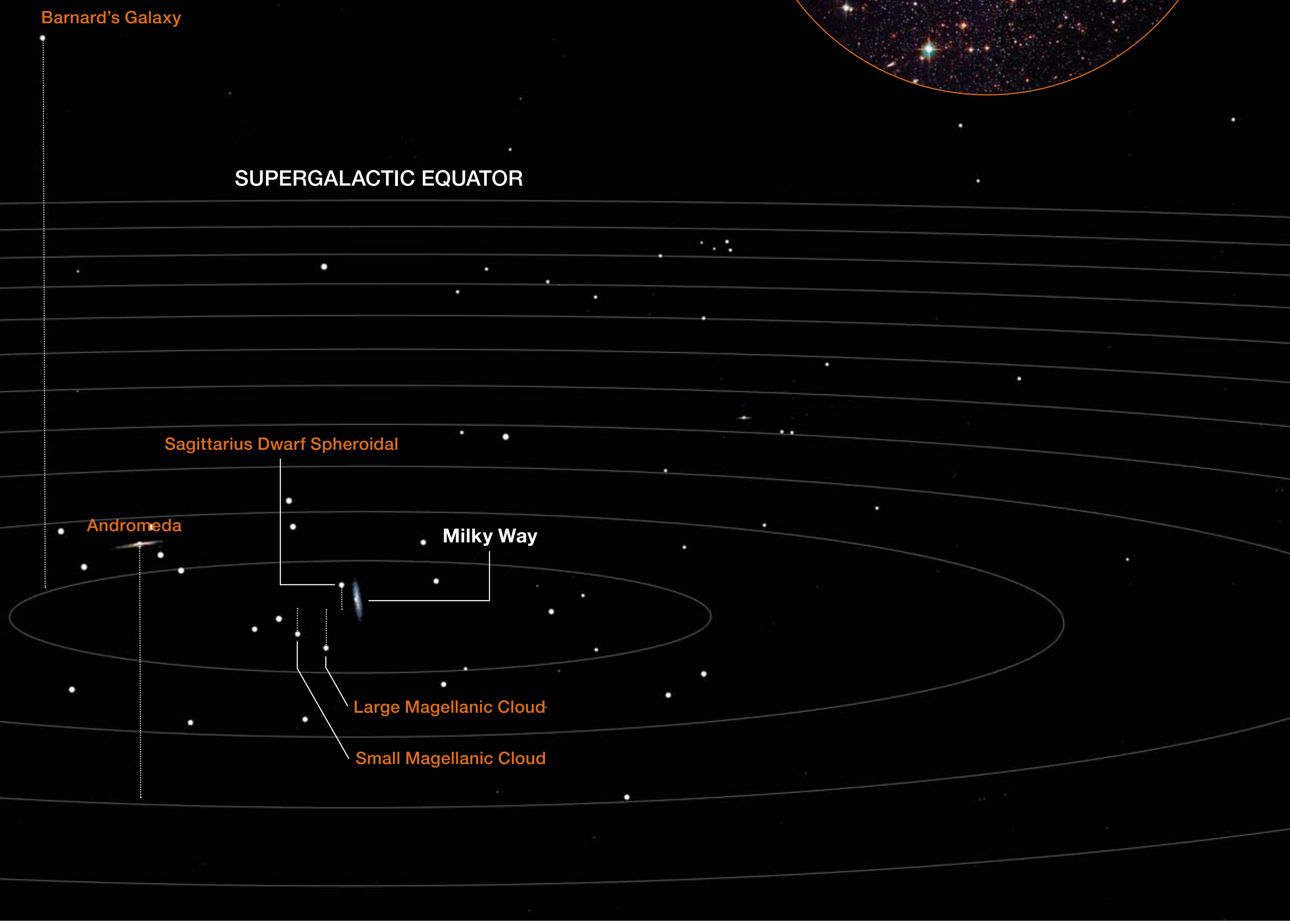
DIAGRAM: DANIEL POMARÈDE (CEA UNIVERSITÉ PARIS-SACLAY); BARNARD'S GALAXY: ESO; SAGITTARIUS DWARF IRREGULAR: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA), ACKNOWLEDGMENT: Y. MOMANY (UNIV. OF PADUA)

▶ BARNARD'S GALAXY This dwarf irregular galaxy, also known as NGC 6822, lies 1.6 million light-years from Earth.

▶▶ SAGITTARIUS DWARF IRREGULAR GALAXY Not to be confused with the Sagittarius Dwarf Spheroidal near the Milky Way, this galaxy floats 3.4 million light-years away at the edge of the Local Void.



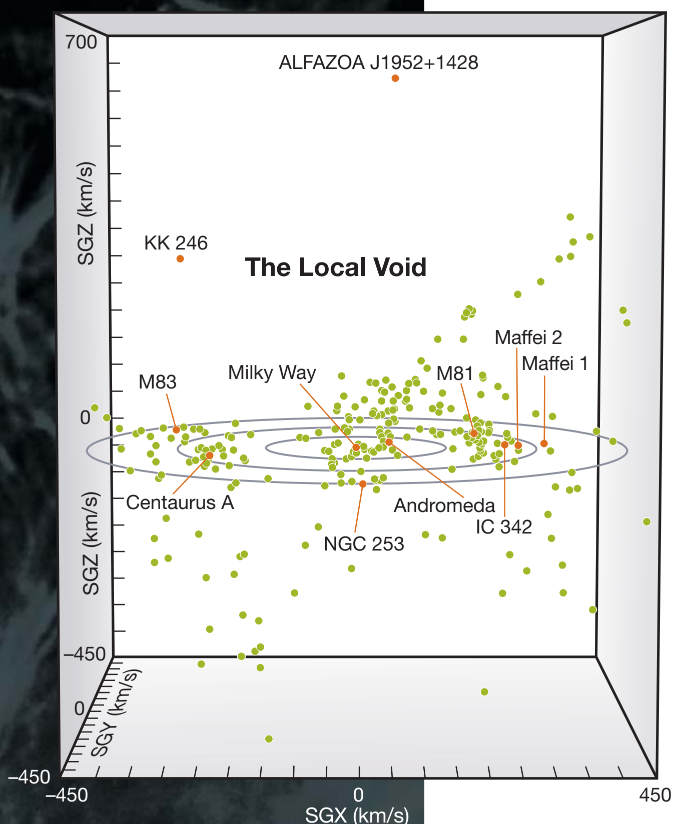




THE EIGHT GREAT GALAXIES NEXT DOOR

The Milky Way is such a colossus that only eight other galaxies within 20 million light-years rival its size, mass, and luminosity. Remarkably, all of the great galaxies nearby occupy the same plane, one that is proportionately even thinner than an American dime: the Milky Way and Andromeda Galaxies, the two superpowers of the Local Group; the giant spiral galaxy M81 in Ursa Major; the giant elliptical galaxy Maffei 1 and its giant spiral neighbors Maffei 2 and IC 342, which all hide behind interstellar dust in Cassiopeia and Camelopardalis; the giant edge-on spiral galaxy NGC 253 in Sculptor; and the giant elliptical galaxy Centaurus A and the giant barred spiral galaxy M83 in Hydra.

This plane nearly coincides with the so-called supergalactic plane, which includes the Virgo Cluster. In supergalactic coordinates, the SGX and SGY coordinates describe the supergalactic plane, and SGZ is perpendicular to it. The Great Attractor and Shapley Concentration lie at negative SGX and the newfound distant void lies at positive SGX; the Virgo Cluster lies at positive SGY; and the Local Void lies at positive SGZ, above the supergalactic plane. These clusters and voids move us toward negative SGX, positive SGY, and negative SGZ, explaining the Local Group's high speed through space.



▶ **LOCAL SHEET** Nine galaxies, including the Milky Way, dominate the Local Sheet, which sits below the Local Void from the perspective of the supergalactic plane. Circles on this plane mark 6.5 million, 13 million, and 20 million light-years. Two galaxies, KK 246 and ALFAZOA J1952+1428, are flying out of the void and toward the plane.

By then, astronomers had realized that most galaxies link up via dark matter to form a filamentary network across the universe. Between the bright nodes and filaments are dark voids, the sparsely populated countryside of the cosmos (*S&T:* Feb. 2015, p. 20). According to standard cosmology, voids are regions that started off with a bit less matter than average and then expanded.

The overall universe is also expanding, of course, but different parts do so at different speeds. Some regions, such as the Local Group, don't expand at all, thanks to the gravitational pull of the member galaxies. In contrast, voids contain so little matter that their gravity barely brakes the expansion, so they expand faster than the average. Over time, galaxy groups and clusters use their gravitational pull to lure additional galaxies into their lairs, tugging galaxies out of the centers of voids and toward their glowing edges.

"The rich get richer and the poor get poorer," Tully says. Just as gravity causes water to flow from mountaintops to valleys, so gravity makes galaxies stream from voids to groups and clusters. Voids therefore assist groups and clusters in shaping the universe's large-scale structure.

Recent searches behind the Milky Way's dusty veil confirm the Local Void's existence. "With a radio telescope, we can actually peer straight through the stars and the dust that obliterate the optical and even the infrared view," says Lister Staveley-Smith (University of Western Australia).

His team used the Parkes Observatory to seek unseen galaxies by the 21-centimeter radiation that their neutral hydrogen gas emits. "Astonishingly, we find very few external galaxies behind the central bulge of the Milky Way within quite a large radius," he says.

Voyage to the Void

Visiting this dark realm is easy. Just aim your starship into the Milky Way's disk, keeping Aquila on your left and Sagittarius on your right. After 27,000 light-years you speed past the Milky Way's center in Sagittarius, then reach the far side of the galaxy. As you zoom past the disk's edge, you look beneath the galactic plane to see the Sagittarius Dwarf Spheroidal, 85,000 light-years from Earth. This galaxy is a satellite of the Milky Way that our galaxy's tidal forces are tearing apart.

The Milky Way is mighty, far larger and brighter than most of its peers, but you soon leave our galaxy and its many satellites behind. You hurtle past two more Local Group galaxies in Sagittarius. The first, 1.6 million light-years from Earth, is Barnard's Galaxy, also known as NGC 6822. Farther out, at

GALAXIES DIAGRAM: LEAH TISCIONE / *S&T*, SOURCE: DANIEL POMARÈDE (CEA UNIVERSITÉ PARIS-SACLAY; SIDEBAR BACKGROUND: KRIANTI / GETTY IMAGES

"I love to talk about nothing. It's the only thing I know anything about."
—**Oscar Wilde**

3.4 million light-years, you spy the dim Sagittarius Dwarf Irregular Galaxy patrolling the Local Group's lonely frontier.

Then you plunge into darkness. The vast emptiness of the Local Void stretches out ahead of you for another 250 million light-years. That's right: 100 times the distance between the Milky Way and the Andromeda Galaxy, with almost nothing to see, left or right, up or down. It's the intergalactic equivalent of driving through western Kansas.

Nothing Really Matters

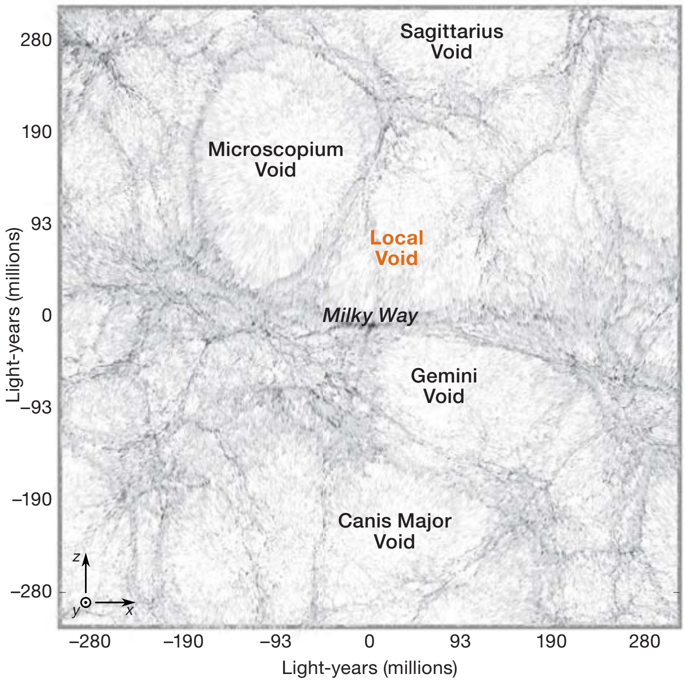
The Local Void is essential for understanding our motion through the universe. Astronomers measure our movement relative to the cosmic microwave background, the Big Bang's afterglow, which cosmologists define to be at rest relative to the universe. This radiation is blueshifted in the direction we're approaching and redshifted in the direction we're racing away from.

These measurements reveal that the Milky Way and its neighbors are zipping through the universe at 630 kilometers per second, or 1.4 million mph. That's fast: Earth circles the Sun at only 30 km/s, the Milky Way moves toward the Andromeda Galaxy at only 110 km/s, and the Sun revolves around the galactic center at approximately 250 km/s.

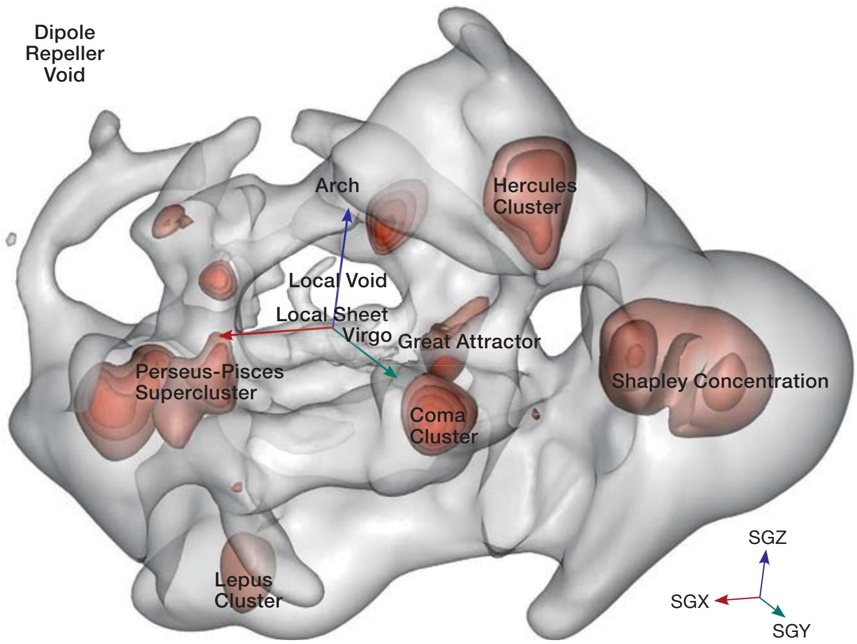
Astronomers have long known of two strong gravitational tugs that explain most of our motion through the universe. One comes from Virgo, the nearest galaxy cluster at 54 million light-years away, whose gravitational force tries to pull us toward it. The other tug comes from a grander gathering of more distant galaxies in a direction nearly perpendicular to Virgo — the Great Attractor and, beyond it, the Shapley Concentration. Plus, a newfound void dubbed the Dipole Repeller, much farther than the Local Void and on the opposite side of us from these clusters, helps them in this effort, making us flow down a steeper gravitational slope toward the clusters (*S&T:* May 2017, p. 8).

But these mighty structures explain only two of the three dimensions of our motion through space. The Local Void supplies the third.

In 2008, Tully's team found that we stream away from the gravitational hill the Local Void creates at about 260 km/s. That's greater than the Virgo-induced velocity, which the astronomers put at 185 km/s, but less than the speed toward



▲ **VOIDS IN THE NEIGHBORHOOD** Using computational geometry, Johan Hidding and others visualized the flow of matter near the Milky Way, which serves to outline the Local Void and several other nearby cosmic voids. The walls and filaments shown here represent dark matter structures, based on the distribution of galaxies cataloged in the 2MASS Redshift Survey.



▶ **ALL AROUND US** Several cosmic structures determine the motion of our galaxy, and indeed of the whole Local Group of galaxies, through space. We can understand this motion in three dimensions relative to the supergalactic plane: Our galaxy is moving back along the *x* axis, sliding down the gravitational hill created by the dense collections of galaxies in the Great Attractor and the Shapley Concentration on one end, and the Dipole Repeller void on the other end. The Virgo galaxy cluster pulls us along the *y* axis; meanwhile, the Local Void steepens the gravitational hill that our galaxy slides down on the *z* axis.

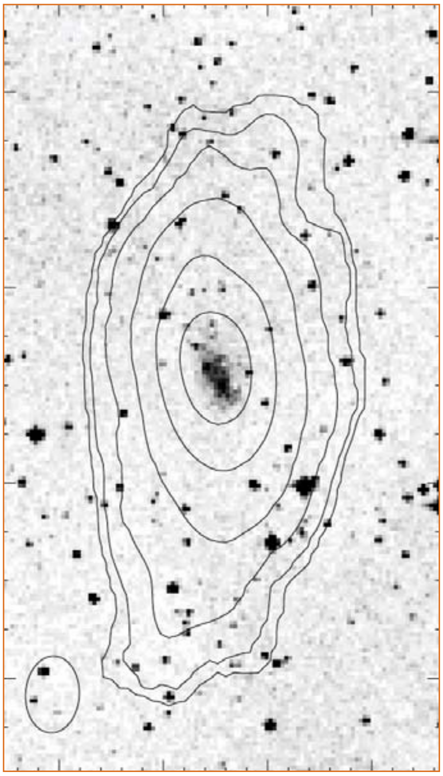
STRUCTURE: DANIEL POMARÈDE (CEA UNIVERSITÉ PARIS-SACLAY, ACKNOWLEDGMENT: YEHUDA HOFFMAN (HEBREW UNIV. OF JERUSALEM), HÉLÈNE COURTOIS (UNIV. OF LYON, FRANCE), R. BRENT TULLY (UNIV. OF HAWAI'I); LOCAL VOID IN CONTEXT: JOHAN HIDDING / UNIVERSITY OF GRONINGEN / KAPTEYN INSTITUTE

Patient observers could help cosmologists reconcile reality with theory by turning up new galaxies in the void.

the Great Attractor and the Shapley Concentration, which amounts to 455 km/s.

Furthermore, the Local Void's "push" is nearly perpendicular to the pulls from both Virgo and the Great Attractor. To picture the situation, you must know an amazing fact about the eight great galaxies nearest our own: Every galactic goliath within 20 million light-years of us resides in nearly the same plane (see box on page 16).

These great galaxies constitute part of what Tully calls the Local Sheet, which is a wall of the Local Void. The Local Void is above the Local Sheet and causes it to move down. As evidence for this movement, he points to the Leo Spur, a filament some 35 million light-years below the Local Sheet. Because of the Local Sheet's downward movement, the Leo Spur's galaxies have smaller redshifts than they would otherwise.



▲ **KK 246** The gaseous disk of this void galaxy in Sagittarius, marked here as contours, extends five times farther out than its stars do, as seen in the background black-and-white image.

Void Where Prohibited

Despite its name, the Local Void is not completely free of galaxies. "The void is partitioned by these wispy filaments that trace through it," Tully says. The filaments contain chains of galaxies that glow like dimly lit towns on a rural road. Nor is the Local Void perfectly round. Instead, it's lumpy.

The two nearest-known inhabitants of the Local Void are KK 246 and ALFAZOA J1952+1428; the two galaxies lie about 25 million light-years away, in Sagittarius and Aquila, respectively. Both galaxies are dwarf irregulars, miniature versions of the two brightest satellites of the Milky Way, the Large and Small Magellanic Clouds. The void galaxies emit only a few percent as much light as the Large Magellanic Cloud, but like the Magellanic Clouds they both possess gas that is spawning new stars.

In fact, it was the gas, not the stars, that first signaled the presence of the void galaxy in Aquila. Travis McIntyre, then a graduate student at the University of New Mexico, was searching for 21-centimeter radiation from neutral hydrogen gas in galaxies hiding behind the galactic plane. He found lots of new galaxies, but the one in Aquila stood out by virtue of its small redshift. "It was special because it was so close to our own galaxy," McIntyre says. Only later did he and his colleagues spot the galaxy's stars.

Because these two void galaxies are nearby, the Hubble Space Telescope can detect their red giants, aging stars whose apparent magnitudes reveal precise distances to their galactic homes. That's important, because by comparing the galaxies' distances with their velocities derived via redshifts, astronomers can see whether the void is actually expanding.

It's not easy, though. "Observing empty space is very hard," says Luca Rizzi (W. M. Keck Observatory).

Fortunately, the two void galaxies nearby are like glowing flotsam tracing the currents of a dark sea. "They are in the void, but they are closer to us than to the center" of the void, Rizzi says. In a study published last year, his team reported that both void galaxies are racing away from the Local Void's center and toward its wall at hundreds of km/s, a sign that the void is indeed expanding and growing ever emptier. "Voids like to get rid of galaxies as fast as they can," he says, as galaxies outside the voids tug the void galaxies away.

Both void galaxies are extremely isolated. Whereas lots of galaxies dwell close to our own, KK 246 doesn't have a single known neighbor within 10 million light-years.

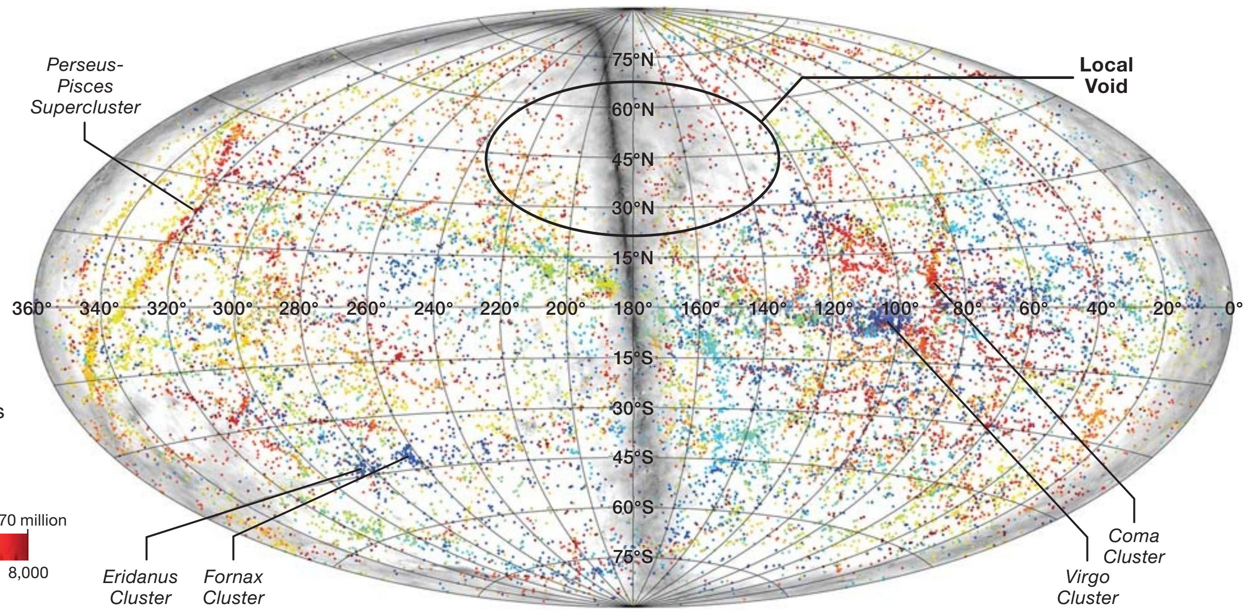
And yet, despite their extreme isolation, the void galaxies seem normal. They have gas, just like most of the Local Group's outlying members, and probably for the same reason: because there's no giant galaxy nearby to steal it. In fact, KK 246's gas disk extends five times farther out than its stars do. Even that isn't unique, however, as a few dwarf galaxies elsewhere have equally impressive gaseous envelopes.

Thus, as long as a dwarf galaxy steers clear of gas-grabbing giants, it can lead a normal life, whether or not it's in a void. Internal processes govern the galaxy's evolution.

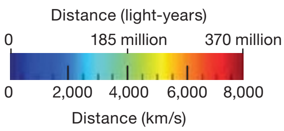
THE LEO SPUR

The Leo Spur is a filament of galaxies beneath the supergalactic plane and thus on the other side of us from the Local Void. Members include the irregular galaxy NGC 2337, which is 37 million light-years away in Lynx, and the edge-on spiral NGC 2683, which is 31 million light-years from Earth, also in Lynx.

DIAGRAM: KRECKEL ET AL., *THE ASTRONOMICAL JOURNAL*, JUNE 2011; SIDEBAR BACKGROUND: KRIANTI / GETTY IMAGES



▶ HIDING IN PLAIN SIGHT In this all-sky view of nearby galaxies, the plane of the Milky Way (gray) is almost directly perpendicular to the supergalactic plane, which extends from left to right. The Local Void (black oval) sits directly behind the galactic plane, which makes finding galaxies in this vast expanse a challenge.



Nothing Ventured, Nothing Gained

Still, the Local Void poses a possible problem for standard cosmology. "The Local Void is fascinating," says P. James Peebles (Princeton University). "From the point of view of a cosmologist, the enigma is how few stars there are in this void." Numerical simulations of cosmic evolution predict that voids should have a mass density that is about 10% of the mean density of the universe.

"That density — 10% of mean — is far greater than the number density of galaxies in the Local Void," says Peebles. He estimates the actual number density of Local Void galaxies is only about 1% of the cosmic mean.

So where are all the galaxies? Giants like our own don't form in such a sparse environment, but Peebles says dwarfs should still arise, albeit in smaller numbers than elsewhere. Because they are dim, dwarfs are harder to find than giants. However, the Local Void is so close that astronomers should have found more dwarf inhabitants than they have.

Not everyone thinks this "void phenomenon" spells trouble, though. Jeremy Tinker (New York University) says the apparent lack of dwarf galaxies agrees with numerical simulations of cosmic evolution. The matter that exists in voids consists primarily of dark matter plus a smattering of gas. In voids, this material may have gathered into dark galaxies that produced few if any stars.

"If there was literally no matter inside of the voids, that would completely blow the doors off" standard cosmology, Tinker says. "You would have to come up with some extra force to evacuate the mass out of the void, because gravity itself can't do it."

Peebles wonders whether amateur astronomers making long exposures with CCDs at dark sites might discern new dwarf galaxies in the Local Void.

"Wouldn't it be lovely?" he asks. "Amateurs pointing at the Local Void and just painfully stitching across it could pick up much fainter galaxies." He cites the work of amateur R. Jay GaBany, whose superb images have revealed dim structures around other galaxies (*S&T:* Jan. 2009, p. 92).

The ideal hunting ground would probably lie away from the Milky Way's dusty plane. Because the Local Void is so large, it juts out well above the galactic plane in Ophiuchus, northernmost Scorpius, and southernmost Libra. It can also be seen well below the galactic plane in Capricornus and southeastern Sagittarius. As a result, patient observers of these constellations could help cosmologists reconcile reality with theory by turning up new void galaxies in the vast expanse of darkness next door.

Meanwhile, voids themselves will keep expanding, evicting their remaining residents and thereby helping to build the glittering galactic architecture that spans the cosmos. Sometimes you really do get something from nothing.

▲ ALFAZOA J1952+1428 The second nearest galaxy known in the Local Void also abounds with gas. It's 20 million light-years from KK 246 and 27 million light-years from Earth. Searchers found the galaxy not by its stars but by the radio glow from its neutral hydrogen gas.

■ **KEN CROSWELL** earned his PhD at Harvard University for studying the Milky Way Galaxy and is the author of *The Alchemy of the Heavens: Searching for Meaning in the Milky Way*, which was a *Los Angeles Times* Book Prize finalist.

LOCAL VOID BEHIND GALACTIC PLANE: COURTOIS ET AL., *THE ASTRONOMICAL JOURNAL*, SEPTEMBER 2013; ALFAZOA: RIZZI ET AL. 2017, *THE ASTROPHYSICAL JOURNAL*, 20 JANUARY 2017

\`Oumuamua's Dramatic Visit

SOLAR SYSTEM VISITOR This artist's impression shows the first discovered interstellar body, called \`Oumuamua. Although estimates for the true shape vary wildly, its discoverers are sticking with this strange, highly elongated profile. In this model, it's about 400 meters (1,300 feet) long.

ESO / M. KORNMESSER

The space rock from beyond the solar system has left us amazed and perplexed.

The Minor Planet Center announces dozens of new solar system discoveries every week. Most notices are mundane, describing the orbits, appearances, and sky locations of unremarkable, newly detected comets and asteroids. But last October 25th, the MPC's Electronic Circular 2017-U181 reported the discovery of a singular outsider: a faint object rushing through the inner solar system that, based on its trajectory, was making a one-time visit from the stars.

Postdoc Robert Weryk (University of Hawai'i, Mānoa) had made the discovery a week earlier on October 19th, while looking for near-Earth objects with the aid of the 1.8-meter Pan-STARRS 1 scope. This robotically controlled telescope of the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) program sits near the summit of the Haleakalā volcano on Maui. Its primary charge is to locate thousands of new asteroids and identify those that might threaten Earth (*S&T:* June 2018, p. 12).

Weryk says he noticed the object "in the process of doing my daily job." (His official title is Planetary Defense Researcher.) The body was moving very fast across the sky, which suggested it was close to Earth. Checking the archive, Weryk also found it in images from the previous night. "When I put the data together to compute an orbit, the orbit didn't make sense. It wasn't moving as you'd expect a near-Earth asteroid to move."

Weryk quickly contacted a colleague in Italy, Marco Micheli (European Space Agency), who had serendipitously gathered data with an ESA telescope that also showed the object. "When the three nights were put together," Weryk says, "it strongly suggested that we had something with an origin outside our solar system."

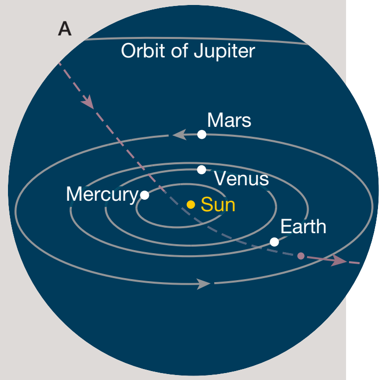
To the Telescopes!

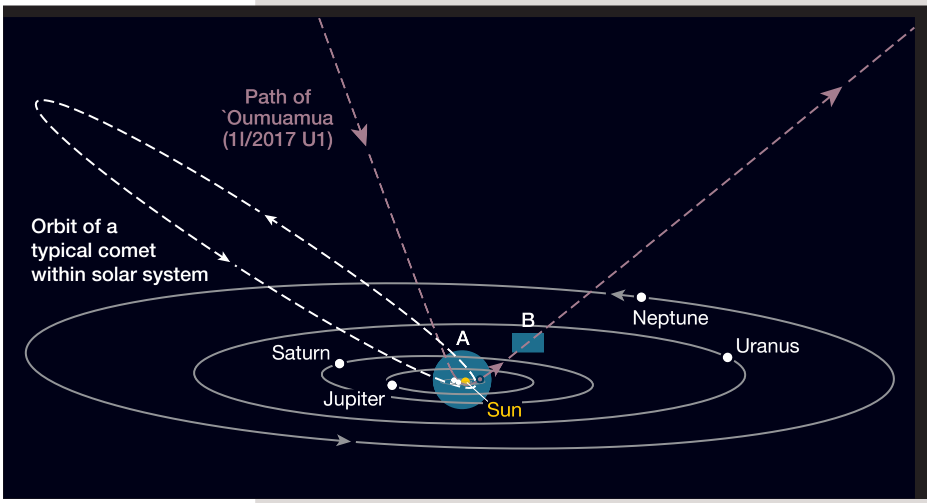
The reason Weryk and his colleagues suspected they had an interstellar visitor on their hands was the object's orbit. It was notably *hyperbolic*, shaped like a flattened U instead of the elongated loops or parabolic paths that comets usually follow. Occasionally a planet will torque a comet into a slightly hyperbolic trajectory, but planetary scientists had never seen one so extreme. It meant that, unlike our solar system's planets, asteroids, and comets, the body wasn't gravitationally bound to the Sun.

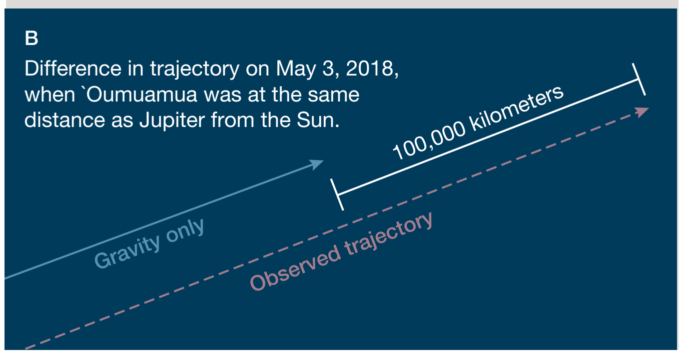
Time was very short. When first spotted by Pan-STARRS, the interstellar visitor — which was initially estimated from its brightness to be more than 100 meters (300 ft) across — was already well on its way out of the solar system. It had reached perihelion on September 9th, with a searing close approach that brought it four times nearer to the Sun than Earth comes. Outward bound, it passed below Earth's orbit on October 10th and shortly thereafter cruised by our planet at a distance only 63 times that of the Moon. By the time the MPC announcement went out, it was nearly as far from the Sun as Mars.

