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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

SPECIAL ISSUE

THE Moon

JULY 2019
skyandtelescope.com

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The view outside Buzz Aldrin's window after landing PHOTO: NASA

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A Night to Remember

WHEN I WAS NINE YEARS OLD, my parents dragged me out of bed one night around 10:30 p.m. and led me to the living room. I'm guessing they also rousted my brother and sister, but I don't remember them. All I recall is sitting in my pajamas on the rug against the sofa and rubbing sleep from my eyes as I tried to focus on grainy images playing across our small black-and-white TV set.

It was July 20, 1969.

To this day I thank my parents for ensuring I didn't miss those historic first human steps on the Moon. The next morning I asked if I could keep that day's *New York Times*. Fifty years later, as we started preparing this special Moon issue in honor of Apollo 11's pioneering visit, I retrieved that paper from a box where it had lain all these many years (see photo). Long ago an attic mouse had nibbled an edge, but the paper was largely intact, and I spent a nostalgic hour reading that day's first section, which was entirely devoted to Apollo 11.


The New York Times
MEN WALK ON MOON
ASTRONAUTS LAND ON A PLAIN
AFTER STEERING PAST CRATER

SEAN WALKER / S&T

Often those events that freeze moments in our collective mind are wrenching ones — Kennedy's assassination, the Challenger disaster, 9/11. But the first humans on another world was a celebratory moment for all humanity. (Well, there were exceptions: My rodent-chewed *Times* quoted Picasso, when asked what he thought of the landing, responding, "It means nothing to me. I have no opinion about it, and I don't care.")

S&T readers at the time likely would have leaned more toward the perspective of visionaries like the Dalai Lama, who commented on the same page: "The American landing on the moon symbolizes the very acme of scientific achievement." Or perhaps that of Vladimir Nabokov: "Treading the soil of the moon, palpitating its pebbles, tasting the panic and splendor of the event, feeling in the pit of one's stomach the separation from terra . . . these form the most romantic sensation an explorer has ever known. . . ."

To help trigger memories of those who were also watching on that July night a half-century ago, or to inspire those who weren't yet born or old enough then, we offer a dedicated Moon section beginning on page 13. It showcases three features — on lunar science, observing, and imaging, respectively — plus an infographic on upcoming missions to our neighbor. Other Moon pieces in this issue include Chuck Wood's column on a clever new technique for dating lunar craters (page 52) and a moving tribute to how viewing the Moon brought a long-time deep-sky observer out of a slump (page 84). We hope you enjoy this special issue.

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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H in mm 118, D in mm 66, weight 21.2-Oz	53684	**229.00**
2" Panorama II eyepiece 21mm		
H in mm 118, D in mm 71, weight 24.9-Oz	53561	**229.00**

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All Our Fault

Ever since you published Kelly Beatty's cover story "Where Are the Young Astronomers?" (*S&T:* Sept. 2000, p. 82), that article has haunted me.

The Crewe Astronomy Club was founded in 1998, and as many other clubs do, we brought out our telescopes and explained the night sky to the general public at five Virginia state parks. But since September 2000, we altered the course of our programs to let children have a hands-on approach to discovering the night sky. We stopped bringing the fancier telescopes — equatorial, tracking, Go To — and brought 12 smaller refractors, reflectors, and several Dobsonians that kids could operate and let them have control. My wife and I also built an observatory and science center in our barn so kids could come to our 30-acre farm if they couldn't make one of the state park dates. Between the parks and the farm, we have about 15 programs per year.

Since September 2000, access to the internet has exploded with tablets and smartphones. So last year I wrote and produced astronomy programs for beginners in five lessons and put them on the internet. There are also two eclipse videos that explain why eclipses happen and feature the August 2017 solar eclipse that I filmed in South Carolina and the 2019 lunar eclipse this past January filmed on our farm. You can access these videos by going to YouTube and typing in "Crewe Astronomy Club Lesson 1," and they will all pop up.

I used children's graphics that I drew, wrote and produced all the animations, and composed the music. Lesson 5 on Telescopes Part 2 features the cover of *S&T*'s September 2000 issue and explains how it inspired us.

▲ Mimi Wagner loved the views she got through Cassiopeia, her 10-inch Dobsonian, as shown in the September 2000 cover photo.

So thank you, *S&T*, for changing my life and the lives of so many people by helping us explore our universe!

Kim Kenny • Crewe, Virginia

First Look

I recently read Roger Sinnott's 75, 50 & 25 Years Ago (*S&T:* Apr. 2019, p. 7) and was surprised to see no mention of the original discoverers of the Crab Pulsar at Kitt Peak Observatory on January 15, 1969. It was a trio of young astronomers in Tucson, Arizona, who made the first optical observation of the pulsar, and not, as Sinnott implies, S. Miller and E. J. Wampler at Lick Observatory.

Nathaniel Johnston
Dobbs Ferry, New York

Roger Sinnott replies: *You're right. An earlier article (*S&T: *Mar. 1969, p. 135), gives that credit: "The first detection was by W. J. Cocke, M. J. Disney, and D. J. Taylor, with the 36-inch reflector of Steward Observatory, University of Arizona." That article goes on to name members of three other teams at other observatories that also detected the flashes (a few days later).*

The Herschel Hustle

I want to congratulate Tom Reiland on his incredible accomplishment of observing and documenting the entire Herschel Catalog (*S&T:* Mar. 2019, p. 30). This is a monumental achievement for sure, and in my opinion one of the best all-time articles in *Sky & Telescope*. This quest required observations over a period of years and with great patience. In the days of instant gratification, spending many nights outside with a telescope in the freezing cold of winter, the heat of summer, and for years would be beyond the comprehension of many.

What Tom has done is the "true heart" or purpose of amateur astronomy, which I've always believed to be visual observing and documenting each and every object. With the current popularity and advancement of digital imaging, it's great to see that there are still a few visual observers left, following in the ways of Messier and the Herschels.

Roger Ivester
Boiling Springs, North Carolina

Memories of Canopus

Fred Schaaf's articles on Canopus (*S&T:* Feb. 2019, p. 45 and Mar. 2019, p. 45) reminded me of the first time I saw this star. It was Spring Break 1986, and I was in Florida. One evening, when we were by the lagoon at Epcot Center, I noticed a bright star to the south of Sirius. It was, of course, Canopus, and seeing it created another memory for an already memorable trip.

It was a thrill to gaze upon one of the fabled southern stars that we northerners can read about but don't often get an opportunity to see.

Steve Breutzmann
Greenfield, Wisconsin

From our coastal California town (latitude 36.94976°N), Canopus is one of our favorite observational objectives. We're slightly north of the 37° visibility limit without atmospheric refraction. The star appears just above the Pacific Ocean for about 20 minutes during optimal viewing times when viewed from the 40-foot coastal cliffs. The object is faintly visible to the naked eye; through binoculars, it oscillates between blood-red and deep-blue colors.

I've always enjoyed seeing the star directly overhead on our winter trips to the Southern Hemisphere.

Mark Conover
Santa Cruz, California

MARSHA ROBINSON

Request for Information

I've been asked by several astronomical societies to put together a lecture on the creation and early history of *Sky & Telescope*, and I need background information on a number of people. Dates and places of birth and death, photographs, and biographical details (including middle names) for any of the following are welcomed:

- Clement S. Brainin (editor of *The Amateur Astronomer* 1929–36);
- Leland S. Copeland (wrote observing articles during the 1940s);
- Marian Lockwood (wrote for *S&T* during the 1940s);
- Earle B. Brown (wrote Gleanings for ATMs up to the 1950s);
- Jesse A. Fitzpatrick (wrote Observer's Page 1941–45);
- Catharine E. Barry of Hayden Planetarium (wrote Sky Guides for *The Sky* and *S&T* during the 1930s and '40s);
- Alphonse P. Mayernick (wrote about astronomy stamps for the first six issues of 1959 and issue 3 of 1962);
- Alan T. Moffet (wrote a maverick installment of Astronomical Anecdotes in May 1965 *S&T*).
- Also, I'd like an image of Robert Edward Cox (wrote Gleanings for ATMs from the 1950s to '70s) as well as any information and images relating to Loring B. Andrews (editor of *The Telescope* 1933–37) and the editor preceding him.

If you can help, please email me at **stars@starlight-nights.co.uk** with details, images, etc. Thank you!

Brian Jones
Bradford, United Kingdom

Through a Glass, Darkly

Jerry Oltion was certainly correct that dust-covered mirrors can still provide good views (*S&T:* Mar. 2019, p. 36).

I recently "rescued" an old 8.75-inch Dobsonian from a charity shop. The main mirror was filthy, corroded, and covered in dust. You wouldn't use it as a shaving mirror. I turned the scope on the night sky that evening without cleaning anything or expecting to see anything. But the views and the optics were superb. The obscuring dust and corrosion merely reduced aperture and contrast.

I'm now in the process of getting it re-aluminized and refurbished.

Peter Gibbons
Carrigrohane, Ireland

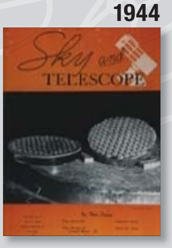
FOR THE RECORD

● In Binocular Highlight (*S&T:* Apr. 2019, p. 43), M44, the Beehive Cluster (592 LY), should have been included in the discussion of best and brightest star clusters for binocular observing.

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

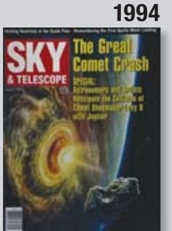
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1944



1969

1994



◖ **July 1944**

Lunar Atmosphere? "Walter H. Haas, of Upper Darby, Pa., writes: 'The occultation of Jupiter by the moon on April 30th – May 1st was observed with the 18-inch refractor of the Flower Observatory, using 150×. . . . When the planet emerged from behind the bright limb of the moon, a hazy gray band concentric with the lunar limb was seen across the face of Jupiter. The angular width of the band was estimated to be three seconds of arc.

"'I am greatly interested in this marking because of the interpretation that W. H. Pickering put upon it [in an 1892 article:] 'The Lunar Atmosphere and the Recent Occultation of Jupiter.' . . .'"

A keen observer, Walter Haas later founded the Association of Lunar and Planetary Observers. But what had he seen? The Moon's atmosphere is vacuum-thin. One theory is lunar dust, kicked up by high-speed particles from space. Apollo astronauts did find the Moon to be quite dusty.

◖ **July 1969**

"Go" for Apollo 11 "The Apollo 10 mission that ended so successfully on May 26th provided the final tests for the lunar module. The strange-looking craft that the astronauts called Snoopy proved the workability of that kind of space vehicle. Now the Lem is ready to carry two men to the moon's surface about July 20th. . . .

"When flying their Lem, the astronauts stand at their control stations, supported by a network of cords and pulleys. Hooked Velcro on the soles of the men's boots 'sticks' to Velcro strips on the deck of the Lem to keep the astronauts from floating around. . . .

"The historic moment when [Neil] Armstrong emerges from the Lem to set foot on lunar soil is due Monday, July 21st, at 12:12 a.m. [EDT]. . . ."

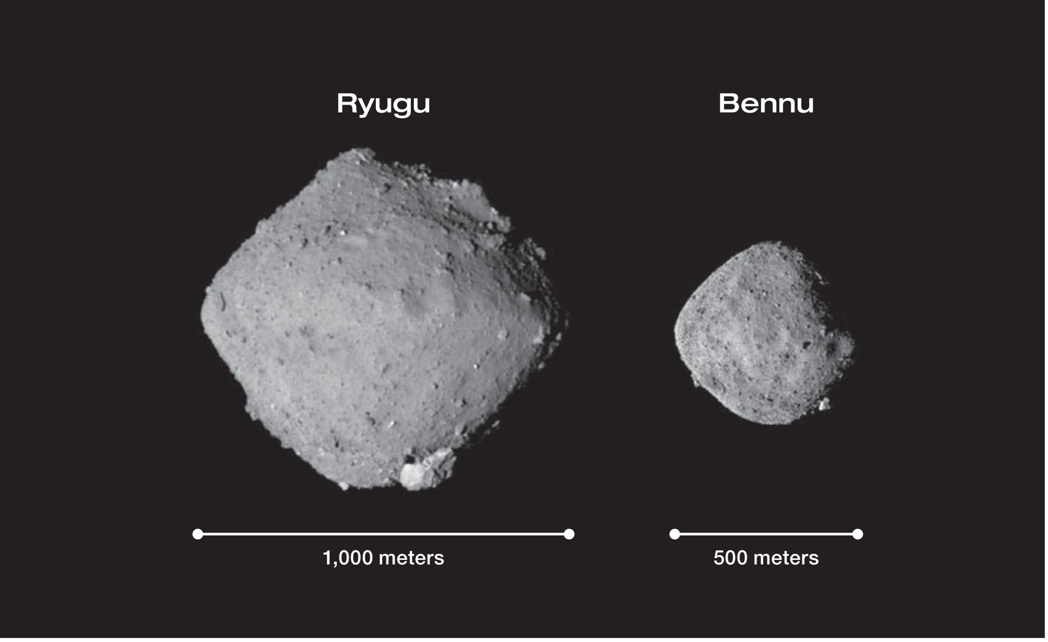
As it turned out, Neil Armstrong took his "one small step" an hour and 16 minutes sooner than this preflight estimate.

◖ **July 1994**

Robots in Space "Today scientists are still analyzing the lunar samples and Apollo's other data for clues to the evolution of the Moon and the inner solar system. Of course, there are plenty of gaps in our understanding that Apollo did not fill, leaving openings for Clementine and other automated missions. The increasing sophistication of such robotic explorers tempts us to wonder whether they might ever replace their creators. . . .

"The men who made the journey can tell stories of the Moon's stark beauty, of the giddy buoyancy of walking in one-sixth gravity, of seeing the Earth as a blue and white marble afloat in blackness. Those stories . . . demonstrate what Neil Armstrong said in 1989 . . . : 'A human being can be amused and amazed. A robot can do neither.'"

Apollo authority Andrew Chaikin was writing in Focal Point.



▲ Particles spewed from Bennu on January 19th.

SOLAR SYSTEM

Ryugu vs. Bennu: Updates from the Asteroids

SCIENTISTS WITH NASA'S Osiris-REX and the Japan Aerospace Exploration Agency's Hayabusa 2 spacecraft provided preliminary results at the annual Lunar and Planetary Science Conference regarding their respective explorations of near-Earth asteroids 101955 Bennu and 162173 Ryugu. A slew of papers in *Nature*, *Nature Astronomy*, *Nature Geoscience*, and *Science* accompanied the presentations.

Except for size, Bennu and Ryugu are hard to tell apart in photos. Both are so-called "rubble piles," collections of debris weakly bound by gravity. Their low densities imply Swiss-cheese interiors. On the surface, both terrains are dark (reflecting about 4.5% of incident sunlight) and strewn with large boulders. And, despite being around for more than 100 million years, both bodies have few small craters, suggesting that something — perhaps shaking from bigger impacts — is filling them in.

Because of the hazardous surface terrain, NASA is still planning Osiris-REX's descent. Bennu's *regolith* — the loose gravel and rocks on the surface — might also present a problem. There are no large patches of fine regolith, but sample collection systems were designed to retrieve particles less than 2 cm (0.8 inch) in diameter. Another potential difficulty is that the surface reflectivity varies more than predicted, which poses a challenge for the spacecraft's laser-based navigation systems. Bennu's surface thus presents a scenario "beyond the spacecraft design specifications," notes the Osiris-REX team. Nevertheless, the scientists are confident they can work with what they have within the current schedule.

The Japanese spacecraft is a bit ahead of its American counterpart, having arrived at Ryugu roughly five months earlier. Hayabusa 2 has already successfully deployed three rovers that snapped pictures as they hopped around the asteroid's surface. The mother ship also skirted boulders to collect a sample of regolith (*S&T:* June 2019, p. 10). And on April 5th, Hayabusa 2 shot a copper cannonball at Ryugu to create an artificial crater, with the aim of studying the newly exposed ejecta.

Early observations have also revealed the asteroids' differences. Over time, rapid rotation has led to the formation of ridges along their equators, but their spins point to unique pasts. Bennu rotates every 4.3 hours, and it's accelerating with time. Its period shortens by a second every 100 years due to uneven solar heating of its surface, known as the *YORP effect* (named for scientists Yarkovsky, O'Keefe, Radzievskii, and Paddack). On the other hand, Ryugu's shape suggests that it has slowed from spinning as fast as every 3.5 hours to its current rotation period of 7.6 hours.

The asteroids also have unexpectedly different water content. There are hydrated minerals on both objects, and Osiris-REX found evidence of past interactions with water on Bennu (*S&T:* Apr. 2019, p. 10). However, Ryugu appears drier than expected; its parent body might not have had much water.

The biggest surprise, though, is the discovery of rocky plumes that occasionally spew from Bennu. The first plume was detected on January 6th. The team has detected a total of 11 events so far, three of them substantial enough to eject dozens to hundreds of particles. Most of these particles move relatively slowly and eventually make their way back to the asteroid's surface, but some particles reach escape velocity. The probability of any of these rocks hitting the spacecraft is very low.

■ **JAVIER BARBUZANO**

BENNU: NASA / GSFC / UNIV. OF ARIZONA; RYUGU: JAXA / TOKYO UNIV. / KOCHI UNIV. / RIKKYO UNIV. / NAGOYA UNIV. / CHIBA INSTITUTE OF TECHNOLOGY / MEIJI UNIV. / AIZU UNIV. / AIST; PARTICLES: NASA / GSFC / UNIV. OF ARIZONA / LOCKHEED MARTIN

MARS

Is There Methane on Mars?

TWO STUDIES ARE FINDING conflicting results about whether methane exists on Mars. Its presence would point to certain geochemical processes or, less likely, biological activity.

Researchers using the Planetary Fourier Spectrometer (PFS) aboard Europe's Mars Express orbiter spotted 15.5 parts per billion by volume (ppbv) of methane in 2013, a day after NASA's Curiosity rover measured a spike of 5.78 ppbv. Atmospheric simulations and geological analysis helped track the emission's origin to a fault area southeast of Gale Crater, Marco Giuranna (National Institute of Astrophysics, Italy) and colleagues report April 1st in *Nature Geoscience*.

However, the European-Russian ExoMars Trace Gas Orbiter (TGO), a spacecraft designed to measure vanishingly small amounts of gases in the carbon dioxide–based atmosphere, has failed to find any methane during the first months of its science operations. The TGO team reported the result April 10th at the European Geosciences Union General Assembly in Vienna, Austria, and in *Nature*.

TGO's lack of detection limits methane abundance to less than 0.05 ppbv. However, TGO makes its measurements using the *solar occultation method*, looking through the atmosphere at sunset from orbit. This method limits TGO to detections at altitudes above about 5 km (3 mi); methane could still lurk lower down. Conversely, PFS looks down at Mars, so its observations include lower altitudes.

Nevertheless, Oleg Korablev (Russian Academy of Sciences) says it's difficult to reconcile TGO measurements with the spikes of methane emission other missions have reported, because atmospheric circulation should spread the gas to higher altitudes. Giuranna and others have suggested that methane might not always be present in the Martian atmosphere. But even if marsquakes or small meteorite impacts release small puffs of methane from underground reservoirs, these clouds should still survive in the Martian atmosphere for at least 300 years before breaking apart under the Sun's ultraviolet radiation.

An unknown mechanism might remove the gas, but if so, it must work efficiently, at low altitudes, and only on methane, as current models successfully reproduce other components of Mars's atmosphere. Another option is that some mechanism may keep the gas near the surface.

■ JAVIER BARBUZANO

Mars Express

MARS EXPRESS: NASA / JPL-CALTECH / CORBY WASTE; GRAPH: H. NIIKURA ET AL. / *NATURE ASTRONOMY* 2019

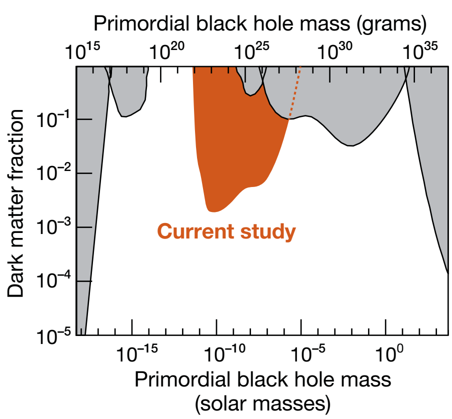
COSMOLOGY

Could Dark Matter Be Black Holes?

NEW OBSERVATIONS LIMIT the role that *primordial black holes* can play in explaining dark matter.

Even before there were stars, primordial black holes (PBHs) could have been born when patches of the radiation and plasma that filled the early universe became sufficiently dense to collapse into black holes. Astronomers have looked for PBHs using *microlensing*: When a black hole passes in front of a more distant star, its gravity bends the star's light toward us, boosting its brightness. No PBHs have been definitively detected yet.

As part of ongoing efforts, Hiroko Niikura (University of Tokyo) and colleagues turned the 8.2-meter Subaru Telescope's Hyper Suprime-Cam on an estimated 100 million stars in the Andromeda Galaxy. The galaxy is far enough away that each camera pixel contained the light from several suns, so the astronomers couldn't look at individual stars' behavior. Instead, they searched for pixels that flashed, presumably because one of the stars had briefly brightened. The astronomers then reduced these candidates to those that only flashed once, brightened and faded in the right way, and weren't created during image processing.



▲ Studies have ruled out (shaded regions) a range of possible primordial black hole masses.

If dark matter is made of PBHs with masses between that of Earth and Saturn's moon Mimas, then the astronomers calculate that they should have turned up roughly a thousand microlensing events. They found one.

The current data can't determine whether even this flash definitely comes from a PBH, Niikura and colleagues write April 1st in *Nature Astronomy*. However, the results nevertheless limit what PBHs in this mass range might contribute to dark matter: At most they make up a hundredth of the universe's invisible mass.

Microlensing searches can't catch all events, as the appearance of such blips depends on details such as the black hole's distance. The team continues to explore the data on Andromeda for additional candidates, and the researchers may even rope in citizen scientists to help them investigate.

■ CAMILLE M. CARLISLE

SOLAR SYSTEM

New Results Probe Origin of "Ultima Thule"


"Ultima Thule"

AS OBSERVATIONS TRICKLE IN from NASA's New Horizons spacecraft, mission scientists at the annual Lunar and Planetary Science Conference shared new insights on how their two-lobed target — designated 2014 MU_{69} and nicknamed "Ultima Thule" — formed in the Kuiper Belt.

Early returns from New Horizons revealed a snowman-shaped object, but as more images reached Earth, it became clear that the two like-sized lobes are both somewhat flattened, the larger one (dubbed "Ultima") more so than somewhat smaller "Thule." William McKinnon (Washington University in St. Louis) likened the shape to "a meatball attached to a pancake."

Overall the lobes are dark and red, akin to other Kuiper Belt objects in circular, uninclined orbits. Ultima Thule has a lumpy texture but isn't heavily cratered. Observations of the narrow "neck," the brighter area where the two lobes join, suggest they merged gently: There are no "splat" deposits or stress fractures, for example.

Meanwhile, spectral analysis revealed the presence of water ice and methanol (CH_3OH); the latter forms when methane (CH_4) is oxidized. These data fit with the idea that Kuiper Belt objects formed with ample water ice and methane. Over time, ultraviolet photons from the distant Sun and cosmic rays would have converted these molecules into more complex hydrocarbons, known as *tholins*, with distinctly dark and reddish hues.

The lobes' axial alignment — to within 10° — offers another clue to their formation. They must have been lined up when they came together, McKinnon says — and not by chance.

One way to assemble solar system bodies rapidly, and often as paired objects, is via a process called *streaming instability*. Within the solar nebula's rotating disk of gas and dust, the gas would have dragged on the dust particles, causing them to pile up and clump together. The little clumps would rapidly grow into large masses. Meanwhile, turbulence would spin up the clumps, causing many to fragment into pairs, explaining why the Kuiper Belt veritably bristles with binaries.

If that's how 2014 MU_{69} formed, then it's still unclear how Ultima and Thule lost their angular momentum to evolve from a close-orbiting pair to a contact binary. Nor is it clear why the now-joined pair rotates so slowly, in roughly 15 hours. Yet-to-be-transmitted observations from New Horizons might offer more clues.

■ J. KELLY BEATTY

● Watch the flyby set to Brian May's soundtrack at https://is.gd/UTflyby.

GALAXIES

The Milky Way Contains the Mass of 1½ Trillion Suns

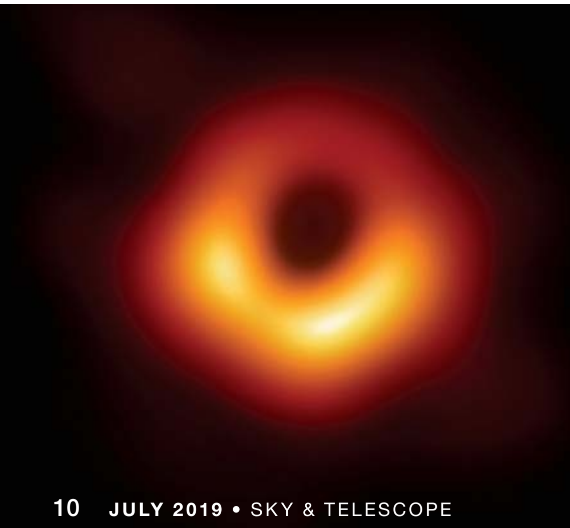
ASTRONOMERS HAVE MADE the most precise estimate of our galaxy's mass yet.

Laura Watkins (Space Telescope Science Institute) and colleagues used data recently released by the European Space Agency's Gaia satellite, as well as roughly 10 years of Hubble Space Telescope observations, to peg the motions of 46 globular clusters around our galaxy. Gauging how quickly they move in their orbits helps astronomers pin down the Milky Way's mass.

Previously, astronomers have clocked the speeds of clusters approaching or receding from Earth. But Gaia and Hubble can observe *proper motions*, sideways movements across the sky, providing more precise velocities. By better measuring the clusters' motions, the team finds the Milky Way's mass to be equivalent to 1½ trillion Suns. The result appears in the March 10th *Astrophysical Journal*.

The heft of our galaxy affects our understanding of its formation and even the nature of dark matter. Until now, astronomers have only known the Milky Way's mass to within a factor of two: between 0.5 trillion and 3 trillion Suns. The new study has tipped the scale towards a heavier Milky Way, says Ana Bonaca (Center for Astrophysics, Harvard & Smithsonian). "We now know that a very low value for the mass of the Milky Way is unlikely."

■ MONICA YOUNG



First Image of a Black Hole

Black hole science forever changed on April 10th, when the Event Horizon Telescope collaboration revealed this image. It's the silhouette of the supermassive black hole at the center of the giant elliptical galaxy M87 in the constellation Virgo, made visible by the light from hot gas just outside the event horizon. The international team created the image by combining four days of observations in April 2017 from seven radio telescopes scattered across the world. The telescopes observed simultaneously, effectively acting as a planet-size dish to resolve the shadow's 42-microarcsecond width — equivalent to the diameter of an atom seen at arm's length. This reconstructed image is the first direct observation of a black hole and the first image ever made at a wavelength of 1.3 mm using this telescope network method, called *very long baseline interferometry*. We'll have an in-depth discussion of the image, its creation, and what it tells us in an upcoming issue.

■ CAMILLE M. CARLISLE

ULTIMA THULE: NASA / JHU-APL / SWRI; BLACK HOLE: EHT COLLABORATION

GALAXIES

Two Galaxies Missing Dark Matter

ASTRONOMERS HAVE DISCOVERED a second galaxy without dark matter.

This *ultra-diffuse galaxy* is one of thousands of large, star-poor objects discovered in recent years. Most of these galaxies have more than the usual amount of dark matter — it's all that keeps their sparse stars from disbanding. But last year, Pieter van Dokkum (Yale) and colleagues discovered one without much dark matter at all, dubbed NGC 1052-DF2 (*S&T:* July 2018, p. 8). Now the team has discovered a second one in the same region, suggesting more might be present.

Van Dokkum and colleagues found NGC 1052-DF4 in images taken with the lenses of the Dragonfly Telephoto Array (*S&T:* May 2019, p. 64). They followed up with Hubble Space Telescope imaging and spectroscopy through the Keck I telescope on Mauna Kea, Hawai'i. The observations appear in the March 20th *Astrophysical Journal Letters*.

For both DF2 and DF4, the team measured the velocities of unusually luminous globular clusters, finding that the galaxies' total masses were equivalent to their mass in stars — there's no need for dark matter in either case.

The discovery of the second dark matter–less galaxy lends credence to the first find, in part because van Dokkum and colleagues followed an anonymous referee's suggestion to measure the mass of DF4 (and DF2) a second way: by gauging the velocity of the galaxy's stars. Unlike the globular clusters, these stars can't be resolved, so the astronomers used Keck to obtain the velocity of the stars' diffuse light. The measurements confirmed the galaxy's low mass.

Michelle Collins (University of Surrey, UK) had voiced doubts about DF2 when it was first discovered but said the new study has convinced her there's something to the low-mass claims.

NGC 1052-DF2, DF4's doppelgänger

Nevertheless, there's work to be done. Circumstantial evidence suggests that DF2 and DF4 belong to the cluster of galaxies around NGC 1052, but their distance remains uncertain.

"If [DF2 and DF4] were truly closer, the galaxies would appear more typical, and would have a typical amount of dark matter," Collins explains. Hubble observations in July or August should finally decide the distance question.

■ MONICA YOUNG

SOLAR SYSTEM

An Explanation for 'Oumuamua's Odd Exit?

THE BRIEF INTERSTELLAR VISITOR 1I/2017 U1 'Oumuamua (*S&T:* Oct. 2018, p. 20) appeared to leave the inner solar system a bit faster than it should have if the only effect on its motion was the Sun's gravity. Scientists speculated that ices vaporized from 'Oumuamua's surface by the Sun's glare had given the body an extra kick, but no observations had detected any outgassing.

Now, Darryl Seligman (Yale) and colleagues argue in the *Astrophysical Journal Letters* that outgassing could indeed be to blame.

The researchers looked at what would happen if a thruster-like jet of water vapor emanated from a spot on 'Oumuamua pointed directly at the Sun. As the body tumbled, this spot would have changed location, so the jet would have migrated across the surface.

The tiny thrust from this migrating jet would have caused the body to rock back and forth like a pendulum, which would explain both its acceleration and the periodic pattern in its brightness, the researchers say.

Artist's impression of 'Oumuamua

The study does a nice job of trying to reconcile what we know of this mysterious world, says Karen Meech (University of Hawai'i), who led the main 'Oumuamua observational campaign. But Roman Rafikov (University of Cambridge, UK) is more skeptical. The outgassing should have doubled 'Oumuamua's pendulum-like tumbling as it raced away from the Sun, he says. That wasn't observed.

Coauthor Gregory Laughlin (Yale) agrees that 'Oumuamua's period should have doubled as the sunlight and outgassing dropped. However, he notes that accurate period information only comes from late October. November observations showed that the period had changed, but it's unclear by how much.

■ CAMILLE M. CARLISLE

IN BRIEF

2020 NASA Budget Boosts Exploration, Not Science

The President's FY2020 budget request puts $21.019 billion toward NASA — a drop of a half billion dollars from the just-approved 2019 budget. The proposal doubles funding for NASA's return to the Moon via the Lunar Gateway, which aims to put a crewed outpost in lunar orbit. The budget request also initiates a Mars sample-return mission. At the same time, the proposal decreases funding for astrophysics (-20%), planetary science (-5%), and Earth science (-8%). And while the James Webb Space Telescope gains $46.6 million in funding, the Wide-Field Infrared Space Telescope (WFIRST) is canceled. The request also zeroes out funding for NASA's Office of STEM Engagement. However, the FY2019 budget request likewise canceled WFIRST, STEM outreach, and several Earth science missions, but instead Congress pushed through a budget increase. The question is, will Congress step in again?

■ DAVID DICKINSON

'OUMUAMUA: ESO / M. KORNMESSER; NGC 1052-DF2: NASA / ESA / P. VAN DOKKUM (YALE)

Can a Planet Think?

Due to one species — us — Earth's biosphere has begun to resemble a human brain.

IN THE 1970S, scientists James Lovelock and Lynn Margulis proposed the *Gaia hypothesis*, which likens our biosphere to a self-regulating organism. In the decades since, the idea that biological evolution is inseparable from planetary processes became part of mainstream Earth-system science. Just as an individual living thing such as a sea slug can exhibit sophisticated internal self-regulation without needing abstract thought, our biosphere may help regulate the planet without any self-awareness.

Yet sometimes I wonder.

Through our influence on our planet's history, cognitive processes have become, in a way, planetary processes. Humans are the first geological force to be aware of its own existence. But beyond this, could there actually be some emerging mind — and not just metaphorically — that is global in scale?

Many have noted superficial ways in which the internet resembles a giant brain, with myriad nodes exchanging billions of signals. But several of our other aggregate, global-scale activities also involve the complex, planet-wide interchanges of matter, energy, and information we might expect from an individual, self-regulating entity.

In the 1970s we humans saw that our use of certain refrigerants was endangering our ozone shield. We thought about it for a few years then stopped using them. If an asteroid menaced Earth now, we'd deliberate then swat it away. And, in a painfully slow way, we're realizing that our energy systems threaten our well-being, and we're starting to seriously consider replacing them.

ANTONIOKHR / ISTOCK / GETTY IMAGES PLUS

In other words, humans, working on a global scale, are acting like a single, sentient planet. We exhibit unified behavior and respond to memories, lessons learned, and data gathered about the situations we find ourselves in.

Obviously there are many ways in which none of this activity seems like "planetary intelligence" — the 6,000-billion-trillion-kilogram rock we live on isn't cogitating. And if humankind is a sensing, thinking, and acting beast, it's quite sluggish, and perhaps even borderline psychotic. All this global behavior is plainly incoherent and very slow to respond to perceived danger. What we see is chaos, discord, and noise. Yet is this really so different from a human mind?

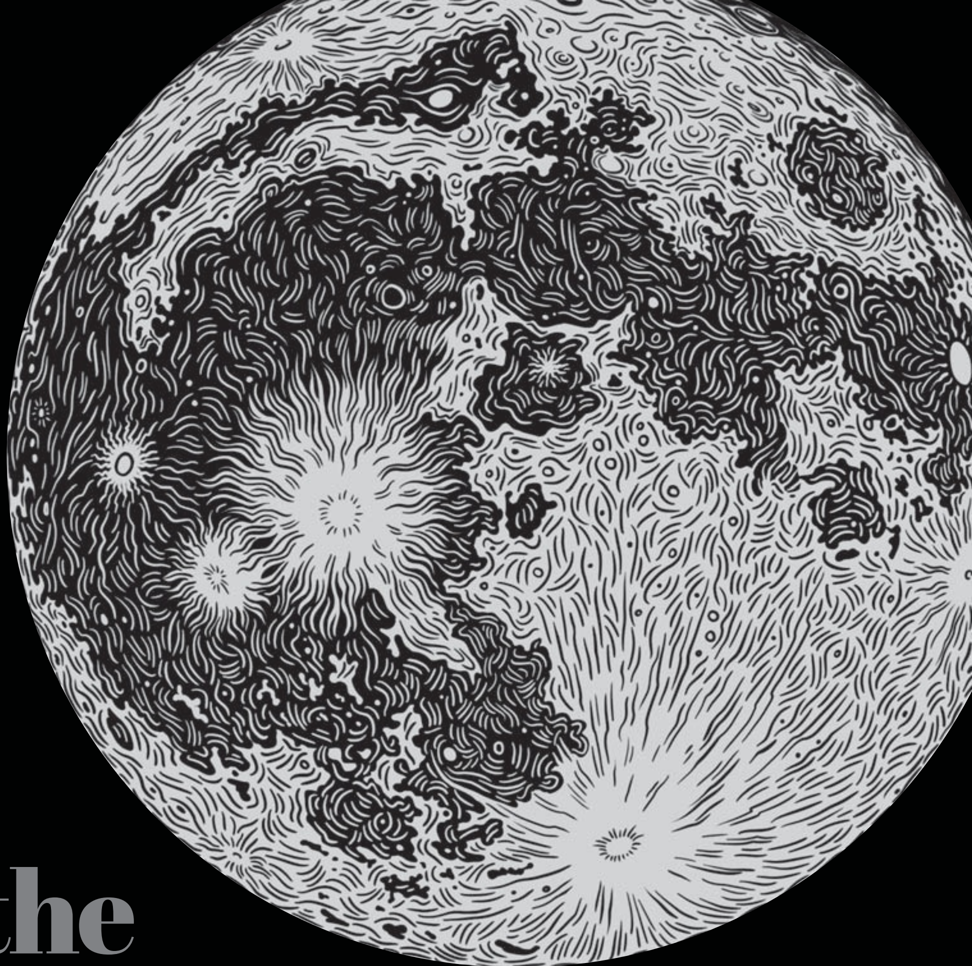
Imagine if you could make yourself minuscule and descend into your own brain in the midst of trying to make a decision. What you'd observe might be every bit as chaotic as our world. Yet somehow out of all those competing thoughts and firing neurons comes a pattern, and a decision is made.

The mechanics of decision-making for groups is on some level not that different than those of an individual mind. Group members accept input and apply some manner of reason and store of memories and knowledge to determine how to act on that input. There is a deliberative process, which may involve conflict, competition, cooperation, and communication, ultimately resulting in a course of action.

In the end, the similarities between cognition, biological evolution, and globalization might provide insight into the nature of collective decision-making on planetary scales. Maybe the Gaia hypothesis is strangely correct. Maybe the world didn't originally evolve with purpose — but now, through our actions and desires, it's becoming invested (or infested?) with it.

Just a thought.

■ Astrobiologist **DAVID GRINSPOON** is the author of *Earth in Human Hands: Shaping Our Planet's Future*.



Over the Moon

What springs to mind when you think of the Moon? Fantastic crater landscapes? Unwelcome moonlight intruding on your deep-sky observations? Cheese?

The Moon is all these — well, maybe not the cheese — and more. Every day, this fragment of cosmic violence parades through our skies. But if we don't take the time to stop and appreciate its wonders, we're liable to become apathetic to them. So for our celebration of the first human footfalls on the lunar surface, we're taking a look at the Moon from several angles, past, present, and future.

We start with a jump back to the heyday of the Apollo program, submerged into the post-landing thrill of discovery by planetary scientist John Wood's firsthand account of the revolution that Apollo 11 brought to our understanding of this alien world next door. Next, Contributing Editor Bob King takes us on an observing adventure that has something for every level of lunar tourist, from naked-eye sightseers to those committed to hauling out the 16-inch and getting to know our natural satellite more intimately.

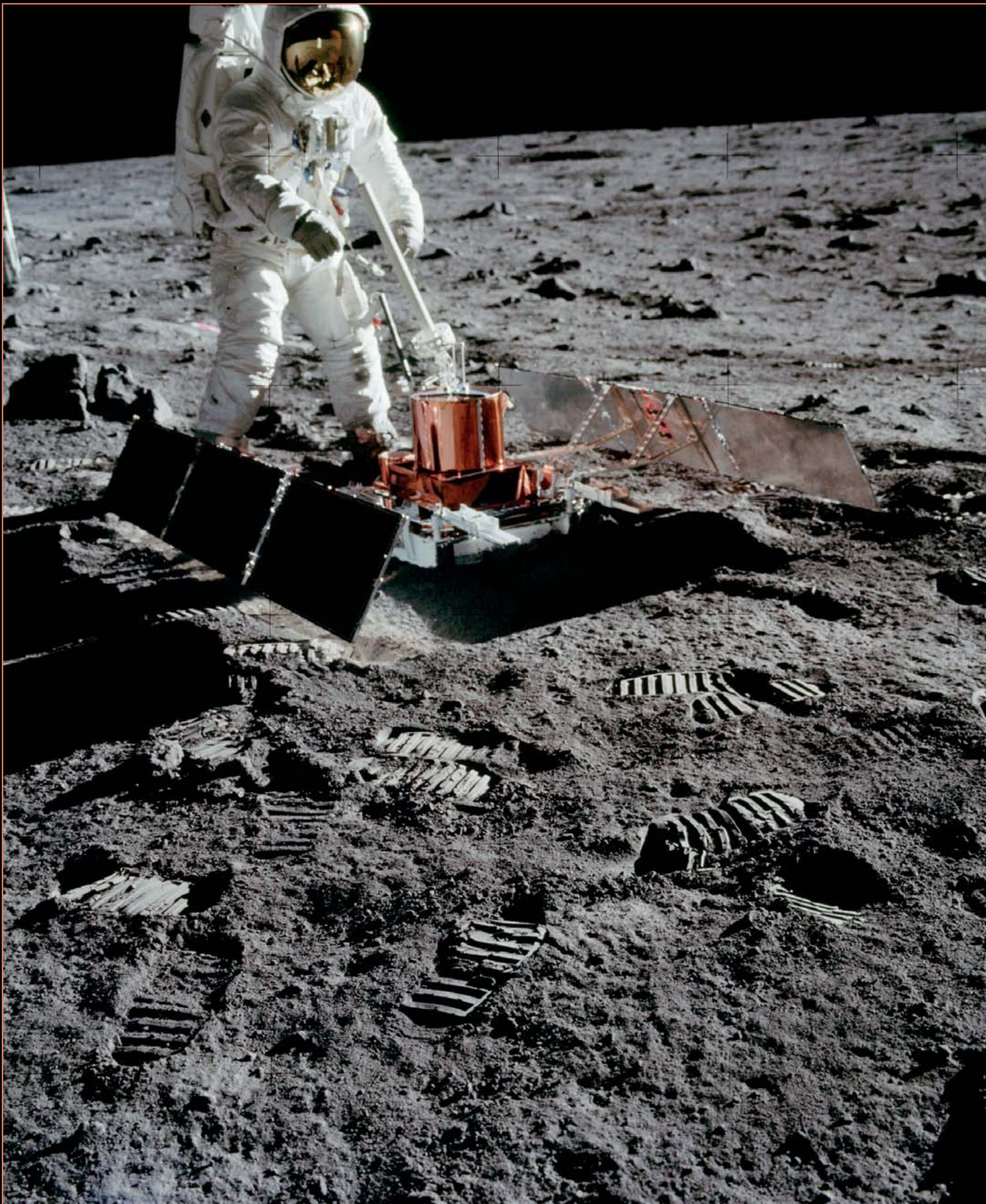
As the largest and brightest object in the night sky, the Moon is the first target many astrophotographers aspire to capture well. Associate Editor Sean Walker teaches us how to take great photos of the Moon with practically any camera and optic. And finally, News Editor Monica Young and Art Director Terri Dubé partner to consider the future of lunar exploration, with an infographic about current and upcoming missions.