The Pan-STARRS astronomers turned to Karen Meech (University of Hawai'i, Mānoa) to take the lead in organizing their follow-up efforts. While no roadmap existed for what to do when confronted with an object arriving from the interstellar depths, Meech had successfully coordinated worldwide ground-based observing programs in support of several NASA

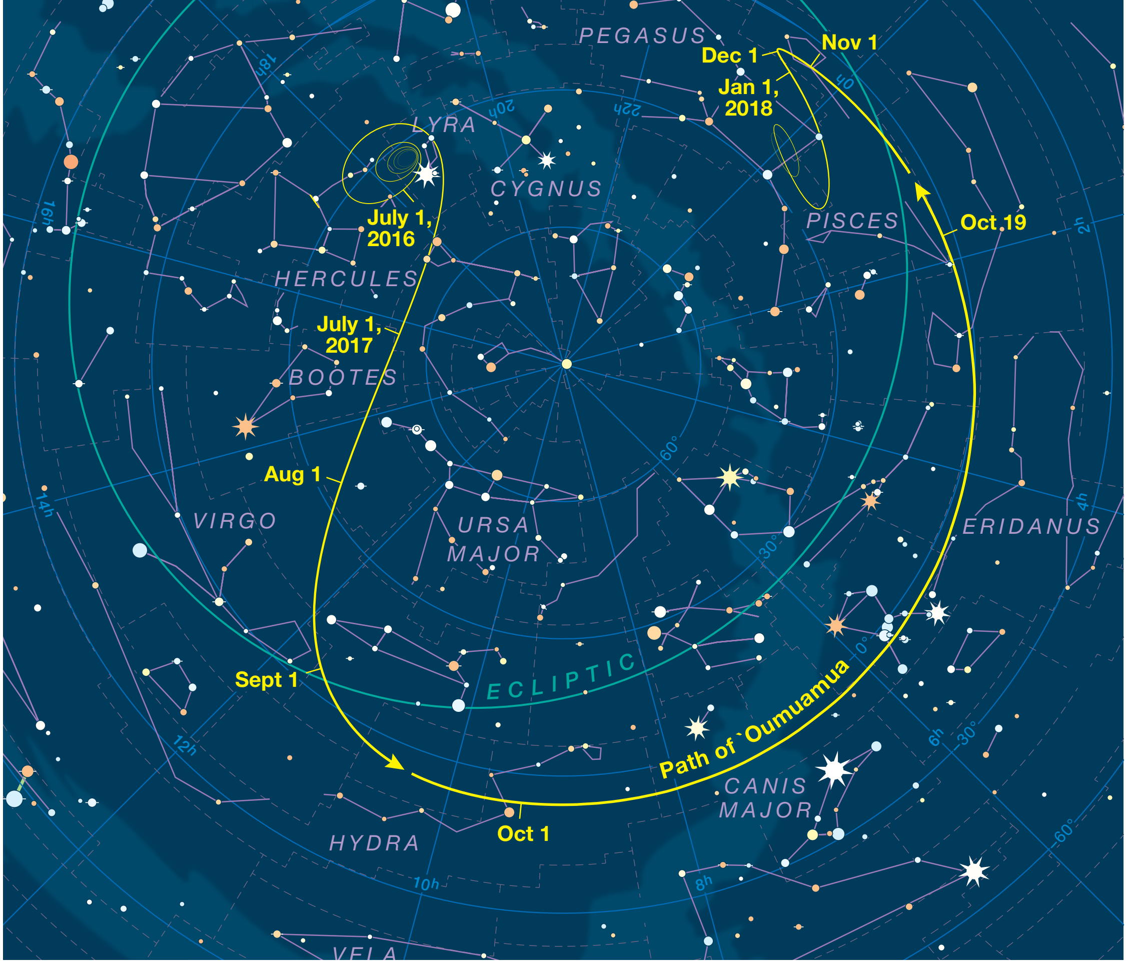
WHIRLWIND TOUR The track of the first-known interstellar object through the solar system. The round inset shows its location when it was discovered on October 19th. Observations when the object had passed the orbit of Jupiter indicate that it had traveled farther than expected, perhaps propelled by jets of sublimating ice (see page 25).







GREGG DINDERMAN / S&T, TRAJECTORY CHANGE SOURCE: ESA



▶ **SKY PATH** `Oumuamua came tumbling out of Lyra in 2017 (not that anyone saw it), looped through the sky, and was discovered cruising near the Pisces-Cetus border on October 19th. It quickly receded in the direction of Pegasus. The trajectory spans 2012 through 2020, and the loops at its ends are a parallax effect due to Earth's yearly circuit around the Sun.

missions and had a good idea of how to tackle the challenge.

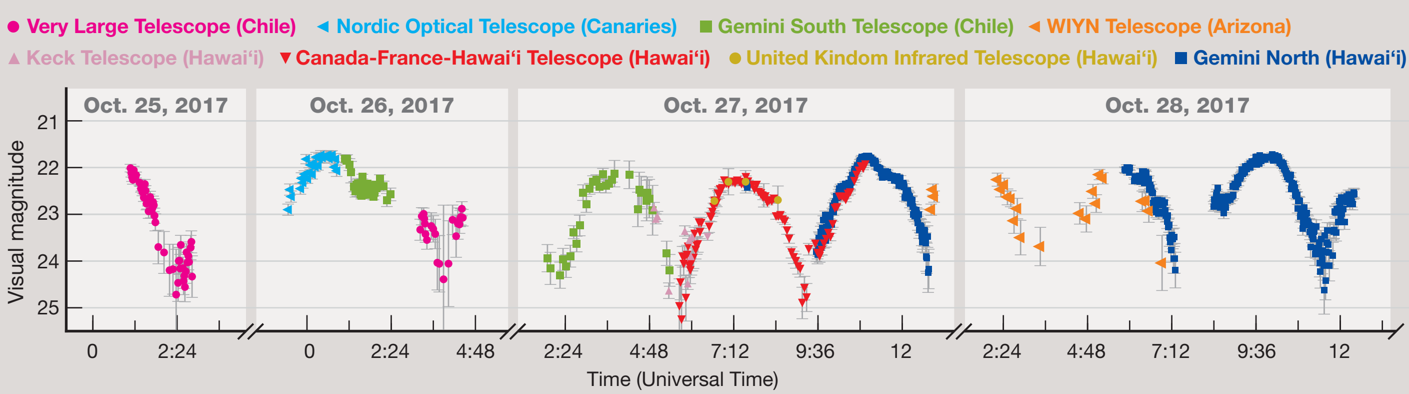
"It meant dropping everything and really working around the clock," Meech says. Her team immediately submitted emergency requests for observing time to facilities including the Very Large Telescope, the Gemini South Telescope, and the Hubble Space Telescope and were approved. Over the coming nights, the world's most capable instruments turned to the mysterious object.

They weren't alone. Within minutes of the Minor Planet Center's October 25th announcement that a comet of possible interstellar origin had been located, other telescopes also began chasing the object. Joseph Masiero (Jet Propulsion Laboratory) happened to be observing with the venerable 5.1-meter Hale Telescope at Palomar Observatory. Under less-than-perfect conditions, he obtained spectra indicating a dull red overall color. Early observations also revealed the object looked point-like, with no hint of cometary activity.

Early returns also came from a group headed by David Jewitt (University of California, Los Angeles) and Jane Luu (MIT Lincoln Laboratory), who in 1992 were the discoverers of 15760 Albion, the first Kuiper Belt object (besides Pluto). The team including Meech and Weryk also elicited critical results by piecing together several successive nights of observations from different telescopes. Most importantly, all this effort revealed that the body is not a comet in the traditional sense. Even in the deepest exposures, it appeared as a com-

SKYCHART: GREGG DINDERMAN / *S&T*; LIGHT CURVE: GREGG DINDERMAN / *S&T*, SOURCE: MICHAEL J. S. BELTON ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2018 856:L21

▼ **`OUMUAMUA'S LIGHT CURVE** Compiled by 13 telescopes, this composite light curve shows how `Oumuamua's brightness changed as it tumbled through space. Although there is a clear periodicity, it doesn't always follow the exact same pattern. Note that although the data have been converted to visual magnitudes, many observations were taken in infrared.



pletely star-like point; scientists estimated that it could be spewing out no more than a spoonful of powdery dust per second.

`Oumuamua at a Glance

Size	~100 meters
Perihelion	0.26 a.u. (September 9, 2017)
Orbital eccentricity	1.2 (hyperbolic)
Distance from Earth when it crossed below Earth's orbit, outbound	0.23 a.u. (October 10, 2017) *90 lunar distances*
Closest approach to Earth	0.16 a.u. (October 14, 2017) *63 lunar distances*
Apparent magnitude when discovered	~20

A Class of Its Own

With measurements obtained over a series of nights, observers constructed a light curve of how the object's brightness changed with time. That plot was illuminating. First, the body is clearly rotating, executing a full spin roughly every 8 hours. Second, the light curve shows a startling degree of variation during the course of a single rotation, as well as from one rotation to the next. The most likely interpretation is that the object has a highly elongated shape, like a weaver's shuttle, with estimates of its *aspect ratio* (length vs. width) ranging up to 10:1. This measurement strongly suggests that it's a monolithic object with some material strength: Were it a loose pile of rubble, as many asteroids are, it wouldn't be able to prevent itself from flying apart as it rotates.

Moreover, the irregular brightness changes suggest that it is tumbling chaotically as it falls through space. Although some speculated that at least part of the oddness could arise from patchy reflectivity on the surface, spectra from all of the telescopes that observed the body consistently indicate a uniformly reddish surface that would be perfectly in place among the icy, carbon-rich bodies (such as the Centaurs) that inhabit our own outer solar system.

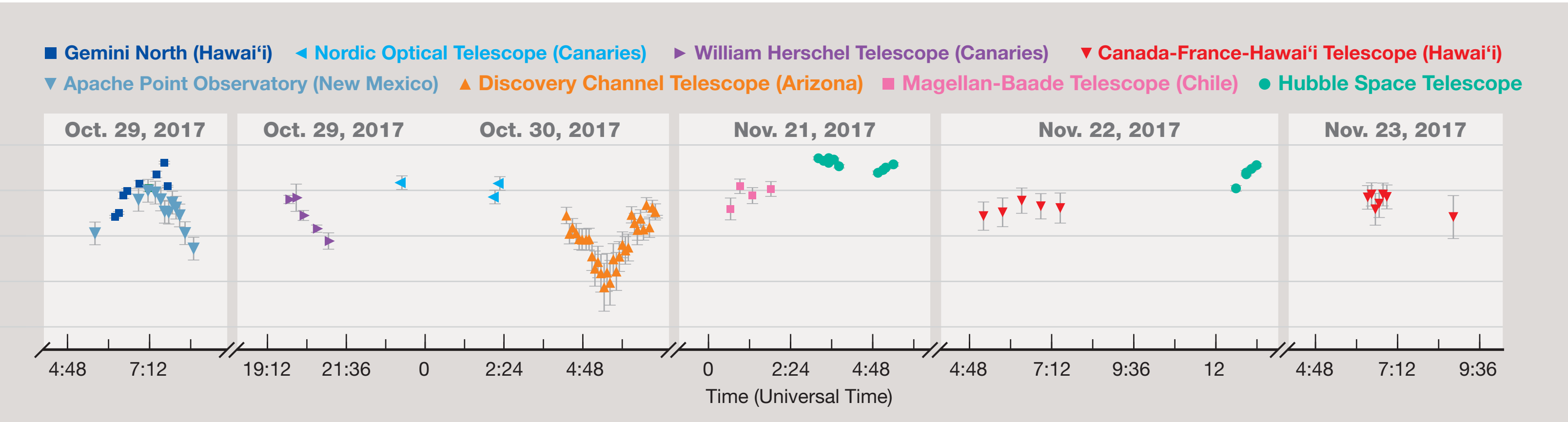
The newcomer presented a problem of nomenclature. Based on its wildly noncircular orbit, the MPC's first announcement classified it as a comet, giving it the designation C/2017 U1. Shortly thereafter, as it became clear that the body showed no hint of a coma, it was reclassified as asteroid A/2017 U1. As a storm of updated trajectory determinations proved beyond doubt that the community was witnessing an arrival from beyond the solar system, the International Astronomical Union announced an official naming scheme, with code letter "I" for *interstellar*. In place of the discoverer's name — in this case, Pan-STARRS — the IAU accepted the team's proposed name of *`Oumuamua*, a Hawaiian word for scout (see sidebar, page 26).

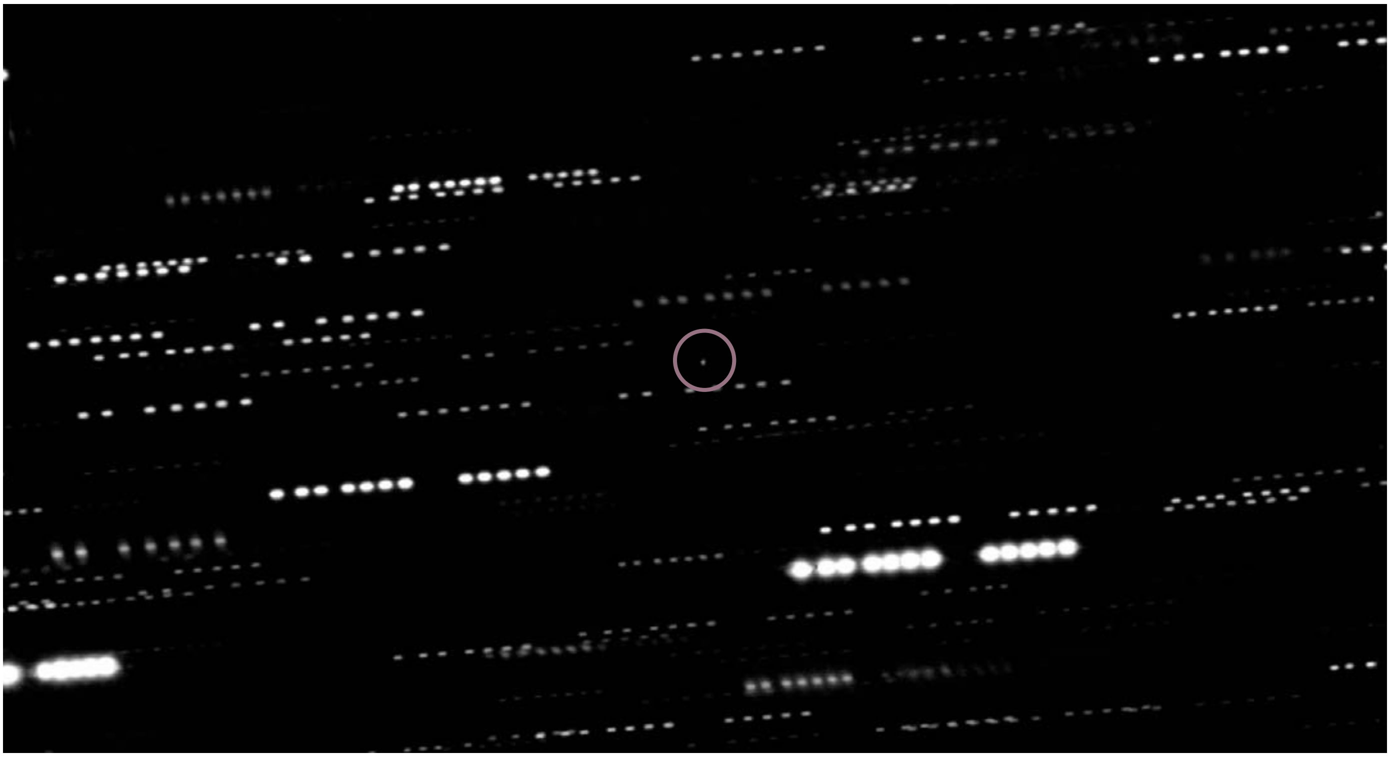
With its remarkable name and its remarkable properties, `Oumuamua was ready for stardom. On November 20th, the European Southern Observatory circulated a news release describing the Meech team's results. The document linked the undeniably weird properties of a first-ever object with a name that brings to mind the hand of some far-distant extraterrestrial agency and a stunning artist's impression of a menacing starship-like shard silhouetted against a glowing field of stars. The story, which had gained international attention after being reported first by *Sky & Telescope* nearly a month prior, vaulted to massive prominence. The eerie parallels to Arthur C. Clarke's novel *Rendezvous with Rama* were given wide remark, and in a story for NBC News, astronomer Seth Shostak (SETI Institute) memorably wondered "if it's a rock or a rocket."

To rule out the latter, the Breakthrough Listen project marshaled an effort in which the 100-m Green Bank Telescope listened for radio broadcasts from `Oumuamua as it rushed away from the Sun. Results of the radio surveillance showed no sign of technological activity. As much as it *looked* like a spaceship, `Oumuamua was just a rock.

Slingshot Victim

`Oumuamua leaves both insights and unanswered questions in its wake. It is small and faint enough that an automated survey telescope such as Pan-STARRS 1 was lucky to spot





▲ **JUST A SPECK** This deep composite image shows `Oumuamua (circled), surrounded by the trails of faint stars that were smeared out as the telescopes tracked the moving object. The image combines multiple images from the Very Large Telescope and the Gemini South Telescope.

it. Had it arrived a few weeks earlier or later, the difference in Earth's orbital vantage point would likely have let it slip through undetected.

The very fact that `Oumuamua was found hints that it is part of a very large population of similar objects pervading the galaxy — it's supremely unlikely that we would have been lucky enough to see the lone example. Granted, extrapolations that point to a vast multitude on the basis of a single example do not generally inspire a great degree of confidence. Nonetheless, by taking careful account of the total volume of space that Pan-STARRS searches, Aaron Do (University of Hawaiʻi, Mānoa) and colleagues estimated the interstellar density of `Oumuamua-like objects. They concluded that, if we were to slice up our galaxy into regions equal in size to the sphere circumscribed by Earth's orbit around the Sun, there should be about one interstellar voyager per region. Their calculation suggests that one or more of these bodies is nearly always in the act of rushing through the inner solar system. Equally impressively, it suggests that more than a trillion quadrillion (10^{27}) of them are orbiting in the galactic disk.

Projecting `Oumuamua's path back in time indicates that it came from the direction of the constellation Lyra. Using its exact point of origin and the speed with which it approached the solar system, astronomers further backtracked its trajectory to check whether it may have been ejected from a known nearby star system. Piotr Dybczyński (Adam Mickiewicz University, Poland) and Małgorzata Królikowska (Polish Academy of Sciences) assessed more than 200,000 nearby stars but concluded that none is a particularly compelling candidate for `Oumuamua's parent. They did find that, about 800,000 years ago, `Oumuamua traversed within roughly 7 light-years of the planet-bearing red dwarf Gliese 876. But the miss distance, while intriguing, was too large to be anything but a chance close encounter; almost certainly, it was just one of

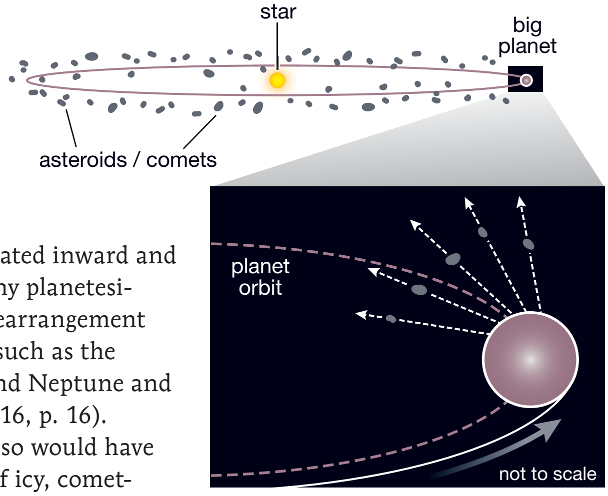
▼ **ALTERNATIVE IDEAS** Astronomers have suggested several different shapes for `Oumuamua. The squatter cigar gained popularity, but the body's strange wobbling spin also leaves open the possibility that it's a pancake (*S&T:* July 2018, p. 8).

STAR TRAILS: ESO / K. MEECH ET AL; ALTERNATIVE SHAPES: PANCAKE: © 2018 WILLIAM K. HARTMANN, SQUAT CIGAR: ESO / M. KORNMESSER thousands of similarly wide stellar passes that `Oumuamua has experienced during billions of years of galactic wandering.

Such forlorn travelers were likely set on their journeys by massive planets in their home systems. We think the same happened here. In the so-called Nice Model, the giant planets that orbit our own Sun migrated inward and outward as they were forming, launching many planetesimals into interstellar space. This haphazard rearrangement explains several features of our solar system, such as the existence of Trojan asteroids around Jupiter and Neptune and the structure of the Kuiper Belt (*S&T:* June 2016, p. 16).

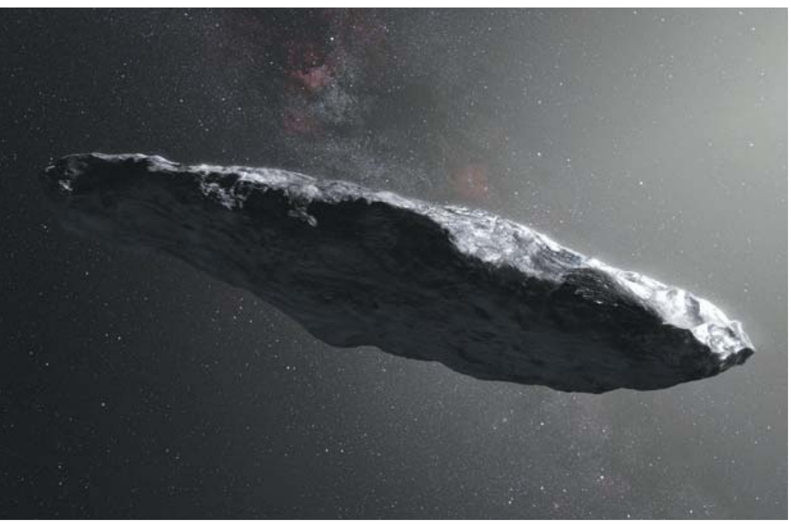
As the giant planets moved around, they also would have wrested at least several Earth masses' worth of icy, comet-like planetesimals — comprising quadrillions of individual objects — from the Sun's grip and spewed them into interstellar space. These losses occurred via the same gravitational slingshot mechanism that enabled Jupiter and the other giant planets to send the Voyager, Pioneer, and New Horizons probes barreling out of the solar system. When replicated across the formation of all the stars in our galaxy, the process could produce a vast population of `Oumuamua-mass bodies.

Yet conundrums remain. In order for a particular planet to eject a small body from its parent system, that planet must simultaneously be relatively massive and relatively far from its parent star. Put more precisely, the escape velocity from the planetary surface must comfortably exceed the planet's own orbital velocity. Earth cannot produce solar system escapees using its gravity alone, and interestingly, neither can the vast majority of known exoplanets. Hot Jupiters and short-period super-Earths are simply too close to their parent stars to be effective, and in general, planets orbiting in "warm" regions near the star where rocky and metallic bodies form can't eject them. A flurry of `Oumuamuas might shoot from binary-star systems or, alternately, they might owe their independent orbits to countless Neptune analogs orbiting Sun-like stars at Neptune-like distances.



◀ **GRAVITY ASSIST** Giant planets orbiting far from their stars can kick small bodies out of their planetary systems. When a body encounters the planet, the planet's gravity boosts the object's velocity such that it whizzes away at high speed. The new trajectory could take any of a variety of angles emanating forward from the planet's direction of motion.

GRAVITY EJECTION: LEAH TISCIONE / *S&T*



Dust Problem

If passing interstellar objects have a lot of ice, we'd expect them to behave like comets when they are warmed by the Sun. `Oumuamua, however, showed no sign whatsoever of a volatile-powered coma, indicating that it had no dust-infused ice that was heated to vaporization — despite passing perihelion just 0.26 astronomical unit from the Sun, a region where the solar radiation is 16 times stronger than at Earth. At first glance, this absence of activity would suggest `Oumuamua didn't have any near-surface ice.

But Jewitt and his collaborators soon pointed out that it's possible the ice is there but couldn't vaporize. `Oumuamua spent a very long time in the interstellar medium, and over the eons it would have been both continually bombarded with the relativistic particles called cosmic rays and episodically bathed in extreme-ultraviolet light from massive, young stars. Under such conditions, laboratory experiments (carried out by scientists such as Scott Sandford at NASA Ames Research Center) show that simple carbon-containing molecules gradually refashion themselves into complicated tar-like complexes that evolve to have `Oumuamua's characteristically ruddy hue. They also serve as remarkably good thermal insulators. A beverage cooler made from comet crust would keep bottles cold for much longer than one made from Styrofoam.

Thermal modeling simulations by a number of groups show that if `Oumuamua is indeed covered by a modest insulating layer, then the Sun's intense but brief heat likely would not have been sufficient to warm any underlying ice to the sublimation point. Moreover, `Oumuamua's odd shape and its tumbling motion may have provided further protection. At many orientations, a cigar-like figure exposes only a small fraction of its surface area to direct irradiation, and the chaotic tumbling would have kept any one section from being regularly heated, helping to prevent isolated hot spots from blistering out.

As `Oumuamua zipped away from the Sun, it rapidly grew dimmer, and by the end of 2017 it was about 27th magnitude.

A team led by David Trilling (Northern Arizona University) trained the Spitzer Space Telescope in `Oumuamua's direction but registered *no* infrared heat signature from it. Their non-detection suggests that it is both smaller than initially believed and also much more reflective at visible wavelengths — which is strange, given the hints of a tarry surface. No one really knows what to make of it.

Meech's team made a series of ground-based and HST observations of its fleeting departure, and these last looks imparted one final surprise: `Oumuamua's trajectory out of the solar system failed to adhere to the hyperbolic arc that one would expect from Newton's Law of Gravity. Rather, something gave the departing body an extra kick.

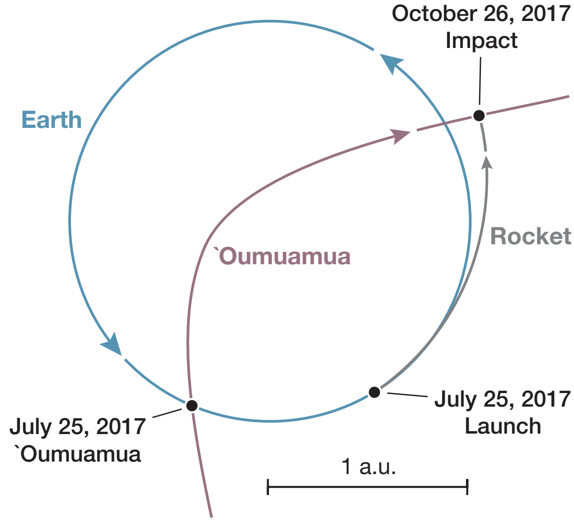
The team's best guess is outgassing. Rocket-like gas emission that provides acceleration in a specific direction is not unexpected for a comet, but it's somewhat awkward to square that with the fact that no one ever observed any gas from `Oumuamua. A thruster-like jet should have been visible thanks to the light scattered by dust caught up with the expelled gas. Perhaps any dust particles entrained were larger than expected and hence ineffective at scattering light.

They're still going with the bizarre 10:1 aspect ratio, too, Meech says. The spindle shape corresponds best to the observed 2½-magnitude dips in the light curves, though an alternative, pancake shape is also possible (see page 24). A more definitive analysis could be obtained by completely modeling the rotation state and the shape in a consistent manner, she explains — a project that is feasible but very computationally intensive.

Preparing for the Next One

While detailed modeling will still bring results, we won't get any more direct observations of `Oumuamua itself. Yet its appearance may herald many such visitors. Now that astronomers know what to look for, facilities such as Pan-STARRS will probably detect similar objects once every several years or so, and the upcoming Large Synoptic Survey Telescope will be sensitive enough to spot objects like `Oumuamua at distances roughly equal to the Earth-Sun separation. As a consequence, it is likely to report a new one every several months.

Astronomers are eagerly awaiting the next arrivals to see which of `Oumuamua's properties — its color, its spin, its shape, and its lack of coma — turn out to be emblematic of the population. If, for example, none of the incoming bodies shows evidence of evaporating ices, we will be left with an origins mystery that will be answered only by an up-close view, or even by excavating a patch of crust to determine what lies beneath.



▲ **IN HINDSIGHT** If astronomers had discovered `Oumuamua early enough, a mission launched in late July 2017 would have had enough time to intercept the object in late October. However, estimates put `Oumuamua's average brightness in June 2017 at a visual magnitude of 26, too faint for Pan-STARRS to detect. (Although when seen from above `Oumuamua crossed Earth's orbit in late July, it was not 1 a.u. from the Sun until early August.)

LEAH TISCIONE / *S&T*, SOURCE: D. SELIGMAN AND G. LAUGHLIN / *ASTRONOMICAL JOURNAL* 2018 (155:217)

A number of spacecraft missions that match velocities to fly alongside small bodies such as asteroids and comets have been successfully carried out, most recently the comet-chasing Rosetta (*S&T:* May 2017, p. 14) and the asteroid-sampling Osiris-REX and Hayabusa 2 (*S&T:* June 2018, p. 22). A sample-return mission to an object like `Oumuamua would be the scientific equivalent of a grand slam, but unfortunately it's unlikely to be feasible. Pulling alongside a body on a hyperbolic trajectory and then returning to Earth requires too much energy for chemically propelled rockets to do the job.

A one-way interceptor mission, however, would be doable. A flight plan of this type has precedent with NASA's 2005-era Deep Impact mission, in which a kinetic impactor smashed into Comet Tempel 1, creating a debris plume that was observed from both a companion flyby probe and from Earth. Had `Oumuamua been detected a few weeks before it crossed the sphere of Earth's orbit in early August on its way to its closest solar approach, and if a rocket had been ready to launch, a modest deep-space boost of a few kilometers per second would have been adequate for a high-speed rendezvous with a shard from an alien solar system. Hopefully, in coming years, there will be similarly fortuitous chances!

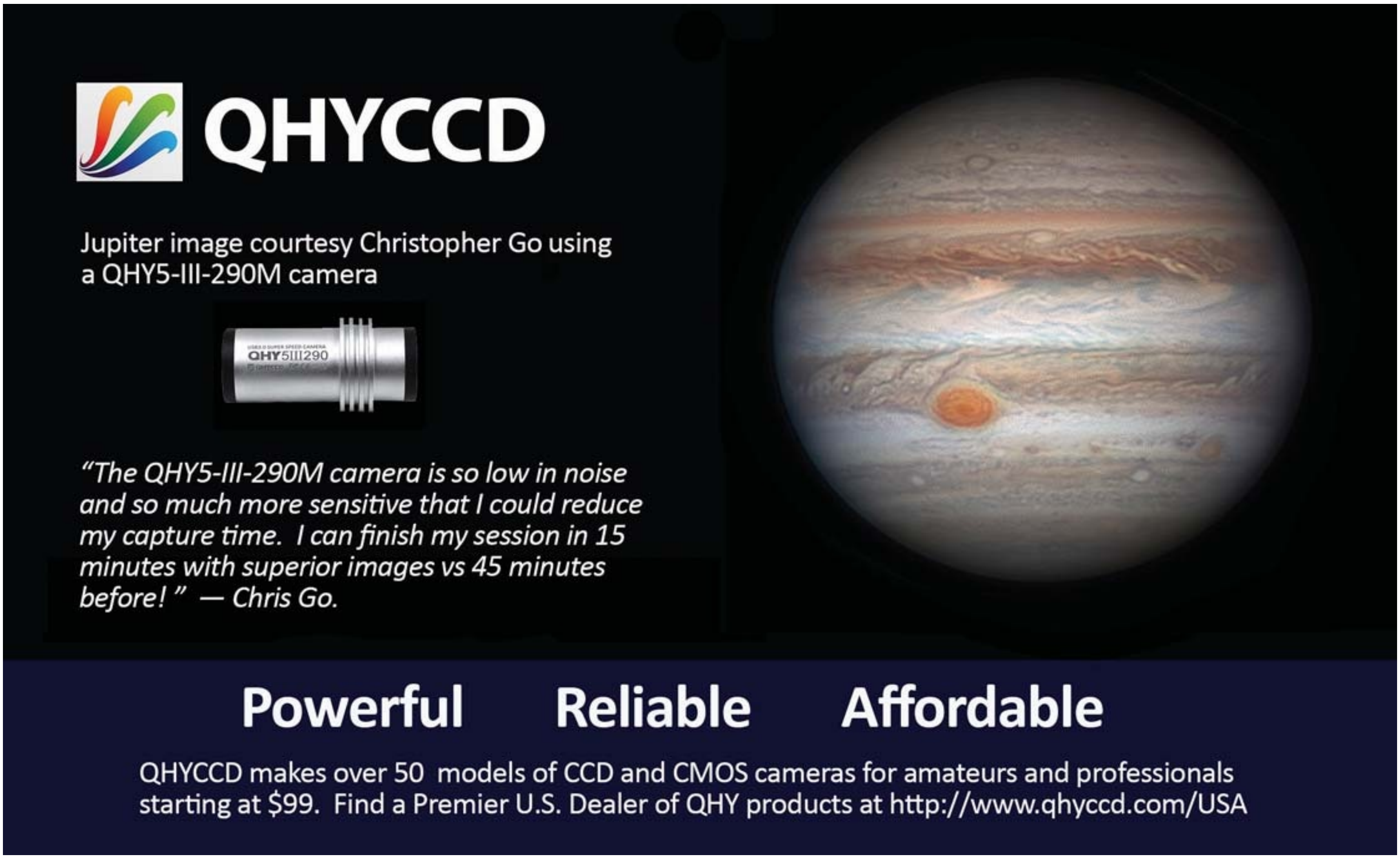
■ **GREG LAUGHLIN** is an astronomy professor at Yale University. He blogs about planets at **oklo.org**.