At a mere 384,400 kilometers (238,900 miles) average distance, the Moon is our closest neighbor in the vast landscape of space. Let's take this opportunity to get to know it a little better.

—Camille M. Carlisle

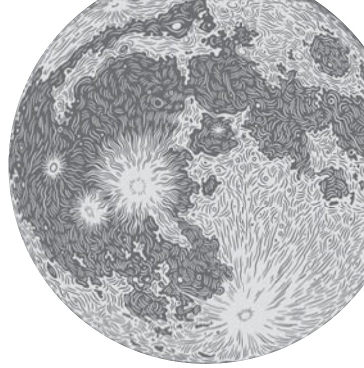
LEAH TISCIONE / S&T

Follow us on Twitter for a play-by-play of Apollo 11 moments, complete with photos and mission recordings: @SkyandTelescope.



LUNAR SCIENCE Apollo 11 astronaut Buzz Aldrin sets up a seismometer on the Moon. The instrument worked for three weeks, detecting moonquakes and gathering information about the Moon's internal structure. Later missions' seismometers transmitted data until 1977.

NASA



The Science of APOLLO

Samples brought back by the astronauts revolutionized our picture of the Moon.

September 17, 1969, found me in one of many white buildings on the campus of NASA's Manned Spacecraft Center in Houston, Texas. I had been summoned there by a telegram. It had been nearly two months since astronauts first stepped onto the lunar surface, and while the world was still enchanted, NASA had called scientists to get to work on an often-underappreciated aspect of the Apollo missions: samples.

In response to President Kennedy's 1961 challenge to America to land a man on the Moon and return him safely to Earth by the end of the decade, NASA had designed and implemented an audacious and dangerous space program. The pinnacle of this program was the Apollo 11 mission, which on July 20th placed Neil Armstrong and Edwin (Buzz) Aldrin on the lava plain of Mare Tranquillitatis, near the lunar equator. They stayed there for 21 hours and 36 minutes, then returned to Earth — along with 22 kg (49 pounds) of Moon rocks and soil, more properly called *regolith*. ("Soil" is a misleading term to use for the loose, dusty impact debris that covers the Moon's surface, since it contains none of the humus and water that allow plants to grow in terrestrial soil.)

Those precious samples arrived at the Lunar Receiving Laboratory (LRL) in Houston on July 25th, where the curatorial staff evaluated and sorted them. Fifty-four days later, I came to pick up my 10-gram allocation — about the weight of a single AAA battery. To the untrained eye, the rocky debris didn't look like much. But thanks to those hard-won samples, our understanding of the Moon's history would never be the same.

Uniting the Team

Knowing in advance that it wanted scientists to study material collected on the Moon, NASA issued an invitation in the early 1960s to qualified individuals to submit proposals to be lunar sample investigators. About 140 principal investigators from around the world were chosen. Their projects included studying the chemical and isotopic compositions, the physical properties, and the mineralogy and petrography ("min-pet," the latter is the descriptive end of the rock-classification business) of the lunar materials.

I was approved as a min-pet principal investigator (PI). I am a hard-rock petrologist (Virginia Tech, MIT), which means I study igneous and metamorphic rocks instead of sedimentary ones. Once in college I overheard a business-school guy tell his girlfriend that soft-rock geologists work for oil companies and drive Cadillacs, while hard-rock geologists are lean and hungry. I liked that — it made me quietly proud of the choice I had made.

In graduate school I had focused my hard-rock passion on stony meteorites when I learned that they are the oldest rocks we can find, meaning they might contain information about the origin of Earth. Beginning in 1958, I spent my career (with a few diversions) at the Smithsonian Astrophysical Observatory (SAO) in Cambridge, Massachusetts. My boss in the Apollo era was Fred Whipple, the first director of the SAO, and he encouraged me to set up a meteorite laboratory.

At first I worked alone. But once accepted to the lunar sample program, I knew I needed help. I recruited two freshly minted petrology PhDs, John Dickey from Princeton and Ben Powell from Columbia, and I enlisted Ursula Marvin, a

▶ **THE TEAM** The author and his team stand in their laboratory at the Smithsonian Astrophysical Observatory. From left: the author, Ben Powell, Ursula Marvin, John Dickey, and Janice Bower.

TEAM: JOAN ELIZABETH DICKEY; PHOTO TEMPLATE: ROBINOLIMB / DIGITALVISION VECTORS / GETTY IMAGES; MOON SKETCH: LEAH TISCIONE / *S&T*

▲ **SIGN HERE PLEASE** Upon arrival in the Lunar Receiving Laboratory in Houston, scientists were met with a table of paperwork along with their samples.

◀ **HANDLE WITH CARE** The first Apollo 11 samples, safe in their protective packaging, arrive at NASA's Manned Spacecraft Center in Houston on July 25, 1969.

mineralogist and X-ray diffraction expert who was already at SAO. I also hired Janice Bower, a remarkably adept and adaptable graduate of Wentworth Institute of Technology, to operate and service the instrument critical to much of our work, called an *electron probe microanalyzer*. Electron probes reveal the chemical makeup of mineral samples by analyzing the X-rays created when the samples are bombarded by a beam of accelerated electrons in a vacuum. Together, we five would be the SAO lunar sample team.

Precious Vials

When I arrived in a windowless room at the Manned Spacecraft Center in Houston, I found several fellow PIs huddled around a table covered with sample vials and paperwork. Along with the NASA research grant each of us was awarded, the paperwork included much legalistic detail about my responsibility to safeguard my samples: They were not mine, I was only borrowing them from NASA. (I had already taken steps to have a small safe installed in my lab, bolted through its bottom to the concrete floor.)

At last I received two polyethylene cylinders, each about five inches tall, containing my group's lunar samples. Opening these, I found packing material and two much smaller plastic vials, labeled 10085,24 and 10084,108. The first contained 11 grams of coarse lunar fines, larger than 1 millimeter in size and mostly smaller than 2 mm. The second held 5 grams of "fine fines," particles smaller than 1 mm in diameter. The LRL curatorial staff had sieved the bulk soil sample collected by the astronauts into these fractions. With NASA's concerns about security fresh in my mind, I borrowed a needle and thread from one of the secretaries in the room and sewed both small vials into one pocket of my sports jacket for the trip home.

I boarded an Eastern Airlines flight to Boston with a stopover in Washington, D.C. In the plane I found a half dozen or so other scientist friends and acquaintances who were also flying home to Boston or D.C. with lunar samples they had picked up in Houston. We were all psyched and had much high-spirited conversation in the plane's aisle. We were probably obnoxiously loud. All this made me very warm, so I tore off my jacket and stuffed it in an overhead bin. Not until much later did I realize I had parted company with those two precious vials. Fortunately they survived, or this would be a very different story.

NASA's warnings about safety didn't forbid showing the samples (carefully) to the public, and I couldn't resist inviting my family, then our neighbors and their kids, to gaze up close at pieces of the Moon. The next day I displayed them in our lab for personnel at the Harvard Observatory and their families. Everyone was excited and curious, never mind the grains' nondescript gray appearance.

When my group was finally alone with our lunar samples, we examined them under a binocular microscope. To our surprise, we found that not all of our regolith samples were pulverized mineral dust, as I had pessimistically assumed. The coarse-fines sample (10085,24) consisted of miniature rocks, each with a distinctive texture and assemblage of minerals. We had hundreds of separate lunar samples in our tablespoonful! So we set to work to study as many of those rock-ettes as we could in the time we had. It wasn't much: NASA had decreed that on January 5, 1970, all of the lunar sample investigators were to convene at the Albert Thomas

SAMPLE ARRIVAL: NASA; PI HUDDLE: THE AUTHOR

Convention Center in Houston, Texas, and present the results of their studies. Counting from when I picked up our vials, that gave us just 110 days.

Petrographers study rocks in thin sections, slices about 30 micrometers thick (a human hair is about that diameter) on glass microscope slides. These rock slivers are created by a rather tedious process of diamond sawing, grinding, and polishing on the surfaces of spinning laps. NASA would make thin sections and send them to us, but these would be few and long in coming. So we prepared our laboratory to make our own. Soon our lab was a beehive of activity as we sectioned, photographed, and analyzed 1,676 coarse-fine particles in batches on slides for our electron microprobe.

The Discovery

As data accumulated, it became clear what the Mare Tranquillitatis regolith consists of. About half of our fragments were *soil breccias*, volumes of fine lunar dust that impacts had crammed together and lithified into rock. Since impacts also create the regolith itself, you could say that destructive impacts giveth lunar soil and they taketh it away by consolidating it into breccia (an Italian word meaning broken).

About 5% of the remaining particles were *glasses*, volumes of rock or soil that had been melted by the energy of impacts and then had cooled rapidly in the near-vacuum conditions on the lunar surface. The amount of impact-melted glass in the Apollo samples surprised everyone.

Another 40% of the regolith was particles of *crystalline igneous rocks*, solidified directly from lava. Scientists had long known that the lunar maria must be lava plains, and you might expect that, as representatives of the solidified lava that lies beneath Tranquility Base, the rocks brought back to Earth would all have fairly similar compositions. But that was not to be the case. Debris from a cratering impact can travel great distances before it comes to rest on the surface, and so particles at any one point have come from many far-flung sources. Most of the igneous particles in our samples consisted of hardened basaltic lava, but there were many varieties, differing in chemistry and texture.

However, another 3–4% of the particles were something quite different and unexpected: a white type of once-molten rock called *anorthosite*. Anorthositic rocks consist principally of the mineral anorthite ($CaAl_2Si_2O_8$). They are rare on Earth; an important deposit lies in the Adirondack Mountains of New York. John Dickey, reading the microprobe analysis of a colorless glass droplet in our collection, was the first to say the word out loud: "That's an anorthosite composition." No one had predicted that the Moon would contain a rock type so rich in aluminum and calcium as anorthosite.

THE AUTHOR (3)

▶ **SMALL BUT PRICELESS** *Top:* The author's two capsules (front-most) sit with a collection of other Apollo 11 samples in Houston. *Center:* The team's coarse-fine grains. *Bottom:* A close-up of some washed and sorted particles. The scale lines in both grain images are in millimeters.

Why Anorthosite on the Moon?

This find puzzled us. It is not enough for scientists to describe things; the whole point is to understand them. First, where had the light-colored anorthositic particles come from? That question was not so hard to answer. The Apollo lander *Eagle* had set down on the edge of the dark, basalt-filled Mare Tranquillitatis, only about 50 km from the beginning of the whiter lunar highlands, called terrae. Impacts on the terra regolith surely would have scattered some of it over into the mare regolith. This must have been the source of the anorthositic fragments in our sample.

Second, did this unexpected composition hold for all of the terra rock that covers most of the Moon, or just that corner of it? Terrae make up more than 80% of the lunar surface, counting both the near- and farside hemispheres; if all that rock is anorthositic, then it must comprise a significant fraction of our planet's natural satellite.

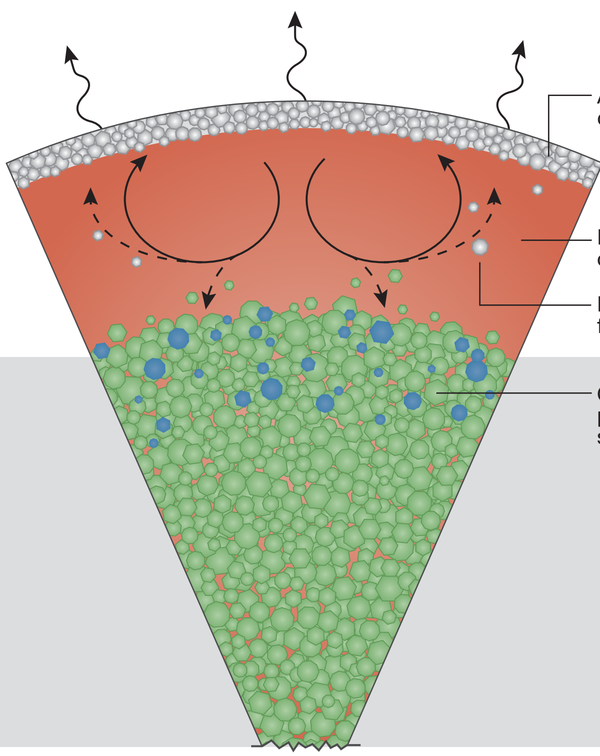
An earlier robotic mission to the Moon, Surveyor 7, appeared to hold the answer to that question. Surveyor 7 carried a device called an *alpha-scattering surface analyzer*, which measured the chemical composition of the ejecta blanket surrounding the large crater Tycho, whose dramatic rays splay across the face of the Moon. Tycho is in lunar highlands material 1,600 km from Tranquility Base. Although ambiguities in the instrument's data (in particular the device's inability to distinguish between calcium and potassium) had left the analysis somewhat unsatisfying, the result was consistent with an anorthositic composition there, too.

Generalizing boldly, a highly reflective, anorthosite-rich crustal layer seems to cover the whole Moon like a thick veneer, except where giant impactors have blasted holes through it that later filled with basaltic lava.

▲ **SURPRISE DISCOVERY** Pieces of the white igneous rock anorthosite puzzled the team when discovered in the samples. Scale is in millimeters.

Can we estimate the thickness of this layer? Yes, using the principle of *isostasy*. Rock has plastic properties over long periods of time, meaning a heavy load on the crust will push rock below it aside, making room for the load to sink. Because of isostasy, a mountain range can stand only if the mountains are less dense than the rock beneath them, so they can "float" in it like enormous rocky icebergs. The lunar crust, with a density of only 2.9 g/cm^3, floats 3 km above the denser interior material (the Moon's overall density is 3.3 g/cm^3). That elevation would only be possible if the crustal thickness is about 25 km. A lot of anorthosite!

Third, where did this layer of rare anorthite-rich rock come from? It must have solidified out of a huge amount of cooling magma. The experimentally determined crystallization sequence for molten rock with a lunar composition predicts a specific order of mineral formation: Olivine crystallizes first, then pyroxenes and calcic feldspar (anorthite), then feldspar richer in sodium. Olivine is dense, and it would tend to sink to the floor of a magma layer during crystallization. Anorthite is lighter, and under some circum-



▶ **FORMING THE LUNAR CRUST** If the Moon began largely (or completely) molten, then as it cooled its constituent minerals would separate. Dense olivine and pyroxene would sink in the magma. Then feldspar minerals, which include anorthosite, would crystallize. Feldspars would float in the denser magma, and so they would rise to the magma ocean's surface, where they would form a crust like that found by the Apollo astronauts.

stances it would tend to float rather than sink, accumulating at the top of the body of magma like a thick rock froth. This seems to be the only possible explanation for the Moon's anorthositic crust.

How much magma would it take to form the lunar crust this way? Assuming a plausible bulk chemical composition for the Moon, it turns out that most or all of the Moon must have melted in order for 25 km of anorthite crystals to float to the top! I coined the term *magma ocean* to describe this huge molten mass, and the term stuck.

Rewriting Lunar History

I persuaded my group that this anorthosite story was what I (as our principal investigator) should stress in my talk at the impending Apollo 11 Lunar Science Conference.

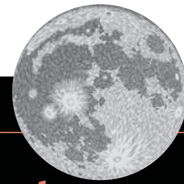
The conference was a colorful experience. It began with a cocktail party at Rice University. NASA had told us that we should not release our findings to the public; we should save them instead for a special issue of *Science* magazine that was to be dedicated to the first lunar-sample reports. Most of us took that to mean we should not even spill the beans to other research groups — though this was not NASA's intent — so the party was an amusing cat-and-mouse game in which most of us were trying to find out what our colleagues had learned without revealing our own discoveries.

The first two days of the conference featured results from the elite research groups (ours was a no-name team in comparison). Jerry Wasserburg's self-styled "Lunatic Asylum" at Caltech, for example, used the ratio of two strontium isotopes to determine that the basaltic mare was 3.65 billion years old, about a billion years younger than the solar system.

At a banquet on the second evening of the conference, astrophysicist Fred Hoyle spoke on whether someday we might realize that Apollo's most important contribution was not the political victory it represented but the majestic view the astronauts gave us of the whole pale blue Earth in the firmament. He compared the situation to one from the composer Handel's time, and his words so struck me that I wrote them down:

> *Our judgment of what were the significant issues in past times differs tremendously from contemporary judgment. In the middle of the 18th century, the English celebrated victory at the end of a seven-year European war. Someone had the idea of getting George Frideric Handel, who was then an old man, to write a suite of music to celebrate the famous victory. An astute commentator, two centuries later, remarked that the whole meaning and purpose of this seven-year war had now been lost, and that in retrospect it appeared like an elaborate device to get old man Handel out of retirement and to get him to write his* Music for the Royal Fireworks.

Perhaps, Hoyle thought, future generations would forget the Apollo program's political achievements and instead remember a greater success: that the Apollo astronauts' view



Grains from the Past

Investigators' tests indicated that basaltic rocks collected by Apollo 11 astronauts had an age of more than 3½ billion years; the crust was about a billion years older. Samples brought back in November 1969 by the Apollo 12 team, on the other hand, were about 500 million years younger. These rocks all formed at extremely high temperatures. The findings suggested that, in the words of a *New York Times* report from the conference, "the moon had a history of fiery, cataclysmic upheavals."

▼ **APOLLO 11 VIEW OF THE MOON** The Apollo 11 crew took this photo while homeward-bound, some 19,000 km (10,000 nautical miles) from the Moon. This picture should look a little abnormal: It catches some of the lunar farside's highlands (right), unseen from Earth. Mare Crisium lies at center; Mare Tranquillitatis, where the team landed, is the lunar sea directly to Crisium's left.

SAMPLES: THE AUTHOR; DIAGRAM: GREGG DINDERMAN / *S&T*, MOON PHOTO: NASA; MOON SKETCH: LEAH TISCIONE / *S&T*

▲ **THE CONFERENCE** Attendees collect materials *(left)* and people study samples *(right)* at the Apollo 11 Lunar Science Conference in Houston. The meeting was the first of what would become the annual Lunar and Planetary Science Conference, which meets every spring in The Woodlands, Texas.

brought home Earth's fragility to its inhabitants and inspired them to take better care of their home.

If only.

My presentation for the SAO group came at 5:20 p.m. Wednesday afternoon — the last talk of the day, when everyone was tired and looking forward to dinner. But the anorthositic-crust story interested people, and no one else had told it. Several groups had noticed and described the anorthositic particles in their own samples, but none had pursued their meaning. Other min-pet groups tended to focus on the larger rocks, fragments of the titanium-rich basaltic lava that filled Mare Tranquillitatis. Still, everybody's reports painted a picture of a molten history for the Moon.

This consensus would soon answer a burning question the media had been asking us: Did the Moon form hot or cold? There was no way of knowing prior to Apollo 11. The betting had been on a "cold" Moon — one that slowly accreted alongside Earth, or perhaps was caught gravitationally — because that was the opinion of chemist Harold Urey, a highly respected Nobel laureate. In order to distance himself from his earlier work on the atomic bomb, Urey had interested himself in the chemistry of the solar system. On the basis of much hard thinking but little observational evidence, he formulated a model to account for the solar system. In this model, small *primary objects* formed in dusty gas and then were caught in the cloud that collapsed to form the Sun and planets. In this model, the Moon is a surviving primary object that Earth captured into orbit.

The Apollo 11 evidence of a once-molten Moon laid this concept to rest. Our picture, with the anorthite floating to the surface during the crystallization of a magma ocean, could not be reconciled with it. And ultimately, it was our magma ocean scenario that itself rose to the top. Within a few years, scientists realized that the Moon was likely instead created by a giant planetary collision, in which a Mars-size body spalled off a disk of molten debris from the early Earth, with our planet and its orbiting satellite coalescing from the debris (*S&T:* Aug. 2018, p. 26). Such a process easily could have been energetic enough to account for the initial molten state of the Moon.

It is gratifying that our analysis of just a few rocky chips changed forever our view of Earth's companion. Often when we reflect on Apollo 11's importance, we focus on the political, cultural, and historical sectors. Of course, these are important. But doubtless one of the program's greatest impacts was the revolution it brought to lunar science.

▶ **BIG NEWS** A young girl holds the July 21, 1969, issue of *The Washington Post* in this photo taken by her father and posted decades later online by her son.

■ Retired planetary scientist **JOHN A. WOOD** has studied meteorites, lunar samples, and Venus to understand the solar system's origins. Since 2004 he has turned his talents to oil painting.

WEBLINK: Listen to the Apollo 11 mission recordings at **https://archive.org/details/Apollo11Audio**.

CONFERENCE: LUNAR AND PLANETARY INSTITUTE (2); GIRL WITH PAPER: RUFUS330CI / WIKIMEDIA COMMONS / PUBLIC DOMAIN

EARTHRISE The Apollo 11 astronauts took this photo of our home planet early on July 20th (Universal Time) as they came around the limb of the Moon, before the landing. The lunar terrain is the region near Mare Smythii.

NASA

The Moon Three Ways

Celebrate the anniversary of the Apollo 11 mission by kick-starting your lunar observing.

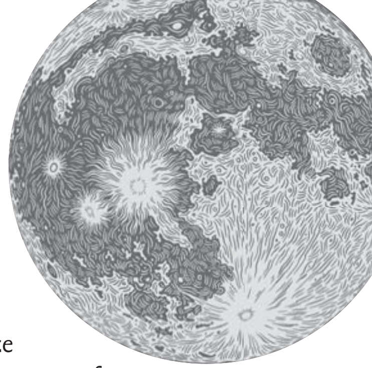
I love the Moon. There's nothing like it in the sky. It's totally alien and yet completely accessible. No spacecraft needed. No squinting through a telescope to eke out a dim feature. No going online to look at the latest flyby photos. Just look up! It's big, bright, and there to enjoy and inspire in so many ways — moonlit walks, moonrises, eye-popping pairings with bright stars and planets, and in wondrous detail through a telescope. No other body offers such easy access to the cosmos better than the one closest to home. Even for the casual observer the Moon is beautiful and approachable. I can't count the number of times someone has come to up me, cellphone in hand, excited to share their latest photos of the moonrise.

Sitting 384,400 km away on average, the Moon is the closest planetary body to the Earth. Proximity gives it a brilliance greater than any other object in the sky except the Sun or a rare fireball meteor. But that brightness is all a ruse. The lunar surface reflects just 12% of the light it receives from the Sun, meaning that it's as dark as a charcoal briquette. I once held a vial of Moon dust collected by the Apollo 17 astronauts, and I could hardly distinguish it from copy toner.

Astronomers believe the Moon formed from the shards of a collision between Earth and a Mars-size asteroid some 4.5 billion years ago, soon after Earth itself took shape. The fragments regathered and forged our only natural satellite, a happenstance body made of recycled worlds that redirects sunlight to soften the darkness and inspires us to great deeds. The accident of its birth became humanity's first cosmic outpost during the Apollo missions.

HILARY KLADKE / GETTY IMAGES

LUNAR ALLURE A waning crescent above a Florida lake demonstrates that even without optical aid, the Moon is a glorious sight.



TRUE COLORS Have you ever wondered why the Moon appears so colorful when it sits low in the sky? Denser air at the horizon scatters the blues and greens in moonlight, so the Moon appears more yellow, orange, or pink. This image, taken by the author at Lake Superior in February 2019, shows how refraction can compress the Moon's figure, making it bulge like a stress ball under tension.

Follow the Moon around for a month, and you'll get a sense of its orbital motion and how its changing position in relation to the Sun results in the familiar phases. The Moon takes 27.3 days — a *sidereal month* — to orbit 360° around Earth relative to the "fixed" stars. And because it rotates on its axis at the same rate as it orbits, we always see the same lunar face. How much of that face we see (its *phase*) varies according to the Moon's position in relation to the Sun as viewed from Earth. The time between successive Moon phases, one full Moon to the next, for example, is about 29.5 days, the Moon's *synodic period*. The two periods differ because Earth is always on the move as well, orbiting the Sun. During a sidereal month, Earth covers about 30° of its orbit. For the Moon to align again with the Sun and Earth at full Moon, it must travel another 2.2 days (around 30°) to compensate for Earth's revolution.

At new phase, the Moon is almost directly in line with the Sun, with its nearside in darkness. Sunlight floods the lunar farside. If we could get around it for a look, we'd see a full Moon! We rarely think about it, but the farside goes through the same phases as the near, but in reverse order. Only during a solar eclipse does the new Moon "come out of hiding" as a black disk sliding across the glaring Sun.

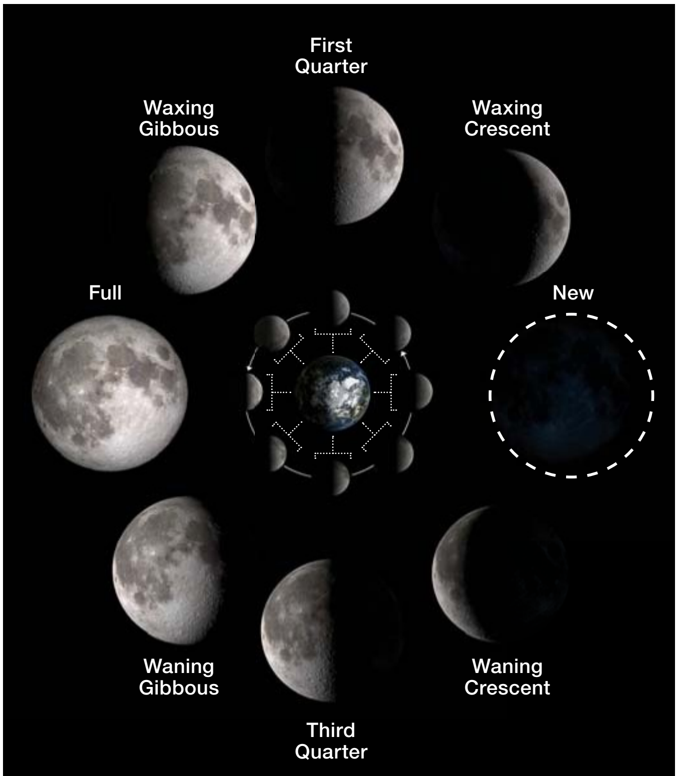
If you've ever tried talking to someone standing directly in front of the Sun, it's not easy. You might ask them to move off to the side so you can see their face more clearly. The Moon does the same thing. A day or two after new, it separates enough from the Sun for solar rays to illuminate its edge as a crescent at dusk. Few astronomical sights mesmerize like a sliver Moon at dusk or dawn with its pointed horns pricking the rose-hued sky. The Moon may be 22 billion km^3 of solid rock, but on such occasions, it looks delicate enough to sail away on the breeze.

The *terminator* marks the division between the sunlit and nighttime hemispheres of the Moon. As the Moon swings upward from the Sun, the terminator acts like a curtain slowly drawn back to let in the sunshine. At first-quarter phase, when the Moon has completed one-fourth of its orbit, the terminator runs straight up and down: One half of the Moon stands in sunlight while the other half still lies in darkness.

At rising and setting, the Moon reveals just how weird our own atmosphere is. Denser air at the horizon scatters away the violets, blues, and greens in moonlight, turning it yellow, orange, and pink. Refraction by the air squeezes the Moon into a pinto bean at moonrise and moonset. At full — two weeks past new — the Moon shines directly opposite the Sun and rises around sunset. Glorious colors and atmospheric hijinks aided by the *Moon illusion*, when the Moon appears larger on the horizon than it does when it's higher in the sky, make full moonrises not-to-miss events.

There are several explanations for the full Moon's illusory, jumbo-size appearance on the horizon, none of which is completely satisfying. In one, we compare the Moon to familiar sights nearby, like trees, buildings, or beaches, and unconsciously inflate it to fit the scene. In another, our brains judge the horizon to be farther away than it actually is, so we artificially increase the Moon's size to accommodate the greater distance. Humans have documented the optical illusion at least since the time of Aristotle, yet we still don't have a definitive explanation for the phenomenon!

The Moon's distance from Earth varies during its orbit because it travels along an ellipse. When nearest to Earth, or at *perigee*, it's about 50,000 km closer to us than when it's at *apogee*, the far end of its orbit. If a full Moon occurs within 90% of the perigee distance, it's known as a supermoon. Supermoons are about 14% larger than the same Moon at apogee (dubbed a micromoon) and get at least 5,000% more media attention. With careful observation and recollection, some can discern the difference between the two, but it's always been moot for me without the use of a sighting device.



THE SUNLIGHT SHUFFLE From our vantage point on Earth, the amount of the lunar surface illuminated by the Sun changes as the Moon follows its month-long orbit around our planet.

LARGE MOON: BOB KING; MOON PHASES: NASA / BILL DUNFORD; MOON SKETCH: LEAH TISCIONE / *S&T*

The Moon increases its distance from the Sun about 13° per day, delaying its rising time an average of about 50 minutes a night. After full phase, the Moon continues to rise later and later after sunset until it reaches last-quarter phase, when it rises around midnight and stands due south at sunrise. Morning crescent phases follow until the terminator shaves away our satellite to nothing, and a new Moon returns to begin the cycle afresh. As the Moon waxes to full, the terminator defines the line of advancing sunrise; during the Moon's waning phases it becomes the line of advancing sunset.

Along the way, the Moon passes near the bright planets in eye-catching pairings called *conjunctions*. Conjunctions are a natural consequence of the Moon and planets following similar paths through the zodiacal constellations. Novice astronomers can be grateful for the Moon's help in pointing out both the planets and brighter stars as it makes its monthly rounds.

Naked-eye Sights

You might be surprised by how much you can see on the Moon without optical aid. In addition to phases and conjunctions, treat yourself to an eyeful of *earthshine*, the soft, faint glow that illuminates the shadowed portion of the Moon when it's a crescent. Sunlight reflected from Earth to the Moon and back is the source of this ghostly light.

WILD IMAGINATION The contrast of the Moon's dark maria (seas) with light-colored highlands offers a chance for the creative mind to run wild. How many figures can you compose out of the variegated lunar surface?

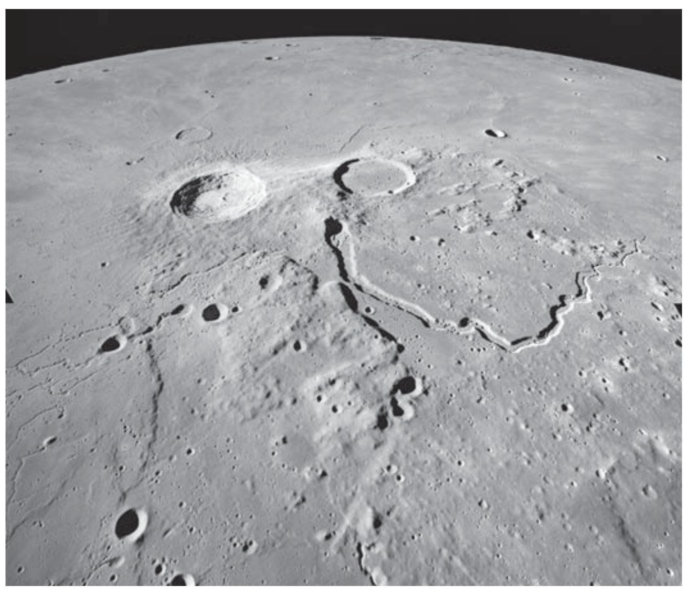
Many people can find the Man in the Moon, a crude face formed by the contrast between light-toned lunar highlands and the darker seas or *maria* (MAH-ree-uh). But have you ever seen the rabbit? How about the woman wearing a jeweled pendant? Or the moose? Our natural tendency to see distinct shapes in random patterns is known as *pareidolia*. These shapes are fun to find, but what they truly represent on the Moon is far more fascinating.

The highlands comprise the original lunar crust that cooled from a global magma ocean around 4.5 billion years ago. Lighter materials rich in calcium and aluminum floated to the top and solidified to create a white, rocky landscape. Intense cratering from meteorite and asteroid bombardment between 4 and 4.5 billion years ago pulverized the outer crust into the lunar soil, or *regolith*, that now bears the boot prints of twelve Apollo astronauts. (For more on this, see page 52.)

The seas, so called because pre-telescopic observers mistook them for bodies of water, are actually gigantic impact basins blasted out by asteroid collisions roughly 4 billion years ago. Between 3.2 and 3.9 billion years ago, the fissures that riddled their fractured floors bled magma to fill these gigantic holes and create vast, dark plains. Our ancestors had the "sea" part correct, just not the liquid that filled them. Pale minerals dominate in the crust, but the basaltic lavas were rich in darker minerals containing iron, magnesium, and titanium, which is why the plains appear dark in contrast to less disturbed regions of the Moon's surface.

The lunar landscape is truly ancient. Although subsequent impacts have churned the regolith and blotched the maria, the Moon would appear much the same to the naked eye if

▼ **SOURCE OF THE TROUBLE** This stunning image of the Aristarchus plateau was captured with a 76-mm Fairchild mapping camera using 5-inch film by the Apollo 15 astronauts. The "Cobra head" volcanic vent released a river of lava that flowed down the plateau and onto the lava plains of Oceanus Procellarum. Aristarchus Crater is east (left) of the vent, the shallower crater Herodotus west of the vent.

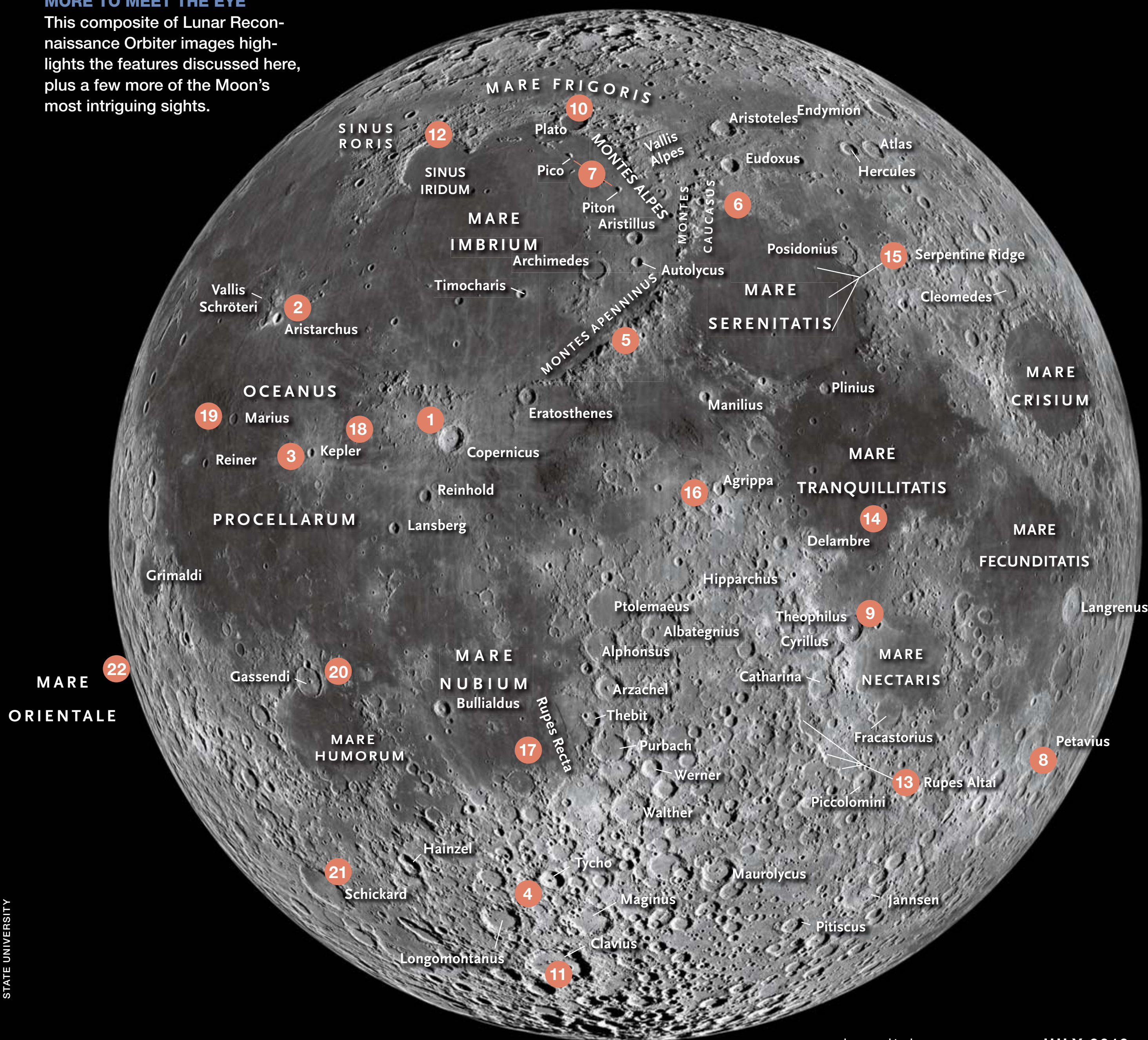


RABBIT MOON: GREGORY H. REVERA / CC BY-SA 3.0; ARISTARCHUS PLATEAU: NASA / JSC / ARIZONA STATE UNIVERSITY humans could jump into a time machine and throttle back 3 billion years or so.

Most craters require a telescope or binoculars to see, but several are visible after a fashion with the naked eye. Take a few minutes at the next full Moon to closely examine the broad, dark über-mare **Oceanus Procellarum**. Within it you'll see three fuzzy blotches arranged in a triangle. In order of size, they are 1 **Copernicus** (93 km in diameter), 2 **Aristarchus** (40 km), and 3 **Kepler** (32 km). Each sports a broader nimbus of bright rays created by falling ejecta after an impact, expanding them into whitish spots visible without optical aid. The brilliant, rayed crater 4 **Tycho** (85 km), tucked just inside the southern limb, can also be seen as a bright "spot" at full Moon.

Lunar and solar eclipses (viewed with a suitable filter or via projection) make for grand naked-eye events. For an eclipse to occur, the Moon, Earth, and Sun must be precisely in a line. When that occurs at new Moon, the Moon eclipses the Sun. When it happens at full Moon, the Moon passes behind Earth and into its shadow. Because the Moon's orbit is inclined 5.1° to the plane of Earth's orbit, eclipses don't occur at every full Moon. The Moon normally passes above or below the shadow, or above or below the Sun, meaning no eclipse results. A close miss!

MORE TO MEET THE EYE
This composite of Lunar Reconnaissance Orbiter images highlights the features discussed here, plus a few more of the Moon's most intriguing sights.



NASA / GSFC / ARIZONA STATE UNIVERSITY

◀ **FOND FAREWELL** The Apollo 11 astronauts took this photograph of the full lunar disk during their return trip to Earth.