What's in a Name?

The term *`Oumuamua* refers to a leader or scout. It comes from *`ou* ("reach out for") and *mua* ("first, in advance of," repeated for emphasis). The discoverers chose the name in consultation with Hawaiian language experts to highlight the object as a messenger from the distant past reaching out to us. But the term also has military connotations and can refer to a leader in battle or a scout sent to survey an enemy's position.

An interesting choice for something that looks like an alien spaceship.

—Camille M. Carlisle


QHYCCD
Jupiter image courtesy Christopher Go using a QHY5-III-290M camera
QHY5III290
"The QHY5-III-290M camera is so low in noise and so much more sensitive that I could reduce my capture time. I can finish my session in 15 minutes with superior images vs 45 minutes before! " — Chris Go.
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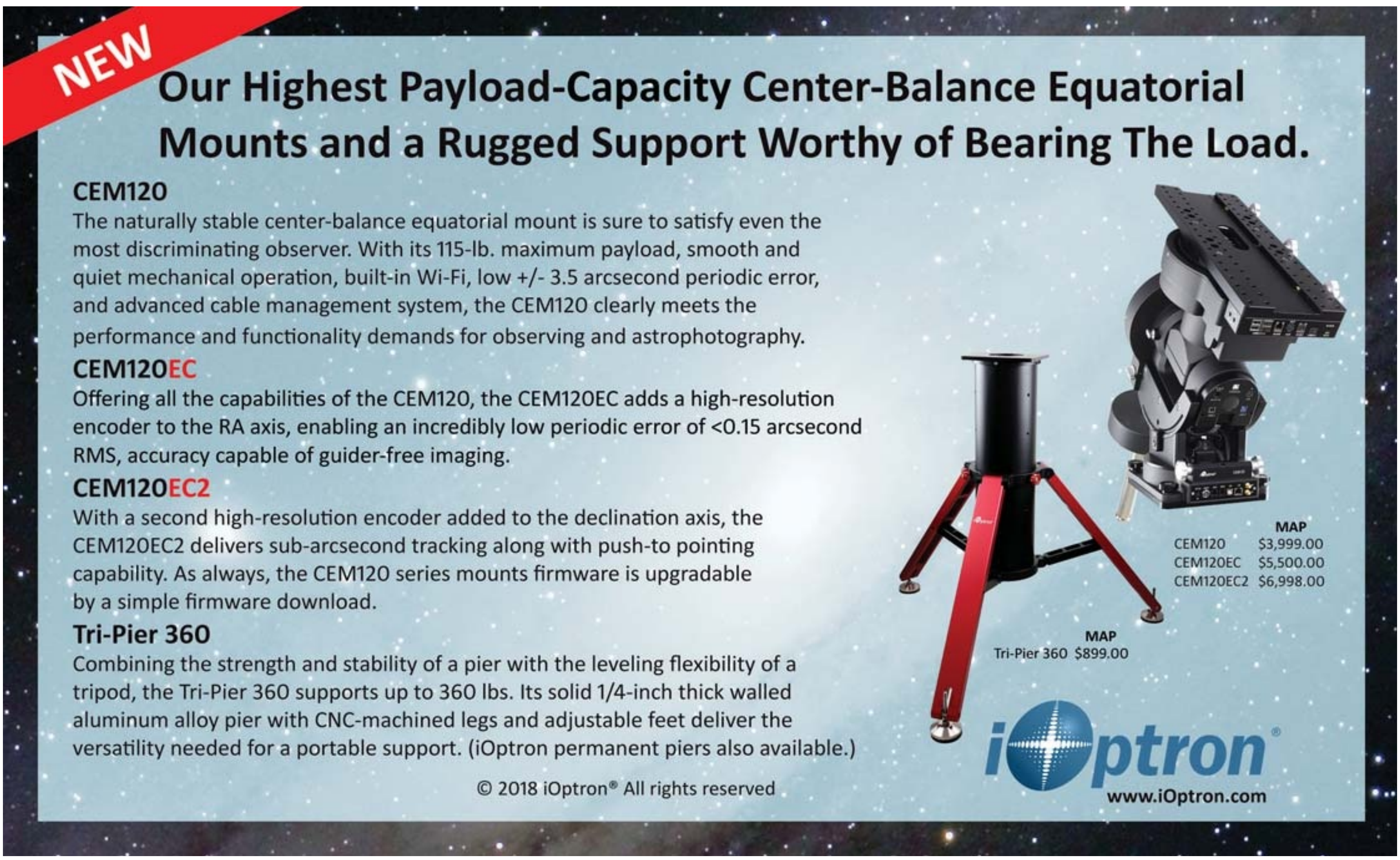
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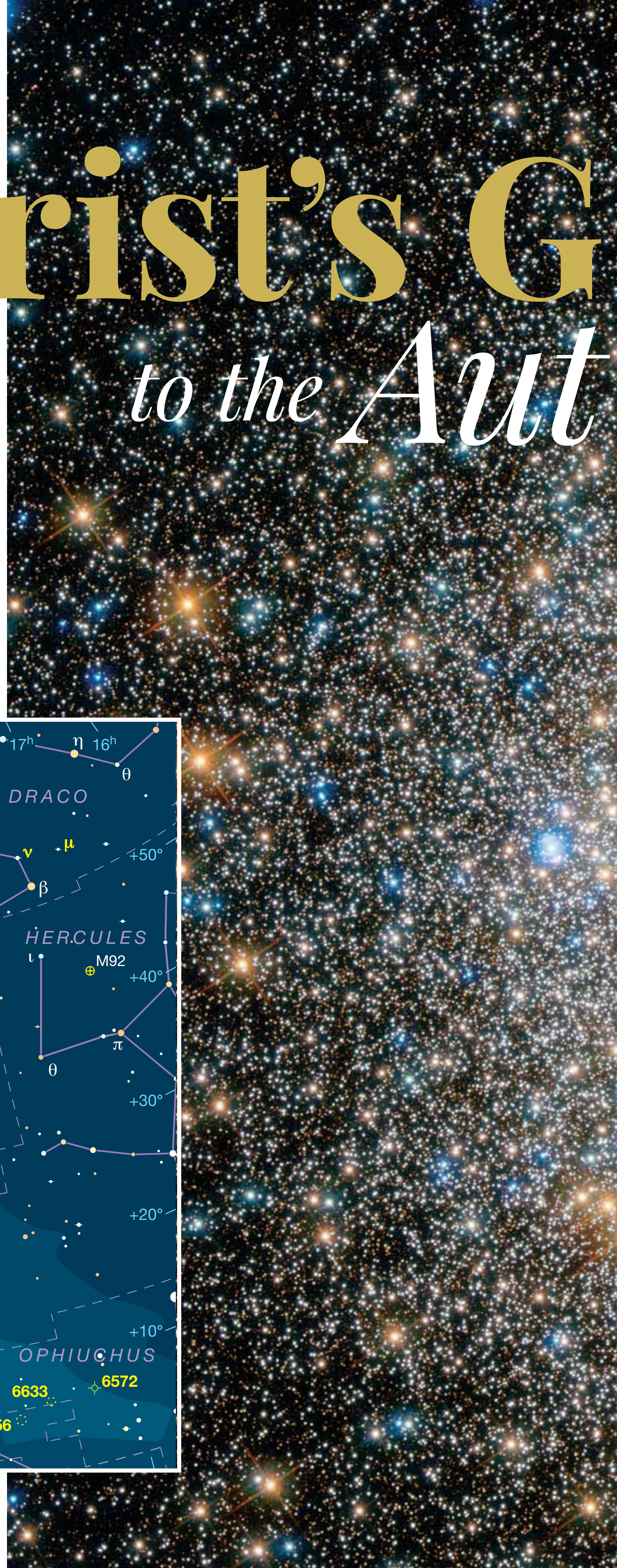
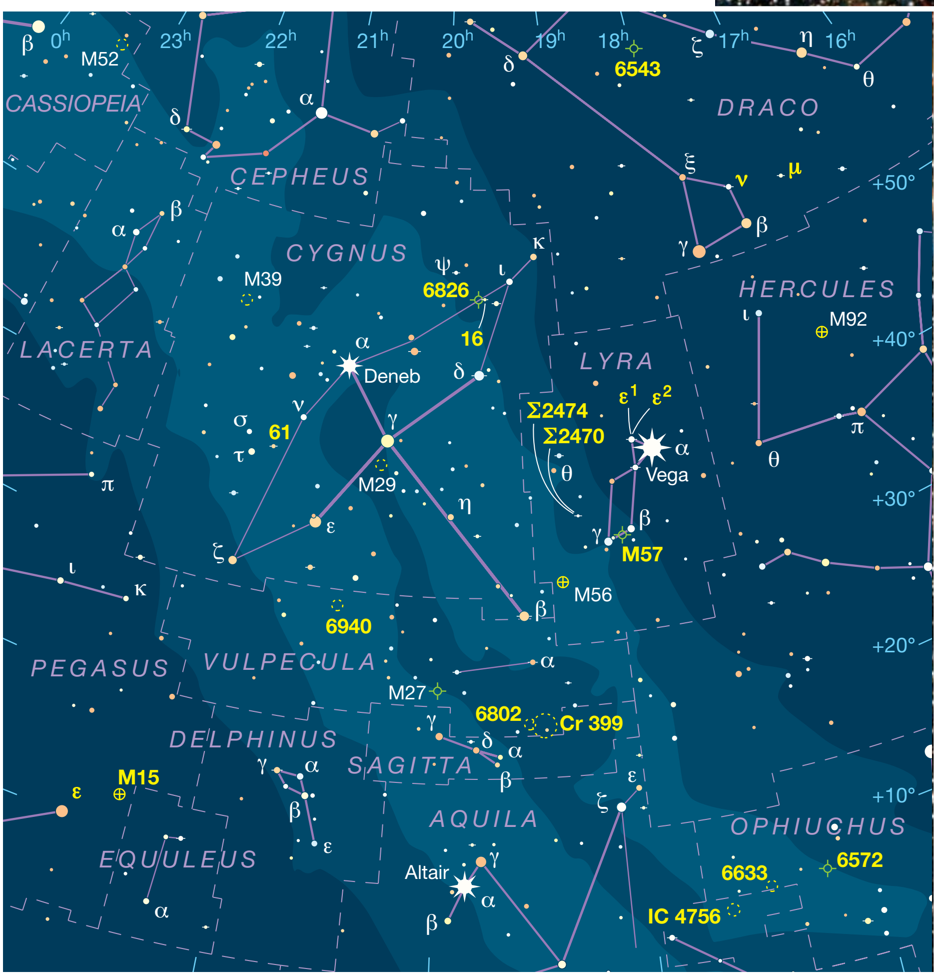
BIG, BOLD, BRIGHT, BEAUTIFUL by Jerry Oltion

A Tourist's G to the Aut



Ramble through the skies of fall and check in on some favorite targets.

Go ahead and look at Saturn first. We all do. Whenever I go out with a telescope and Saturn is up, that's the first thing I look at. It's one of the most stunning objects in the sky, and besides, it's one of the first to appear in the evening twilight. So have a look, admire it, tease out the Cassini Division, check out the moons . . . then settle in for an evening of equally wonderful objects scattered all across the celestial vault of autumn.



NASA / ESA

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umn Highlights

BIG, BOLD, BRIGHT, AND BEAUTIFUL
The globular cluster M15 in Pegasus bedazzles with more than 100,000 stars.

This article is for the tourist. Whether you're new to the hobby or a hoary veteran, we all have nights when we just want a light show. When we grow tired of looking for faint fuzzies, autumn offers a veritable smorgasbord of eye candy for the spectacle-hungry. Here are some of my favorites, working more or less from north to south for a couple of hours after sunset in October.

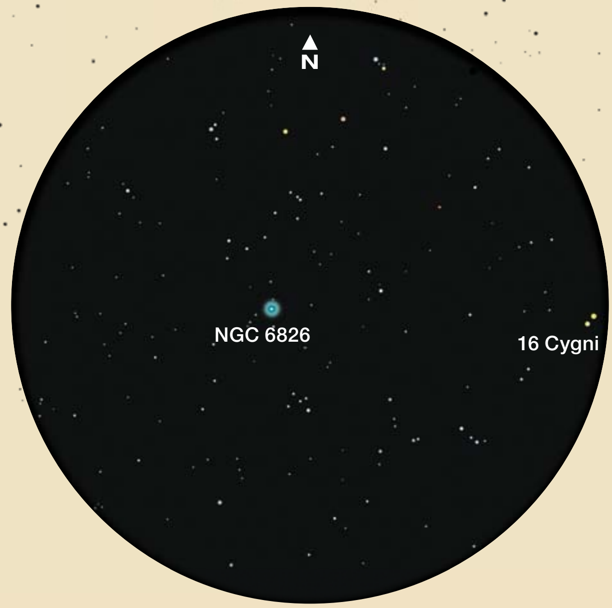
Let's start with **NGC 6543**, the Cat's Eye Nebula. This bright (8th-magnitude) planetary nebula in the neck of Draco, the Dragon, is one of the most popular planetaries in the northern sky. It's small but bright enough to see in almost any telescope, and it takes magnification well, so crank it up and admire this twist of stellar atmosphere that has blown off a dying star. It's decidedly oblong and does indeed look like the elongated pupil of a cat's eye. With some aperture and steady sky you can see the central star, and maybe even detect the nebula's greenish color. When you're looking at the Cat's Eye, you're looking toward the north ecliptic pole, which means you're looking straight up out of the plane of the solar system.

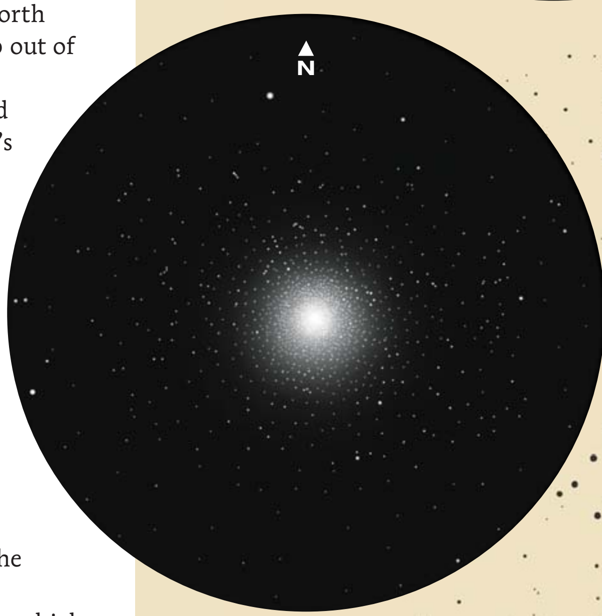
As long as we're in Draco, we can't skip **Nu (ν)** and **Mu (μ) Draconis**. They're two double stars in Draco's head, and they provide two completely different viewing experiences. Nu Draconis, also known as Kuma, is a wide, even double of two 4.9-magnitude stars separated by an easy 63″. You can split it in binoculars if you hold them steady enough. The two components are so evenly matched that in a telescope they look like the headlights of an approaching car.

Mu Draconis is another perfectly matched pair, with both components glowing at 5.7 magnitude, but at a much closer 2.3″ separation. This is a medium-tough split, but well worth the effort, especially after looking at Nu's easy divide. It looks like the same pair of headlights, only much farther away.

Fun fact: Mu Draconis's common name is Arrakis, which Frank Herbert thought was cool enough to name his desert planet in his groundbreaking science fiction novel, *Dune*.

From Arrakis, a quick hyperspace jump through Draco's head takes you into the upper wing of Cygnus, the Swan. About where the pinion feathers would attach you'll find **NGC 6826**, the Blinking Planetary Nebula. The Blinking Planetary is even smaller than the Cat's Eye, so you'll need some magnification here, but I include it because it's one of the best interactive objects in the night sky. How can something 5,200 light-years away interact with you?





▲▲ **NGC 6826** The Blinking Planetary Nebula is one of the night sky's few interactive objects. FOV = 50′

▲ **DENSE SWARM** M15 is one of the tightest globular clusters in the galaxy. FOV = 20′

▶ **SPEEDY STAR** 61 Cygni moves so quickly relative to background stars that you can watch its position change from year to year. Component A is upper right, B lower left. FOV = 20′

By disappearing when you look directly at it! The central star that produced the nebula is bright enough (magnitude 10.6) to overwhelm the soft glow of the nebula when you look straight at it, but averting your eyes brings the nebula right back to surprising prominence. The nebula isn't doing the blinking; *you* are by moving your eyes away and back. It's a great effect, probably best in an 8-inch telescope, but you can play with magnification or an aperture mask to get it the right brightness in just about any scope.

If you're having trouble finding the Blinking Planetary, look for **16 Cygni**, a double star about ½° due west. 16 Cygni is naked-eye visible (its components are magnitudes 6.0 and 6.2, for a combined brightness of 5.3) and easy to split (39″), and it makes for a good signpost that you're close to the Blinking Planetary. Since the planetary lies directly east of it, just center 16 Cygni, wait three minutes, and the Blinking Planetary will be centered.

> Whether you're **new to the hobby or a hoary veteran,** we all have nights when we just want a light show.

As long as we're playing with interactive objects, there's another great one to the south a ways: **Epsilon (ε) Pegasi**, or Enif, the nose of Pegasus. This one is a wide double star with enough difference in brightness between its components (magnitudes 2.5 and 8.7) to play a neat trick on your eye. If you wiggle the telescope in a direction perpendicular to the binary split, you'll see the bright component move back and forth just as you would expect, but the dim component lags behind looking for all the world like a glittering diamond swinging back and forth at the end of a string attached to the primary. For this reason, Enif is called the Pendulum Star. What's happening here? It's a latency effect: Your eye takes a moment longer to register a dim star than it does a bright one, so when the stars are in motion the dim one lags behind.

While you're in Enif's neighborhood, you might as well move 4° to the northwest and have a look at **M15**, a tight, bright globular cluster that's spectacular in any scope. This is one of the most tightly packed globulars in the sky, with half its mass concentrated in the central 10 light-years of its 175 light-year expanse. You can really see that when you crank up the magnification and try to split the core into individual stars. There are just too many to do it!

Let's move back up toward the zenith again to pick up a couple more neat objects we passed over on our way to Enif. We've probably all heard of, and seen, **Epsilon (ε) Lyrae**, the famous double-double star in Lyra. With two tight (2.1″ and 2.4″) pairs separated by a generous 210″, this is a favorite test of telescope optics. But Lyra holds a second double-double that I think is even prettier: **Struve 2470** and **Struve 2474**. These pairs are separated by an even more generous 10′, and the individual pairs are separated by 16″ and 14″. Both of them split east-west, and both have the brighter component to the east. They look like a double and its reflection in still water. This is a great object for star parties; they're much easier to split than Epsilon, and more beautiful.

JERRY OLTION (5)

▲ **EPHEMERAL CLUSTER** Soft and delicate NGC 6940 is one of the most beautiful open clusters in the sky. FOV = 1° 20′

▶ **DO YOU SEE IT?** The Coathanger looks just like its namesake. In Newtonian scopes, it's right-side up. Look for diminutive NGC 6802 just to the east of it. FOV = 3°

While you're in the neighborhood, of course you should check out **M57**, the Ring Nebula. This is probably the most accessible planetary nebula anywhere. It has all four B's — Big, Bold, Bright, and Beautiful — and I never pass by without a look. If you've got serious aperture (18 inches or better) and steady seeing, try for the central star. It's a tough find, but the feeling of accomplishment when you spot it is well worth the trouble.

At the risk of overdoing it with double stars, I have to point out at least one more in the autumn sky: **61 Cygni**, or Piazzi's Flying Star. This is another easy split (31″) between bright (magnitudes 5.3 and 6.1) stars, both with a distinctly reddish hue to them. But the cool thing about this system isn't the pair itself; it's the split with tiny little 11th-magnitude TYC 3168-590-1 next door. 61 Cygni is only 11.4 light-years away and moving fast, so it really scoots across the sky. It moves 5″ per year, which is 1/6 of its separation. TYC whatever is way off in the background, so it doesn't move much, which makes it a great marker for watching 61 Cygni's position from year to year. In 2012, 61 Cygni A crossed right over it, and this year it's the same distance from A as A is from B. With a little patience, you can watch a star move! This is a double to look at several times a year, and you should make an effort to sketch it at least once a year for the rest of your life. If you keep watching, you'll be amazed at how far it moves.

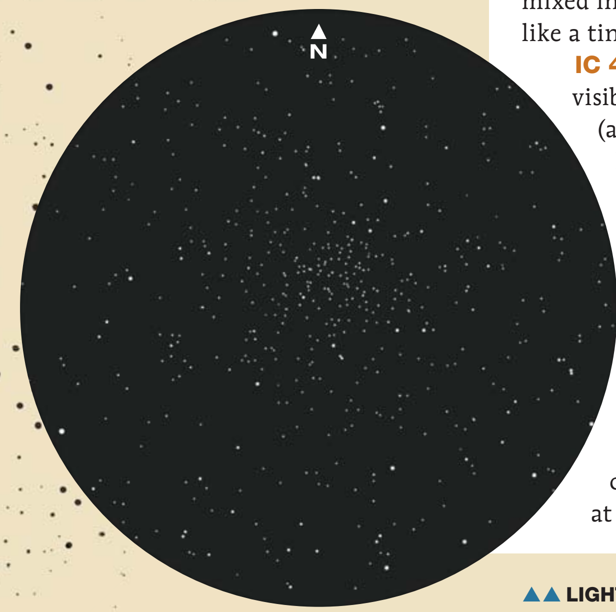
We haven't looked at any open clusters yet. How about **NGC 6940**, often overlooked but Big, Bold, Bright, and Beautiful nonetheless. It's in Vulpecula, right under the body of Cygnus, below the Great Rift in the Milky Way. There are dozens of open clusters in the area, but this one stands out for me because of its size (nearly as big as the Moon) and the relative uniformity of its stars. There are a few bright stars, including a nice red giant near the cluster's center, but most of the 50–100 stars that you can see easily are about 11th to 12th magnitude. That makes for a soft, delicate, yet very definite concentration amid the general glow of the Milky Way. If most clusters look like salt on velvet, this looks like powdered sugar sifted over chocolate ice cream.

You'll want low power for NGC 6940. Give yourself at least a degree of field, more if you can, so you can see it in context. It looks great in binoculars, too.

Celestial Ramble

Object	Alternative Name	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 6543	Cat's Eye Nebula	Planetary nebula	8.1	20″	17^h 58.6^m	+66° 38′
Nu Draconis	Kuma	Double star	4.9, 4.9	63″	17^h 32.2^m	+55° 11′
Mu Draconis	Arrakis	Double star	5.7, 5.7	2.3″	17^h 05.3^m	+54° 28′
NGC 6826	Blinking Planetary	Planetary nebula	8.8	36″	19^h 44.8^m	+50° 32′
16 Cygni		Double star	6.0, 6.2	39″	19^h 41.8^m	+50° 32′
Epsilon Pegasi	Pendulum Star	Double star	2.5, 8.7	144″	21^h 44.2^m	+09° 53′
M15		Globular cluster	6.3	18′	21^h 30.0^m	+12° 10′
Epsilon Lyrae	Double Double	Double star	5.0, 5.3	210″	18^h 44.3^m	+39° 40′
Epsilon^1 (ε^1) Lyrae		Double star	5.0, 6.1	2.1″	18^h 44.3^m	+39° 40′
Epsilon^2 (ε^2) Lyrae		Double star	5.3, 5.4	2.4″	18^h 44.3^m	+39° 40′
Struve 2470		Double star	7.0, 8.4	14″	19^h 08.8^m	+34° 46′
Struve 2474		Double star	6.8, 7.9	16″	19^h 09.1^m	+34° 36′
M57	Ring Nebula	Planetary nebula	8.8	76″	18^h 53.6^m	+33° 02′
61 Cygni	Piazzi's Flying Star	Double star	5.3, 6.1	31″	21^h 06.9^m	+38° 45′
NGC 6940		Open cluster	6.3	25′	20^h 34.5^m	+28° 17′
Collinder 399	The Coathanger	Asterism	3.6	90″	19^h 25.4^m	+20° 11′
NGC 6802		Open cluster	8.8	5′	19^h 30.6^m	+20° 16′
NGC 6633		Open cluster	4.6	20′	18^h 27.2^m	+06° 30′
IC 4756		Open cluster	4.6	40′	18^h 38.9^m	+05° 26′
NGC 6572	Emerald Nebula	Planetary nebula	8.1	11″	18^h 12.1^m	+06° 51′

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.



JERRY OLTION (3)

Another excellent binocular target is **Collinder 399**, also known as Brocchi's Cluster and The Coathanger. It's an asterism, a chance alignment of stars that in this case looks like a coathanger. It's upside-down in binoculars but upright in a Newtonian telescope. You'll want your widest field possible for this one since it spans 1½°.

Just a little to the east of The Coathanger, straight in line with the bar, you'll find the small open cluster **NGC 6802**, whose stars are arranged in an oblong oval that looks a little like a figure 8 or a helix. Plus there's a bonus to the cluster's north: yet another double-double.

Heading back into the southwest toward Saturn, we find two more nice open clusters. The first, **NGC 6633**, is all four B's. At 4th magnitude it's easily visible by naked eye, and in binoculars or a telescope it's beautiful. The cluster is elongated northeast-southwest with a scattering of bright (7th–9th-magnitude) stars, with many more faint ones mixed in. On the western edge is a mini asterism that looks like a tiny Cassiopeia.

IC 4756 is another open cluster nearby that's also visible by naked eye under dark sky, and even bigger (although a little sparser) than NGC 6633 next door. It spans more than ½° and looks great in binoculars or at low power in a telescope.

For our grand finale let's look at **NGC 6572**, the Emerald Nebula. This is a small planetary nebula, but it's bright enough (magnitude 8.1) to see in any telescope, and if you have even a little bit of aperture (say 4 inches or better) it'll be bright enough to trigger color vision. And when that happens, it's amazing! This is one of the most brilliant green objects in the sky. You only have color vision when you're looking directly at an object, so it's green when you look straight at it, and it turns to gray (but it gets brighter) when you look away. NGC 6572's surface brightness is 100 times greater than the Ring Nebula's, so it will handle magnification well, but I've found that it looks brightest and greenest with just enough magnification to make it bigger than a point source. Somewhere around 80–90× seems to be ideal.

By now, Saturn has probably set. If not, have another look. Hey, cool, the moons have moved!

▲▲ **LIGHT DUSTING** NGC 6633 is a fine mix of bright and faint stars between Aquila and Ophiuchus. FOV = 1° 30′

▲ **SPRINKLING OF STARS** In the same neighborhood as NGC 6633, IC 4756 is larger but somewhat sparser. Both clusters are visible by naked eye under dark sky. FOV = 5°

◀ **SHIMMER IN THE SKY** The Emerald Nebula is one of the most vivid green objects in the night sky. Use just enough magnification to make it stand out but not so much that you dim it. FOV = 30′

■ Contributing Editor **JERRY OLTION** loves interactive tourist attractions. Contact Jerry at **j.oltion@gmail.com**.

RESTORATION DOWN UNDER by Trudy E. Bell

New Life for the Great Melbourne

▲ **THE MOON REVEALED** Joseph Turner, a local photographer and amateur astronomer, was appointed lead astronomer at the GMT after Albert Le Sueur's resignation in May 1870. Though Turner completed many fine drawings and spectroscopic studies, he also mastered the telescope's photographic equipment. Turner captured this view of the Moon through the GMT in 1875.

Next year is the 150th anniversary of first light for the 48-inch Great Melbourne Telescope (GMT) of the state of Victoria, Australia. For more than two decades after the English-mounted reflector was completed in 1869, the GMT was the largest equatorial telescope in the world, and it remained the largest telescope in the Southern Hemisphere until 1922. Its users' early achievements include the first visual observation of the spectrum of an extragalactic nebula (1870), the world's finest photographs of the Moon (1872), the first photographs of southern nebulae (1883), and the discovery of more than 50 nebulae and galaxies.

However, the GMT eventually fell on hard times. Challenges in printing delicate nebulae sketches plus a worldwide financial crisis in the 1890s that also took its toll on Australia prevented the publication of two decades of observations, making it seem that the telescope had been unproductive. In part as a result, telescope optician George W. Ritchey (who later helped figure Mount Wilson Observatory's 100-inch mirror) famously passed off the GMT as a "failure" in 1904.

In 1945, the GMT was sold to Mount Stromlo Observatory near Canberra. There, it was reconstructed three times (1950–55, 1960–61, and 1989–91), including being fitted with two different 50-inch borosilicate glass mirrors. During each rebuild, more of the GMT's original parts were removed. Fortunately, Museums Victoria retrieved them for safekeeping in off-site collection storage in the 1980s. The telescope's last incarnation, as an automated instrument that discovered a form of dark matter in 1993, incorporated just five assemblies of the GMT's original mount. In January 2003, the telescope was engulfed in raging wildfires that swept Mount Stromlo.

The upshot of this story: Many today are left thinking that the GMT was originally flawed and then was taken out of commission. However, neither of these "facts" is true. For the past decade, several organizations in Melbourne have been documenting, cleaning, and reassembling the GMT from its original parts — 70% of which survive at Museums Victoria. Their goal is to reconstruct the instrument with as much historical authenticity as possible, but with modern optics so the public may look through it and amateurs can use it for research. In so doing, they also seek to restore the GMT's reputation and its rightful place in history.

Chronology of the GMT

Beginning with William Herschel's large reflecting telescopes in the 1780s, astronomers used a half dozen major instruments to reveal thousands of faint nebulae amidst the stars in the northern heavens; in the 1830s, William's son, John Herschel, discovered countless more in the southern heavens. Were these nebulous clouds of gases relatively nearby, lying within our own "sidereal system"? Or were they independent "island universes" at such vast distances that their stars could not be resolved?

Those fundamental questions might be answered by stationing a capable observer at the eyepiece of a gigantic telescope in the Southern Hemisphere, to compare later observations with John Herschel's meticulous drawings of decades earlier to see whether any nebulae had changed appearance. In 1852, the British Association for the Advancement of Science and the Royal Society of London jointly appointed a Southern Telescope Committee of the British Empire's top astronomers, to determine what kind of instrument should be built, who should build it, and where it should be located.

By 1853, the committee had settled on a design and appointed a subcommittee to oversee a proposed contract with Dublin telescope engineer Thomas Grubb — but then the Crimean War (1853–1856) halted everything. It seemed the project was dead.

MOON: MUSEUMS VICTORIA / CC BY 4.0; PATTERN: HUI-YING TING-BORNFREUND / GETTY IMAGES

COLOSSAL INSTRUMENT *The London Illustrated News* dedicated a full-page review to the Great Melbourne Telescope in November 1868. The writer enthusiastically described the mechanics of the Cassegrain focus, which gave the telescope “some important advantages, foremost among which is the fact the observer is never more than about 4 ft. off the ground.” The benefits of the lattice-work optical tube were listed as “great stiffness and freedom from tremor, combined with lightness and freedom from currents of air . . .” The scope was also praised for its “improved” equatorial mounting and “efficient photographic apparatus.”

Australian groups are restoring what was once the world’s largest equatorially mounted telescope.

Telescope

HULTON ARCHIVE / STRINGER / GETTY IMAGES

▲ **SOUTHERN SUCCESS** Following improvements of developing and printing processes, astronomers at Melbourne Observatory began photographing nebulae with the GMT in 1882. Taken on February 26, 1883, Turner's image of the Great Orion Nebula was one of the earliest photos of nebulae taken in the Southern Hemisphere.

A decade passed. In 1863, the British colony of Victoria — wealthy from a gold rush since 1851 and hankering to establish itself as a cultural center of learning — authorized £5,000 for a large telescope for Victoria's capital city of Melbourne. The Southern Telescope Committee dusted off its plans. After extensive discussion about technical advances over the intervening decade, it reaffirmed the major concepts of the original plan. The telescope's final specs were thus a combination of conservative and innovative design choices.

Something Old, Something New

The proposed mirror would be 48 inches in diameter, made of polished speculum metal — a white bronze alloy of copper and tin whose casting, figuring, and maintenance were well understood. Despite the adaptation of a process for depositing a thin coat of silver on glass to telescope mirrors by physicists Léon Foucault and Carl August von Steinheil in 1857, casting and silvering such a large glass mirror was as yet untried; the long-term stability of glass as a material and silver as a coating were unknown; and silver, although more reflective than speculum metal, tarnished more quickly. Moreover, the use of speculum metal would minimize differences in reflectance as a factor in comparing observations made decades apart.

The telescope was to have a Cassegrain focus rather than Herschelian or Newtonian, a pioneering choice that let the astronomer observe more safely from the ground or low steps instead of perched two or three stories up in the air in the dark. Nebulae were to be drawn by hand by a visual observer using a precision bifilar micrometer (photographing them was impossible with the very slow emulsions of the 1860s), but the secondary mirror cell could be swapped out for a camera to allow photography of bright objects at prime focus.

The mounting would be an equatorial made of cast iron, rather than an alt-azimuth built largely of wood (like John Herschel's) or masonry (like Lord Rosse's). Despite the telescope's moving mass topping 18,000 pounds, Grubb devised a pioneering system of counterweights to relieve frictional loads on bearings. Thus, one person could slew the telescope with ease, and a gravity-powered clock drive acting on the polar axis could compensate for Earth's rotation. The telescope would be sited at low elevation near a thickly settled area (a practical cost-saving choice, then the norm).