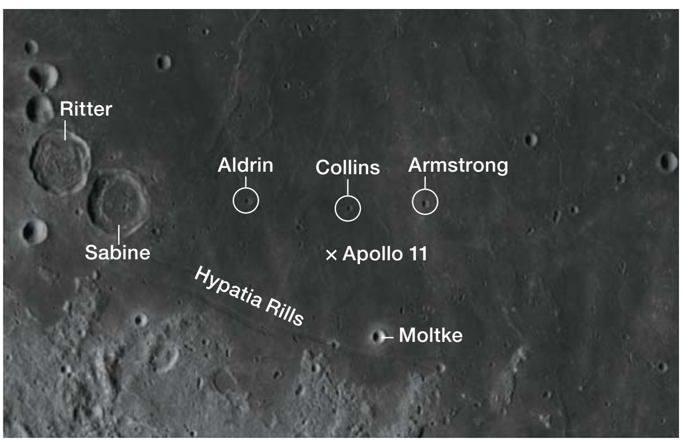
Binocular Sights

Binoculars easily provide a first introduction to lunar craters. In a typical pair of 8×40s or 7×50s, all the maria, many lunar craters, and the major mountain ranges including the 5 **Montes Apenninus**, 6 **Montes Caucasus**, and 7 **Montes Alpes** come into view. Craters are best visible from 3 to 9 days after new Moon and from 4 to 10 days after full Moon. During these times, the terminator slices through the Southern Highlands, the most battle-scarred region of the nearside. Slanted sunlight streams across the moonscape near the terminator, casting long shadows that throw the smallest hills, craters, and cracks into stark relief.

Standouts among the many visible craters include the four aforementioned naked-eye sights plus 8 **Petavius**, the trio of 9 **Theophilus, Cyrillus**, and **Catharina**, 10 **Plato**, 11 **Clavius**, and the giant, mare-filled crater 12 **Sinus Iridum**. You'll also be able to truly appreciate the vast extent of Tycho's rays at full Moon.

Binoculars will reveal the larger maria lurking on the Earth-lit Moon, provide spectacular views of the totally eclipsed Moon floating in a field of stars, and reveal prismatic color changes and atmospheric layering across the Moon at moonrise and moonset. I've also found them quite useful for observing occultations of brighter stars and planets.

The small amount of magnification binoculars provide will also make you privy to the Moon's monthly "rolling of the eyes," better known as *libration*. Remember that 5.1° inclination? That plus the tilt of the Moon's axis lets us see a little under the bottom and over the top of the Moon. In addition, the Moon moves faster in its orbit when closer to Earth and slower when farther away, making it appear to rock from side to side each month, exposing areas beyond the east and west limbs to view. Combined, the two cycles create the equivalent of a lunar eye roll.



▲ **HONOR GUARD** Three craters celebrating the astronauts of Apollo 11 — Buzz Aldrin, Michael Collins, and Neil Armstrong — form a neat line east of Sabine Crater in the southern reaches of the Sea of Tranquility.

Telescopic Sights

The Moon is so close and bright that even a 3-inch telescope will do a great job revealing more features than you'll have years to observe. That said, a slightly larger telescope — in the 6- to 8-inch range of aperture — works even better by providing greater resolution and, more importantly, a brighter image when switching to high magnification. Lunar features such as the gully-like rilles and blister-shaped domes are much easier to see at magnifications of 150× and higher. And few sights are more arresting than the cratered highlands at high power at half Moon; it's the closest most of us will get to orbiting the Moon.

I have a long list of lunar favorites of which the ones below are but a small sample. You'll find many more in the *21st Century Atlas of the Moon* (see sidebar on facing page). As a general rule, the best place to observe lunar features is near the terminator, where the Sun is either rising or setting. Far from the terminator, the Sun stands high in the lunar sky and washes out much detail.

A word on compass directions. North and south are the same on the Moon as in the sky, but east and west are reversed from their celestial equivalents. The terminator always sweeps from lunar east to west across the Moon, the same direction as the line of sunrise on Earth. The optimal evening times during waxing phases are shown for each object because that's when most of us are out looking. But the same features are also optimally placed during the waning phases in the predawn sky.

Once you've spent some time exploring the Moon, beware! You may never go back to faint fuzzies.

8 **Petavius** (177 km diameter) — This big crater shows a wide rim and convex floor warped by subsurface lava flows and sliced by a prominent rill, which is easily visible in a 3-inch scope. The rill likely formed through faulting of the crater floor. (Best 3 days after new Moon; 2 days after full)

9 **Theophilus**, **Cyrillus**, and **Catharina** (each about 100 km) — This trio is a spectacular example of overlapping and adjacent craters with different ages. Theophilus is the youngest with a sharp rim. It overlaps Cyrillus, an older, more eroded ring adjacent to Catharina, which is the oldest of the three. (5–6 days after new)

13 **Rupes Altai** — Informally known as Altai Scarp, this long, curving escarpment rises 1 km above the surrounding terrain that forms part of the outer rim of the Mare Nectaris basin. It's a striking sight under low sunlight. (5–6 days after new)

14 **Apollo 11 astronaut craters** — In honor of the 50th anniversary of the first crewed Moon landing, I include this trio of tiny craters named for the Apollo 11 astronauts. Aldrin, Collins, and Armstrong make a neat line a short

MOON FROM APOLLO: NASA; APOLLO CRATERS: NASA / GSFC / ARIZONA STATE UNIVERSITY distance north of the Apollo 11 landing site and due east of the Ritter and Sabine crater pair. Armstrong, the largest, is 4.2 km across followed by Aldrin at 3.4 km, and Collins at 2.4 km. A 6-inch scope at 250× on a night of steady seeing should coax all three into view. (6 days after new)

15 **Serpentine Ridge** — This snaking, low-elevation ridge in Mare Serenitatis formed when the lava inside the basin cooled. As it settled, it fractured, sending pieces of hardened rock sliding over one another to create long ropes of debris. (6–7 days after new)

16 **Triesnecker** and **Ariadaeus Rilles** — Two of the Moon's most prominent rille systems formed from faulting of the crust. The Triesnecker complex is so rich in chasms that it looks like a spider web at high power on nights of good seeing. Spectacular! (7–8 days after new)

Southern Highlands — This craterscape, which includes Tycho and Clavius, is crater heaven. Thousands of overlapping craters greet the eye, a forceful reminder of the Moon's impactful history. Tycho, with its sharp rim and point-like central peak (a stunner at lunar sunrise), is one of the Moon's largest and youngest craters, with an estimated age of 108 million years. (Most lunar craters are a few hundred million to a few billion years old.) Nearby Clavius (231 km) hosts its own crater farm, a scenic arc of five sizable impact holes contained within its rim. (6–9 days after new)

17 **Rupes Recta** — Commonly known as the Straight Wall, this 300-meter-high, 116-km-long cliff, which runs along the eastern edge of Mare Nubium, is the Moon's most prominent geologic fault. The delicate rille Rima Birt just to its west is also worth a visit. (8 days after new)

10 **Plato** (101 km) — It looks like a swimming pool, but don't dive in or you'll hurt your head. At first glance, the crater's floor appears perfectly smooth, but crank up the power to see if you can spot the craterlets — "easy" ones are about 3 km across — that make it wonderfully imperfect. (8–9 days after new)

5 **Montes Apenninus** — The lunar version of the Apennine Mountains forms a prominent arc of rugged peaks with elevations of 2–5 km. While tectonic forces drive the formation of mountains on Earth, the Moon's Apennines formed 3.9 billion years ago from material pushed up during the giant impact that created nearby Mare Imbrium. (8–9 days after new)

1 **Copernicus** (93 km) — A most wonderful crater! Catch it around sunrise when its sunlit rim frames a bowl of darkness. With terraced walls and multiple central peaks, this crater will keep you glued to the eyepiece. Chains of secondary craters, visible at high magnification, perforate the landscape in all directions. (9 days after new)

12 **Sinus Iridum** (249 km) — An enormous, mare-filled impact crater along the northwestern edge of Mare Imbrium. At sunrise, ridges of lava look like waves on a sea. (10 days after new)

18 **Milichius Pi (π)** (10 km) and 19 **Marius Hills** (6–16 km) These are great examples of lunar domes, a type of shield volcano similar to those found on Earth. You can even spot the craterlet at the summit of the Milichius dome at 150× or higher in good conditions. The Marius dome field lies immediately west of the crater Marius. The region is "warty" with rough-textured domes. (10 days and 12 days after new, respectively)

20 **Gassendi** (110 km) — This crater's fractured floor is riddled with rilles and partially flooded by lava via a breach in its north wall. (10–11 days after new)

2 **Aristarchus** and **Aristarchus Plateau** (40 km) — Shining at full Moon like a 1,000-watt LED light at the center of prominent rays, Aristarchus is the brightest of the larger lunar craters. The crater dominates a pale green-yellow-colored volcanic plateau. (12 days after new)

21 **Schickard** (227 km) — The floor of this giant crater near the Moon's southwestern limb is covered with material ejected from the nearby Mare Orientale impact, giving it a two-toned appearance. (12–13 days after new)

22 **Mare Orientale** — At 3.85 billion years old, this is the Moon's most recent impact basin. Due to extreme foreshortening at the western limb, Mare Orientale looks like a series of vaguely concentric stripes of dark lava separated by lighter highland material. (Full Moon to 3 days before new, when a favorable libration exposes the western limb).

■ Contributing Editor **BOB KING** has been an avid observer since childhood. He's a long-time member of the American Association of Variable Star Observers and author of several observing guides, including *Night Sky with the Naked Eye* and *Wonders of the Night Sky*. Visit his website at **astrobob.areavoices.com**.

A Little Help

Here are a few books and tools to make it easier to visit the Moon, our closest planetary companion.

Charles Wood and Maurice Collins, *21st Century Atlas of the Moon* (West Virginia University Press, 2002). This atlas features high-quality photomaps and detailed descriptions of features.

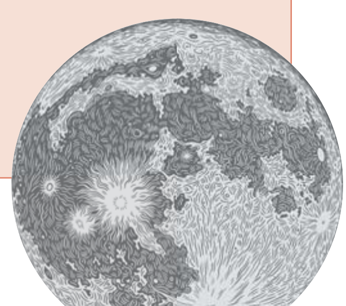
Antonin Rükl, *Atlas of the Moon* (Sky Publishing, 2007). Rükl's is the current "bible" of lunar atlases, but it's only available on the used market.

LROC Quickmap (**quickmap.lroc.asu.edu**). This fantastic online Moon browser is based on images from NASA's Lunar Reconnaissance Orbiter Camera.

Virtual Moon Atlas (**ap-i.net/avl/fr/start**). Use this handy, free desktop atlas to plan your next lunar observing session.

Moon Globe (**https://is.gd/MoonGlobeApp**). This easy-to-use, free Moon atlas works on iPhones and iPads.

Moon Atlas 3D (**https://is.gd/MoonAtlasApp**). Download this lunar atlas app for your Android phone.



LEAH TISCIONE / S&T

Targeting Luna

Taking photos of the Moon can be as simple as you want it to be.

Perhaps the initial thing in the night sky people look at with their first telescope is the Moon. After all, it's the brightest object in the sky, which doesn't require any special equipment to see detail on. In fact, no optical aid at all is necessary to see the dark lunar maria. The Moon can be seen from virtually any location on Earth and is completely impervious to light pollution. As such, our satellite is possibly the most tempting target for any amateurs to begin their journey in astrophotography. Whether you're just starting out shooting the Moon or are considering some high-resolution close-ups, here are some tips to help you come away with pleasing shots.

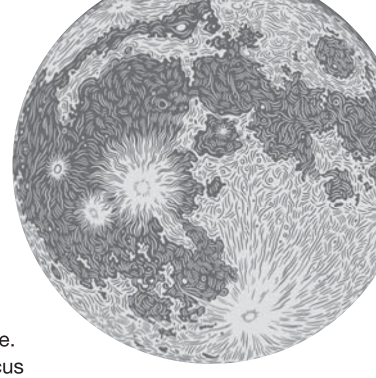
Without a Scope

The Moon is one of the most accessible objects you can shoot in the night sky. Due to its proximity, pretty much any camera can record it as more than just a point of light. And you probably have a camera to begin shooting it in your pocket. Today's smartphones have incredibly powerful cameras. My Samsung Galaxy 9+ has enough resolution to record the Moon well enough to show the maria even in handheld photographs.

To capture the Moon with your phone, first look at its camera settings to see if it allows any manual controls over the exposure. If so, experiment with the exposure length to avoid overexposing the Moon's disk — I've had good luck with 1⁄250 of a second. If your phone doesn't include manual exposure control, try shooting it in the evening before the sky gets completely dark, so that the satellite isn't that much brighter than the background sky and your camera's auto-exposure won't overexpose the disk. Focusing is also straightforward if you shoot a gibbous phase; partially shadowed craters make excellent reference points for your device's autofocus.

If you're looking to take better photos than your phone can provide, there are some excellent and inexpensive pocket cameras with powerful built-in zoom lenses that will let you close in on the Moon and take impressive shots that will resolve many shadowed craters along its terminator.

▲ **A MOON OF YOUR OWN** Imaging Earth's satellite can reveal more detail than any other celestial object. This 26-panel mosaic of the waning Moon was recorded through a 7-inch Maksutov-Cassegrain and an Imaging Source DMK 21AU04.AS video camera.



CAMERA AS EYEPIECE With the addition of a T-adapter and lens bayonet, a DSLR or MIL (mirrorless interchangeable-lens) camera can replace the eyepiece on your telescope. This is known as prime focus photography.

You'll have better luck with either your smartphone or a pocket camera if you mount it on a tripod and use the camera's timer function to allow any vibrations to die down before the photo is taken. A tracking mount will also make framing up the Moon and keeping it centered effortless, as well as allow you to take many individual images that you can later transfer into a planetary stacking program such as *RegiStax 6* or *Autostakkert!3* to achieve a sharper result. I'll discuss more on stacking later.

Stepping up to a DSLR or MIL (mirrorless interchangeable-lens) camera with a quality telephoto lens will permit you to take even better lunar photos. It also simplifies attaching your camera to a telescope.

More Aperture

The next leap most take when shooting the Moon is to shoot pictures through their telescope — a natural progression, because users can think of their telescope as a long telephoto lens. In fact, a good telescope is often sharper than most camera lenses, and it generally costs much less per inch of aperture. Just make sure that your scope is collimated before attaching your camera (*S&T:* Feb. 2018, p. 28 for Cassegrain telescopes, and *S&T:* Apr. 2019, p. 68 for Newtonians).

Getting started with this technique is only slightly more challenging than holding your phone up to the sky and snapping away. The difference is you'll need to hold your phone's camera close to the eyepiece of your telescope — a technique known as eyepiece projection. While it is possible to do, you'll have a far easier time if you pick up one of the many inexpensive adapters available that can connect your phone to the eyepiece on your telescope. While most major manufacturers offer smartphone adapters, it's important to consider which one works best for your particular phone. I've used models from a variety of manufacturers, though I prefer the ones offered by Celestron (**celestron.com**), Orion Telescope & Binoculars (**telescope.com**), and Tele Vue (**televue.com**).

One note about eyepiece projection: The eyepiece you choose to project the image of the Moon into your smartphone will have a noticeable effect on the quality of your images. Using a Huygens or other simple eyepiece design will introduce aberrations into your images; these are particularly noticeable on the high-contrast limb of the Moon. Simple eyepiece designs can add color fringing along the lunar limb even when you're shooting through a Newtonian reflector or an apochromatic refractor. Consider upgrading your eyepiece choice if you intend to get the most out of this technique.

Attaching your phone or camera to a telescope complicates things a bit. If your scope is on a simple manual alt-azimuth mount as a Dobsonian is, aiming and focusing may be particularly frustrating. Having a solid tracking mount with slow-motion controls eliminates much of the problem by keeping your target centered while you focus and change exposure settings. An electronic focuser will also make focusing much less frustrating, because you won't have to touch the telescope at all, potentially imparting jiggles that are highly magnified by your telescope's long focal length.

Adding a tracking mount also permits you to take longer exposures to record earthshine without the Moon trailing during the exposure, or to record the Moon during a total lunar eclipse, which often requires exposures of several seconds during totality.

A side benefit of using your tracking telescope with a smartphone attached is that the combination also offers a great way to share views of the Moon with others. Your phone acts like a small video screen and permits everyone to see the image without having to lead visitors to the eyepiece or change focus.

Prime Focus

If eyepiece projection with your smartphone has whetted your appetite for better results, you could move up to prime-focus photography using a DSLR or MIL camera. Prime focus is when your camera replaces the eyepiece on your telescope, and light coming through the instrument is focused directly

EASY PEASY Modern smartphones can capture the lunar maria even in handheld shots. The author's wife took this photo using a Samsung Galaxy 9+ simply by holding her phone steady in evening twilight.

UNLESS NOTED, ALL PHOTOS PROVIDED BY AUTHOR; MOON SKETCH: LEAH TISCIONE / *S&T*; MOON AND CLOUDS: JANE WALKER

◀ *Left:* Shooting high-resolution close-ups of individual craters is best achieved with a well-collimated telescope, a high-quality Barlow lens or tele-extender, and a high-speed planetary camera. *Right:* Using a 12½-inch Newtonian, a Tele Vue 4× Powermate, and a ZWO ASI120MM planetary camera, the author captured this sharp image of the craters Messier A (left) and Messier along with many smaller craterlets in the area.

onto the camera's sensor. This technique takes advantage of the telescope's natural focal length and reduces the number of glass elements that can introduce the aberrations mentioned earlier.

Prime-focus photography requires the addition of a T-adapter and bayonet mounting for your particular camera. Each camera manufacturer uses its own proprietary bayonet connection to mount lenses, so make sure you pick up the right adapter for your particular camera.

Using a DSLR or MIL camera opens up new possibilities that aren't as practical with a smartphone. For one thing, cameras with APS-size CMOS detectors will let you record the entire lunar disk at relatively high resolution in focal lengths up to about 1,300 millimeters, while cameras with full-frame 35-mm detectors can capture the entire Moon at around 2,000 mm. At these focal lengths, you can resolve small craters and some valleys and rilles when the seeing is steady.

Another benefit of DSLR or MIL cameras is that most newer models can record HD or even high-resolution 4K video. Shooting high-speed video can improve your chances of recording frames during moments of near-perfect seeing, which you can often miss if you are recording single exposures. These videos can be converted into a common format (such as AVI) and then brought into stacking programs, which will then combine only the sharpest frames, producing a final image that is much smoother and sharper than a single image.

Of course, the biggest advantage of these cameras is that they have detectors with lots of pixels, and that translates into your ability to make large prints of your images.

Dedicated astronomy cameras such as CCD and CMOS models can also record excellent photos of the Moon and are easier to connect to your telescope. These cameras were designed to attach directly to a telescope, so you wouldn't need to purchase any additional adapters. Perhaps their only drawback is they require a computer to operate in the field. But a dedicated astronomy camera has many advantages. For one, several models can record many frames per second at the camera's full resolution, something that DSLR and MIL cameras can't do (yet). These frames can then be processed just like a video, with the same advantage of stacking only the sharpest frames.

Another benefit of dedicated astronomy cameras is that they are offered with either one-shot-color or monochrome detectors. The advantage to this is that, while the Moon has very subtle color differences, it appears nearly monochromatic, so a sharp black-and-white photograph is almost indistinguishable from a color photograph. Also, one-shot-color detectors like those found in all smartphones, pocket cameras, and DSLR and MIL cameras, incorporate a matrix of color filters over their individual pixels. This matrix divides up the detector into a grid of 25% red, 50% green, and 25% blue pixels that must be interpolated to make a color image, and it creates a slightly lower resolution result than what can be accomplished with a monochrome camera.

The Highest Resolution

If you're looking to record the smallest details on the Moon possible with your telescope, the best choice these days is to invest in a planetary video camera, as well as some high-quality Barlows or image amplifiers. A premium Barlow or tele-extender (such as Tele Vue's Powermates) will increase your telescope's focal length so that you can resolve details smaller than 1 arcsecond under ideal conditions. Using either is almost always better than eyepiece projection to increase

EYEPIECE PROJECTION To get a little closer in, many vendors (such as Celestron, maker of the NexYZ shown above) offer excellent smartphone adapters to securely hold your phone's camera centered over an eyepiece. When using this method, high-quality eyepieces will yield the best results.

the magnification of your image, since they are designed to fit directly between a telescope's focuser and eyepiece (or astronomy camera).

Combining a telescope and Barlow or tele-extender with a high-speed video camera and frame-stacking is the go-to method for lunar and planetary photographers. These cameras, offered by manufacturers including, among others, Celestron, Meade, QHY, and ZWO, are compact and lightweight, and they produce amazingly high frame rates at full resolution. Some can record more than 100 frames per second, which allows users to "beat the seeing" in most cases. And while these cameras require an additional computer to operate, nothing comes close to the quality of their stacked results.

Just be sure to spend lots of time focusing — watch a small craterlet on your laptop screen as you rack focus in and out.