The order was signed with Thomas Grubb in early 1866, and the entire 48-inch telescope was completed by February 1868. Construction was supervised primarily by Grubb's 21-year-old engineering student son Howard, who was in the process of launching his own illustrious telescope-making career. The Grubbs cast and figured two speculum primary mirrors, so that (following the method used by John Herschel in South Africa) one could always be used for observing while the other was being repolished to remove tarnish. They deliberately designed the English cross-axis equatorial mount to be strong and stiff enough to carry the mass of a 60-inch reflector, should a larger telescope someday be desired. And to support the 2,200-pound 48-inch mirror without noticeable distortion at all viewing angles, Howard refined his father's 48-point floating suspension system of counterbalanced triangular levers — a design still often used today.

After meticulously inspecting the assembled GMT in the Grubb factory yard and testing the mirrors and photographic system on various celestial objects, including the Moon, double stars, and nebulae, the Southern Telescope Committee was delighted with both its optics and mechanics. The GMT was disassembled, crated, and shipped to Australia, arriving at Melbourne in November 1868. It was reassembled on bluestone (basalt) foundations and piers. A rectangular telescope house with a novel roll-off roof — likely the world's largest at the time (although not the world's first) and now the oldest surviving — was built around it so observing could be done in the open air (a choice both conservative and prophetic). At last, in mid-1869, the GMT turned its giant eye up toward the spectacular southern heavens.

ORION NEBULA: MUSEUMS VICTORIA / PUBLIC DOMAIN; PHOTO OF TELESCOPE: MUSEUMS VICTORIA; MELBOURNE OBSERVATORY: MUSEUMS VICTORIA / PUBLIC DOMAIN; PATTERN: HUI-YING TING-BORNFREUND / GETTY IMAGES

Disentangling Controversies

Almost immediately, complaints arose about poor imaging. Finger-pointing letters sailed between the Northern and Southern Hemispheres, some printed in British newspapers. The Southern Telescope Committee and the Grubbs had made what in retrospect was a problematic call. Instead of sending Howard south with the telescope to supervise its installation, the intended primary observer — a Cambridge mathematician named Albert Le Sueur — was hired by the Melbourne Observatory. Le Sueur was sent to the Grubb factory to witness the casting of the mirrors and other key milestones, and to learn how to reassemble and operate the telescope, as well as the mirror grinding and polishing machine. But once en route to Australia, Le Sueur was on his own and had to make judgment calls. Grubb had specified that the mirrors' protective coating of shellac be removed with pure ethyl or methyl alcohol. But pure alcohol was in short supply in Victoria. Instead, Le Sueur started the job using methylated spirits and finished with pure alcohol. Although the smaller mirrors retained their high polish, either the shellac applied to one of the primary mirrors in Dublin or parts of its surface may have been contaminated. A cloudy residue yielded diffuse reflections, and accusations flew. Making matters worse, an irate Melbourne amateur astronomer wrote angry letters both to British and Australian scientific societies, claiming (inaccurately) that "[t]he instrument has cost us colonials £14,000" and asserting, "It is a grievous failure."

Over the next year, Le Sueur hand-polished both primaries with washed chalk to near perfection, but in August 1870 he resigned in frustration and returned to England. Although he and Melbourne Observatory director Robert Ellery were staunchly backed by the observatory's capable Board of Visitors, the bad-PR mud stuck.

▲ **OBSERVATORY OVERVIEW** This image offers a view of the Melbourne Observatory as it appeared in the 1880s. The main observatory building is at center. The GMT, workshop, and engine for the mirror-grinding apparatus are at the far right.

In the meantime, no one in the Southern Hemisphere had experience in working with a telescope of such a large aperture, so on nights of ordinary seeing, a person accustomed to observing with smaller apertures could find the GMT's performance on a planet or double star actually "disappointing," noted Ellery. But "on really good nights it is quite different . . . indicating an optical perfection which under other conditions was not apparent."

Moreover, the Southern Telescope Committee's intended observing program — visual observations of nebulae to detect changes — was highly subjective, depending on individual observers' visual acuity and artistic skill. Indeed, for those nebulae that were distant galaxies, detecting any change (short of an extragalactic supernova) over mere decades was downright impossible — although, of course, absence of change was a crucial test.

Finally, after the financial crash of the 1890s nearly halved the observatory's budget at a time when it had committed heavy resources to the international Astrographic Catalogue, the GMT was not adequately maintained and most of the astronomers' meticulous drawings were never published.

Against this background of woes, in 1904 Ritchey parenthetically commented in a treatise on making and testing

◀ **PHOTO ASSIST** Since no original drawings for the GMT survive, photographs such as this one, which shows the telescope as it was in 1875, have been crucial in helping the restoration team reverse-engineer the telescope's assembly. The weight hanging next to the man (who is believed to be Joseph Turner) and the chain going over the top of the larger pier were part of Thomas Grubb's design to relieve frictional load on the main bearing of both axes so the telescope could be clock-driven. The clock drive is next to the weight.

telescope mirrors, "I consider the failure of the Melbourne reflector to have been one of the greatest calamities in the history of instrumental astronomy; for by destroying confidence in the usefulness of great reflecting telescopes, it has hindered the development of this type of instrument . . ." Ritchey never looked through the GMT, much less tested it. Nonetheless, his offhand remark was the last straw for the GMT's reputation.

Phoenix from the Ashes

Fast forward a century to the year after the devastating Mount Stromlo bushfire. Members of the Astronomical Society of Victoria (now 1,000+ members strong) began brainstorming with managers at Museums Victoria. If the major castings of the equatorial mount were retrieved from Mount Stromlo, could the GMT be reconstructed from surviving original parts using modern optics? In November 2008, the GMT's cube, polar axis and bearing mounts, declination axis and bell-shaped housing, north bearing quadrant, modern mirror cell, and fragmented 50-inch mirror were retrieved from the incinerated building and trucked to Melbourne.

▲ **AFTER THE FIRE** In 1945, the GMT was moved to Mount Stromlo Observatory, where it was modified three times. The only original parts engulfed by a wildfire in 2003 were the cube (center), the polar axis south or upper cone (above the cube), the declination axis with its bell-shaped housing (left of the cube), and the north bearing quadrant (unseen below the wall). Fortunately, they survived. This photo was taken in 2008 before those pieces were retrieved for restoration.

Extensive talks led to a formal memorandum of understanding among Museums Victoria (owner of the GMT parts and eventually of the completed GMT), the Royal Botanic Gardens Victoria (manager of the Melbourne Observatory site where the original GMT house still stands), and the Astronomical Society of Victoria (ASV, source of volunteer labor with optical and engineering skills). The projected cost of the restoration project was estimated at A$3,000,000, a sum the groups hoped to raise via grants and donations. In 2013, the Bureau of Meteorology also joined as Melbourne Observatory had operated the Victorian Weather Office from 1863 to 1907.

Since 2009, a dozen or so ASV volunteers — mostly retired engineers and optical specialists — have spent Wednesdays working under the leadership of museum curators and conservation staff in Museums Victoria's cavernous warehouse, complete with 10-ton overhead crane. Because the telescope is part of Victoria's State Heritage Collections, decisions are guided by the Australia International Council on Monuments and Sites (ICOMOS) Burra Charter for the conservation of historic structures.

Volunteers began by photographing, weighing, and measuring every component as it existed (including any Mount Stromlo modifications) and ascertaining their positions and functions in the GMT. Then came the writing of a proposal for the work needed to restore the telescope. Every part and fastener was numbered and tracked; by the end of 2017, the inventory identified some 1,200 components and included some 700 drawings.

Because no original engineering records survived the 2003 Mount Stromlo bushfire (or an earlier one in 1952), CAD drawings had to be reconstructed for the entire GMT — including the shapes and dimensions of missing components (40 to 50 major parts plus several hundred knobs, gears, and other small items). Although schematic drawings for some larger assemblies were published in 1868, for other parts all that remained were several 19th-century photographs. Finally, a gigantic flow chart was drawn up to identify critical paths: which jobs needed to be done in what order, including contracting for custom-made missing pieces.

Then came the heavy physical labor: unbolting and disassembling every subassembly and cleaning every part and fastener by hand down to bare metal. To support the project, both individuals and philanthropic organizations donated half a million dollars plus crucial in-kind design and engineering work.

In late 2014 came a trial reassembly of the cleaned parts. The cube and southern cone of the polar axis were bolted together, the upper and lower bearings placed on a giant frame, and the tube suspended from the overhead crane for a staged photo shoot giving a feel for the GMT's mass, size, and eventual appearance.

Optics and Observatory Plans

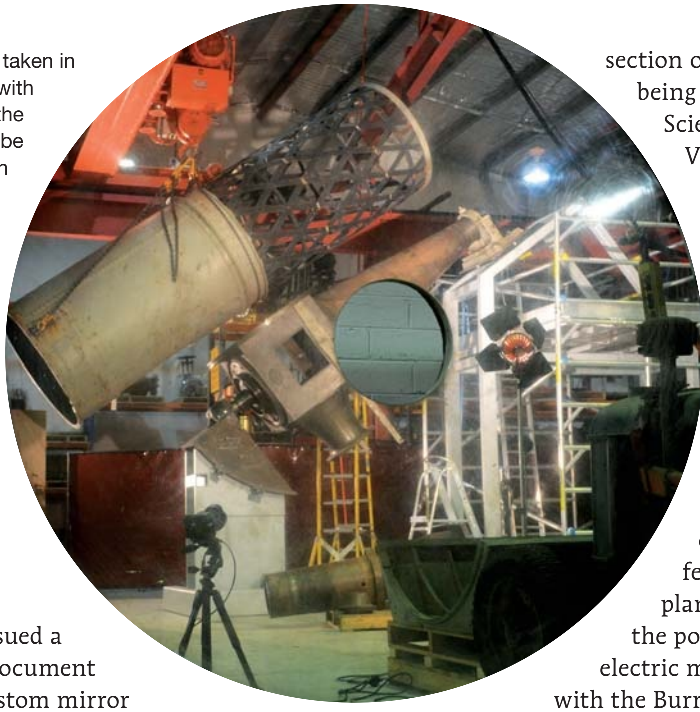
Only one of the two original 48-inch speculum mirrors is extant; the other broke at Mount Stromlo c. 1948. The GMT restoration team intends to put the remaining mirror on static display with its 48-point flotation system. For actual use, the team first sought donation of a secondhand mirror (including, through this author in 2012, the 48-inch mirror from the former Table Mountain Observatory). All attempts ran afoul of either legalities over an international transfer or lack of a central hole for a Cassegrain focus. So in October

FIRE AFTERMATH: STEVE ROBERTS; GRINDER: STEVE ROBERTS; CENTRAL CUBE: TRUDY E. BELL; DAD'S ARMY: TRUDY E. BELL; PATTERN: HUI-YING TING-BORNFREUND / GETTY IMAGES

▲ **THE GREAT GRINDER** While most ASV volunteers focused on the telescope itself, the oldest ASV team member, David Linke, devoted his attention exclusively to Thomas Grubb's two-ton mirror-grinding and polishing machine. The apparatus was used several times in the 19th century to remove tarnish that gradually accumulated on the GMT's speculum mirrors.

▲ **EXEMPLARY EFFORT** Some 8 to 15 members of the Astronomical Society of Victoria — most of them retired engineers, machinists, and other technical professionals — meet at the Museums Victoria warehouse every Wednesday to work on the GMT restoration. Much of the work has been done by hand or using original techniques. Here Graeme Bannister was photographed in 2011 removing rust from the central cube.

▲ **DAD'S ARMY** ASV volunteers at the Museums Victoria warehouse stand in front of a wall-sized photograph of the GMT as it appeared in 1875 — an image essential to the task of recreating detailed engineering designs. Nicknaming itself "Dad's Army" after a 1970s BBC TV sitcom about the work of a detachment of Home Guard older than those sent into combat during World War II, some two dozen ASV members have dedicated well over 20,000 hours of volunteer labor over 400+ weekly sessions since 2009.



▶ **REFLECTED GLORY** This image, taken in 2014 during a photo shoot to assist with fundraising, shows the polar axis of the GMT's mount — consisting of the cube and upper (south) cone — joined with the bell-shaped housing of the declination axis. The entire assembly is anchored to a custom stand whose design was donated by an engineering firm. An overhead crane holds the surviving section of the original optical tube near its correct position. The scene is reflected in the partially cleaned front surface of the surviving original 48-inch speculum-metal mirror. The scene was shot in the storehouse of Museums Victoria, where the 150-year-old instrument is being brought back to life.

JOHN ROBINSON / ASTRONOMICAL SOCIETY OF VICTORIA, AUSTRALIA

2017, the restoration project issued a formal Expression of Interest document to the optical industry for a custom mirror of low-expansion borosilicate glass, fused silica, or glassy ceramic.

The original GMT primary mirrors had a focal length of 366 inches (f/7.625); at the f/41.5 Cassegrain focus, the effective focal length (EFL) was 1,994 inches. That gave an actual field of view of just 13 arcminutes with the lowest-power eyepiece, somewhat narrow for public viewing. Although current plans still call for reconstructing the GMT's iconic open lattice tube to full length, actual optical focal lengths will be somewhat shorter to allow a usable field of 17 arcminutes while keeping the secondary obstruction under 14 inches. The new perforated Cassegrain primary is to be f/7.0 (336 inches); with a new secondary, the final focal ratio will be f/31.2 (EFL 1,498 inches).

By June 2018, it was evident that the quoted prices for the new optical train were higher than the budget could afford, so the ASV is looking for more cost-effective alternatives. One possibility is for a team of ASV optical specialists to grind, polish, and figure the hyperboloidal secondary themselves, using a secondhand 310-mm Schott Zerodur blank.

Meanwhile, in February 2018, the Melbourne Observatory was permanently added to Australia's Federal Heritage List, opening up both greater protection and a new source of funds for the GMT restoration. In May, the Australian federal government awarded a grant of A$250,000 (about U.S.$185,000) to restore the roll-off roof of the GMT's telescope house to working order. The bluestone piers must be rebuilt as well (the original stone blocks went to Mount Stromlo but were discarded when the mount was modified). In 2013, an inspection revealed that the piers' remaining bluestone foundations were still in excellent condition. Restoration of the brickwork is expected to be completed by 2019.

The team is also focusing on rebuilding lost telescope components. The biggest missing part — the upper lattice section of the telescope tube — is now being fabricated in the workshop of Scienceworks, another Museums Victoria institution. And the Australian Antiquarian Horological Society has generously offered to make replacement telescope clockwork. The original clock drive was gravity-powered by descending weights that could run for up to two hours before requiring winding; its speed (sidereal, diurnal, or lunar) was regulated by a centrifugal governor and differential gearbox. The current plan for most observing is to drive the polar axis with an unobtrusive electric motor. However, in accordance with the Burra Charter, which advocates a cautious approach to change but allows for the introduction of new material during reconstruction as long as it doesn't damage a site's historical significance, a working reproduction of the missing clock drive will be installed.

The current goal is to fit the telescope with its new, full-length tube and put it on display at Scienceworks by June 2019, the 150th anniversary of the GMT's first light from Australia. There, its magnificence will be seen by the public as well as by the media, and by federal and state politicians. That, it's hoped, will result in more funding to support the original ambitious goal: reconstructing the GMT to full working order inside its original observatory building to make it the largest telescope in the Southern Hemisphere for astronomy public outreach.

■ Contributing Editor **TRUDY E. BELL**, formerly an editor for *Scientific American* and *IEEE Spectrum* magazines and senior writer for the University of California High-Performance AstroComputing Center, is the author of a dozen books and over 500 articles. Her journalism prizes include the 2006 David N. Schramm Award of the American Astronomical Society. She can be reached at **t.e.bell@ieee.org**.

She gratefully acknowledges information and images from the following sources: Roger Ceragioli, Matthew Churchward, Barry Clark, Philip Edwards, Richard Gillespie, Frederick Orthlieb, Jim Pollock, Steve Roberts, John Robinson, and Matilda Vaughan. Some information they and primary source documents provided corrects errors in earlier secondary literature.

FURTHER READING: The 19th-century debates over the design and viability of the GMT are detailed in Richard Gillespie's book, *The Great Melbourne Telescope* (Melbourne: Museum Victoria Publishing, 2011).

4 EARLY MORNING: Watch as the thin waning crescent Moon and the Beehive Cluster (M44) rise together in the east-northeast and climb ever higher before sunrise.

5 EARLY MORNING: A thinner Moon has slipped down into Leo, the Lion, and leads Regulus by about 7° as they soar into the pre-dawn sky.

11 DUSK: Resplendent Jupiter gleams in Libra as a crescent Moon, only a few days past new, stands guard 3° above.

13 DAWN: Look toward the east before morning twilight for the soft glow of the zodiacal light. You must be at more northerly latitudes, but if you are you might see this phenomenon for the next two weeks. Look for a tall pyramid of light stretching up to Gemini, tilted toward the right.

14 DUSK: After sunset, the waxing crescent Moon and Saturn will emerge from the gloaming, 2° or fewer apart. Look for the pair where Saturn has been roosting the past few months, above the Teapot in Sagittarius. Fading Jupiter and fiery Mars anchor at either end to complete a graceful celestial arc.

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:50 p.m. PDT.

17 & 18 EVENING: Watch as the fattening gibbous Moon hopscotches over Mars, first appearing some 5° right of the Red Planet and then 6° upper left, as it continues on its trek along the ecliptic.

20 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:39 p.m. EDT.

20–22 MORNING: The medium-strength Orionid meteor shower is expected to peak in the afternoon of the 21st. Best opportunities for spotting meteors are in the early morning, but the nearly full Moon will hamper viewing somewhat (see p. 49 for more on this shower).

26 ALL NIGHT: The Hyades cradle the waning gibbous Moon until sunrise.

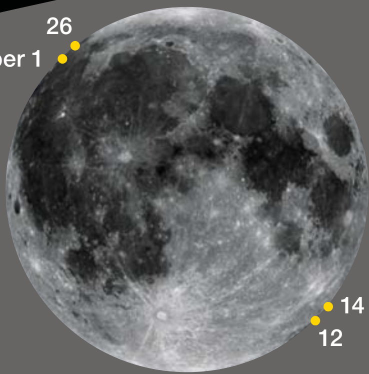
31 NIGHT: We have come full cycle, as the last quarter Moon rises in Cancer. Watch as the Beehive Cluster and the lunar crescent sweep across the sky, some 4° apart.

The Milky Way arches overhead while the zodiacal light spills along the ecliptic in this all-sky view captured in northern Maine.
BABAK TAFRESHI

OCTOBER 2018 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			

LAST QUARTER
October 2
09:45 UT

NEW MOON
October 9
03:47 UT

FIRST QUARTER
October 16
18:02 UT

FULL MOON
October 24
16:45 UT

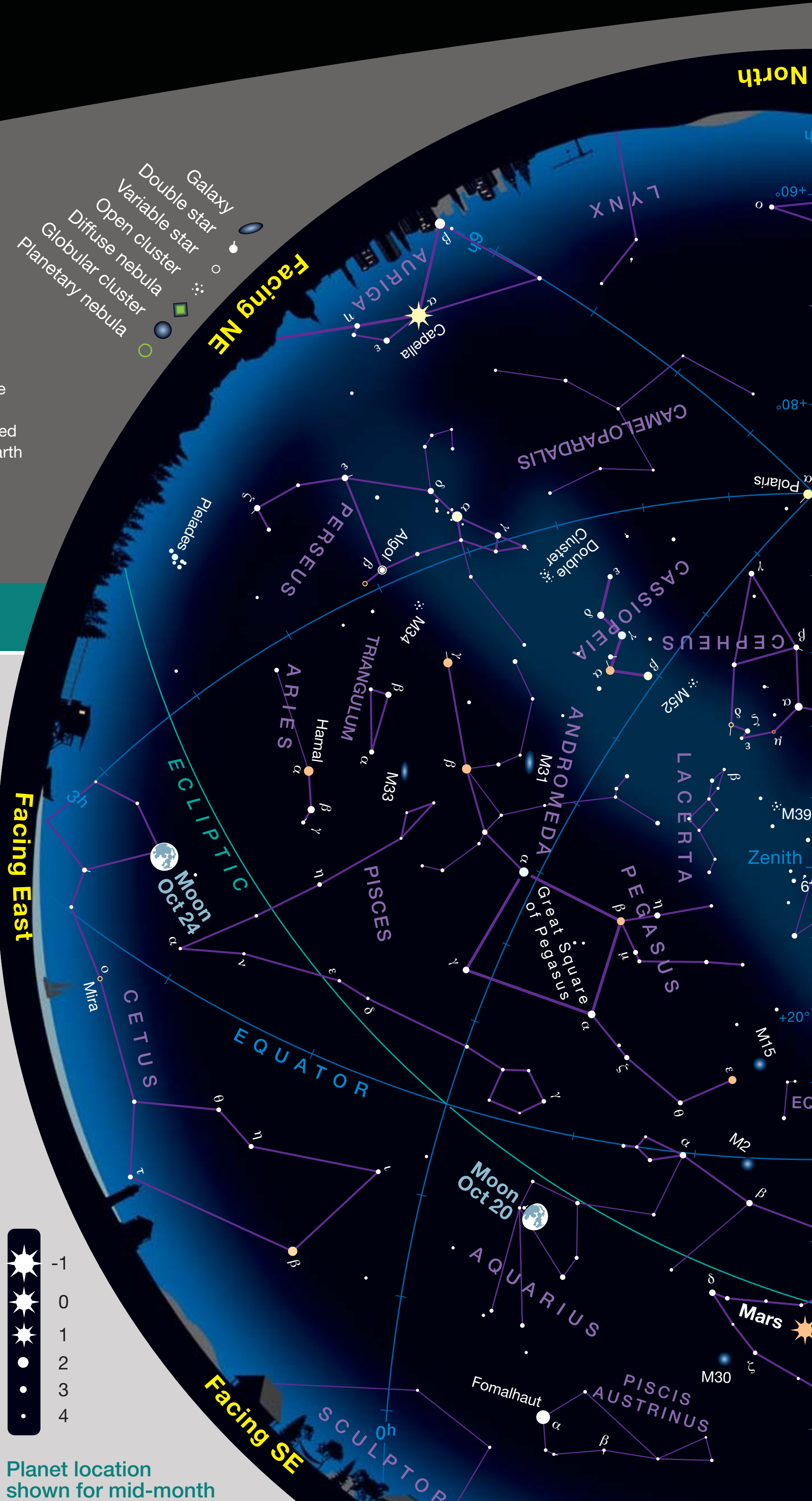
LAST QUARTER
October 31
16:40 UT

DISTANCES

Perigee 366,392 km	October 5, 22^h UT Diameter 32′ 37″
Apogee 404,227 km	October 17, 19^h UT Diameter 29′ 34″
Perigee 370,204 km	October 31, 20^h UT Diameter 32′ 17″

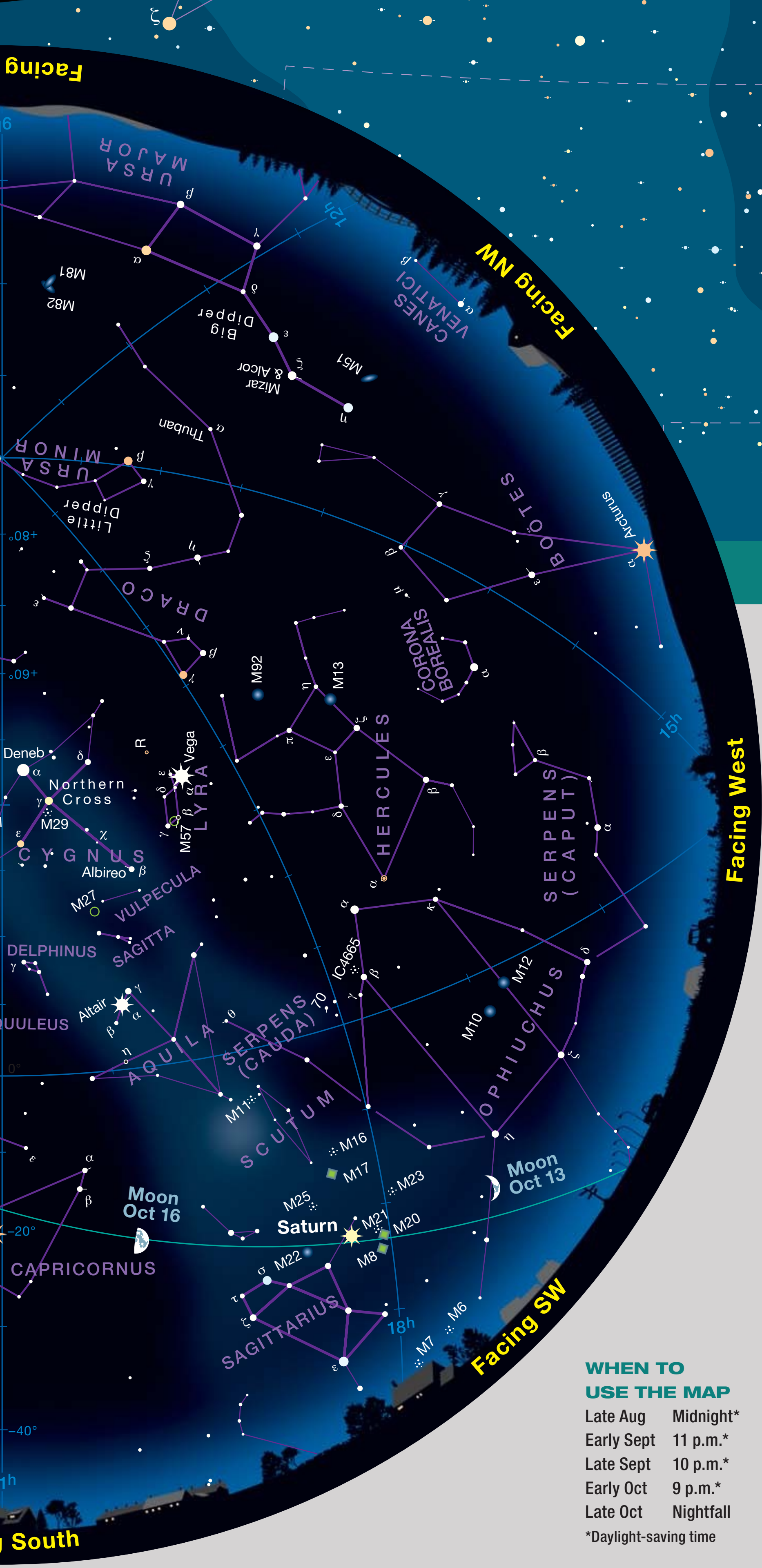
FAVORABLE LIBRATIONS

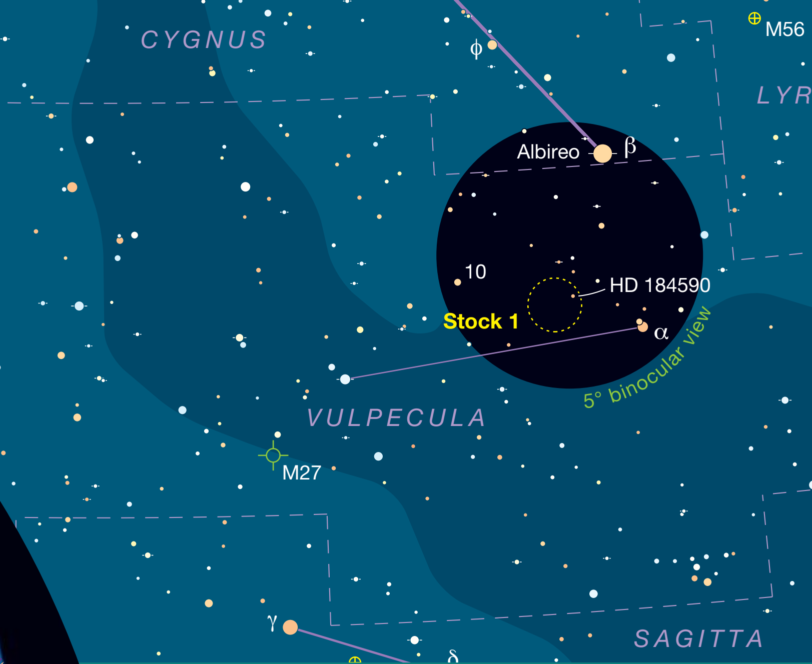
• Bunsen A Crater	October 1
• Mare Australe	October 12
• Gum Crater	October 14
• Regnault Crater	October 26



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

Harvest the Stars

The Milky Way offers so many open clusters that I have to consciously resist their pull, lest this column turn into "all open clusters, all the time." Still, there's no denying that open clusters offer a larger variety of rewarding binocular targets than any other class of celestial object. This month we'll visit one that's easy to find, but which hasn't reaped as much attention as its neighbors.

Imagine an equilateral triangle, about 3.5° on a side, formed by Albireo, Alpha (α) Vulpeculae, and 10 Vulpeculae. About halfway between the latter two stars lies the open cluster **Stock 1**. Perched on the western edge of the dark Cygnus Rift, Stock 1 sprawls across almost a full degree of arc. At about 15 light-years in diameter, it's not an unusually big cluster. Rather, it appears large because it is fairly close to us, only 1,000 light-years away.

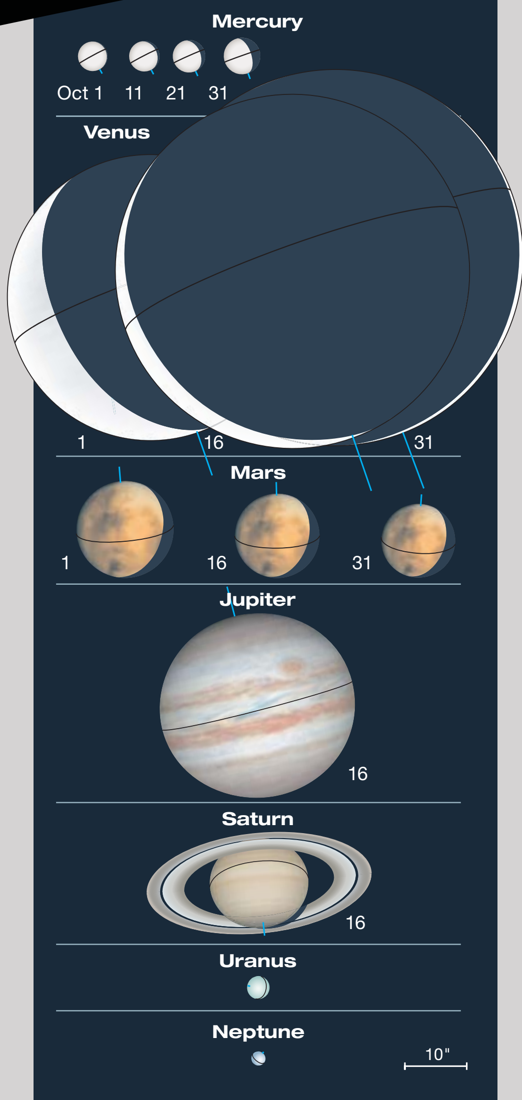
The cluster is noticeably asymmetric. Its stars are most concentrated toward the southeast, and they spread out to the northwest. In fact, instead of coming to a sharp cutoff, the northwest end of the cluster grades smoothly into several chains of stars that seem to radiate north-northwest toward Albireo. Especially in this season, I always see the cluster and its neighboring spray of stars as a sheaf of grain, bundled from the harvest. The illusion is enhanced by a number of *K*-type orange giants that lend the scene a golden hue. Most of these aging stars are as close or closer to us than Stock 1, but HD 184590, an *M*-type orange-red giant, glares back at us across 2,000 light-years. At 7th magnitude, it's bright enough to show up even in smaller binoculars. Look for it perched right on — or rather, *behind* — the north-western edge of Stock 1.

■ **MATT WEDEL** is out in the dark with his binos, bringing in the harvest. You should give him a hand.

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



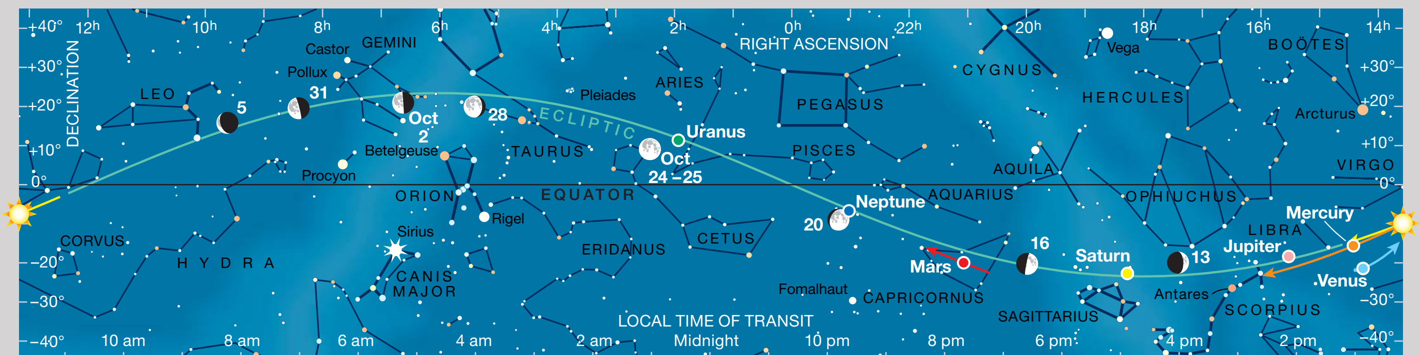
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY Mercury: hidden in the Sun's glow all month • **Venus:** visible at dusk through the 7th • **Mars:** visible at dusk, sets after midnight • **Jupiter:** visible at dusk, sets early evening • **Saturn:** visible at dusk, sets mid-evening

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h 27.6^m$	–2° 59′	—	–26.8	31′ 57″	—	1.001
	31	$14^h 19.6^m$	–13° 56′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$12^h 56.8^m$	–5° 27′	8° Ev	–0.9	4.8″	98%	1.406
	11	$13^h 55.6^m$	–12° 27′	14° Ev	–0.4	4.9″	93%	1.365
	21	$14^h 52.4^m$	–18° 16′	19° Ev	–0.2	5.3″	86%	1.276
	31	$15^h 46.9^m$	–22° 32′	22° Ev	–0.2	5.9″	75%	1.138
Venus	1	$14^h 21.8^m$	–21° 19′	33° Ev	–4.8	46.2″	17%	0.361
	11	$14^h 20.5^m$	–21° 52′	24° Ev	–4.6	53.9″	8%	0.310
	21	$14^h 05.4^m$	–20° 13′	11° Ev	–4.2	59.9″	2%	0.278
	31	$13^h 44.6^m$	–16° 34′	9° Mo	–4.2	60.9″	1%	0.274
Mars	1	$20^h 36.3^m$	–22° 37′	118° Ev	–1.3	15.8″	88%	0.592
	16	$21^h 03.0^m$	–20° 02′	110° Ev	–1.0	13.7″	87%	0.682
	31	$21^h 34.1^m$	–16° 56′	103° Ev	–0.6	12.0″	86%	0.781
Jupiter	1	$15^h 18.4^m$	–17° 29′	44° Ev	–1.8	32.6″	100%	6.046
	31	$15^h 43.2^m$	–19° 01′	21° Ev	–1.7	31.4″	100%	6.285
Saturn	1	$18^h 12.0^m$	–22° 46′	85° Ev	+0.5	16.5″	100%	10.097
	31	$18^h 20.0^m$	–22° 47′	57° Ev	+0.6	15.7″	100%	10.563
Uranus	16	$1^h 54.8^m$	+11° 10′	172° Mo	+5.7	3.7″	100%	18.884
Neptune	16	$23^h 02.1^m$	–7° 16′	142° Ev	+7.8	2.3″	100%	29.153

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.

The Sea Goat in the Skies

The ancient constellation Capricornus bears an interesting history.

LIBRARY OF CONGRESS / RESTORATION: ADAM CUERDEN

Capricornus is certainly not a very bright constellation, nor one with a lot of notable deep-sky objects within its bounds. Even so, I find it more fascinating and more of a standout than many other constellations, even some others of the zodiac.

Why do I find it so compelling? First of all, no other constellation represents something so peculiar — a creature half-goat and half-fish. Yet its strange goat-fish form is also the key to directly identifying it as one of the most ancient of all constellations. Other notable attributes of Capricornus include its compactness, its rich connections with language, its remarkable double stars, and its position with regard to the zodiac, the Summer Triangle, and certain deep-sky objects.

Capricornus, the compact standout. At the time of our October all-sky map, the pattern of Capricornus is at its exact highest in the south. Capricornus is fairly dim, though certainly no more so than the other two constellations that form the autumnal zodiac, Aquarius and Pisces. But according to the modern boundaries of the constellations, the area of the heavens that belongs to Capricornus is actually smaller than that of any other zodiac constellation, even a little smaller than that of Aries. Aquarius and Pisces are both more than twice as big in area as Capricornus (so is Capricornus's western neighbor, Sagittarius — and Virgo is more than three times larger). But the fact that the pattern of Capricornus is rather compact makes it easier to find and study than the more sprawling and complicated forms of Aquarius and Pisces.

What should also be quite noticeable to those who follow the planets is how large the gap — consisting of mostly faint and disorganized starry heavens — actually is between the Teapot of Sagittarius and the interesting western end of Capricornus. Of course, in recent years the Teaspoon asterism in Sagittarius has (rightfully) gained greater fame. But the naked-eye dullness of eastern Sagittarius still may be the largest such gap anywhere along the zodiac — and western Capricornus is at the end of that gap.

The goat or boat. Astronomy writer Guy Ottewell has said that the pattern of Capricornus looks more like a boat than a goat — though I would say a oddly formed little paper boat or an origami bird. However, we now know that Capricornus was indeed imagined to be a boat — the boat of the god Enki — in Mesopotamia about 5,000 years ago (*S&T:* Mar. 2015, p. 36). Interestingly, only a few hundred years later the pattern became associated with one of Enki's various forms — front-half goat and back-half fish. And up to our present day, Capricornus is still pictured that way. It is supposed to be a "Sea Goat" or "Goat-Fish."

Capricornus in name and language. The name Capricornus is Latin for "horned goat." The second half of the name is the "horn" part: A cornucopia is a horn of plenty ("copia" as in copious) and a mythical one-horned creature is a unicorn. But the first part of the name Capricornus means "goat" — baby goats (kids) hopping around playfully are capering, and we call their behavior capricious. One of several possibilites is that the age-old Italian resort, the Isle of Capri, was named for being the "isle of goats." At the very time of our October all-sky map, with Capricornus at its highest, the brilliant star just rising in the northeast is Capella, which means "she-goat" (the mother goat held by Auriga, the Charioteer).

Capricornus to be continued. The head of the Sea Goat is marked by Alpha (α) and Beta (β) Capricorni, just a few degrees apart — with Alpha a wide naked-eye double star and Beta a wide binocular double star. Next month we'll examine them, plus several other choice deep-sky objects in and near Capricornus. We'll also consider other fascinating aspects of Capricornus's positioning and objects to which its odd shape has been compared.

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

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

Enter the Ice Giants

The brighter planets begin to give way as Uranus and Neptune jostle for our attention this month.

The glorious evening bridge of four bright planets we've enjoyed through summer comes to an end this month. Venus falls and fades from sight into the Sun's afterglow, then leaves the evening sky altogether later in October. Jupiter is visible in the west-southwest at nightfall, lower and for less time, and near month's end is close to low and elusive Mercury. Saturn shines in the south-southwest at dusk, much higher than Jupiter, and remains visible into the second half of evening. Mars at nightfall burns in the south-southeast and, though it fades, still shines brighter than any star until after the midnight hour when it sets and Sirius rises.

The only bright planet visible at dawn this month is Venus, very low and late in morning twilight, at the end of October.

DUSK

Venus starts October very low in the west after the Sun sets for viewers around latitude 40° north. It gets even lower and even more difficult to spot with each passing day. It's out of sight by the 7th. Venus reaches inferior conjunction on October 26th and is then 6° south of the Sun — after which it starts emerging before sunrise (see below).

Jupiter shines at magnitude –1.7 by late October and the interval between sunset and Jupiter-set decreases to only about 1 hour by month's end. Even Jupiter is less than 32″ wide by the second half of October and presents a shaky image so low in the sky.

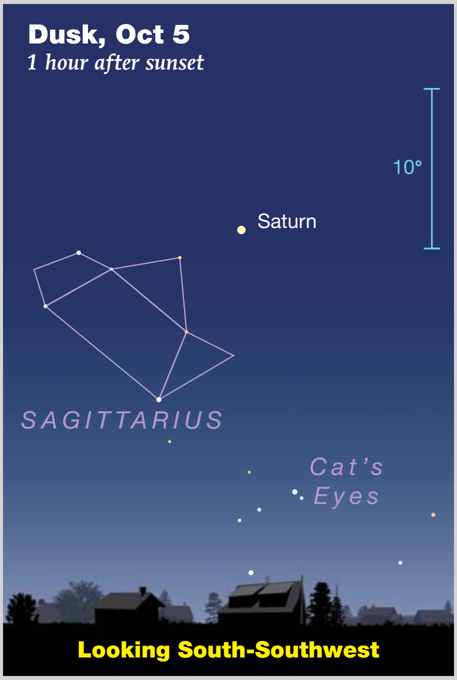
Mercury may be glimpsed very low in the west shortly after sunset toward the end of the month; optical aid will help.

DUSK THROUGH EVENING

Saturn is already past the meridian as night falls but doesn't set until after 11 p.m. October 1st and after 9 p.m. late in the month. Serene Saturn dims from magnitude +0.5 to +0.6 during October and its globe shrinks to less than 16″ in equatorial diameter. But the rings, though now a year past their time of maximum tilt, are only slightly less tilted and remain a stirring sight. Saturn is slowly trekking eastward above the Teapot of Sagittarius.

Mars loses half its brightness yet again this month, dimming from magnitude –1.3 to –0.6 — but even the latter figure is impressive. The Red Planet culminates around 9 p.m. in early October, and about an hour earlier by the end of the month. That's when it's high-

▶ 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.

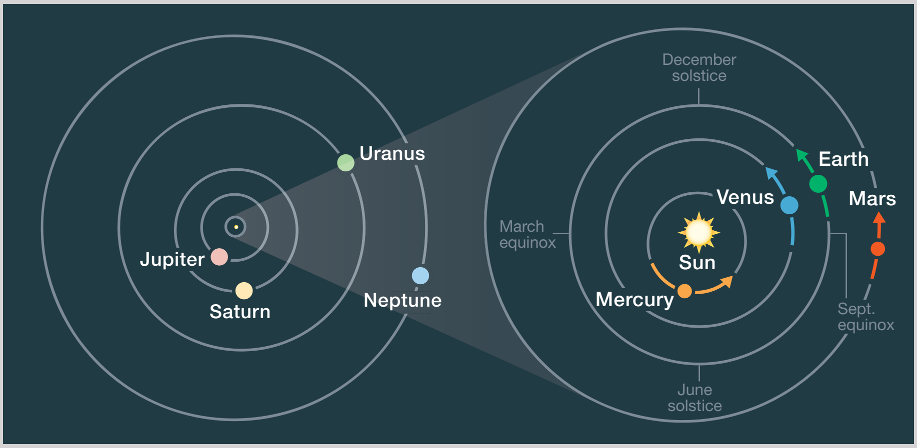


est and most likely to provide a steady sharp image in telescopes. The apparent diameter of Mars shrinks from 16″ to 12″ in October — only half as wide as it was in late August. Nevertheless, this is still large enough to get some fine views of Martian surface and atmospheric features with a good telescope on a good night. The northern hemisphere of Mars reaches its winter solstice on October 16th. For information about observing the Martian north polar hood clouds and north polar icecap, along with other features at this apparition, see p. 22 in the July issue.

Mars races eastward across most of the compact pattern of Capricornus this month. At the end of October the planet approaches the eastward end of the Sea Goat, marked by the magnitude-2.85 star Delta (δ) Capricorni, also known as Deneb Algedi (see p. 45 for more on the stars of Capricornus).

ALL NIGHT

Uranus arrives at opposition on October 23rd so is highest in the middle of the night this month. It shines at magnitude 5.7 in southwestern Aries and thus is capable of being seen with the naked eye at dark locations. Telescopes show its blue or blue-green globe 3.7″ wide.



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.

Neptune, in Aquarius, is only magnitude 7.8 and 2.3″ wide but is already on the meridian by late evening or mid-evening. Finder charts for Uranus and Neptune appear in the September issue.

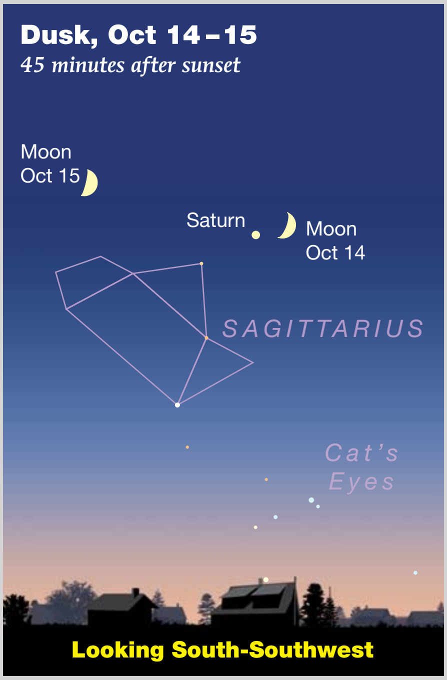
DAWN

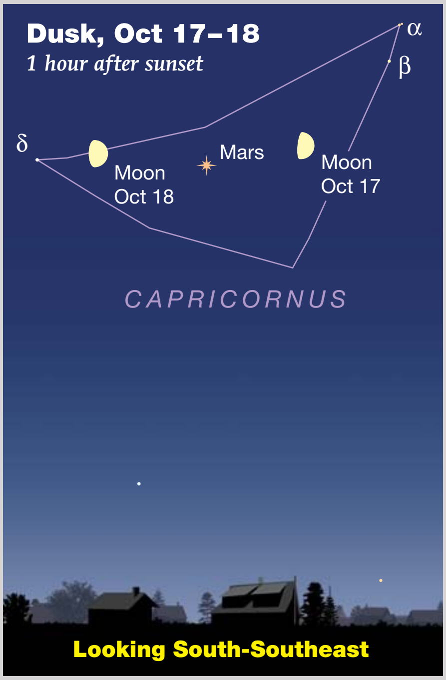
Venus leaps back into view at the very end of October, rising less than 40 minutes before the Sun on the 31st. Venus is then about 61″ wide and little more than 1% lit. Viewers around latitude 40° north can see it that dawn about 4° high and upper right of the Sun at sunrise.

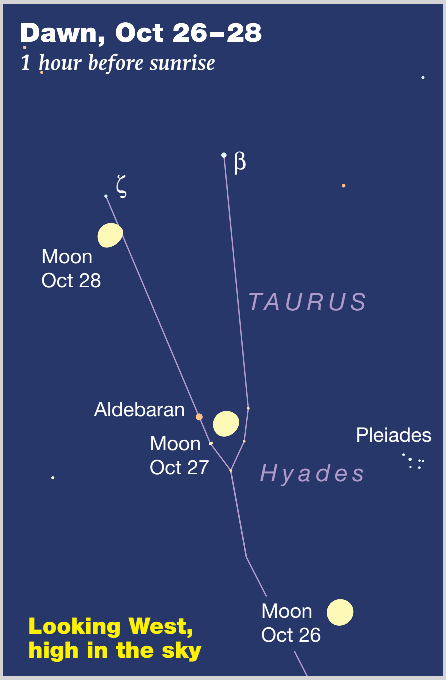
MOON PASSAGES

The Moon is a thin waxing crescent some 3° upper right of Jupiter at dusk on October 11th and a thicker crescent 2° upper right of Saturn on October 14th. The waxing gibbous Moon is about 6° either side of Mars on October 17th and 18th. The waning gibbous Moon shines in the Hyades on October 27th at dawn.

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

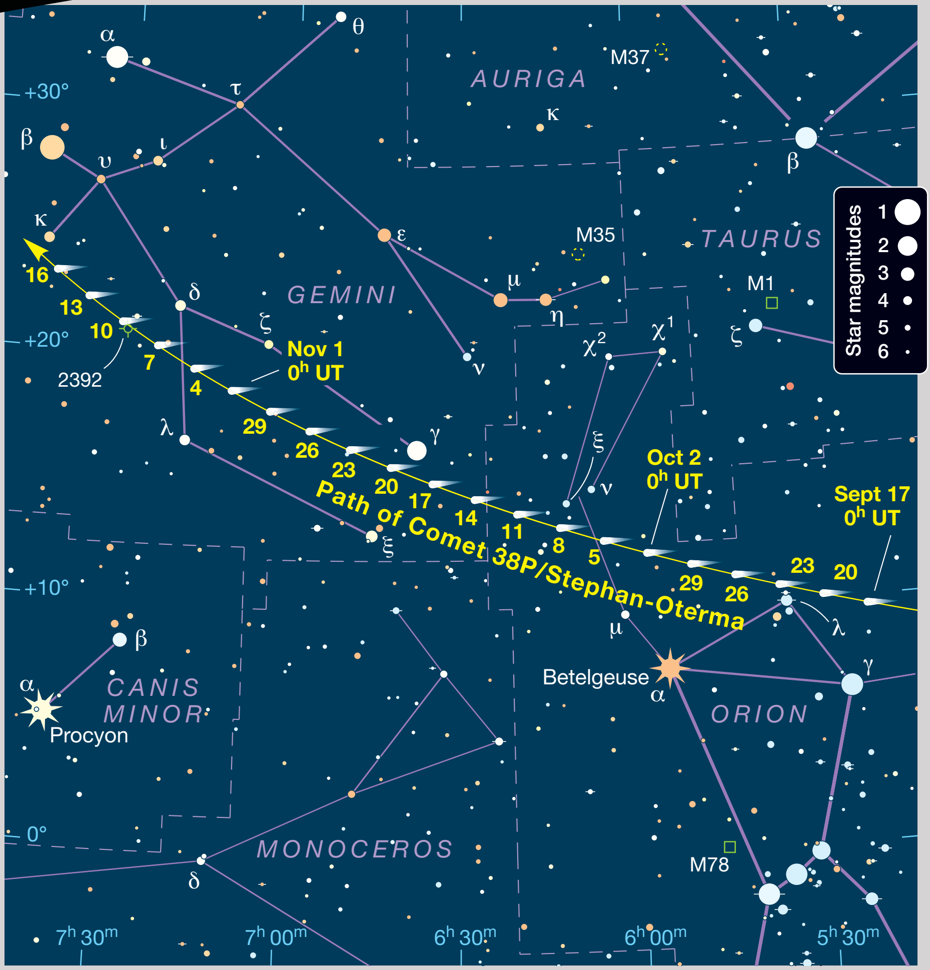






Another Bright Comet?

Comet 38P/Stephan-Oterma is ideally placed in the northern skies this month.



Periodic comet 38P/Stephan-Oterma skates across the night sky this autumn. Look for it north of Betelgeuse at the beginning of October. It will be at its brightest in November, when it passes through southeastern Gemini. Stars are shown to magnitude 6.5 with 38P's position marked at 0^h UT every three days.

This month sees the return of the Halley-type comet **38P/Stephan-Oterma**. It feels like ages since a binocular-bright comet graced the northern skies. As we put this issue to bed, we're waiting to see if Comet 21P/Giacobini-Zinner will hit its predicted 7th-magnitude peak and/or if Comet PanSTARRS (C/2017 S3) will get even brighter after a series of outbursts in mid-July bumped it to magnitude 8. Comet 38P shouldn't grow brighter than 9th magnitude — comparable in brightness to what it reached during previous apparitions — but that still puts it within easy range of small binoculars and telescopes.

Comet 38P last arrived at perihelion in late 1980. French astronomer Jérôme Eugène Coggia discovered 38P from Marseilles Observatory on January 22, 1867, and added it to his list of uncataloged nebulae. Credit for the discovery was given to the observatory's director, Édouard J. M. Stéphan, who confirmed the comet's (new) position on January 24th and subsequently authored the discovery bulletin. The comet was then lost, with return predictions ranging from 34 to 40 years based on the 1867 observations. The second half of the comet's familiar name rewards the rediscoverer, Liisi Oterma. Oterma, the first woman to receive a PhD in astronomy in Finland, picked up 38P while observing from Turku Observatory in November 1942. Subsequent observations led to tighter orbital and period calculations; the apparition in 1980 allowed even more refinement, giving us an orbital period of 37.96 years. This means that what should have been 38P's second apparition in 1904–05 went unobserved.

Comet 38P should come into visual range in September, when it will still be an early-morning object in Orion. By the first week of October, it's predicted to shine at magnitude 10.5 about 5° north of Alpha (α) Orionis (Betelgeuse). The comet then passes south of Orion's club, spending several mornings a bit more than 1° from Xi (ξ) Ori. From there, it zips across Gemini on its way to a November 10th perihelion.

Fortunately, the Twins climb higher each October night, so 38P will be well placed in the late evening throughout the month, about one-third of the way up the eastern sky for observers at mid-northern latitudes. November sees the icy dust ball at its brightest and possibly most photogenic, but it should remain a 10th-magnitude object through the New Year.

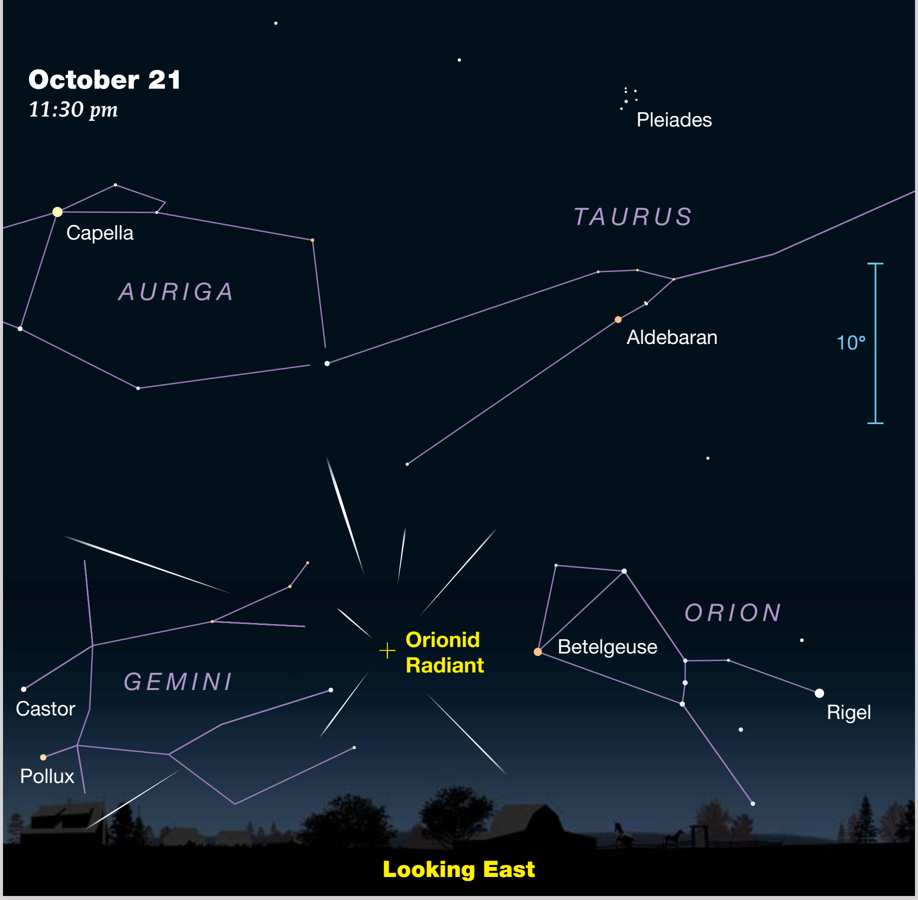
October Orionids

TWICE A YEAR, barring interference from weather and moonlight, we get to see Halley's Comet again — or at least the bits and pieces it's left in our region of the solar system. In the spring, we experience Halley's dusty detritus as the Eta Aquariid meteor shower, which occurs when Earth passes through a trail of dust that's slowly moving outward from the comet's orbit. In October, we see it as the Orionid meteor shower, when Earth once more encounters a dust stream far from Halley's path. This year, the predicted peak for the Orionids falls on the afternoon of October 21st.

Full Moon is on October 24th, so peak activity coincides with a waxing gibbous Moon. Even at their best, Orionid meteors are fast (66 km/s) but faint. The best viewing for any shower comes when looking 45°–90° away from the radiant, and this year some extra strategizing to avoid moonlight is in order. Try facing north, with the Moon at your back. The shower's radiant peaks over the horizon near 10 p.m. and is highest around 5 a.m. local time. The diagram at right shows the radiant's location at 11:30 p.m. The Moon is already high in the south as the radiant rises in the east.

You may see as many as 20 meteors per hour under ideal conditions, but expect a number closer to 10. It's possible that the Orionids operate on a 12-year cycle, with the number of meteors increasing after a point of lesser activity. The low point was calculated to fall between 2014 and 2016, so the number of Orionids per hour may be on the (slow) rise, on its way to an outburst in or after 2026.

If you see a bright meteor but its path doesn't seem to track back to a point of origin in Orion, check to see if it's a Southern Taurid. Birthed by Comet 2P/Encke, the Southern Taurids appear to emanate from a point close to Mu (μ) Ceti. At the shower's peak on October 10th, only about 5 Southern Taurids per hour will spark through the sky. However, the shower is known for its fireballs, so it's always worth keeping an eye open for them on either side of the peak date.



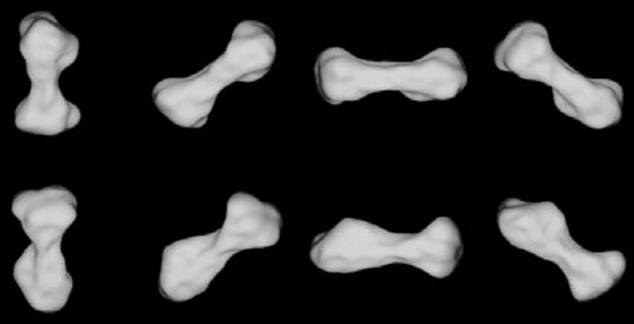
▲ The radiant for the Orionids is located northeast of Betelgeuse. Astronomers once suspected that the shower had several radiants, each tied to a separate ribbon of dust and each with a different peak date, but recent observations suggest that shower activity is quite stable.

Minima of Algol

Sept.	UT	Oct.	UT
2	8:52	1	0:58
5	5:40	3	21:47
8	2:29	6	18:35
10	23:18	9	15:24
13	20:06	12	12:13
16	16:55	15	9:02
19	13:43	18	5:50
22	10:32	21	2:39
25	7:21	23	23:28
28	4:09	26	20:17
		29	17:05

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554+ 2.867324**E**, where **E** is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol**.

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



Asteroid Occultation

▲ Roughly as long as Lake Michigan is wide, 216 Kleopatra looks like a giant dog bone tossed into the Main Belt. Kleopatra is composed mostly of iron and nickel (its "bone heads" may contain solid metal cores), so it reflects radio waves well enough to permit astronomers to construct relatively accurate 3D models.

NASA / JPL

NORTHERN NORTH AMERICA sees the asteroid **216 Kleopatra** occult an 11.1-magnitude star in northern Canis Minor on the morning of Sunday, October 28th. As the asteroid passes between Earth and the star TYC 765-506-1, observers will see the combined light of the two objects drop to 11.4, the brightness of the asteroid, for as much as 10 seconds.

A metallic Main Belt asteroid, Kleopatra boasts a diameter of about 138 km. Don't let that number mislead you, though; Kleopatra offers nothing like the elegant sphere of Ceres or the oblate spheroid of Vesta. Rather, it's uneven and elongated, resembling the classic dog bone more than anything else, as is shown in the above depictions of 3D models based on radar observations. This distorted shape is probably the result of an ancient impact that hollowed out the asteroid's central region, leaving behind a body that's roughly four times as long as it is wide.

The same collision that created Kleopatra's evocative form also may have released the material that now comprises the asteroid's two moons, Alexhelios and Cleoselene. Named for the children of Cleopatra, the last Ptolemaic pharaoh of Egypt, these satellites are quite small in size. The outer moon, Alexhelios, has a diameter of approximately 9 km, while the inner moon, Cleoselene, is only 7 km wide.

The International Occultation Timing Organization (IOTA) notes that although radar data have helped build a strong 3D model, amateur observations are still needed to resolve the asteroid's true shape. The predicted region of visibility for an occultation can be uncertain by about ½ a path width (pw), but the uncertainty with Kleopatra is only 0.13 pw. A line drawn on a map from central Alberta (north of Edmonton) through Syracuse, New York, to New Haven, Connecticut, provides a good estimation of the central occultation path. For observers in Alberta, the event should begin within a minute or two of 8:31 UT (2:31 MDT). Observers near Peterborough, Ontario, can expect it to begin near 8:33 UT (4:33 a.m. EDT), while those closer to the East Coast will see it near 8:34 UT (4:34 a.m. EDT).

About a week before both events, more precise predictions and path maps will be available from Steve Preston's minor planet occultation website (**asteroidoccultation.com**). For advice on timing occultations and reporting observations, see the IOTA website (**occultations.org/observing**) as well as **asteroidoccultation.com/observations**.

Action at Jupiter

JUPITER SHINES LOW in the west at nightfall this month. It's still in Libra for the first half of October, shining at magnitude –1.8. On the 11th the gas giant pairs with the waxing crescent Moon before dropping below the horizon in the west-southwest. Bring binoculars to catch it at its highest. Jupiter passes into Scorpius on November 20th and is largely lost to view by the end of the month, when it stands only 5° above the horizon 30 minutes after sunset. When it reappears as a dawn object in December, it will have already moved on from Scorpius to Ophiuchus.

Because Jupiter is low, viewing will be tough this month, but here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

Sept. 1, 1:39, 11:34, 21:30; **2,** 7:26, 17:22; **3,** 3:18, 13:13, 23:09; **4,** 9:05, 19:01; **5,** 4:57, 14:53; **6,** 0:48, 10:44, 20:40; **7,** 6:36, 16:32; **8,** 2:28, 12:23, 22:19; **9,** 8:15, 18:11; **10,** 4:07, 14:03, 23:58; **11,** 9:54, 19:50; **12,** 5:46, 15:42; **13,** 1:37, 11:33, 21:29; **14,** 7:25, 17:21; **15,** 3:17, 13:12, 23:08; **16,** 9:04, 19:00; **17,** 4:56, 14:52; **18,** 0:47, 10:43, 20:39; **19,** 6:35, 16:31; **20,** 2:27, 12:22, 22:18; **21,** 8:14, 18:10; **22,** 4:06, 14:02, 23:58; **23,** 9:53, 19:49; **24,** 5:45, 15:41; **25,** 1:37, 11:33, 21:28; **26,** 7:24, 17:20; **27,** 3:16, 13:12, 23:08; **28,** 9:03, 18:59; **29,** 4:55, 14:51; **30,** 0:47, 10:43, 20:38.

Oct. 1, 6:31, 16:27; **2,** 2:23, 12:19, 22:14; **3,** 8:10, 18:06; **4,** 4:02, 13:58, 23:54; **5,** 9:49, 19:45; **6,** 5:41, 15:37; **7,** 1:33, 11:29, 21:24; **8,** 7:20, 17:16; **9,** 3:12, 13:08, 23:04; **10,** 9:00, 18:55; **11,** 4:51, 14:47; **12,** 0:43, 10:39, 20:35; **13,** 6:30, 16:26; **14,** 2:22, 12:18, 22:14; **15,** 8:10, 18:06; **16,** 4:01, 13:57, 23:53; **17,** 9:49, 19:45; **18,** 5:41, 15:36; **19,** 1:32, 11:28, 21:24; **20,** 7:20, 17:16; **21,** 3:11, 13:07, 23:03; **22,** 8:59, 18:55; **23,** 4:51, 14:47; **24,** 0:42, 10:38, 20:34; **25,** 6:30, 16:26; **26,** 2:22, 12:17, 22:13; **27,** 8:09, 18:05; **28,** 4:01, 13:57, 23:53; **29,** 9:48, 19:44; **30,** 5:40, 15:36; **31,** 1:32, 11:28, 21:23.

These times assume that the Great Red Spot will be centered at longitude 292° measured in System II. If the Great Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 292°. It will transit approximately 1⅔ minutes later for each degree more than 292°.

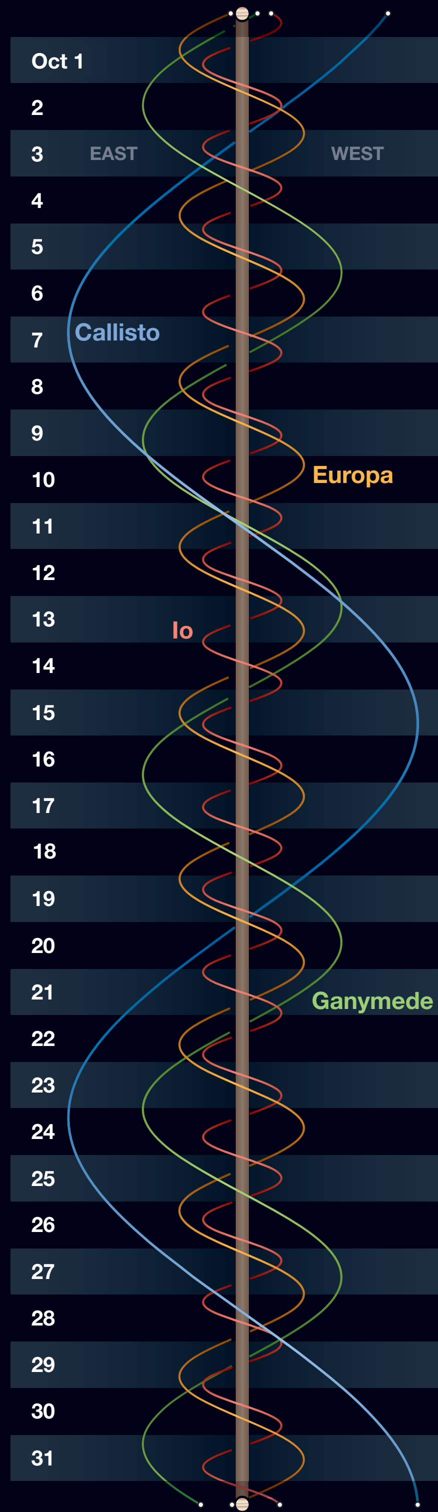
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter slightly increases the contrast and visibility of Jupiter's reddish and brownish markings; an orange filter helps darken the blue features.