▲ **DEEPER EXPOSURE** Some lunar photographs require longer exposures than a typical snapshot. This shot of the total lunar eclipse of September 28, 2015, needed the addition of a tracking mount to record both the eclipsed Moon and surrounding sharp, round stars during the 6-second exposure through an 8-inch f/3 Newtonian reflector.

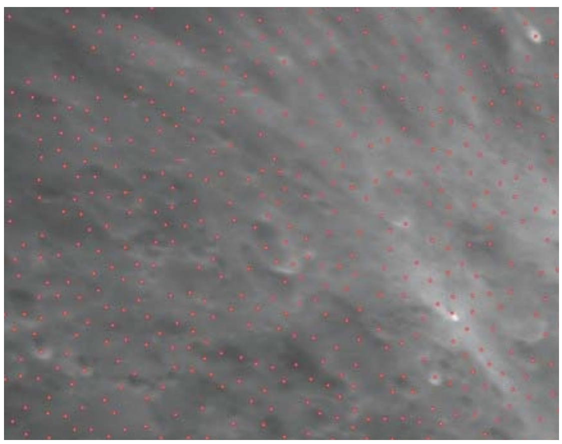
Post-Processing

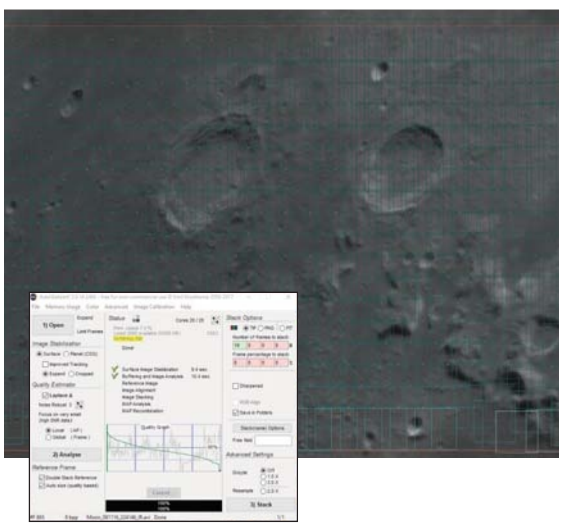
Regardless of which lunar-imaging method you choose, processing your results is simple. In fact, you don't really have to do anything to photos captured with most cameras if you don't want to — lunar photos do not require any stretching or fancy post-processing techniques as in deep-sky photography. A tiny bit of sharpening can often improve your shots, though I'd recommend a light touch when applying unsharp-masking.

Things get a bit more complex if you intend to stack multiple frames. Stacking images improves the signal-to-noise ratio of your result compared to a single frame, which then permits you to sharpen the image without bringing up the noise or graininess of the picture. Stacking is beneficial in most any lunar photography, with the exception of wide-angle nightscape images.

There are several free stacking programs for PC users, the most popular being *RegiStax 6* (**astronomie.be/registax**) and *AutoStakkert!3* (**autostakkert.com**). Both programs are intuitive, and a tutorial of *AutoStakkert!* can be found in our September 2016 issue, page 68. With Apple ending support for *QuickTime* video, Mac users are currently without good options.

Whichever program you choose, the key to getting your best result is to apply either program's multi-point alignment routines, which allows you to only stack the sharpest areas of each frame you import into the software. Either program accepts individual image files or videos, though only *RegiStax 6* has any useful post-processing capabilities after stacking. (Its wavelet sharpening is particularly powerful and superior to simple sharpening in other programs such as *Adobe Photoshop*.)





▶ **M.A.P. STACKING** The two most popular image-stacking programs, *RegiStax 6 (top)* and *AutoStakkert!3 (bottom)* use multi-alignment points to analyze, register, and stack only the sharpest bits of the images or videos you import. The result is a smooth image with very high signal.

How many frames you choose to stack may depend on the conditions you shoot through. Under the typically unsteady skies of New England, I often stack only about 400 of the frames in a lunar video and apply very mild wavelet-sharpening on the stacked result. Other imagers recommend stacking several thousand frames shot under good seeing to get the smoothest result that sharpens best.

No matter which technique you settle on, lunar imaging is perhaps the easiest entry point into the world of astrophotography. And while the Moon may seem to be an unchanging rock to the casual observer, it subtly changes angle illumination every day, an alteration that doesn't exactly repeat for more than 18 years. There is no other object that offers such easily viewed detail in the night sky!

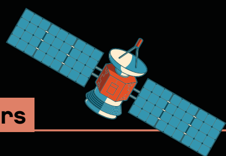
■ *S&T* Associate Editor **SEAN WALKER** has been imaging the Moon for more than 30 years.

 by Monica Young & Terri Dubé

(Back) to the Moon

ALMOST 50 YEARS AGO, humans landed on the Moon. Soon, we are due to return. NASA, Russia's Roscosmos, and the China National Space Administration (CNSA) are all building up to a long-term human presence on or near the Moon. The European Space Agency, as well as space agencies in India, South Korea, and Japan are also ramping up robotic lunar exploration. Meanwhile, a plethora of commercial missions aim to send orbiters, landers, rovers, and even tourists to the Moon, in a private space boom jump-started by Google's Lunar XPRIZE, NASA partnerships, and good old-fashioned entrepreneurship.

Delays will no doubt hound some of these missions, and not all of them will be successful. Nevertheless, here are some of the missions to the Moon that we expect to see over the course of the next five years, including their preliminary launch dates and, where applicable, planned landing sites.



Orbiters

Artemis P1 and P2**
LAUNCH: Feb. 17, 2007
(Entered orbit: June 27 and July 17, 2011)
ORGANIZATION: NASA (U.S.)

Lunar Reconnaissance Orbiter**
LAUNCH: June 18, 2009
(Entered orbit: June 23, 2009)
ORGANIZATION: NASA

Longjiang 2**
LAUNCH: May 20, 2018
(Entered orbit: May 25, 2018)
ORGANIZATION: Harbin University of Technology (China)

Queqiao**
LAUNCH: May 20, 2018
(Entered orbit: June 14, 2018)
ORGANIZATION: CNSA (China)

Hakuto-R Mission 1
LAUNCH: 2020
ORGANIZATION: ispace (Japan)

LunaH Map (via EM 1)
LAUNCH: 2020
ORGANIZATION: Arizona State University (U.S.)

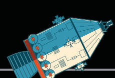
Lunar Flashlight (via EM 1)
LAUNCH: 2020
ORGANIZATION: Morehead State University (U.S.)

Lunar IceCube (via EM 1)
LAUNCH: 2020
ORGANIZATION: NASA

Korea Pathfinder Lunar Orbiter
LAUNCH: Dec. 2020
ORGANIZATION: Korea Aerospace Research Institute

Luna 26
LAUNCH: 2023
ORGANIZATION: Roscosmos (Russia)

EM 3
LAUNCH: 2024
ORGANIZATION: NASA
STATUS: Mission may be revised to include crewed lunar landing



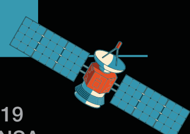
Flyby

Exploration Mission 1 (EM 1)
LAUNCH: 2020
ORGANIZATION: NASA

LUNIR (via EM 1)
LAUNCH: 2020
ORGANIZATION: Lockheed Martin (U.S.)

EM 2
LAUNCH: 2022
ORGANIZATION: NASA

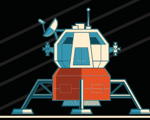
dearMoon
LAUNCH: 2023
ORGANIZATION: SpaceX (U.S.)



Orbiters & Landers

Chang'e 5
LAUNCH: Late 2019
ORGANIZATION: CNSA
LANDING SITE: Near Mons Rümker

Chang'e 6
LAUNCH: 2023–2024
ORGANIZATION: CNSA
LANDING SITE: TBD, could be lunar farside or south pole



Landers

Omotenashi (via SLS EM 1)
LAUNCH: 2020
ORGANIZATION: JAXA (Japan)
LANDING SITE: On western limb (tentative landing site shown)

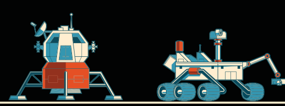
Peregrine
LAUNCH: 2021
ORGANIZATION: Astrobotic (U.S.)
LANDING SITE: Lacus Mortis

Luna 25
LAUNCH: 2021
ORGANIZATION: Roscosmos
LANDING SITE: Near south pole

XL 1
LAUNCH: 2021
ORGANIZATION: Masten Space Systems (U.S.)
LANDING SITE: Aristarchus Crater

Smart Lander for Investigating the Moon (SLIM)
LAUNCH: 2021–2022
ORGANIZATION: JAXA
LANDING SITE: Mare Tranquillitatis

Luna 27
LAUNCH: 2024
ORGANIZATION: Roscosmos
LANDING SITE: Near south pole



Landers & Rovers

Chang'e 3**
LAUNCH: Dec. 1, 2013
(Landed: Dec. 14, 2013)
ORGANIZATION: CNSA
LANDING SITE: Mare Imbrium

Chang'e 4**
LAUNCH: Dec. 7, 2018
(Landed: Jan. 3, 2019)
ORGANIZATION: CNSA
LANDING SITE: Statio Tianhe, inside Von Kármán Crater

ALINA
LAUNCH: 2020
ORGANIZATION: PTScientists (Germany)
LANDING SITE: Taurus-Littrow Valley

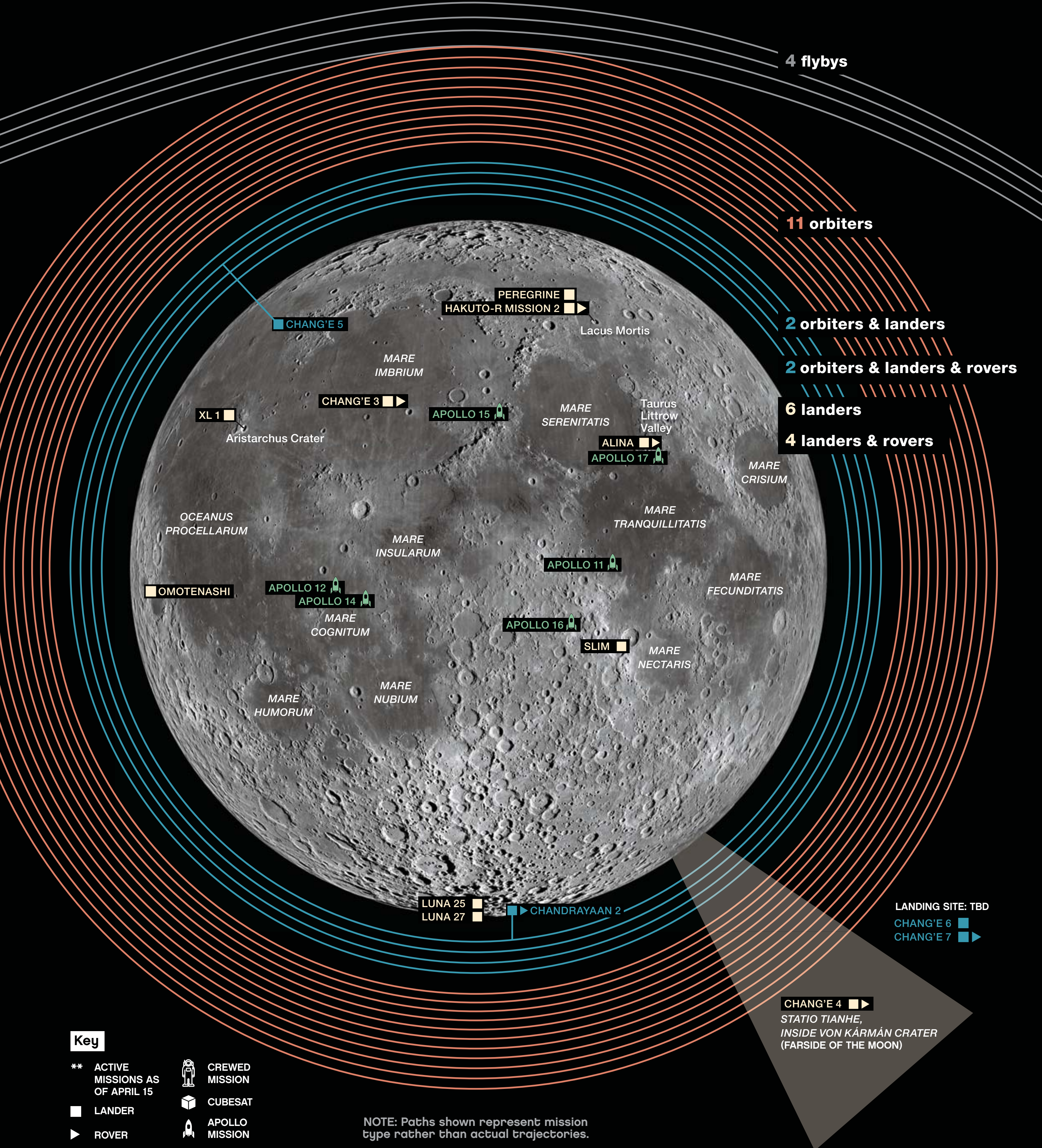
Hakuto-R Mission 2
LAUNCH: 2021
ORGANIZATION: ispace
LANDING SITE: Lacus Mortis

Orbiters & Landers & Rovers

Chandrayaan 2
LAUNCH: 2019
ORGANIZATION: Indian Space Research Organisation
LANDING SITE: Near lunar south pole

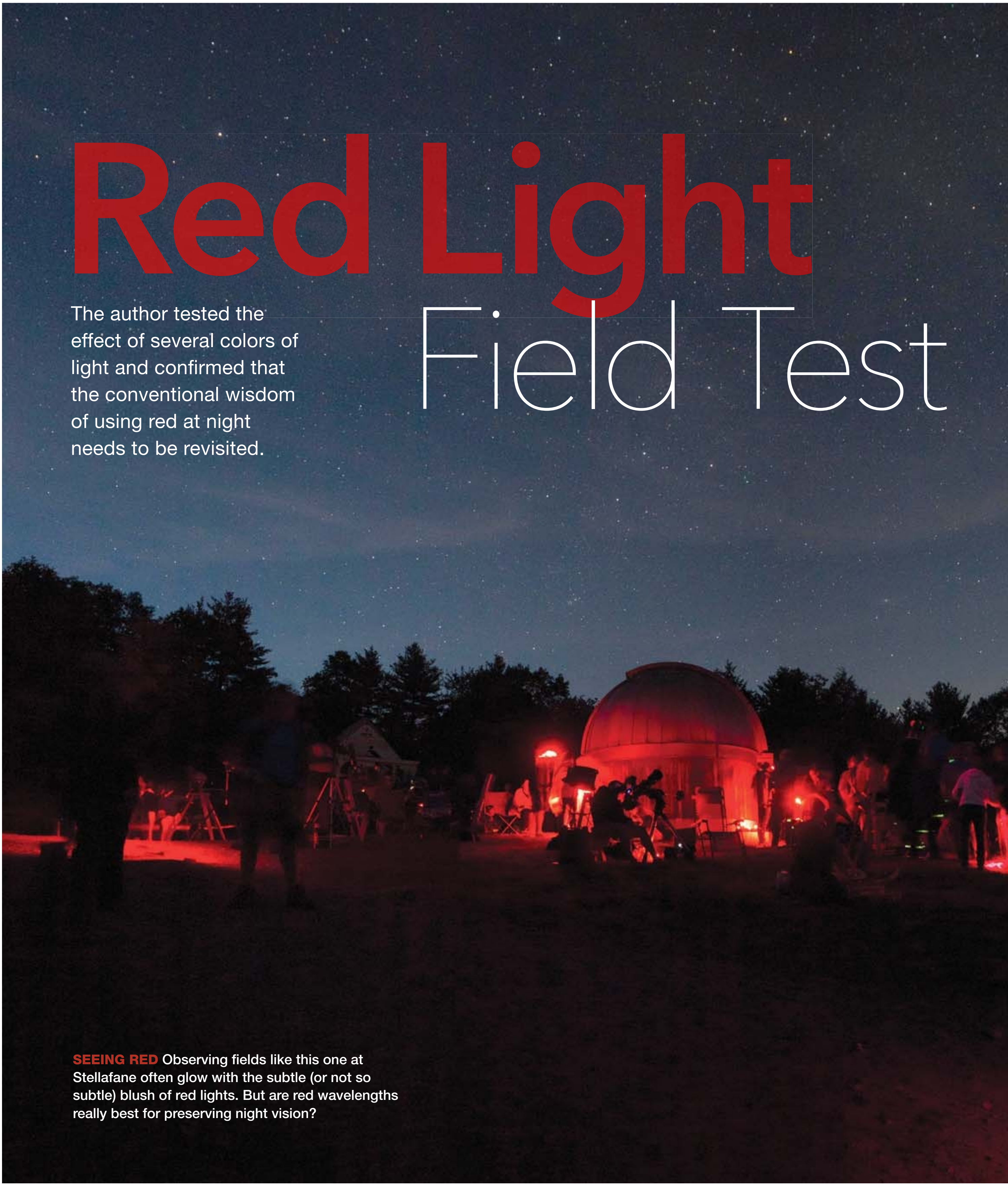
Chang'e 7
LAUNCH: 2023
ORGANIZATION: CNSA
LANDING SITE: TBD, likely south pole

MOON: NASA GSFC / ARIZONA STATE UNIVERSITY; SPACECRAFT ICONS: VECTORPOCKET / ISTOCK / GETTY IMAGES PLUS; ASTRONAUT ICON: ARTEM KOVYAZIN / THE NOUN PROJECT; ROCKET ICON: MISBAHUL MUNIR / THE NOUN PROJECT



4 flybys
11 orbiters
2 orbiters & landers
2 orbiters & landers & rovers
6 landers
4 landers & rovers
PEREGRINE
HAKUTO-R MISSION 2
CHANG'E 5
Lacus Mortis
MARE IMBRIUM
CHANG'E 3
APOLLO 15
XL 1
Aristarchus Crater
MARE SERENITATIS
Taurus Littrow Valley
ALINA
APOLLO 17
MARE CRISIUM
OCEANUS PROCELLARUM
MARE TRANQUILLITATIS
MARE INSULARUM
APOLLO 11
OMOTENASHI
APOLLO 12
APOLLO 14
MARE FECUNDITATIS
MARE COGNITUM
APOLLO 16
SLIM
MARE NECTARIS
MARE HUMORUM
MARE NUBIUM
LUNA 25
LUNA 27
CHANDRAYAAN 2
LANDING SITE: TBD
CHANG'E 6
CHANG'E 7
CHANG'E 4
STATIO TIANHE, INSIDE VON KÁRMÁN CRATER (FARSIDE OF THE MOON)
Key
** ACTIVE MISSIONS AS OF APRIL 15
LANDER
ROVER
CREWED MISSION
CUBESAT
APOLLO MISSION
NOTE: Paths shown represent mission type rather than actual trajectories.

ORANGE YOU GLAD? by Ken Wishaw



Red Light Field Test

The author tested the effect of several colors of light and confirmed that the conventional wisdom of using red at night needs to be revisited.

SEEING RED Observing fields like this one at Stellafane often glow with the subtle (or not so subtle) blush of red lights. But are red wavelengths really best for preserving night vision?

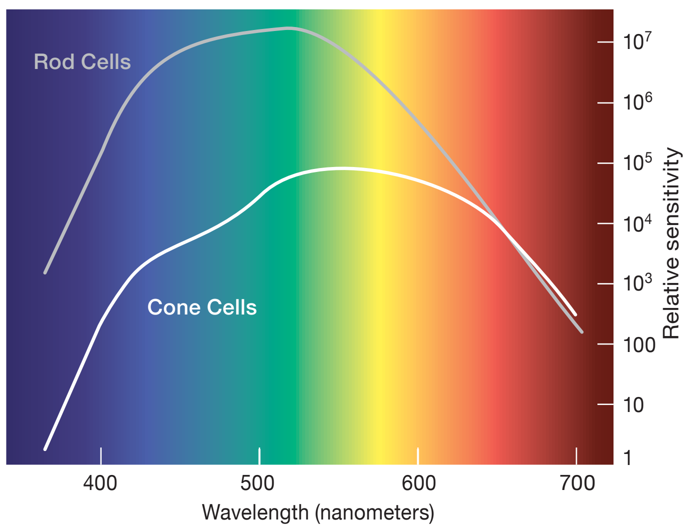
Protection of the eyes' dark adaptation is vital to visual astronomers. They share this need with aviators, mariners, and military and security personnel. Even nocturnal pedestrians benefit from not being "night blind." Yet while we have a decent understanding of how the eye recovers after it's exposed to bright light, few researchers have investigated how exposure to faint light sources impairs vision, or which color least interferes with dark adaptation at low levels.