Phenomena of Jupiter's Moons, October 2018

Oct. 1	2:28	I.Oc.D
	5:32	I.Ec.R
	23:41	I.Tr.I
Oct. 2	0:32	I.Sh.I
	1:51	I.Tr.E
	2:42	I.Sh.E
	3:13	II.Tr.I
	5:01	II.Sh.I
	5:34	II.Tr.E
	7:18	II.Sh.E
	20:58	I.Oc.D
Oct. 3	0:01	I.Ec.R
	18:11	I.Tr.I
	19:01	I.Sh.I
	20:21	I.Tr.E
	21:10	I.Sh.E
	21:40	II.Oc.D
Oct. 4	1:39	II.Ec.R
	5:12	III.Tr.I
	7:17	III.Tr.E
	8:44	III.Sh.I
	10:33	III.Sh.E
	15:28	I.Oc.D
	18:30	I.Ec.R
Oct. 5	12:41	I.Tr.I
	13:30	I.Sh.I
	14:51	I.Tr.E
	15:39	I.Sh.E
	16:37	II.Tr.I
	18:19	II.Sh.I
	18:58	II.Tr.E
	20:36	II.Sh.E
Oct. 6	9:59	I.Oc.D
	12:59	I.Ec.R
Oct. 7	7:11	I.Tr.I
	7:58	I.Sh.I
	9:21	I.Tr.E
	10:08	I.Sh.E
	11:03	II.Oc.D
	14:57	II.Ec.R
	19:36	III.Oc.D
	21:43	III.Oc.R
	22:57	III.Ec.D
Oct. 8	0:48	III.Ec.R
	4:29	I.Oc.D
	7:27	I.Ec.R
Oct. 9	1:41	I.Tr.I
	2:27	I.Sh.I
	3:51	I.Tr.E
	4:36	I.Sh.E
	6:02	II.Tr.I
	7:38	II.Sh.I
	8:23	II.Tr.E
	9:55	II.Sh.E
	22:59	I.Oc.D
Oct. 10	1:56	I.Ec.R
	20:11	I.Tr.I
	20:55	I.Sh.I
	22:21	I.Tr.E
	23:05	I.Sh.E
Oct. 11	0:26	II.Oc.D
	4:14	II.Ec.R
	9:34	III.Tr.I
	11:40	III.Tr.E
	12:42	III.Sh.I
	14:32	III.Sh.E
	17:29	I.Oc.D
	20:25	I.Ec.R
Oct. 12	14:41	I.Tr.I
	15:24	I.Sh.I
	16:51	I.Tr.E
	17:34	I.Sh.E
	19:26	II.Tr.I
	20:56	II.Sh.I
	21:47	II.Tr.E
	23:13	II.Sh.E
Oct. 13	12:00	I.Oc.D
	14:54	I.Ec.R
Oct. 14	9:11	I.Tr.I
	9:53	I.Sh.I
	11:21	I.Tr.E
	12:02	I.Sh.E
	13:50	II.Oc.D
	17:31	II.Ec.R
Oct. 15	0:01	III.Oc.D
	2:08	III.Oc.R
	2:57	III.Ec.D
	4:48	III.Ec.R
	6:30	I.Oc.D
	9:22	I.Ec.R
Oct. 16	3:41	I.Tr.I
	4:21	I.Sh.I
	5:52	I.Tr.E
	6:31	I.Sh.E
	8:51	II.Tr.I
	10:14	II.Sh.I
	11:12	II.Tr.E
	12:32	II.Sh.E
Oct. 17	1:00	I.Oc.D
	3:51	I.Ec.R
	22:11	I.Tr.I
	22:50	I.Sh.I
Oct. 18	0:22	I.Tr.E
	1:00	I.Sh.E
	3:13	II.Oc.D
	6:49	II.Ec.R
	13:58	III.Tr.I
	16:04	III.Tr.E
	16:40	III.Sh.I
	18:30	III.Sh.E
	19:30	I.Oc.D
	22:20	I.Ec.R
Oct. 19	16:41	I.Tr.I
	17:18	I.Sh.I
	18:52	I.Tr.E
	19:28	I.Sh.E
	22:16	II.Tr.I
	23:32	II.Sh.I
Oct. 20	0:37	II.Tr.E
	1:50	II.Sh.E
	14:01	I.Oc.D
	16:48	I.Ec.R
Oct. 21	11:12	I.Tr.I
	11:47	I.Sh.I
	13:22	I.Tr.E
	13:57	I.Sh.E
	16:37	II.Oc.D
	20:06	II.Ec.R
Oct. 22	4:27	III.Oc.D
	6:34	III.Oc.R
	6:55	III.Ec.D
	8:31	I.Oc.D
	8:47	III.Ec.R
	11:17	I.Ec.R
Oct. 23	5:42	I.Tr.I
	6:16	I.Sh.I
	7:52	I.Tr.E
	8:25	I.Sh.E
	11:41	II.Tr.I
	12:51	II.Sh.I
	14:02	II.Tr.E
	15:09	II.Sh.E
Oct. 24	3:01	I.Oc.D
	5:46	I.Ec.R
Oct. 25	0:12	I.Tr.I
	0:44	I.Sh.I
	2:23	I.Tr.E
	2:54	I.Sh.E
	6:01	II.Oc.D
	9:24	II.Ec.R
	18:24	III.Tr.I
	20:30	III.Tr.E
	20:39	III.Sh.I
	21:32	I.Oc.D
	22:30	III.Sh.E
Oct. 26	0:14	I.Ec.R
	18:42	I.Tr.I
	19:13	I.Sh.I
	20:53	I.Tr.E
	21:23	I.Sh.E
Oct. 27	1:06	II.Tr.I
	2:09	II.Sh.I
	3:27	II.Tr.E
	4:27	II.Sh.E
	16:02	I.Oc.D
	18:43	I.Ec.R
Oct. 28	13:12	I.Tr.I
	13:41	I.Sh.I
	15:23	I.Tr.E
	15:51	I.Sh.E
	19:25	II.Oc.D
	22:41	II.Ec.R
Oct. 29	8:53	III.Oc.D
	10:33	I.Oc.D
	12:47	III.Ec.R
	13:12	I.Ec.R
Oct. 30	7:43	I.Tr.I
	8:10	I.Sh.I
	9:53	I.Tr.E
	10:20	I.Sh.E
	14:31	II.Tr.I
	15:27	II.Sh.I
	16:53	II.Tr.E
	17:45	II.Sh.E
Oct. 31	5:03	I.Oc.D
	7:40	I.Ec.R

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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

A Hole in the Moon's Magnetic Field

Astronomers propose a new origin for this mysterious magnetic void.

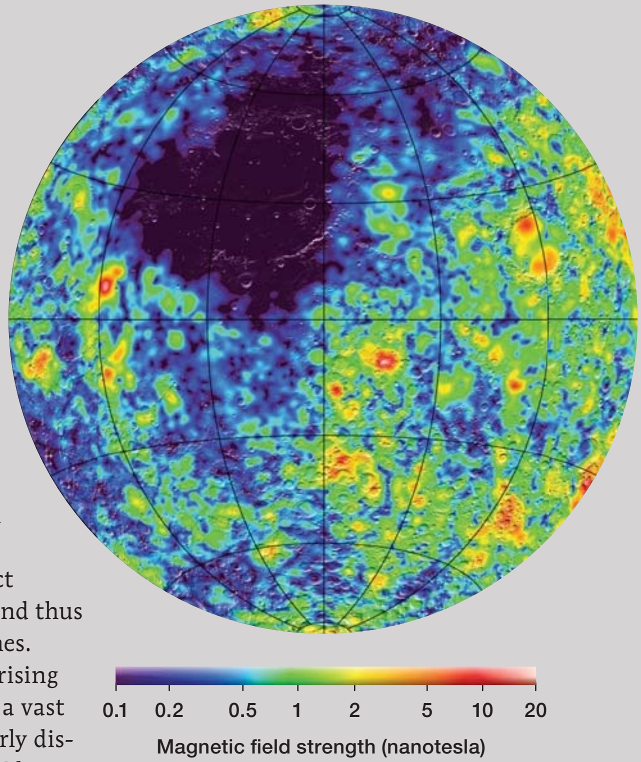
Each time you aim your telescopes toward the Moon, you concentrate on what's visible: the lunar surface. But ever since the first probes entered lunar orbit, scientists have been continually surprised by discoveries invisible to normal telescopes. For example, tracking of NASA's Lunar Orbiter spacecraft in the 1960s revealed that the Moon's gravity field is lumpy. Spacecraft passing over some lunar maria were pulled strongly toward the surface, illustrating that there was a concentration of mass under these areas that didn't occur under highlands. Later studies showed that these *mascons* only occur over maria within impact basins such as Imbrium, Humorum, and Crisium. This realization led to a new understanding that the dense lunar mantle rose up under impact basins.

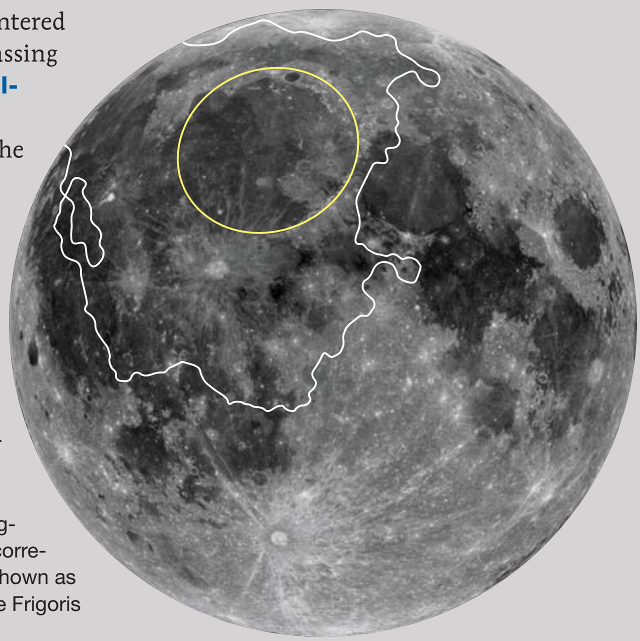
It was no surprise that the Moon has a gravity field because, after all, it has mass. But early spacecraft found no evidence for a global lunar *magnetic* field. Later, samples returned from the Apollo 15 mission showed evidence of an ancient magnetic field roughly one tenth the strength of that at Earth's surface.

Today the field is much weaker, more like a thousandth that on Earth. NASA's Lunar Prospector and JAXA's Kaguya spacecraft, which orbited close to the lunar surface, both carried sensitive instruments that mapped the Moon's weak magnetic field. It's highly variable, much stronger at some locations than elsewhere. The origin of these "magcons" is poorly understood. Some researchers propose that they were caused by ejecta from an iron-rich asteroid that obliquely hit the Moon to form the giant South Pole-Aitken (SPA) impact basin on the lunar farside. Intriguingly, some magcons coincide with enigmatic swirls such as **Reiner Gamma**, suggesting that the SPA event tossed out clumps of debris with enough magnetism to deflect mare-darkening solar radiation and thus preserve these odd, bright splotches.

But the largest and most surprising magnetic feature of the Moon is a vast nearside area where the field nearly disappears. Mark Wieczorek of the Observatoire de la Côte d'Azur in France and his colleagues call this area — centered on **Mare Imbrium** and encompassing nearby parts of **Oceanus Procellarum** and **Mare Frigoris** — the "Great Magnetic Low" (GML). The surface field there is less than a tenth as strong as the average lunar field.

When first discovered about 18 years ago, the GML's asso-





▲▶ *Top:* The total magnetic field strength over the nearside of the Moon compiled from Lunar Prospector and Kaguya data reveals a large "hole" in the northwestern quadrant. *Bottom:* The majority of the "Great Magnetic Low" in the lunar magnetic field corresponds to the Imbrium impact basin (shown as an oval) but also includes parts of Mare Frigoris and Oceanus Procellarum.

ciation with Imbrium suggested that its very low field strength was due to shock waves generated by the collision that formed that impact basin. These shock waves can randomize the magnetic alignments in atoms previously organized by external magnetic fields. According to this theory, the event that formed Imbrium also erased any magnetic field that had been present in the target rocks. It's an elegant and very plausible explanation. But the GML extends beyond the Imbrium basin, and other impact basins lack similarly weak magnetic fields.

Wieczorek and colleagues now propose an alternative interpretation that resolves these conflicts. They note that the GML and its spatial extensions fit within the Procellarum KREEP Terrane (PKT). This is a province of the Moon distinguished by high levels of the radioactive elements thorium, potassium, and uranium that release heat as they decay. KREEP, by the way, is an acronym built from the letters K (the atomic symbol for potassium), REE (rare-earth elements) and P (for phosphorus).

For some still poorly understood reason, radioactive elements are concentrated in the nearside's northwest quadrant, under the lavas of Procellarum, Imbrium, Nubium, and western Mare Serenitatis. The extra heat they released could explain why most of the Moon's nearside lava flows are within the PKT boundaries.

But what does heat have to do with magnetism? It turns out to be plenty. Pierre Curie long ago discovered that as he progressively heated magnetized materials in his laboratory, they lose their magnetization at a certain temperature, now known as the *Curie point*. For iron, which carries magnetism in lavas, the Curie point occurs at 770°C (1418°F). Terrestrial basaltic lavas, similar to flows found on the Moon, typically erupt at about 1100°C and thus don't carry a magnetic field. But as lavas cool below 770°C, they acquire the ambient magnetic field and, once solid, freeze in the field's intensity and direction.

The Moon's abundant lava flows presumably locked in the ambient magnetic field generated by an early lunar dynamo as they cooled. All maria except those in the GML seem to have done this. So what was special about the GML?

Wieczorek's group proposes that excess radioactivity kept the lavas within the PKT crust above the Curie point much longer than those elsewhere. That extra time is crucial, because measurements of lunar lava samples of various ages show that the average magnetic field strength has decreased by a factor of 10 over the past 3½ billion years. The researchers' mathematical models of the decline in PKT radioactive heating show that cooling to the Curie point could have been delayed by as much as a billion years, by which time the lunar dynamo had nearly turned off. Such slowly cooled lavas would only retain a weak magnetic field.

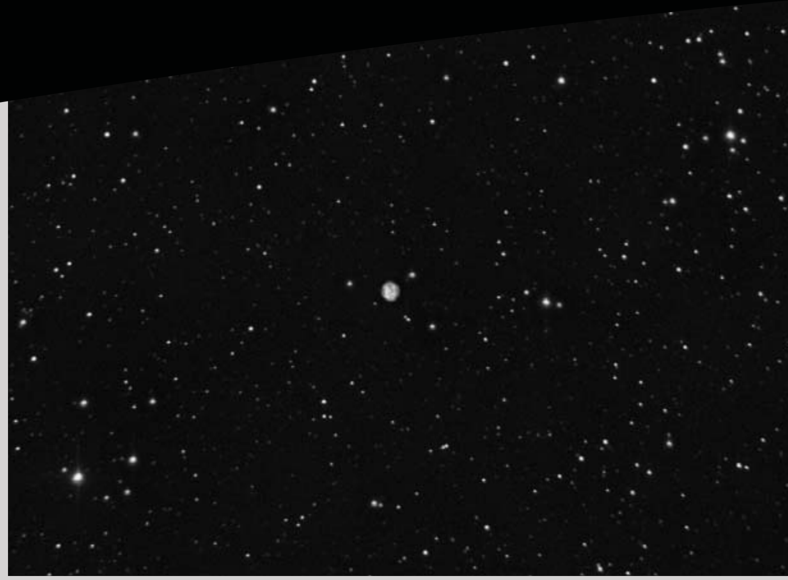
This model, while plausible, still has a few problems. One is that the GML covers an area considerably smaller than the PKT's. Perhaps since the impact and PKT models are both plausible, both happened. The Imbrium-forming impact surely must have heated the crust to great depth. This pulse of extra heat could have extended the time until the Imbrium basin's crust and lavas cooled to the Curie point, accounting for the nearly complete lack of magnetic field there. In this case, the slightly stronger magnetic field exhibited by the rest of the GLM would have resulted from the PKT's radioactive heating alone.

Unfortunately, you can't observe magnetic fields even with the best telescope. But your experience will be enriched when observing Oceanus Procellarum, Mare Imbrium, **Mare Nubium**, and western **Mare Serenitatis** by recognizing that these vast lava plains owe their existence to the PKT, which in turn might also have contributed to the lack of a magnetic field in the Imbrium region of the GML.

■ When observing, Contributing Editor CHUCK WOOD envisions the Moon both inside and out.

▲ Bright swirls such as Reiner Gamma coincide with localized areas of high magnetism, which perhaps has shielded the lunar surface at these locations from the darkening effects of prolonged solar radiation.

MAGNETIC FIELD: JGR PLANETS / HIDEO TSUNAKAWA ET AL; GREAT MAGNETIC LOW: NASA / LUNAR RECONNAISSANCE ORBITER; REINER GAMMA: SEAN WALKER / S&T



I ♥ Planetaries

How do I love these deep-sky wonders? Let me count the ways.

I love observing planetary nebulae. They come in a wealth of fascinating shapes and rank among the rare deep-sky wonders prone to visibly boast color, most commonly interesting blends of blue and green. Their charm isn't lost on other observers, who've bestowed them a collection of nicknames. These names and their origins are included in Kent Wallace's impressive new book *Visual Observations of Planetary Nebulae.*

Our first few planetaries nudge the meridian when darkness falls in early October, so they're best viewed when this magazine first reaches your hands. The lowest of the three, and hence the first to depart our sky, is the Little Gem, **NGC 6818** in Sagittarius. John H. Mallas claims credit for its name and writes, "Of all the planetaries in the heavens, 'the Little Gem' is probably the bluest. Its color is beautiful, and I have yet to see an artist's paint to describe the color." (*The Review of Popular Astronomy:* June/July 1963)

Through my 130-mm refractor at 23×, NGC 6818 stands out as the only object that doesn't look as sharp as the stars. It becomes a small, fairly bright, blue-gray disk at 102×. It remains bluish at 164×, displaying a somewhat darker center and brighter eastern side. In my 10-inch reflector at 43×, NGC 6818 is swathed in a fainter fringe and dressed in the hue of a blue sky softened with haze. At 187× the annulus is fairly wide and slightly oval, aligned nearly north-south. At 299× a faint star sits close to the northwest, and another rests a bit farther away to the east-northeast.

NGC 6781 in Aquila also beckons us for an early view. Its low-surface-brightness glow is fairly sizable in the 130-mm scope, even at 48×. At 102× it looks roundish, about 1¾′ across, and a tad brighter around the rim, mainly in the south. Adding an O III or narrowband filter gives a nice contrast boost, emphasizing the rim. The nebula's structure shows much better with my 15-inch reflector at 216× and is further enhanced with the use of a narrowband filter. The brightest part forms a fat C open to the north-northwest and filled with fainter haze. Massachusetts amateur Lew Gramer observed NGC 6781 with a 17.5-inch scope at 500×. He writes that the nebula's hard edge "coupled with its internal complexity but otherwise smooth outer ring" led him to dub this wonderful little planetary nebula the Snowglobe Nebula.

Also in Aquila, **NGC 6804** is a fairly small, moderately faint glow in the 130-mm scope at 48×. At 102× I see a very faint star superimposed on the northeastern edge. The star vanishes when using an O III or narrowband filter, but the nebula stands out a little better. As shown in my sketch on the facing page, this is a pretty planetary in the 15-inch scope at 216×. The stars were drawn from a filterless view, while filters were used for teasing out nebular detail.

Let's trek eastward to Delphinus where we'll visit **NGC 6891**. My 130-mm scope at 63× shows a bright, very small, bluish disk accompanied by a 12th-magnitude star 1′ west-northwest. The petite disk is quite obvious at 102×,

Planetaries to Love

Object	Mag(v)	Central ★	Size	RA	Dec.
NGC 6818	9.3	16.9	46″	$19^h\ 44.0^m$	–14° 09′
NGC 6781	11.4	16.7	1.9′	$19^h\ 18.5^m$	+06° 32′
NGC 6804	12.0	14.3	66″	$19^h\ 31.6^m$	+09° 14′
NGC 6891	10.5	12.4	21″	$20^h\ 15.2^m$	+12° 42′
NGC 7027	8.5	16.2	55″	$21^h\ 07.0^m$	+42° 14′
NGC 7662	8.3	13.2	37″	$23^h\ 25.9^m$	+42° 32′
NGC 40	12.3	11.5	74″	$0^h\ 13.0^m$	+72° 31′
Messier 76	10.1	15.9	3.1′	$1^h\ 42.3^m$	+51° 35′
NGC 246	10.9	11.9	4.1′	$0^h\ 47.1^m$	–11° 52′

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

NGC 6818: MARTIN GERMANO; NGC 6818 HUBBLE IMAGE: ESA / HUBBLE SPACE TELESCOPE / NASA / JUDY SCHMIDT; HEART ICONS: ALEX C. / THE NOUN PROJECT

◀▲ In the eyepiece at low magnifications, NGC 6818 appears nonstellar and boasts a bright blue-gray color. More magnification will draw out the more ghostly parts of the annulus and mute the blue to a soft blue. Martin Germano's image of the nebula *(left)* represents a total exposure of 75 minutes with a 14.5 f/5 Newtonian reflector. The Hubble Space Telescope image *(right)*, which was processed from data captured across optical wavelengths, shows how stellar winds have elongated the nebula's shell.

with a hue that seems robin's-egg blue to me. Only suspected at 164×, the 12.4-magnitude central star makes a definite appearance against the high-surface-brightness nebula at 234×. The planetary has a slight elongation that points a bit north of the neighboring star. Judging by how many NGC 6891 disks could fit between the central star and the 12th-magnitude star, the nebula is about 10″ across. With the 15-inch scope at 345×, the nebula sports a faint, rounder halo.

Cygnus is the home of **NGC 7027**, also known as the Green Rectangle and the Magic Carpet Nebula. These nicknames are the brainchildren of Kent Wallace, the first for its appearance through his 20-inch scope. He coined the second name after reading about a Hubble image of the nebula being described as a hot coal on a carpet.

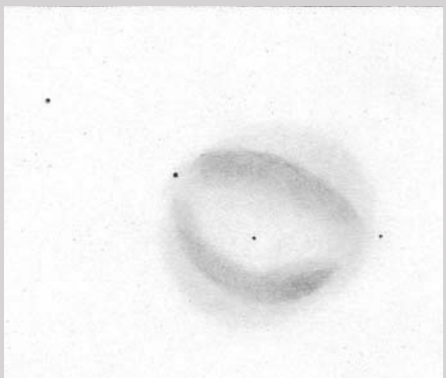
NGC 7027 is a bright, aqua, starlike spot with a halo when seen through the 130-mm scope at 37×, and a small disk blossoms at 102×. The planetary appears oblong northwest-southeast at 164× and flaunts its color even better, while at 234× its southeastern end appears narrower and not quite as bright. The color morphs into a deep sky-blue, still surprisingly bright. NGC 7027 is intriguing through the 15-inch scope. My sketch on the next page was made at 345×, and the features to search for are labeled.

Another brilliant planetary nebula is **NGC 7662** in Andromeda, aka the Blue Snowball. Its common name springs from an article by Leland S. Copeland (*S&T:* Feb. 1960, p. 216), who describes the nebula as "looking like a light blue snowball." It's readily visible as a very small, blue disk in my 130-mm scope at 23×. At 102× it appears annular with a somewhat dimmer fringe and interior. The nebula remains nicely blue and is a beautiful sight at 164×. The bright ring looks slightly oval northeast-southwest, and a 13th-magnitude star lies off its east-northeastern edge. NGC 7662 stays remarkably bright and blue even at 234×. The annulus seems irregular in brightness and more subdued in the northwest. My sketch on the next page shows the view of this stunning nebula through the 15-inch scope at 493×.

NGC 40 in Cepheus is called the Bow Tie or the Scarab nebula. The origin of these monikers is hazy, but it seems to be the consensus that Bow Tie refers to the visual impression given by its two brighter arcs, while Scarab comes from the beetle-like shape seen in images. NGC 40 is a nice little blue-gray disk dotted by its central star in the 130-mm refractor at 48×. At 164× it's vaguely oval, and the long sides seem a bit brighter than the interior or the ends. The nebula is a lovely greenish-blue in the 15-inch scope. At 216× its sides are quite definitely brighter, with the western arc enhanced in the north, while the ends fade away into the background sky.

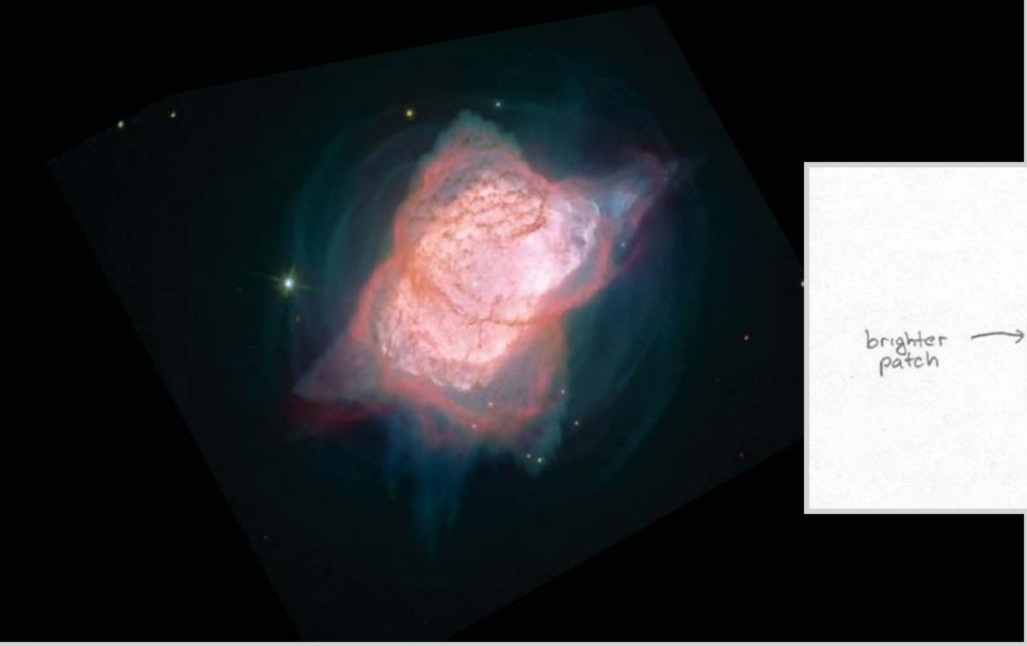
Messier 76 in Perseus bears a few nicknames: the Little Dumbbell, the Barbell, and the Cork. The first two indicate a supposed resemblance to the Dumbbell Nebula (M27) in Vulpecula, while the last depicts the shape of its bar. M76 is moderately faint and cork-shaped in the 130-mm refractor at 48×, and a power of 102× exposes brighter caps at the ends of the cork. Adding a narrowband filter brings out faint extensions ballooning from the cork's long sides, while an O III filter nicely accentuates the lumpy structure of the bar. Examining M76 at 164×, I estimate a cork length of 1¾′. The nebula is gorgeous through the 15-inch scope, and my sketch on the next page shows the view at 345×. While visiting, look for the vividly orange, 6.7-magnitude star 12′ east-southeast of this planetary.

We'll wind up our tour with **NGC 246** in Cetus, nicknamed the Skull Nebula for its appearance in some

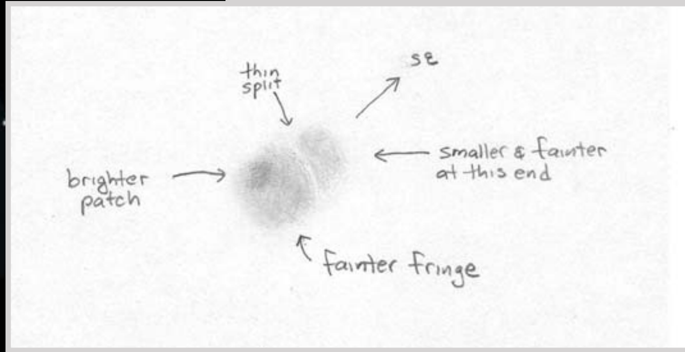


▲▶ Like NGC 6818, NGC 6804 shows some distortion thanks to the effects of the stellar wind on outflowing material. The author used an O III filter to pull out the nebula's details *(above)*. Images such as the one shown at right, which was captured with a 60cm-Hypergraph in secondary focus, can help guide your observations at the eyepiece.

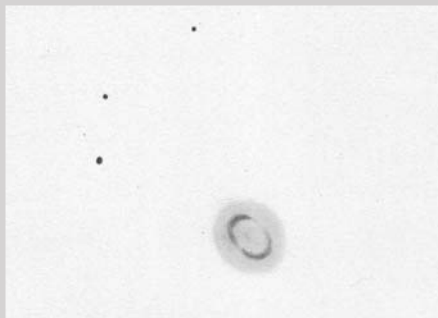
NGC 6804 IMAGE: VOLKER WENDEL / STEFAN BINNEWIES / JOSEF PÖPSEL; NGC 6804 SKETCH: SUE FRENCH



It's easy to see the resemblance of NGC 7027 to the magic carpets of legends old. In the eyepiece, look for a bright aquamarine disk that elongates along a northwest-southwest axis under magnification.



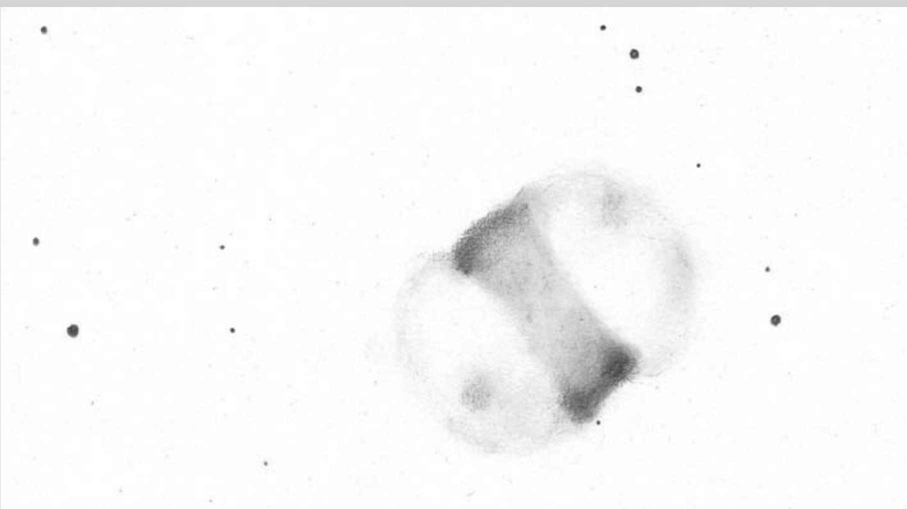
In a tour of planetary nebulae in the February 1960 issue of *Sky & Telescope*, Leland S. Copeland described NGC 7662 as "looking like a light blue snowball." Even at lower magnifications, the nebula is distinctly nonstellar and reveals a bright cyan color. This sketch by the author shows the view through her 15-inch reflector at 493×.

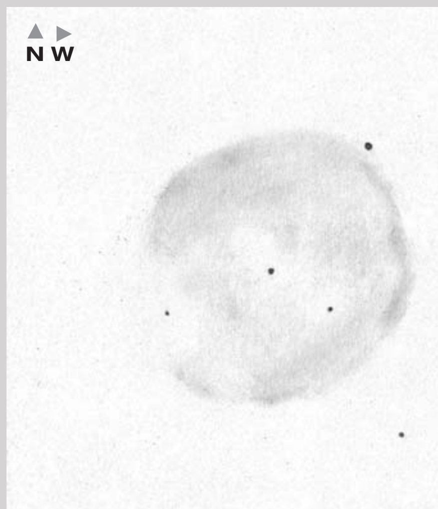


images and the Cetus Bubble, which Kent Wallace credits to Gregg D. Thompson's book, *The Australian Guide to Stargazing*. Although this large bubble has low surface brightness, it's easily spotted as a dim glow with three faint stars, including the central star, through the 130-mm scope at just 23×. At 63× the trio is joined by a dimmer star in the east-southeastern edge. A narrowband filter improves the nebula a skosh and preserves the stars. Upping the power to 102×, it becomes clear that the dimmest star is in a dark cavity denting into that side of the nebula. A 164× view hints at other weak brightness variations. Careful study with the 15-inch scope at 216× teases out these features. My sketch below is a composite of the views with and without a narrowband filter.

I hope you'll these planetaries, too.

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





Left: French astronomer Pierre Méchain discovered M76 in 1780. The planetary nebula's bipolar structure is evident in the eyepiece even under low power. Use an O III filter to draw out more of the shell's details. This sketch shows the view in the author's 15-inch reflector at 345×. *Right:* The faint glow of NGC 246 envelops three dim stars, including the central star, a 12th-magnitude white dwarf. This sketch is a composite of the filtered and unfiltered views through the author's 15-inch reflector.

NGC 7027 IMAGE: ESA / HUBBLE SPACE TELESCOPE / NASA / JUDY SCHMIDT; SKETCHES: SUE FRENCH (4); HEART ICON: ALEX C. / THE NOUN PROJECT

A Conversational Guide to Gravitational Waves

RIPPLES IN SPACETIME: *Einstein, Gravitational Waves, and the Future of Astronomy*

Govert Schilling
Belknap Press of Harvard University Press, 2017
339 pages, ISBN 978-0674971660
$29.95, hardcover.

GRAVITATIONAL WAVES ARE A HEAVY topic that could easily take a college semester to understand. If you can't quite squeeze that into your life, there's an easier way to grasp the history and science behind all the gravitational-wave hoopla: *S&T* Contributing Editor Govert Schilling's *Ripples in Spacetime* provides a comprehensive and approachable guide to a complex subject.