Red has traditionally been the lighting color of choice by visual astronomers, both for navigating safely around their environment and for reading charts. But there are no data to confirm that red is in fact the most appropriate color for this purpose. When asked, astronomers will often (and incorrectly) state that the retinal receptors we use in dark conditions can't detect red light, and therefore night vision is immune to red light. Probably another reason astronomers have used red light is its historic use in photography dark rooms. However, red lighting in dark rooms was not related to visual dark adaptation; rather, black-and-white photography paper was usually made red insensitive, so that developers could work in light that would not affect the paper instead of having to operate in total blackness.

In *S&T*'s June 2016 issue (page 22), Robert Dick argued that from a visual physiology perspective, *orange* may be a better color than red for many people. But he limited his testing to his personal experience. As I am a doctor with postgraduate training in visual physiology, his arguments all made sense to me, and I believed he was onto something. So I decided to test his theory.

Visual Physiology Crash Course

The back of the eye has receptors, called *rods* and *cones*, that convert photons into nerve impulses. Rods only come in one variety in the human eye and are sensitive to a range of wave-



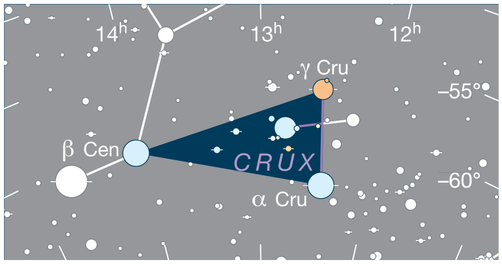
▲ **RODS AND CONES** Rod and cone receptors respond differently to the spectrum of visible light. For most colors, the rod system is far more sensitive to light than the cone system. But the sensitivities are about equal for wavelengths longer than 620 nm.

STAR PARTY: SEAN WALKER / S&T; GRAPH: LEAH TISCIONE / S&T, SOURCE: IDO PERLMAN / WEBVISION AND ROBERT DICK lengths. Cones, on the other hand, come in three types in the human eye: blue, green, and red, corresponding to the colors they detect. The vast majority of the cones are red or green, and these do most of the imaging. There are just enough blue cones to allow the brain to interpret whether an object is blue.

Rods and cones react to color differently. Rods are around 1,000 times more sensitive to green light than cones are, but rods and cones are equally sensitive to red light.

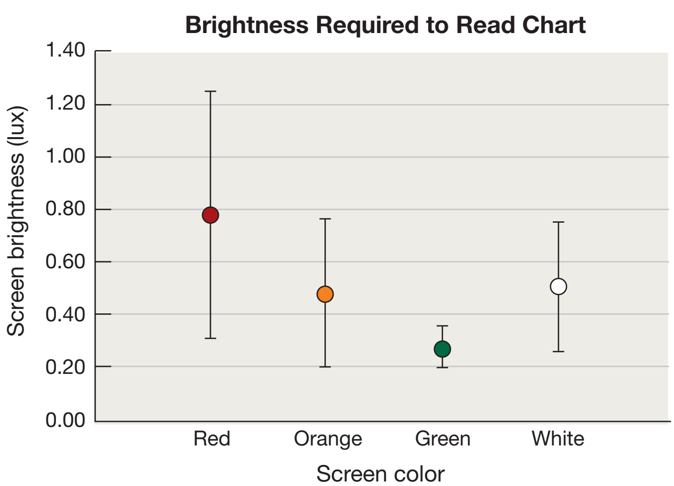
Cones and rods also perform different roles. Cones provide color vision in bright light, known as *photopic* vision, but are unable to detect very low levels of light. Rods provide monochromatic vision in very dim light, known as *scotopic* vision, but bright light quickly saturates them. Intermediate light levels where both cones and rods operate are known as *mesopic* vision.

One significant function of a telescope in visual astronomy is to gather enough light for the eye to operate in the mesopic range, where both rod and cone receptors work. Many observers incorrectly think that visual astronomy relies solely on scotopic vision, but rods only provide low-resolution, monochromatic vision in the peripheral visual fields. Central vision falls on the part of the retina called the fovea, which is exclusively populated by cones packed very tightly together. This high density of cones only occurs in the fovea, which is why only the fovea can perceive fine detail. The acuity of off-axis vision, also known as *averted vision*, decreases by as much as 50% or more per degree. By 10° off axis, observers' visual acuity is less than 20% that of their central vision. Most of the detailed peripheral imagery we perceive is actually concocted by the brain.



▲ **HOW MANY STARS?** After light exposure, participants counted the number of stars they could see with direct vision in the triangle formed by Beta Centauri and Alpha and Gamma Crucis.

Therefore, seeing intricate markings on the Moon or planets, or separating close individual stars, is only possible with cone receptors. Rod receptors' role in visual astronomy is basically limited to detecting the presence or absence of a faint star or nebulosity that is not visible in central vision. This is why observers see nebulosity best with their averted vision, which places the image on the region of maximal rod density, about 20° out from the visual axis. Rods' exquisite sensitivity to green may, however, subtly contribute to observers' color perception.



▲ **RESULTS: READING** Participants required different screen brightnesses in order to read the test chart, depending on the light color used.

Dark Adaptation

An eye that is fully dark-adapted can be up to 500,000 times more sensitive than an eye that is fully light-adapted. Pupil dilation only plays a minor role in dark adaptation, allowing a rapid increase in sensitivity by a factor of 30. Most of the dark adaptation occurs within the rods and cones themselves. As rods and cones receive photons and create neural impulses, they are depleted of the photochemicals that create these impulses. Because these molecules take time to regenerate, the process is a self-regulating sensitivity mechanism tied to light exposure. During periods of darkness, the photochemicals fully regenerate, and sensitivity increases.

Cones take 15 minutes to fully dark-adapt, while rods take at least 30 to 40 minutes. To be able to separate extremely faint objects from the dark background, rod receptors are interconnected with many other rod receptors, producing a combined signal. This acts as a background-noise reduction mechanism but leads to further loss of visual acuity in the periphery.

When using lights during an observing session, our goal is to find the right combination of intensity and color to enable us to read maps and navigate around our equipment with the least effect on our dark adaptation. For most people, the red cone receptors compose the majority of our cones. As observers depend on cone function to see detail, the use of red light may confer no advantage, because we're undermining the dark adaptation of the very cones we need. Conversely, given how sensitive rods are to blue-green light, this color should be the worst color for protecting rod receptor vision.

Dick hypothesized that orange (specifically, "amber") light might be optimal, because it stimulates both red and green cones and therefore may not need to be as bright as red light. Orange light also avoids overstimulating the rods as occurs with blue-green light.

However, it's worth noting that, while the majority of people have around 70% red cone receptors, researchers have recently discovered that in people with normal color vision this fraction may vary from as little as 27% to as high as 90%. This would suggest that the optimal color for protecting dark adaptation might also vary from person to person.

STAR FIELD: S&T DIAGRAM; GRAPH: THE AUTHOR

The Trial

The Queensland Astrofest presented a unique opportunity to test experienced astronomers under exceptionally dark conditions. Held every August, this 10-night festival is held at Camp Duckadang, some 160 kilometers northwest of Brisbane, the capital of Queensland, Australia. Skies are exceptionally dark, with a limiting magnitude of 6 or better, and the core of the Milky Way overhead often casts a shadow!

Given that the test protocol would take up to 90 minutes per astronomer, the 10 nights gave me sufficient time to test 15 (very patient) astronomers. Prior to testing I confirmed they didn't suffer from color blindness, poor visual acuity, diabetes, or other exclusion criteria. I also determined their limiting magnitudes by asking them to count how many stars they could reliably see with dark-adapted, direct vision in a specific area of the constellations of Centaurus and Crux, as defined by the International Meteor Organization.

During the actual test, once participants were fully dark-adapted, they read an optometry visual acuity chart from a laptop computer, comprising black lettering on variously colored backgrounds. They could adjust the brightness as much as they needed to read fluently out loud at their baseline value. I determined the screen brightness using a lux meter. After 1 minute of viewing the chart, I turned the screen off.

I then reassessed their limiting magnitudes 1 and 4 minutes later to see how reading the chart affected their dark adaptation. I used two metrics: The change in star count with direct vision served to test their cones, while the ability to see both the Coalsack dark nebula, which lay within the test field, and the nearby Small Magellanic Cloud were a proxy for rods.

We did the test in turn using red, orange, green, white, and finally bright red (4 lux) backgrounds, with time to fully readapt between each color test. (For comparison, a white sheet of paper illuminated by the full Moon is 0.1 lux.) Viewed in the daytime, all these screens are virtually black! I also conducted each test at the same time each night, with essentially identical sky conditions.

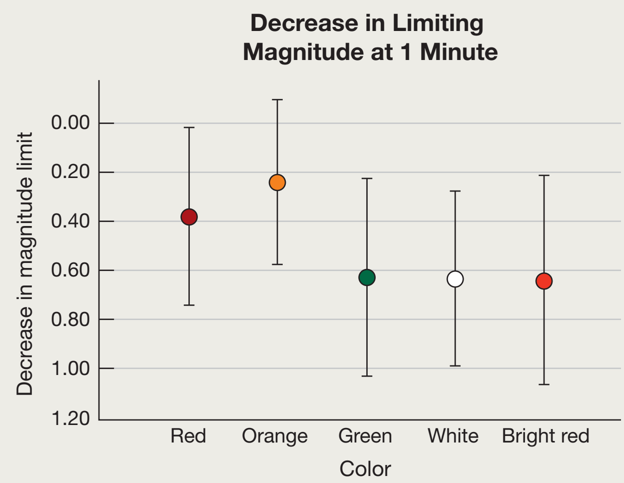
Outcome

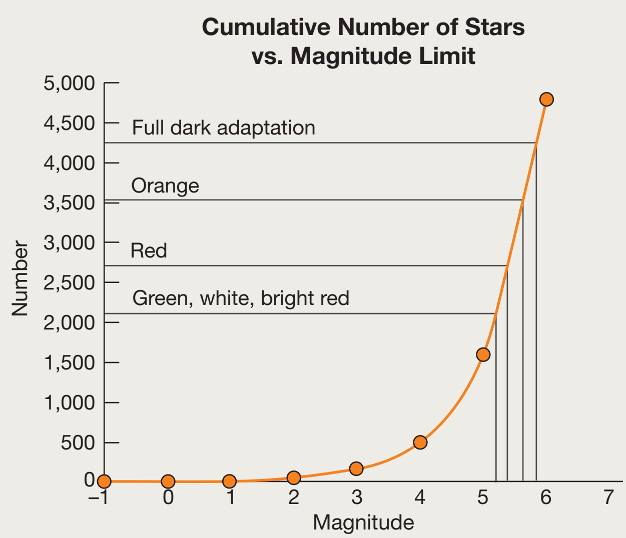
Red screens needed to be three times as bright as green screens for participants to read at their baseline visual acuity level (facing page). The mean brightness of the orange screens was brighter than the green screens but dimmer than the red screens. Orange light caused the least loss of dark adaptation for both cone and rod vision, at both 1 minute and 4 minutes after exposure. As expected, green and white caused the most impairment, but a bright red screen was as damaging to night vision for both rod and cone vision as a green or white screen, confirming night vision is not immune to red light. Green light, even though it was significantly dimmer than other colors, was the most damaging to rod vision.

How this translates to practical viewing can be seen in the diagram comparing the number of stars visible versus limiting magnitude at right. The curved line, developed by Nick Lomb of Sydney Observatory, represents the theoretical number of stars visible at different magnitude limits. The decrease in the number of stars visible after exposure to the various colored screens shows orange lighting to have a clear advantage under the dark skies we enjoy at Queensland Astrofest. Exposure to green, white, or bright red light decreases the total visible star count by around 50%.

Thirteen of the 15 participants could detect the Coalsack and Small Magellanic Cloud 1 minute after exposure to orange light. This fell to 11 participants after red light exposure and only six after exposure to green light.

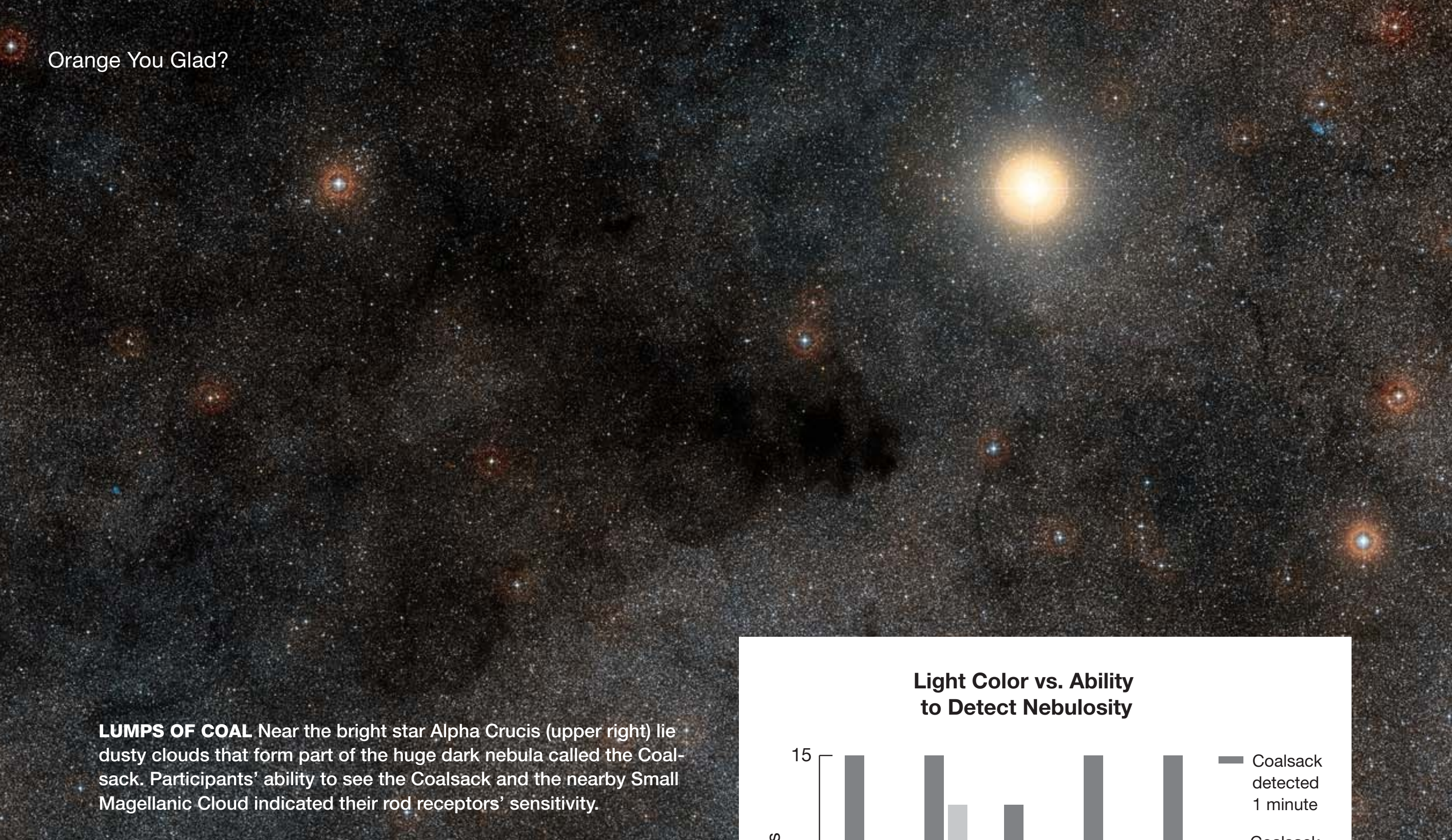
Dark re-adaptation was essentially complete by 4 minutes after exposure to red and orange light, and within 10 minutes after green, white, or bright red light.



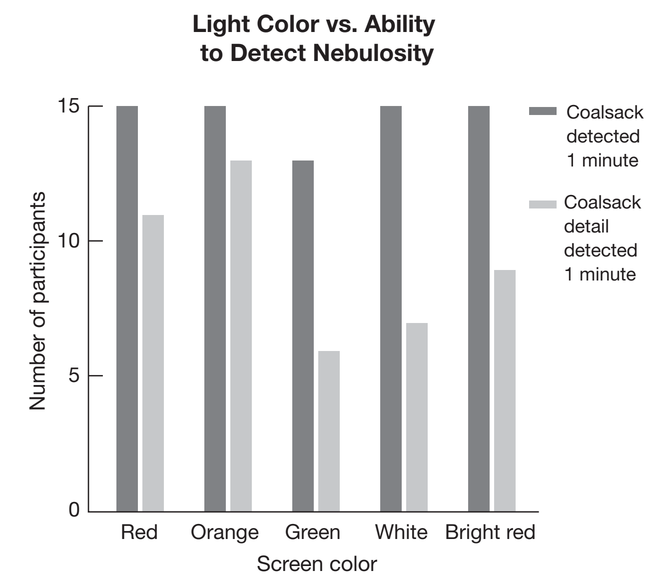


▲ **RESULTS: STAR COUNTS** *Top:* The faintest magnitude observers could see after light exposure changed depending on the color (and brightness) of the test screen. *Bottom:* Translated to number of stars visible, even a small decrease in limiting magnitude has a significant effect.

THE AUTHOR (2), CUMULATIVE STARS GRAPH ADAPTED FROM NICK LOMB, DATA FROM NATIONAL SOLAR OBSERVATORY SACRAMENTO PEAK



LUMPS OF COAL Near the bright star Alpha Crucis (upper right) lie dusty clouds that form part of the huge dark nebula called the Coalsack. Participants' ability to see the Coalsack and the nearby Small Magellanic Cloud indicated their rod receptors' sensitivity.



▲ **RESULTS: ROD VISION** Most observers could detect the Coalsack Nebula after 1 minute, regardless of the screen color they'd been exposed to. But the number of participants who could detect *detail* in the nebula varied noticeably with color.

Star charts are often drawn as light-colored detail on a black background. The selection of black writing on a colored background in this study was deliberate, in order to imitate reading a star chart while also exceeding the colored light exposure. It is reassuring that even after this overexposure, the impaired dark adaptation recovers relatively quickly. Still, if observers are required to reference a star chart frequently, then they should optimize the color and brightness of the light used.

It was likely that in a test of 15 subjects that there would be one or two people with a high ratio of green cone receptors. Such people would likely need substantially dimmer orange screens than red screens. While most people selected orange at around two-thirds the brightness of red, two people needed less than one-third the brightness of orange than red. So there could be significant personal variation; each astronomer needs to find what is right for them.