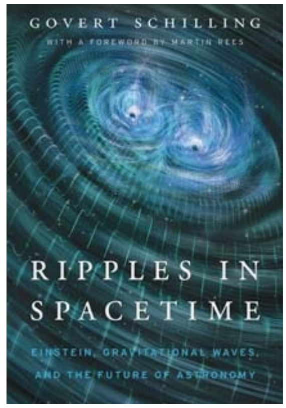
The book begins with a visualization of the first recorded gravitational wave event, known as GW150914, as it passes through the universe, our solar system, and ultimately across the Laser Interferometer Gravitational-wave Observatory (LIGO) detectors. Schilling returns to this history-making event several times throughout the book, each time from a different angle. That thread ties the various chapters together as Schilling tours the history of our understanding of gravity and gravitational waves, covering topics such as cosmology, neutron stars, pulsar timing arrays, black holes, and multimessenger astronomy.

> Have you ever wondered why, if the cosmic microwave background was emitted 380,000 years after the Big Bang, we still see its glow?

Along the way, Schilling takes plenty of conversational detours. The first is delivered Sagan-style: "If you wish to make an apple pie from scratch, you must first invent the universe." Only in this case, it's not apple pie but neutron stars that we want to understand, and for that we delve into a chapter-long overview of stellar evolution.

Likewise, after recounting the long history of gravitational waves and the various detectors made to find them, Schilling leaps back in time to the Big Bang. Even though it's a mind-bending change of topic, it's necessary, as a signature of gravitational waves could lie hidden in the Big Bang's afterglow, the *cosmic microwave background* (CMB). Schilling gently guides the reader through these switchbacks, offering encouragement even as he tackles common misconceptions about the origin of the universe.

Schilling's adept use of analogies is a great help to understanding these heady subjects. For example, have you ever wondered why, if the CMB was emitted 380,000 years after the Big Bang, we still see its glow? Schilling offers the scenario of a crowded city square: If everyone shouts "Boo!" at exactly noon, and sound travels 1 meter per second, then you'd hear "Boo" from people one meter away after one second, from people two meters away after two seconds, and so on. Even an minute after noon, you'd still hear "Boo!" from people 60 meters away — even though no one is shouting anymore. Similarly intuitive analogies abound throughout the book.



Perhaps because of the book's conversational style, Schilling takes several opportunities to explain not only the science itself but also his own role, and that of other journalists, in reporting the science. A great deal of media hype surrounded the detection of gravitational-wave polarization in the CMB, a detection that was later shown to be a hasty misinterpretation of the data (*S&T:* May 2015, p. 12). This was a case in which words like "breakthrough" and "Nobel Prize" weighed more heavily in the mainstream media's attention than did the scientists' cautions, such as, "if confirmed by other experiments." Schilling chronicles the disappointment that followed the initially exhilarating press conference.

Media hype also surrounded the first actual detection of gravitational waves, though this time with the opposite outcome: The detection of GW150914 panned out and revolutionized astronomy. Schilling recounts the early leaks, the LIGO scientists' efforts to keep a lid on the results until they were confirmed, and the elation that followed the official announcement.

Schilling's personal experiences, intuitive analogies, and broad background make this introductory take on the search for gravitational waves both approachable and insightful.

■ News Editor **MONICA YOUNG** carries a book with her at all times, so she prefers light books on heavy topics.

 by Ron Brecher

Lost in the Glare

Some interesting objects await imagers who can tear their cameras away from the showpieces of the night skies.

Years ago, when comedian Rodney Dangerfield said, "I don't get no respect," he might as well have been empathizing with the subjects of this article. I'm talking about deep-sky objects (DSOs) that are often ignored or underappreciated by most astrophotographers. While trophy objects such as M31, the Andromeda Galaxy, or M42, the Orion Nebula, are great, it's time to give some less-imaged (or less-noticed) astronomical gems a moment to bask in the spotlight in their own right.

Not all of these overlooked targets are faint. Even bright DSOs can fail to get the respect they deserve when they lie in the shadow of something "bigger and better." On the other hand, sometimes they occupy a region of sky that amateurs ignore due to a perceived lack of interesting deep-sky objects; these are lost in the dark, rather than the glare.

Targets Near Bright Stars

DSOs that are tucked up against a bright star can literally get lost in the star's glare. In this situation, clean optics and a dry, transparent sky are extra important, since any dirt or moisture amplifies light scatter around bright stars, overwhelming the view of anything nearby.

▲ **STEALING THE SPOTLIGHT** Many fine deep-sky objects reside in the shadow of more glorious targets. Take NGC 2023 above — this complex mixture of reflection and emission nebula resides about 5 arcminutes from B33, the famous Horsehead Nebula, which draws more attention. The close-up image reveals a complex interplay of dust and emission nebulosity that makes this and other similar targets worthy subjects for astrophotographers to pursue. North is to the left in these images. Unless otherwise noted, all images are courtesy of the author.

NGC 2023: S. MAZLIN / M. HANSON / W. KELLER / R. PARKER / T. TSE / P. PROULX (SSRO)

Lying adjacent to the bright, 2nd-magnitude star Gamma Cassiopeiae (γ Cas) are two attractive nebulae, **IC 59** and **IC 63**. Both contain a mix of red emission and blue reflection components. But don't let the brightness of γ Cas scare you away. The right hardware, such as an anti-blooming camera, a hydrogen-alpha filter (instead of or in addition to RGB filters), combined with careful processing, allows these pretty nebulae to be revealed basking in the rays of γ Cas.

Another interesting target also lies beside a bright naked-eye star. The dwarf spheroidal galaxy **Leo I** hides within the glare of 1st-magnitude Regulus. Even though the galaxy has a respectable integrated brightness of magnitude 11.2, it's low surface brightness renders it nearly invisible next to Regulus, which is more than 5,000 times brighter. Leo I displays little detail, but it's an accomplishment just to be able to record it. As a galaxy, it emits light at all visible wavelengths, so narrowband filters won't help to record it. However, careful processing of a combination of short and long exposures will reveal this subtle galaxy while still controlling light scatter around Regulus.

▲ **NEIGHBORS** Another target that gets little attention due to its proximity to a showpiece object, dwarf elliptical galaxy Messier 110 orbits M31 and displays tantalizing dark dust near its core when imaged with larger apertures.

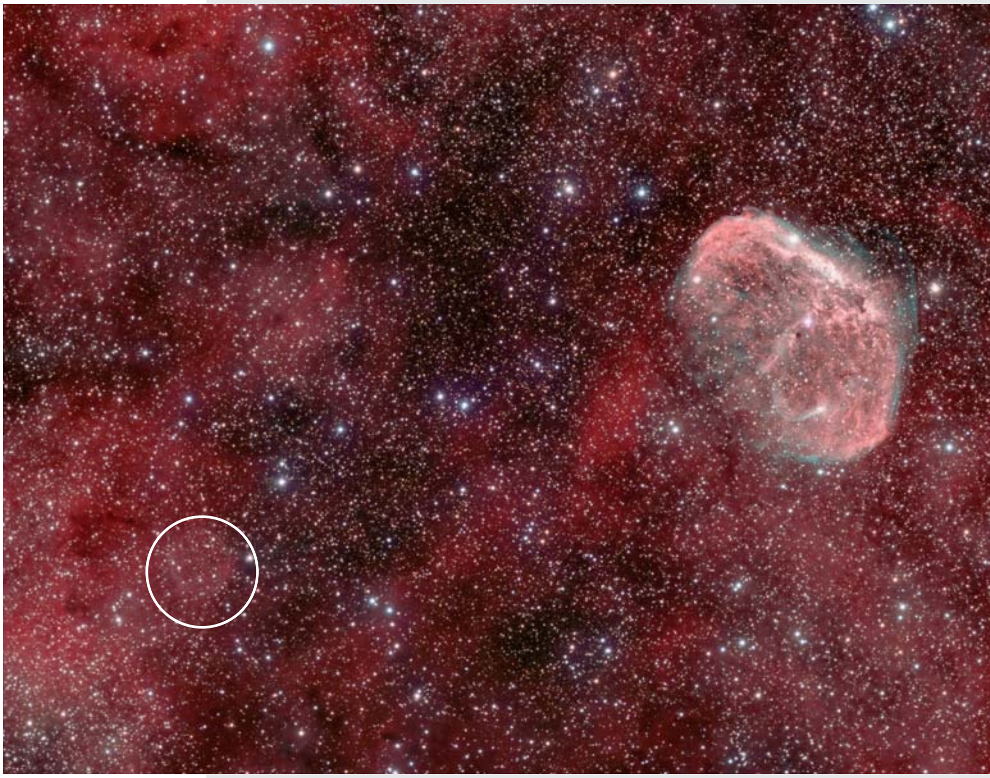
Overlooked Galaxies

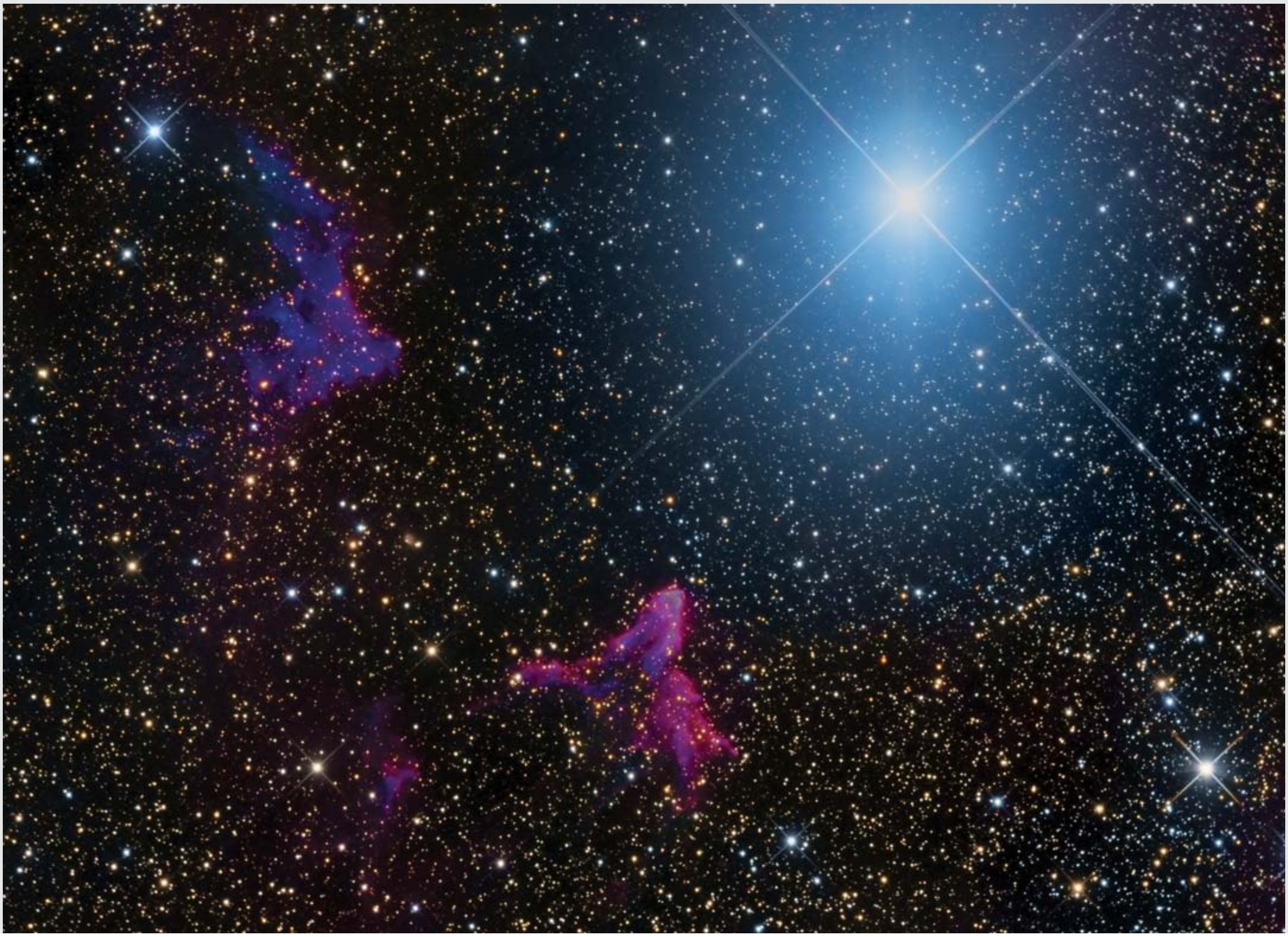
Speaking of galaxies, the best places to hunt them down is usually far from the dense star fields of the Milky Way. This is because the myriad stars and vast clouds of galactic dust seen within the plane of our home galaxy block distant galaxies, making them much harder to detect. But galaxies actually appear all over the sky — you simply need to know where to look for them. In fact, you might have already imaged a few unknowingly.

For example, M13, the Hercules Cluster, is arguably the finest globular cluster visible from mid-northern latitudes. Because of its brilliance, it's easy to give short shrift to the many galaxies in or just outside its halo, including **NGC 6207**. If you're processing your image to highlight the contrast between bold M13 and a dark background, the galaxy might be rendered too dark to see its structure. This approach would also render another galaxy invisible, namely **IC 4617**, which lies just off the line connecting M13 and NGC 6207. Brightening up the background or inverting the image (black stars on white) can make these tiny galaxies stand out better from the background.

Even relatively bright galaxies can sometimes get passed over, particularly when they are members of a crowded galaxy cluster. Markarian's Chain in the Virgo Cluster is one of the most popular fields for galaxy hunters. But next time you're thinking of exploring Virgo, why not go after **NGC 4216** a bit to the chain's west? It makes a

▼ **IN PLAIN SIGHT** NGC 6888, the Crescent Nebula, is immersed in a dense nebulous field. The recently discovered Soap Bubble planetary nebula (PN G75.5+1.7) is the thin sphere just visible on the bottom left side.





photogenic trio with fainter **NGC 4222** and **NGC 4206** and is bright enough (10th magnitude) to record with relatively short exposure times.

Another example of a galaxy gem hiding in plain sight is **M110**, one of the Andromeda Galaxy's large satellite galaxies. It looks like a spider's nest — or perhaps a tightly wrapped meal in a spider's web. Although M110 appears relatively large and bright, it is completely overshadowed by its proximity to spectacular M31 and is rarely the main focus of imagers. But high-resolution images of M110 show mottling and a distinct dark feature, while long integration times reveal a faint bridge of stars that appears to tether the satellite galaxy to M31.

Buried Treasure

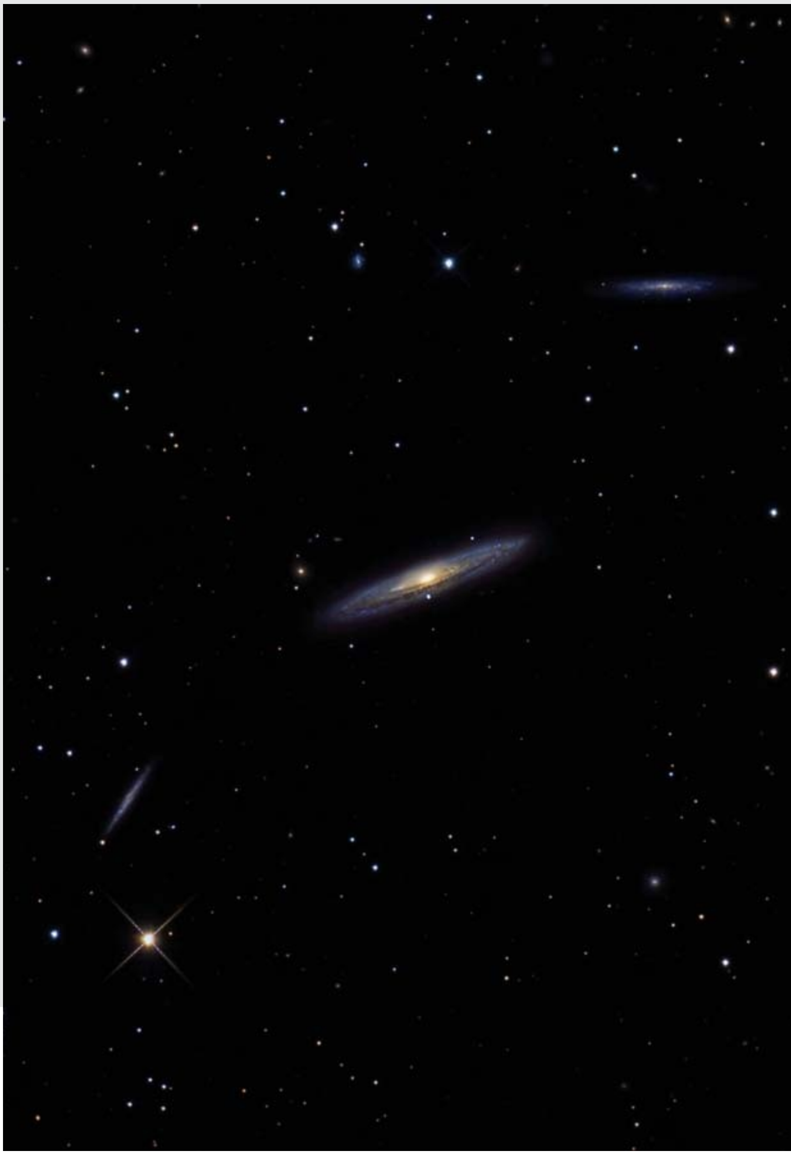
In contrast to galaxies, the rich star clouds of the Milky Way are a great place to find attractive open clusters. Yet they seem to be less popular with astrophotographers than other classes of DSOs, such as galaxies and nebulae. I've heard many people say that open clusters look better through the eyepiece than through a camera. However, some gorgeous examples are worth exploring with your camera, even though they're not easily accessible to most visual observers.

One of my favorites in this category is **Trumpler 5** (Tr 5), which lies not far from the more famous Christmas Tree Cluster and Cone Nebula, together designated NGC 2264. In contrast to most open clusters, which tend to have white or bluish colors, Tr 5 is composed primarily of red, yellow, and orange stars. The cluster is much older than most, so its hotter, more massive blue and white stars have long since faded, imparting a golden hue to Tr 5.

There are a few more "surprise" clusters that I now look for through the eyepiece, having first seen them as bonus objects in my photos. Two favorites are **NGC 436**, which lies beneath the "feet" of the famous E.T. Cluster (NGC 457) in Cassiopeia, and **NGC 6802**, next to Brocchi's Cluster (the Coathanger) in Vulpecula.

Lonely Outposts

I have friends who think that if you've seen one globular cluster you've seen them all. I disagree. I think each has its own character, and I've shot many of them over the years. One of my favorites is **NGC 2419**. It tends to be ignored because there are so many bigger, brighter globular clusters available. I think the location of NGC 2419, in the relatively



◀ **WASHING AWAY** The comet-like shapes of nebulae IC 59 (left) and IC 63 (bottom) are due to the ionizing radiation from the luminous star Gamma Cassiopeiae at upper right, which is slowly dissipating the two objects. North is to the left.

▲ **FAINT TREASURE** While the large, faint emission nebula Sharpless 2-129 has been known for more than a half century, the teal-colored object within called Ou 4 was only discovered in 2011.

▶ **GALACTIC CASCADE** When imaging the Virgo Cluster of galaxies, most imagers focus on Markarian's chain. But only about 2° west is a wonderful cascade of three moderately large spiral galaxies, including NGC 4222 (lower left), NGC 4216 (center), and NGC 4206 (upper right), collectively spanning about ½°. North is at left.

sparse constellation Lynx, also contributes to its obscurity. Its nickname, the "Intergalactic Wanderer," just feels right. About 300,000 light-years away, it's farther than galaxies like the Large and Small Magellanic Clouds and the Sagittarius Dwarf. There's not much in the field around it, except for two bright field stars that enhance the perception that NGC 2419 is tiny, dim, and distant. In reality, it's one of the Milky Way's most massive star clusters.

The dwarf spiral galaxy **NGC 6503** in Draco gives me the same feeling of isolation. Every star in the field surrounding it lies in the Milky Way, so there's mostly empty space between us and it. The galaxy actually does lie at the edge of a vast, nearly empty region of space called the Local Void (see page 12). Only about 30,000 light-years across, the galaxy is puny compared to the Local Void, which might be as big as 250 million light-years across!

Obscure Nebulae

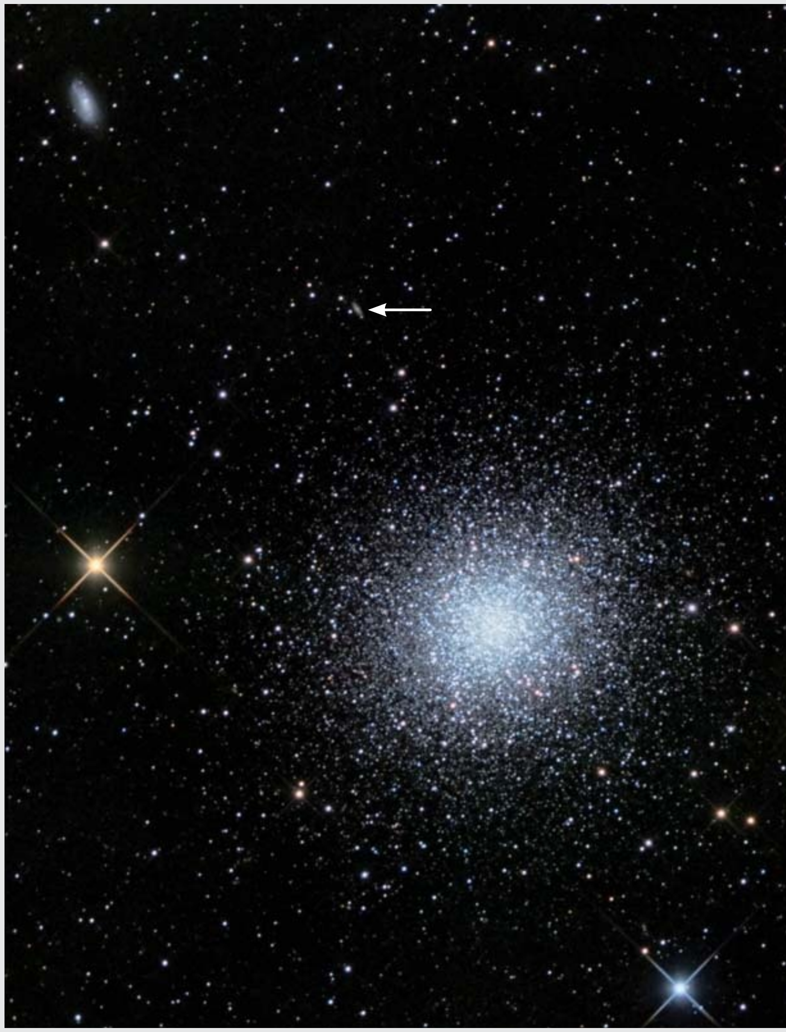
Like star clusters, nebulae abound in the Milky Way. This catchall term includes pinkish emission nebulae, blue (and sometimes yellow) reflection nebulae, and planetary nebulae with a colorful mix of emission nebulosity. The Bubble Nebula (NGC 7635), Pleiades (M45), and Dumbbell Nebula (M27) are examples. But many other, less familiar examples are worthy of your camera's gaze. The Sharpless catalog is full of dim emission nebulae (and some of other types). One of the most interesting yet least appreciated is **Sh2-290** in Cancer. It's a classic planetary nebula, showing distinct red- and teal-colored regions corresponding to hydrogen-alpha and oxygen-III emissions, respectively.

Planetary nebula **Abell 39** in Hercules has to compete for attention with bright globular clusters M13 and M92. This ghostly green object is a near-perfect sphere about 2½ light-years in diameter, making it the largest such sphere currently known. Several background galaxies are seen through the nebula that are thousands of times more distant.

Another faint spherical structure, **PN G75.5+1.7** known as the Soap Bubble Nebula, is hidden in plain sight in Cygnus just ½° southeast of NGC 6888, the Crescent Nebula. In fact,

(continued on page 64)

▶ **LOOK TO THE RIGHT** Just 1° west of NGC 2264 is the beautiful old open cluster Trumpler 5, which is populated by old reddish stars and is a treat for observers and imagers alike.



▲ **LONELY GLOBULAR** Relatively dim, NGC 2419 is the most distant globular cluster associated with the Milky Way.

▶ **CLUSTER COMPANIONS** M13 is perhaps the showpiece globular cluster for northern observers and imagers. Long exposures of this target with 6-inch or larger instruments will reveal a wealth of detail in the bonus spiral galaxy NGC 6207 (top left) just ½° to its northeast. Between it and M13 lies an even more distant galaxy, IC 4617 (arrowed).

▶▶ **BANDED NEBULA** About 1½° south of IC 5070, the Pelican Nebula in Cygnus, resides another large-but-faint nebula, IC 5068, which rewards imagers shooting through narrowband filters with complex, overlapping bands of nebulosity in a roughly rectangular shape.

(continued from page 61)
due to its subtle, thin shape and the nebulous field it sits in, the Soap Bubble was only discovered about a decade ago by amateur astronomer Dave Jurasevich using a 160-mm refractor and CCD camera with narrowband filters. The object was independently noted and reported to the International Astronomical Union by amateurs Keith B. Quattrocchi and Mel Helm who imaged PN G75.5+1.7 in 2008.

▲ **NEARBY PLANETARY** The large nebula Sh2-290 in Cancer, also known as Abell 31, is among the closest and largest planetary nebulae in the sky, but it is exceedingly faint and requires long exposures to reveal all its colorful glory.

HH 170. This hourglass-shaped Herbig-Haro object signals the recent birth of a new star at its center.

One of the most photographed DSOs is the Horsehead Nebula (B33) in Orion, often sharing the field with the spectacular Flame Nebula (NGC 2024). **NGC 2023** usually appears in these portraits too, since it lies more or less between the Horsehead and the Flame. But due to its location, NGC 2023 is rarely imaged at high resolution, when it can reveal tremendous color and detail.

Surrounded by Bling

Speaking of busy nebulous fields, one of my favorites is the region around the Bubble Nebula (NGC 7635), which is full of splashy star clusters like M52 and other emission nebulae. Amid all these sparkling jewels, it's easy to overlook little

Similarly, try photographing the regions in Cygnus around the North America Nebula (NGC 7000), particularly beneath the "Gulf of Mexico" and the neighboring Pelican Nebula (IC 5070). **IC 5068** is a boldly textured, rhombus-shaped patch of emission nebula full of colorful stars. Not far to its west is the blue reflection nebula **NGC 6914**, within a few degrees of **Simeis 57**, the Propeller Nebula, another underappreciated nebula often misidentified as DWB 111.

Lost in the Glare Targets

Object	Type	Size	RA	Dec.
IC 59	Emission nebula	10′ × 5′	0^h 56.7^m	+61° 04′
IC 63	Emission nebula	10′ × 3′	0^h 59.5^m	+60° 49′
Leo I	Dwarf spheroidal galaxy	10′ × 7′	10^h 08.5^m	+12° 18′
NGC 6207	Spiral galaxy	3.0′ × 1.3′	16^h 43.1^m	+36° 50′
IC 4617	Spiral galaxy	1.2′ × 0.4′	16^h 42.1^m	+36° 41′
NGC 4216	Spiral galaxy	8.3′ × 2.2′	12^h 15.9^m	+13° 09′
NGC 4222	Spiral galaxy	3.1′ × 0.5′	12^h 16.4^m	+13° 18′
NGC 4206	Spiral galaxy	6.2′ × 1.0′	12^h 15.3^m	+13° 01′
M110	Dwarf elliptical galaxy	17′ × 10′	0^h 40.4^m	+41° 41′
Tr 5	Open cluster	20′	6^h 36.5^m	+9° 29′
NGC 436	Open cluster	5′	1^h 16^m	+58° 49′
NGC 6802	Open cluster	5′	19^h 30.5^m	+20° 16′
NGC 2419	Globular cluster	4.7′	7^h 38.1^m	+38° 53′
NGC 6503	Dwarf spiral galaxy	7.1′ × 2.4′	17^h 49.5^m	+70° 09′
Sh2-290	Planetary nebula	17′	8^h 54.2^m	+8° 54′
Abell 39	Planetary nebula	3′	16^h 27.5^m	+27° 55′
PN G75.5+1.7	Planetary nebula	4.3′	20^h 15.5^m	+38° 03′
HH 170	Herbig-Haro object	1′	23^h 17.5^m	+60° 51′
NGC 2023	Reflection nebula	10′	5^h 41.6^m	-2° 16′
IC 5068	Emission nebula	40′ × 29′	20^h 50.8^m	+42° 31′
NGC 6914	Reflection nebula	12′ × 12′	20^h 24.7^m	+42° 29′
Simeis 57	Emission nebula	30′ × 20′	20^h 16.1^m	+43° 41′
Sh2-129	Emission nebula	175′ × 113′	21^h 11.7^m	+59° 58′
Ou 4	Emission nebula	68′ × 23′	21^h 11.8^m	+59° 59′

Angular sizes are from recent catalogs. Right ascension and declination are for equinox 2000.0.

Resources

Planetarium software is helpful for identifying potential subjects in locations that are off the beaten track, or in the background that might be worth our attention. My first clue that there were hundreds of galaxies in the same field as the Pleiades was when I zoomed in on the field in Software Bisque's *TheSkyX* (**bisque.com**). While these galaxies appear small and featureless, just being able to resolve them in the distant background imparts a sense of the vastness of the cosmos that M45 on its own can't deliver. Most camera-control and planetarium software can chart the location of celestial objects. A great freeware option is *Stellarium* (**stellarium.org**), which can display Digitized Sky Survey image overlays that provide a more photo-realistic view.

Get familiar with compilations of nebulae, like the Sharpless (Sh) and van den Bergh (vdB) catalogs, as well as Lynd's Bright Nebulae (LBN) and Lynd's Dark Nebulae (LDN). Many of their members aren't visible through the eyepiece and are only revealed in deep exposures. These catalogs are accessible via the planetarium software mentioned previously, with many

EXPANDING SPHERE Abel 39 in Hercules is a challenging target for imagers with larger scopes. This ancient planetary nebula appears as a nearly perfect teal-colored sphere.

online resources providing photos or descriptions. While I don't try to duplicate the aesthetic, I sometimes refer to others' results — or more specifically, their technical information — to help me decide what scope and camera combination might achieve a desired composition, and to estimate how much exposure time might be needed.

Imaging Strategies

Most of these DSOs are much fainter than their better-known kin or are challenging to see due to their environment, such as the proximity to a bright star. Successfully imaging them requires a total integration time long enough to reveal the dimmest features in the field. In some cases, extremely long total exposure time is required, sometimes along with specialized narrowband filters. For example, for my sky conditions and equipment, **Sh 2-129**, the Flying Bat, is known to be exceedingly faint. I didn't stop data acquisition until I had 104 hours total exposure, including 30 hours through an oxygen III filter, which was needed to reveal the exceedingly faint Squid Nebula, **Ou 4**, discovered in 2011 by French astro-imager Nicolas Outters.

While patience is a virtue when going after low-surface-brightness DSOs, at some point you need to call it a day. Increasing exposure time yields diminishing returns in terms of signal-to-noise ratio (SNR). For example, doubling a 10-hour exposure only nets you about a 40% improvement; doubling the SNR would require a whopping 40 hours! "Going long" requires a shift in mindset: When I first began imaging I went after three or four targets in a night. Now I spend several nights — sometimes months during the short nights of summer — dedicated to a single patch of sky.

Your best results on faint objects will come from capturing them when they are at their highest in your sky, say 2 or 3 hours on either side of the meridian (the imaginary line passing through both celestial poles and the zenith). That way you'll be shooting through less atmosphere and will be able to reveal fainter structures and finer details.

Narrowband filters — particularly hydrogen alpha — can be useful to better record fine structure in emission nebulae, planetary nebulae, and supernova remnants. What's more, test shots can be taken even when there's a bright Moon up (*S&T:* Nov. 2017, p. 68).

Conclusion

We all want to capture showpiece DSOs. Those big, bright, and beautiful objects impress astronomers and non-astronomers alike. While you're imaging their amazing fields, be alert to hidden treasures you might be missing. Eventually, you'll have shot most of the popular Messier and NGC objects accessible from your site. When that day comes, it's time to start looking further afield for new wonders to photograph. Use the examples described above to get started, and then dive into the catalogs and online tools I've mentioned to find even more candidates to explore. And when you're preparing to image your chosen subjects, have a good look around it to see what you might be missing — maybe it's worth a test shot or two or a little adjustment to the framing of your shot.

By the way: Don't be surprised if you can't find much technical information about some of your chosen targets. After all, they just don't get no respect!

■ **RON BRECHER** likes to image lesser-known deep-sky objects from his home observatory in Guelph, Ontario. Visit his website at **astrodoc.ca**.

The Meade 70-mm astrograph is dwarfed by the author's large mount used for testing. Any small equatorial mount capable of smooth tracking and autoguiding will be a good match for the little Meade.

Meade's Mini Astrograph

The new Series 6000 70-mm apo astrograph delivers tack-sharp images across a wide field.

70mm Astrograph Quadruplet APO Refractor

U.S. Price: $1,199
meade.com

What We Like

Sharp, well-corrected field with minimal vignetting

Excellent focuser and camera rotator

What We Don't Like

No provision for adding a filter

No optional wide 48-mm T-ring

HERE'S A CLASS OF TELESCOPE I think every deep-sky astrophotographer should have in his or her toolkit. Indeed, for those starting out in deep-sky imaging, it's the class of telescope I often recommend. But even veteran imagers will find a place for a little astrograph like this.

Meade's new Series 6000 astrograph is a 70-mm apochromatic refractor with a focal length of just 350 mm and an f/5 focal ratio. That's fast, short, and wide. With its generous field of 6° × 4° on a camera with full-frame sensor, the Meade astrograph is perfect for framing large Milky Way starfields and colorful regions of nebulosity.

It's called an astrograph, as this is an instrument designed specifically for photography. Unlike many other refractors in the 70- to 80-mm aperture league, the Meade can't really be used to look through — the distance from the focuser to the focal plane is optimized for attaching a DSLR camera body. An eyepiece will reach focus only if it is attached looking straight through without a star diagonal, hardly convenient. In any case, Meade provides no adapters for even a straight-through visual configuration.

ALL PHOTOS BY THE AUTHOR

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But as a photographic instrument, the little Meade really excels.

Photographic Tests

The Series 6000 70-mm astrograph is a four-element design incorporating one element of FPL53 ED glass for color correction. According to Meade, the front objective is a doublet lens, matched to a two-element field-flattener at the rear. The flattener lens is built into the tube assembly and is not an add-on accessory, which makes for a solid design.

As an astrograph, the configuration worked superbly. Color correction was top class, with little sign of blue or magenta haloes around bright stars. Star images across a full-frame DSLR sensor were nearly perfect — tight and sharp — right to the corners. There was no evidence for astigmatism, field curvature, or lateral chromatic aberration affecting off-axis images.

The Meade projects a measured 60-mm illuminated circle, much larger than the specifications promised, and more than enough to cover a full-frame sensor. As a result, I saw little vignetting at the frame corners. Illumination proved uniform in images taken of twilight skies, requiring little correction in processing, with no great need to apply flat-field frames unless the intention is to stretch images to the extreme to reveal the very faintest nebulosity.

Try as I might, I could not get the Meade to produce flaring or ghost artifacts in my images. I shot test frames with bright stars at the edges of the frame and just outside the frame, and I never saw any flares or signs of internal reflections. The multi-coatings and thorough internal tube baffling did their jobs very well. Optically, I had no complaints whatsoever.

Mechanical Features

Much the same can be said of the scope's mechanical performance. In any such instrument, the focuser is paramount, and the dual-speed focuser performed admirably. The 10:1 fine focus was smooth and backlash-free. I did need to tighten one setscrew to prevent some initial slippage of the fine focus knob, but after that the Meade focuser worked consistently well. The focuser can be locked down, and I had no issues with it slipping under the weight of a heavy full-frame DSLR camera when aimed toward the zenith.

While the focuser as a whole cannot rotate with respect to the tube, the focuser does have a camera rotator built in, and this, too, was extremely solid. Loosening the rotator's lock, turning the camera to reframe a target, then re-tightening the rotator produced no shift in focus. Excellent!

The little tube rings that come with the scope are each drilled with a metric M6-1.0 bolt hole on both the top and bottom, with one surface (which could be at the top or bottom) also having a pair of smaller bolt holes on either side of unspecified thread. A Vixen-style dovetail bar is supplied, itself machined with a long slot and several countersunk holes for a variety of mounting configurations. I show it here with the rings close together to allow the dew shield to fully retract for storage, making the tube assembly just 12 inches (30 cm) long.

The dew shield extends 2 inches. A slip-on metal dust cap is supplied for the front and a 48-mm screw-on metal cap for the rear, but it fits on only when the adapter ring is removed.

It is possible to bolt a separate guidescope in rings to the Meade's own tube rings. However, a more popular configuration would be to use the supplied dovetail base to attach an easily removable 50-mm finderscope to serve as a guidescope in conjunction with a small CCD or CMOS autoguider camera, an accessory sold by several manufacturers.

The Series 6000 astrograph focuser is terminated with a 48-mm male thread. To this you can screw on a large-aperture, 48-mm T-ring, which minimizes vignetting but is not a common

1. The astrograph's lens elements are all thoroughly multi-coated and the tube very well blackened and baffled along its entire length. Images were free of flare and ghosting from bright stars off-center and off the frame edge.

2. The dewcap extends 2 inches. DSLR cameras can be attached directly with a wide 48-mm T-ring (here attached to the telescope), or with a more commonly available 42-mm T-ring using the supplied M48-to-M42 step-down ring, shown in front.

3. The field flattener lens is integrated into the rear of the tube assembly. The focuser has a male M48 thread for accepting either the supplied step-down ring (left) or a user-supplied 48-mm T-ring (right).

4. The focuser incorporates a rotator locked with the knob indicated [yellow arrow]. Rotating the camera did not shift focus. The tension of the helical rack-and-pinion focuser can be adjusted, and it can be locked by the knob indicated [blue arrow].

5. The tube rings are tapped with M6-1.0 bolt holes top and bottom for attaching guide-scope rings. Or a small guidescope can be mounted in the standard finderscope shoe, which has two setscrews for a more solid attachment. No finderscope is supplied.

6. The Meade astrograph comes with a compact metal case which can store the telescope with tube rings attached provided they are spaced close together to allow the dewcap to fully retract, as it is here.

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accessory. Meade does not offer one, so buyers will have to search for one from another source. For all my testing I used one I had on hand.

Alternatively, you can use the supplied M48-to-M42 step-down ring to attach the more standard 42-mm T-ring (such as from Meade) for DSLRs, or for attaching other types of CCD cameras fitted with standard M42 threads.

The distance from the back surface of the focuser to the focal plane is 66 mm, and the focuser has 32 mm of travel. When using a DSLR with conventional 55-mm back focus, the focuser is racked out 11 mm, leaving just 22 mm of further outward travel to accommodate the shallower back-focus requirements of many dedicated CCD cameras. CCD cameras with sensors close to the front will require a short M42 extension tube to reach focus.

As good as the focuser is, its primary drawback is that it provides no accommodation for dropping in a filter between the telescope and camera. DSLR owners wanting to shoot filtered images (particularly with modified cameras) would need to use clip-in filters inserted into the camera's mirror box. These require the mirror to be locked up, preventing any use of the optical viewfinder to find or frame objects.

A single 5-minute exposure with a modified Canon 5D MkII DSLR at ISO 1600 shows stars as pinpoints to the very corners of the full-frame sensor (insets). Focus was uniform across the field. The slight asymmetric purple halo around Deneb is an artifact from the camera's internal IR filter and is seen in images taken with all telescopes.

Recommendations

The Meade 70-mm astrograph is the perfect instrument to shoot wide-field deep-sky targets. With a focal ratio of f/5, it's not as fast as some of the competitor's similar instruments, but it does provide an exceptionally large unvignetted field, not true of some faster systems I've used. And f/5 is plenty fast enough under most circumstances.

The Meade's compact size and 5-pound (2.3-kg) weight (including tube rings) make it easy to pack for airline trips. While in a pinch it could be mounted on a small tracker, the Meade performs best on a full-sized but small equatorial mount capable of accepting an autoguider. There are many fine choices these days, including Meade's new LX85 German equatorial mount.

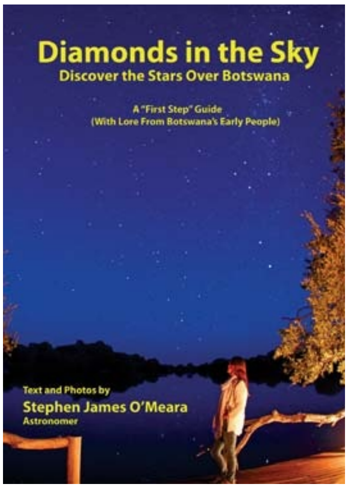
All the required gear could go in checked or carry-on luggage for flights to exotic skies. Or, more to the point, the Meade astrograph and the required small mount simply allow for deep-sky shooting sessions close to home with a minimum of setup fuss and maximum results. I liked the Meade astrograph a lot and can recommend it highly.

■ Visit Contributing Editor **ALAN DYER's** website at **amazingsky.com** with links to his social media connections.

▶ SMARTPHONE ADAPTER

Celestron announces the NexYZ 3-Axis Universal Smartphone Adapter ($59.95). The unit allows you to use most any smartphone camera to capture the brighter solar system objects and even some deep-sky targets. Its spring-loaded clamp and innovative 3-axis adjustments permit you to place your device's camera perfectly against virtually any eyepiece on a telescope, binocular, or microscope quickly and precisely. Simply place your phone on the platform, centering it over the eyepiece with the X and Y knobs, and then moving up or down with the Z knob over the eyepiece until you have the entire field of view in your shot. The NexYZ attaches securely to any eyepiece from 35- to 60-mm in diameter with a padded clamp and adjustable safety lock. Two additional adapter rings are included for connecting the device to smaller microscope eyepieces.

Celestron
2835 Columbia St., Torrance, CA 90503
310-328-9560; celestron.com



◀ SOUTHERN PRIMER

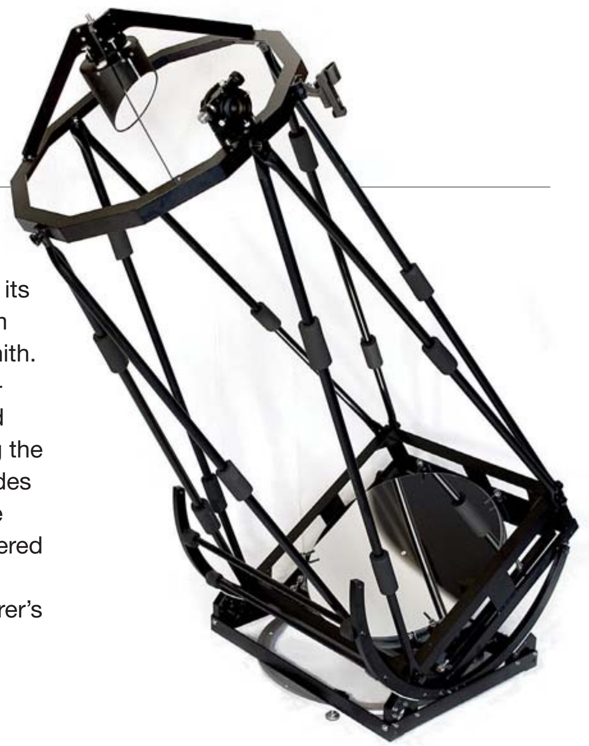
Author (and former *S&T* editor) Stephen James O'Meara rolls out his latest ebook *Diamonds in the Sky: Discover the Stars Over Botswana* ($5.98). This introductory field guide to exploring the night skies is geared towards, though not limited to, anyone considering a trip to the exceedingly dark southern skies of Botswana. *Diamonds* is sprinkled with the perspective and history of the indigenous peoples of the region, beginning with a naked-eye primer on what is visible without optical aid from the country's national parks. O'Meara details specific sights to look for each month throughout the year with insightful recounting of local lore. Additional sections on the Sun, Moon, and planets are included, as well as information about the country's meteor craters. 188 pages.

Diamonds in the Sky
Available on the
Amazon Kindle store.

▶ BIG TRUSS DOB

Hubble Optics, known for manufacturing high-quality Newtonian reflector optics, now offers the UL24, a 24-inch f/3.3 ultra-light Dobsonian ($9,500). This fast Newtonian reflector is built for travel, featuring a lightweight "sandwich" mirror that drastically reduces its weight and cool-down period compared to solid mirrors. The UL24 weighs only 154 lb (70 kg) when fully assembled, and breaks down into its constituent parts to fit into most compact vehicles. The scope's primary and secondary mirrors feature 96% enhanced-reflectivity coatings, and its eyepiece stands just 77 inches from the ground when pointed at the zenith. The telescope uses eight precision-machined trusses and an optimized primary flotation system supporting the primary mirror. The telescope includes a dual-speed, 2-inch Crayford-style focuser with linear bearings engineered to support the heaviest eyepieces available today. See the manufacturer's website for additional details.

Hubble Optics
hubbleoptics.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.*

Starting at only $ 1,649, the Esprit line is offered in 80, 100, 120 and 150mm apertures and comes complete with a 9 x 50 right angle finderscope, 2-inch Star diagonal, 2-element field flattener, camera adapter, mounting rings, dovetail plate and foam-lined hard case.

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Easy and Effective Light Barriers

Block your neighbors' lights with these simple panels.

Ken Martin's light-blocking panels quickly turn his driveway into a fine observatory.

IT SEEMS LIKE NEARLY EVERYONE with a telescope also has a neighbor or twelve with unshielded porch lights. Even if they're good neighbors and keep the lights off when they're not actually using them, interior lights still leave brightly lit windows. Plus, if you observe from your driveway there are the headlights of passing cars, the inevitable street lights, and the person walking his dog with an aircraft landing light for a headlamp.

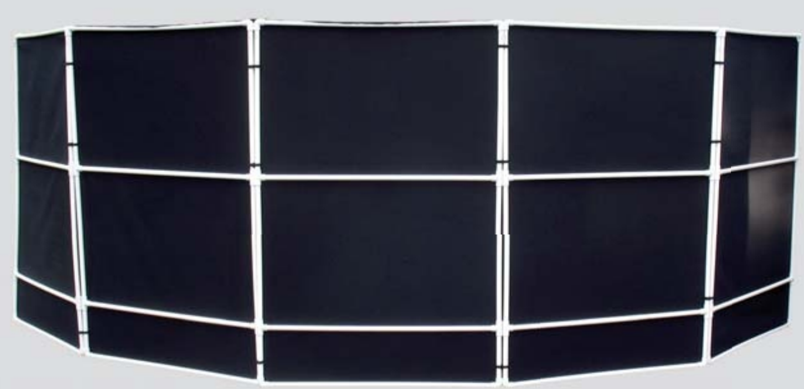
Amateur astronomers need a reliable way to block all those lights so we can protect what dark adaptation we can achieve. I've tried tarps suspended from poles, cut-open cardboard refrigerator boxes, strategically parked cars, and even, I confess, a slingshot. None of those worked as well as the solution that Oregon amateur Ken Martin came up with: multiple panels of light-blocking material that he can place in whatever arrangement is necessary.

Ken looked for inspiration online and reports that "After reviewing the many DIY dark sky panel projects in the 'Carol's Picks' thread on Cloudy Nights, I decided to make these PVC panels." Their construction is simple, straightforward, and relatively inexpensive, yet they're lightweight, durable, and easy to use.

Ken used ¾-inch class 200 PVC pipe for the framework. Class 200 is the lightweight, thin-walled stuff, which is plenty strong for this application. A handful of tees and elbows connect the pipe sections into rectangles, and wide-head screws hold the fabric to the pipe.

Using the proper fabric is the key to success. Plastic tarps, canvas, denim, duck cloth, and similar materials may look dense by day, but at night with dark-adapted eyes it's surprising how much light gets through them. To really block all the light, Ken found that Duvetyne, a black cotton twill commonly used in the stage and movie industry, is ideal. It comes in various widths, so Ken chose 54-inch so he could make his panels 4 feet wide and have 6 inches of cloth left to overlap onto the next panel. He made his panels 6 feet tall, which is high enough to block neighbors' lights but doesn't cut off too much sky. Duvetyne comes in 8-, 12-, or 16-ounce weights. Ken used the 16-ounce for maximum light blocking.

Assembly is simple: Just cut the pipe to length, insert it in the fittings, and attach the fabric. Ken says "I chose not to glue the fittings, as I didn't feel it



◀▲ *Above:* The panels are made of PVC pipe and Duvetyne fabric. *Top left:* Velcro straps hold the panels together. *Bottom left:* Wide-headed screws hold the cloth to the pipe. Ken painted the heads black.

was necessary with the fabric attached. It won't come apart. I did use a rubber mallet to make sure the fittings were seated completely."

Duvetyne has a rough side and a velvety, ultra-dark side. Put the rough side against the pipe so the velvety side faces you when you observe, and no white pipe is visible.

Ken drilled holes in the pipe for the screws. He stretched the Duvetyne snug, but not drum-head tight. (Too tight and it will bend the pipes.) On top and bottom he used Seamless Stitch glue to tack the loose ends to the pipe above the screws, reporting that "The glue worked great to secure the extra ¼- to ½-inch of fabric to the PVC."

Ken made five panels, which together span 20 feet. He arranges them in a curve so they'll stand by themselves, and he holds them together with Velcro straps. (Ken used Gardner Bender "cord organizer grip strips," part #45-V11BKW, but just about any wrap-around Velcro strap will do.)

On top of the end panels, Ken put eye bolts that he can tie ropes to so he can stake the panels down in breezy conditions. Most often though, simply tying them to gallon jugs filled with water is sufficient.

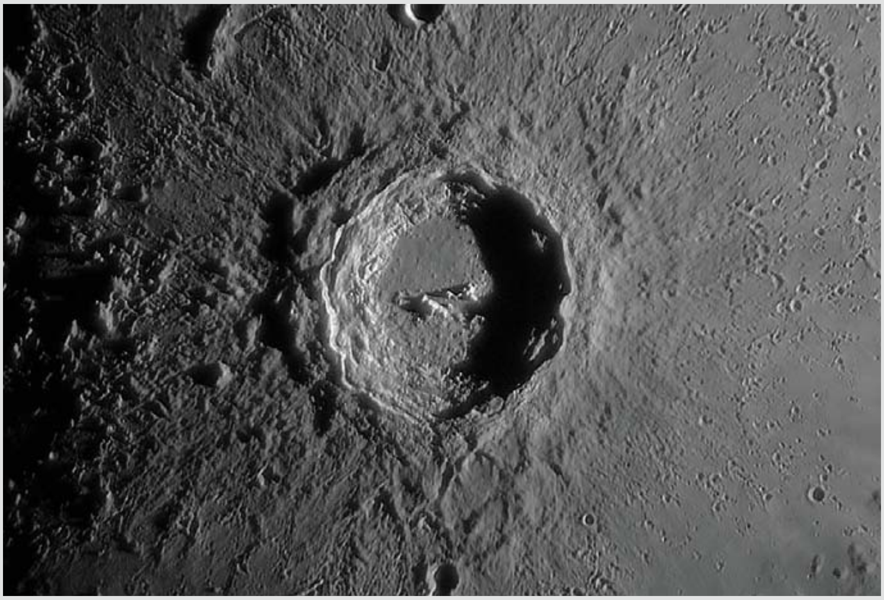
Once the panels are connected together, the extra 6 inches of fabric is Velcroed across the pipe junction so you can't see any pipe and no light can leak through the gaps. When you're inside a semicircle of these panels, it's like having a black hole on one side of you. There's no light coming from that direction at all.

For a nice finished look, you can clean the printing off the pipe before you assemble it. Acetone and paper towels work great for this, leaving the pipe shiny white.

Ken reports that these light-blocking panels have turned his suburban driveway into a decent observatory, and he gets along fine with his neighbors, too.

ALL PHOTOS BY THE AUTHOR

■ Contributing Editor **JERRY OLTION** has shielded most of his neighbors' lights, and has even turned some of those neighbors into amateur astronomers.



△ CRATER SUNRISE

Brian Ford

The massive, 93-kilometer-wide crater Copernicus displays its complex terraced walls and central peaks in this detailed view captured several days after first quarter.

DETAILS: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope with ZWO ASI290MM monochrome video camera.*

▽ PLANET PARADE

Ryan Imperio

A cascade consisting of Saturn, Mars, the Moon, and Jupiter (left to right) rises over Jordan Lake in North Carolina in the early morning hours of March 8th.

DETAILS: *Nikon D90 DSLR camera with 18-to-105-mm zoom lens at 18 mm. Exposure: 70 seconds.*

SHINE DOWN ON SHANGHAI

David Xu

A dramatic display of crepuscular rays fans across the sky in late-afternoon hours as seen from the 118th floor of Shanghai Tower in Shanghai, China.

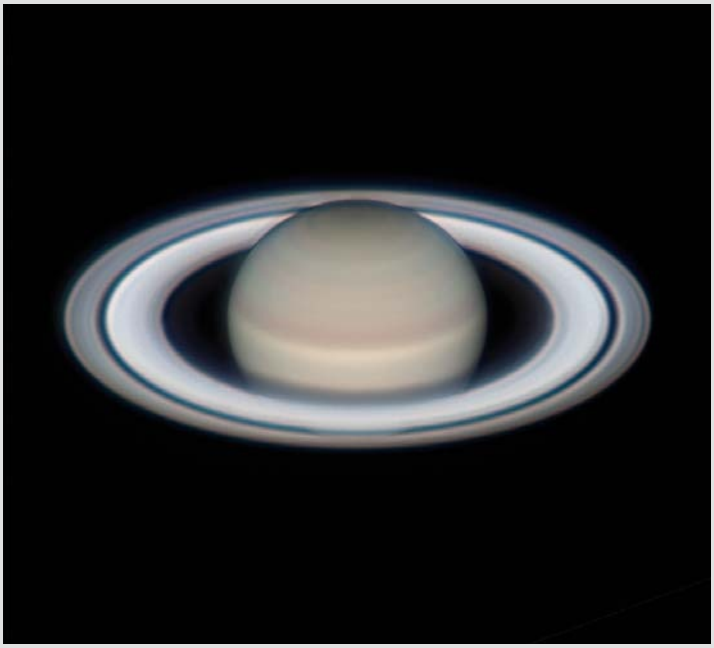
DETAILS: *Nikon D3100 DSLR camera with 18-to-300-mm zoom lens at 52 mm. Exposure: 1⁄400 second, ISO 400.*

▷ KING OF RINGS

Brian Ford

Besides the wide Cassini Division and the thin Encke Gap at the outer edge, Saturn's ring system displays several distinct bright and dark regions in this sharp image captured on July 1st.

DETAILS: *Celestron C14 EdgeHD Schmidt-Cassegrain telescope with ZWO ASI290MM video camera. Stack of 10 de-rotated video results recorded through RGB filters.*



▽ DIAMONDS IN THE SKY

Dan Crowson

A smattering of reddish stars stands out among fainter yellow members of open cluster NGC 6819 in Cygnus.

DETAILS: *Astro-Tech AT90EDT apochromatic refractor with SBIG ST-8300M CCD camera. Total exposure: 4½ hours through LRGB filters.*

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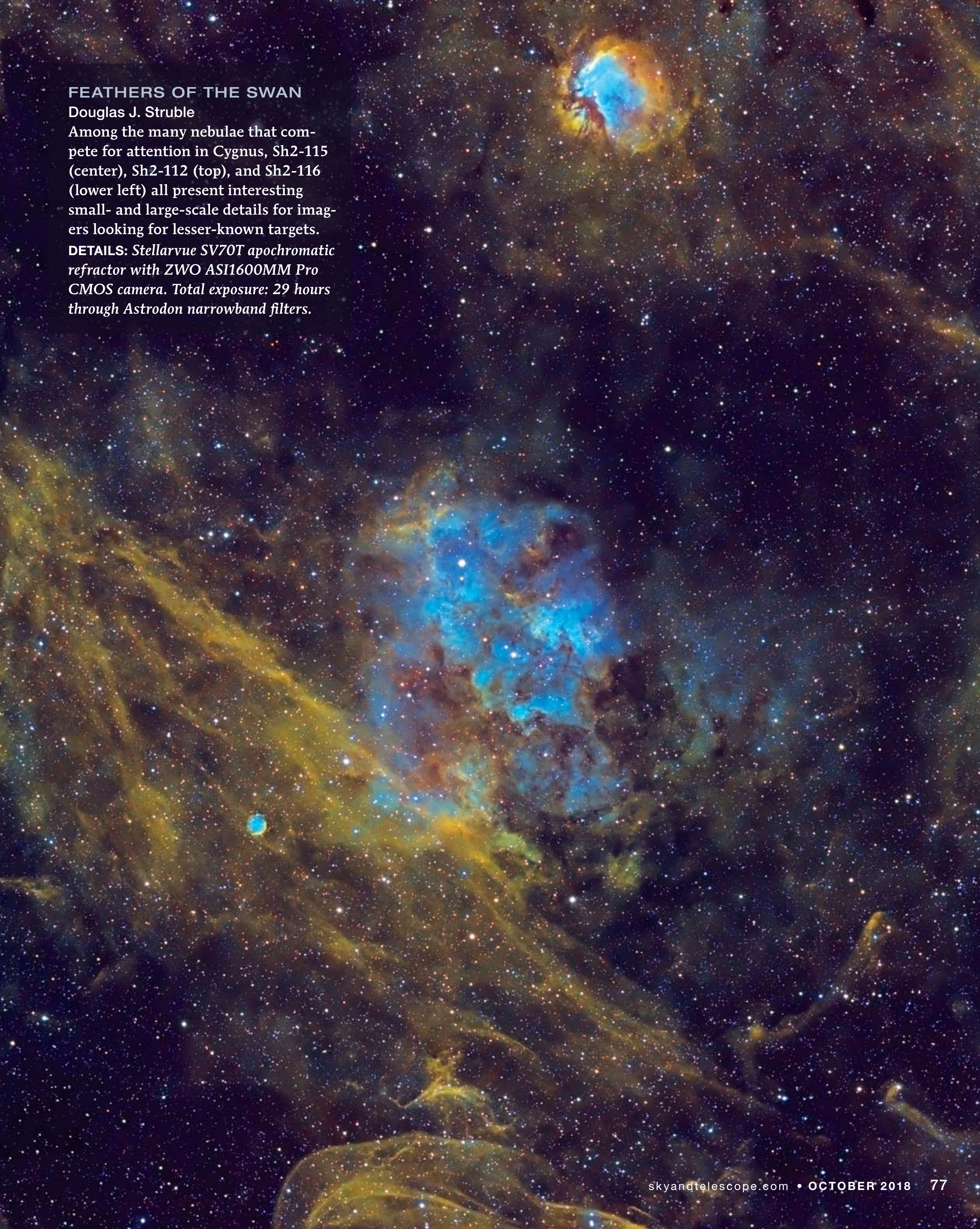

FEATHERS OF THE SWAN

Douglas J. Struble

Among the many nebulae that compete for attention in Cygnus, Sh2-115 (center), Sh2-112 (top), and Sh2-116 (lower left) all present interesting small- and large-scale details for imagers looking for lesser-known targets.

DETAILS: *Stellarvue SV70T apochromatic refractor with ZWO ASI1600MM Pro CMOS camera. Total exposure: 29 hours through Astrodon narrowband filters.*

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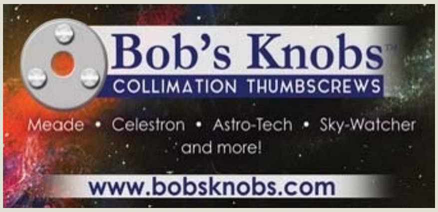

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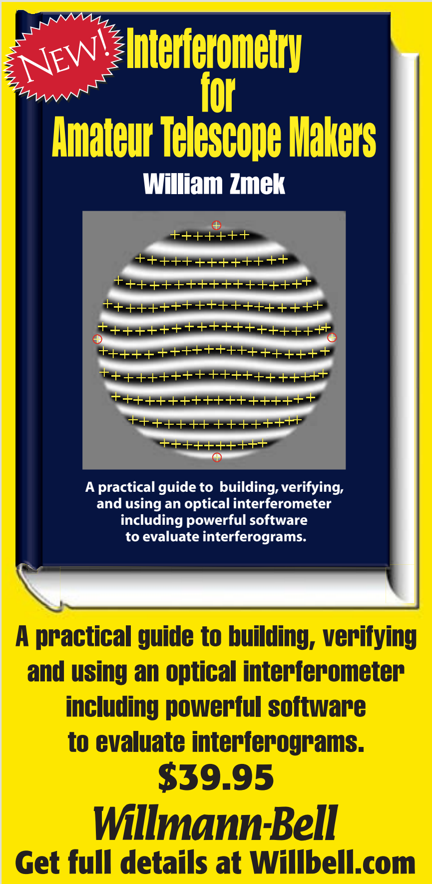

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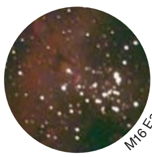

M16 Eagle Nebula

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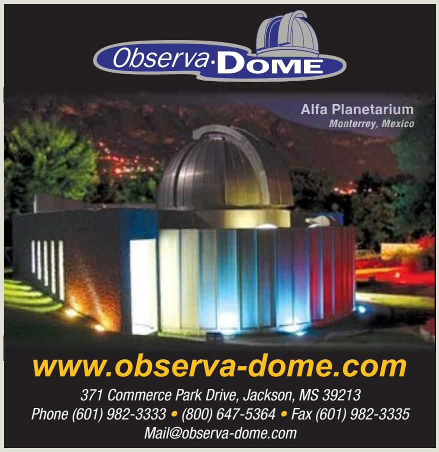

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Outwitted

How the author learned he had galaxies coming out his ears

ASIDE FROM THE ESSENTIALS of life, few things in this world seem to interest everybody. Astronomy happens to be one of those universal passions, one that unites people of all cultures.

My own level of fascination has always been high. At 9 years old, I watched Neil Armstrong's "small step," and since then astronomy's been inside my head . . . in more ways than one.

> I hadn't realized I was stepping into a trap. I was feeling good about myself, but being the brilliant strategist she is, Sue had me right where she wanted me.

My wife Sue, on the other hand, is like most people: curious, but not enough to take it to the next level. Which is why I gave up on encouraging her years ago.

Until one recent evening, that is, when I was lured into trying again. That night, while my 10-inch Dobsonian stood in the backyard cooling off, I was hunched over the dining room table with my journal and star charts when Sue walked in.

"What are you seeking tonight?" she asked, likely just being polite.

I looked at her and smiled. "Galaxies again. It's finally going to be clear." I then focused back on my *Uranometria*.

Knowing that hunting the faint fuzzies was my favorite kind of observing, she playfully commented, "You have galaxies coming out your ears."

Without looking up I quipped, "If there's one thing I've learned about galaxies, it's that they're too big to come out one's ears."

Three nights later while sitting at the same table, with my *Uranometria* open before me and the Dob again reaching ambient temperature under the darkening sky, I was feeling a little clever. When Sue entered the room, I reverted to the old days and tried once again to pique her curiosity.

"Now, honey, tonight I'll observe a galaxy that's 50 million light-years away. Light from that galaxy traveled at 186,000 miles per second on its long trip here. That's as fast as going around Earth seven times in a single second. After traveling that fast for 50 million years, those photons of light will come into our backyard, enter through the top opening of my telescope tube, reflect off two mirrors, and go through the eyepiece and into my eye. Those photons will then end that 50-million-year journey in my brain."

I paused for dramatic effect then added, "Part of that galaxy will literally become part of me."

Finally I had impressed her. I could see the gears spinning as my words soaked into her head like galactic photons sink into mine.

"What happens to the photons then?" she asked.

Caught off-guard, I had to think for a moment. "Well, I suppose that since photons are energy, and energy can't be destroyed, they must turn into body heat inside my optic nerves or brain or somewhere in my head."

I hadn't realized I was stepping into a trap.

"Where does the body heat go after that?" she asked with an innocent face.

I knew the answer to that one. "It just radiates away like all body heat. It will leave as warmth from the top or back of my head or my face. It might even come out my eyes where the photons went in."

I was feeling good about myself, but being the brilliant strategist she is, Sue had me right where she wanted me.

"Ah, so since your ears are part of your head, I guess you do have galaxies coming out of them."

Her wisdom went in one ear and did not come out the other.

DAVID CURTIS STUDIO

ROGER SARGENT has volunteered at the planetarium and observatory at Edinboro University in Pennsylvania for 22 years. He founded the Erie Bluffs Star Party earlier this year.

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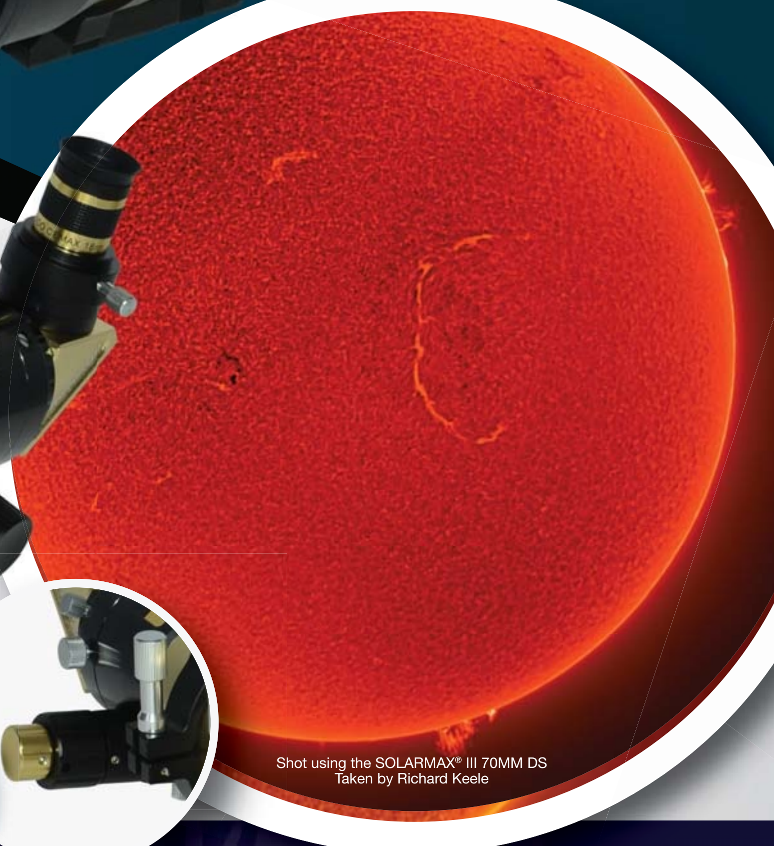

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