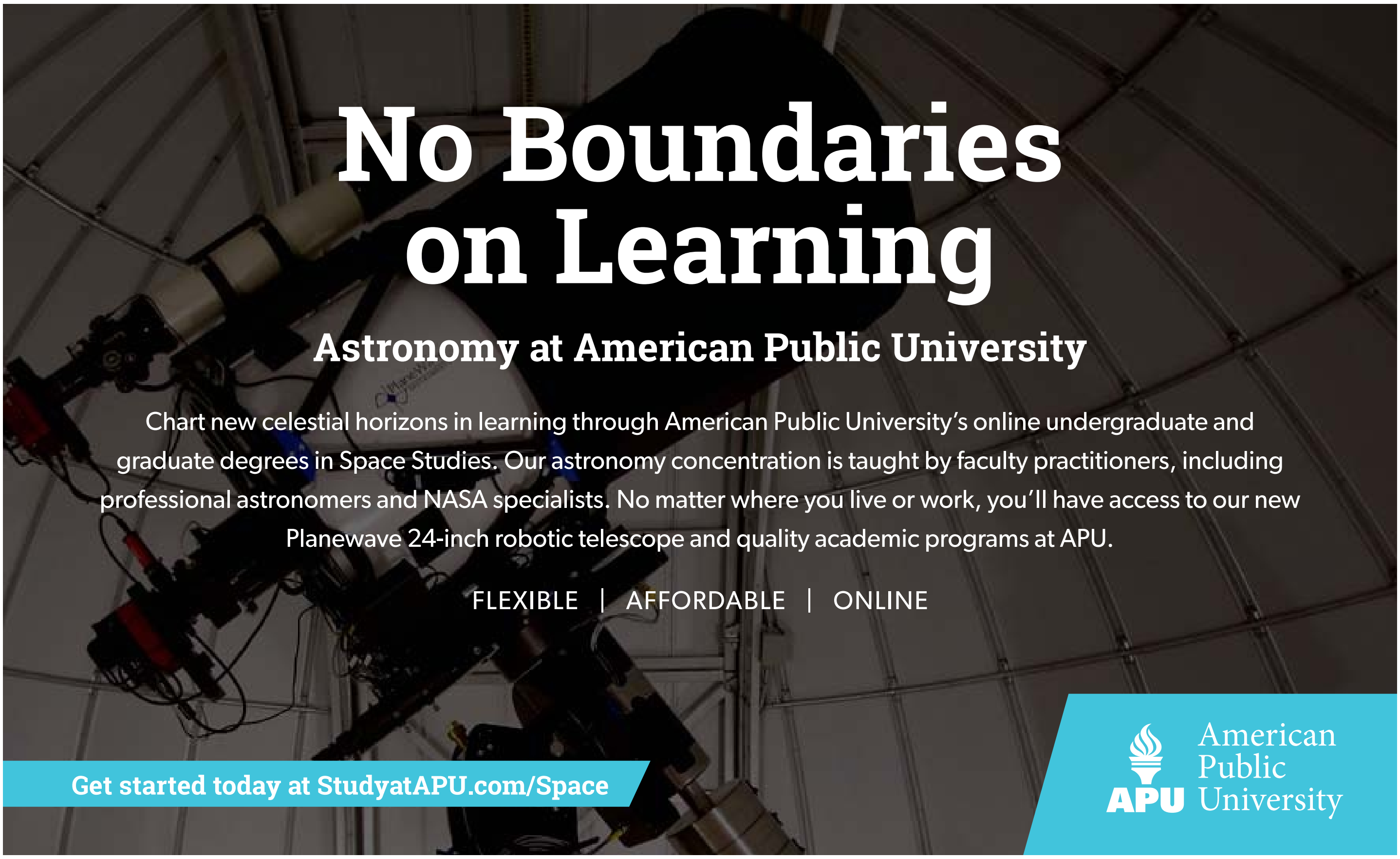
Based on the data, I agree with Dick that orange, rather than red, may be the optimal color for area and chart lighting. While not sufficiently different to warrant astronomers going out and replacing their existing red lighting, the result suggests that new area and chart lighting would best be done in orange. It is also consistent with the International Dark-Sky Association's recommendation to light pedestrian areas with orange-rich, rather than blue-rich, light, not only to minimize light pollution but also to maximize our ability to see into shadows outside the lit area.

Given the ramifications of this finding on many different people who work in low-light-level environments, larger studies — with slightly different design to remove the subjectivity of star counting — is definitely warranted. In the meantime, this study suggests that orange is the new red!

■ **DR. KEN WISHAW** is a retired anesthesiologist and an Honorary Senior Fellow and Adjunct Professor at the University of the Sunshine Coast, Queensland, Australia. He has a post-graduate qualification in astronomy from the University of Southern Queensland and is secretary of the Brisbane Astronomical Society. Contact him at **kenwishaw@gmail.com**.

Find the full research paper on the Brisbane Astronomical Society's website: bas.asn.au.

COALSACK: ESO / DIGITIZED SKY SURVEY 2 / DAVIDE DE MARTIN; GRAPH: THE AUTHOR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OBSERVING
July 2019

1 DAWN: See if you can spot the thinnest sliver of the waning Moon 6° upper right of Venus shortly before sunrise in the east-northeast. The Morning Star will disappear from view later in July, and will only reappear in September in the evenings, so enjoy the view while it lasts.

2 NEW MOON (3:16 P.M. EDT) This is seen as a total solar eclipse in a narrow band crossing parts of the Pacific Ocean, northern Chile, and central Argentina. Much of the rest of South America, a small section of Central America, and some Pacific islands will see the partial phases (page 50 has details).

4 EARTH is at aphelion, farthest from the Sun for 2019, at a distance of 152,104,285 kilometers.

5 DUSK: The thin waxing crescent Moon is in Leo, the Lion, less than 3° right of Regulus.

8 EVENING: The Moon, just shy of first quarter, is 2° from Porrima, or Gamma (γ) Virginis.

9 EVENING: Find the first-quarter Moon, still in Virgo, some 7° from Spica the next evening.

9 ALL NIGHT: Saturn arrives at opposition. The magnificent ringed planet shines all month in Sagittarius, upper left of the Teapot and just below the Teaspoon asterism.

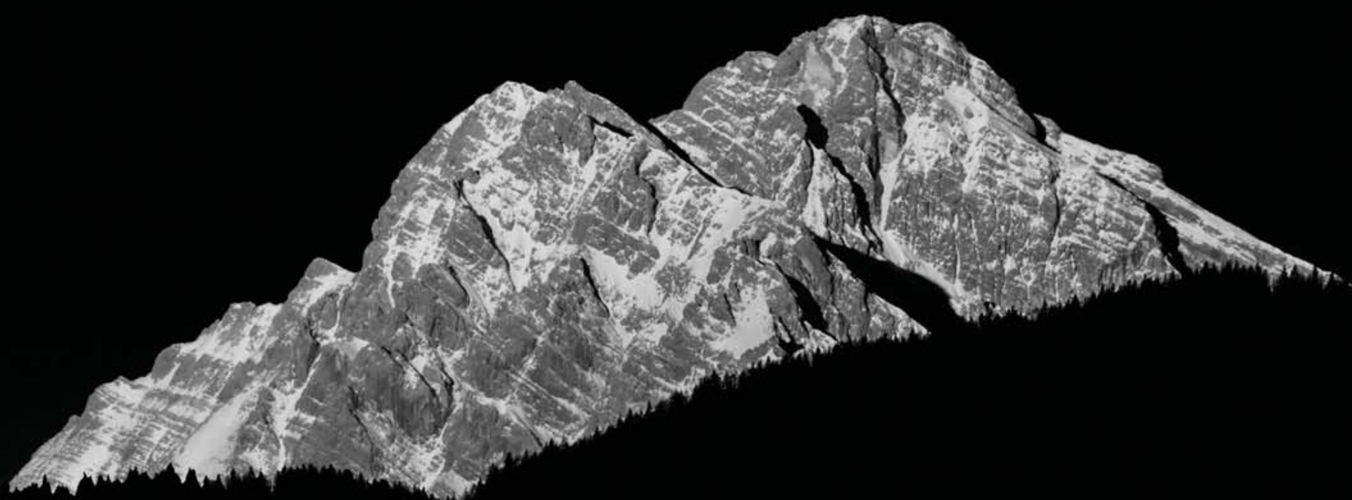
12–15 DUSK: The waxing gibbous Moon is poised to provide quite the spectacle over the next few evenings as it passes from Scorpius through Ophiuchus and into Sagittarius. The first evening it forms a triangle with Jupiter and Antares, sliding over to the other side of the gas giant the following evening. The Moon concludes this quartet of eves nestled against Saturn, less than 2° separating the two.

16 FULL MOON (5:38 P.M. EDT) A partial lunar eclipse is visible over most of the globe; only North America and northeastern Asia will be excluded from viewing any of the phases (see page 50).

20 NIGHT: As the waning gibbous Moon rises in the east-southeast, contemplate the moment 50 years ago when humankind first stepped onto our closest celestial neighbor.

28 DAWN: Taurus rises in the east-northeast with the waning crescent Moon trailing Aldebaran by 5° or more.

29–30 ALL NIGHT: The Delta Aquariid meteor shower is expected to peak (see page 50).
— DIANA HANNIKAINEN



The Moon floats gracefully above Monte Antelao, the second-highest peak — at 3,264 m (10,709 ft) — in the Dolomites in northeastern Italy.
GIORGIA HOFER

JULY 2019 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			

NEW MOON

July 2
19:16 UT

FIRST QUARTER

July 9
10:55 UT

FULL MOON

July 16
21:38 UT

LAST QUARTER

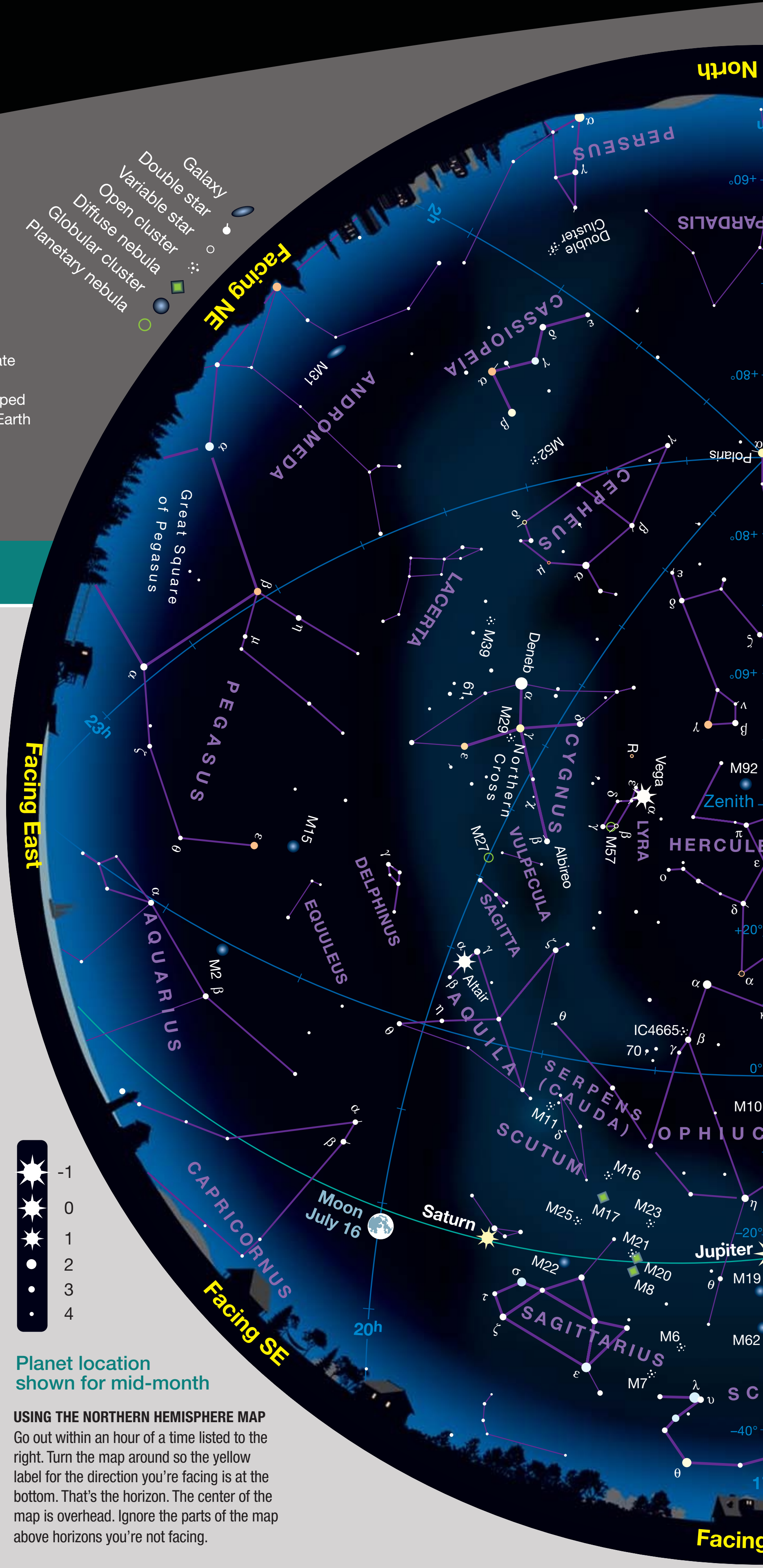
July 25
01:18 UT

DISTANCES

Perigee	July 5, 05^h UT
363,726 km	Diameter 32′ 51″
Apogee	July 21, 00^h UT
405,481 km	Diameter 29′ 28″

FAVORABLE LIBRATIONS

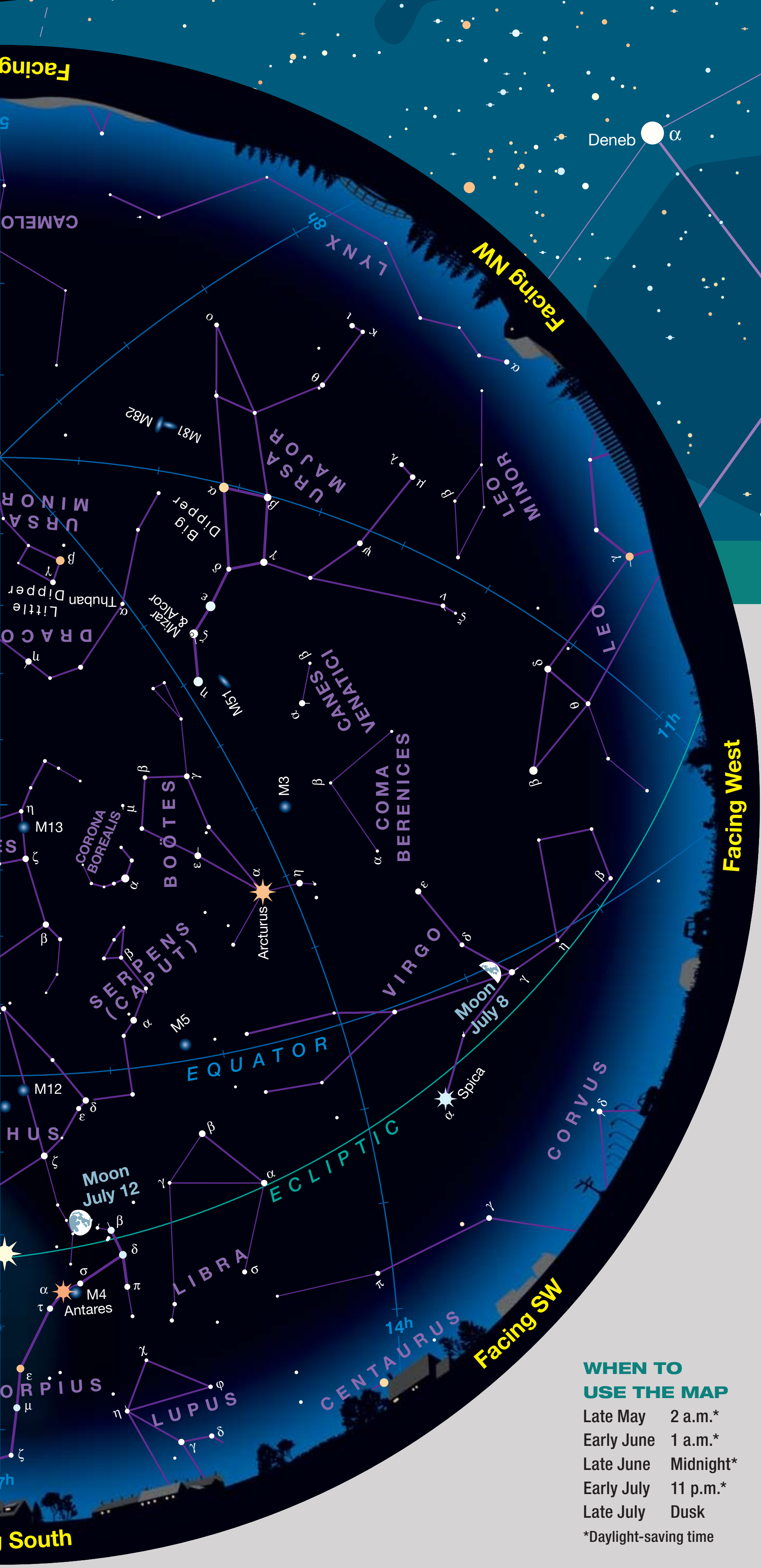
- Boguslawsky Crater July 9
- Lyot Crater July 11
- Lavoisier Crater July 28
- Vasco da Gama Crater July 30

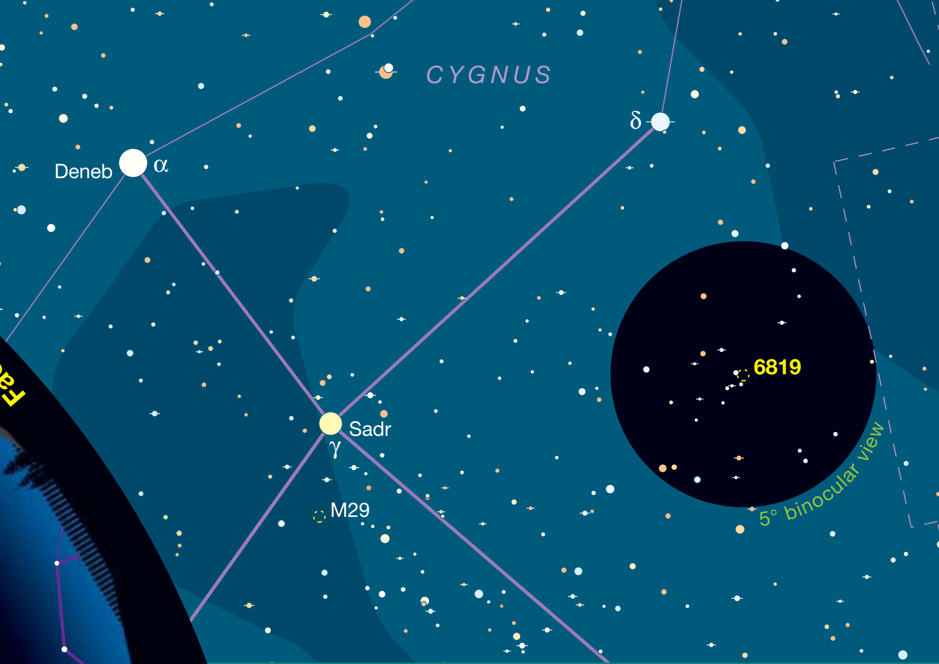


Planet location shown for mid-month

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

Galactic Outpost

Lying as it does along the axis of the Milky Way, the constellation Cygnus, the Swan, is so clotted with clusters, nebulae, and asterisms that one could spend a lifetime exploring it. One of the constellation's lesser-known delights is the open cluster **NGC 6819**. Draw a line 5° south from Delta (δ) Cygni and another line 8° west from Sadr, or Gamma (γ) Cygni. The two lines intersect on a Y-shaped asterism about ½° across. NGC 6819 spills out of the open arms of the Y like fruit from a cornucopia. At 10× all I can make out is a fuzzy patch, but at 15× the cluster starts to show some resolution. The difficult part isn't finding the cluster, it's pulling it out of the very rich Milky Way star field.

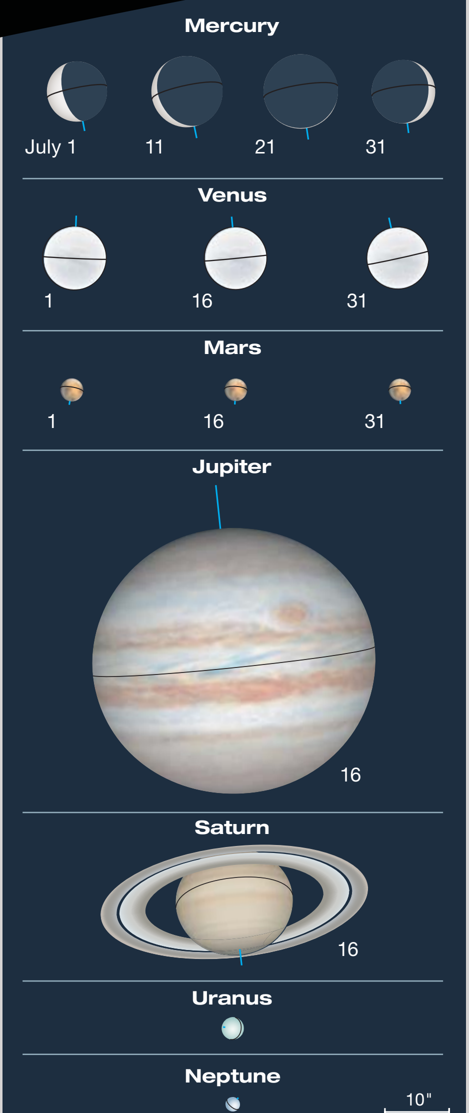
Here's the crazy part: Everything else in that same binocular field is much closer to us than NGC 6819, which lies around 7,700 light-years away. So the challenge isn't picking the cluster out of the background stars, it's peering through the foreground stars — including the Y-shaped asterism — to perceive the distant cluster. A couple of quirks of galactic geography make the detection possible. First, NGC 6819 floats just far enough above the plane of the Milky Way to rise out of the foreground clutter that lies along the neck of the celestial Swan. And second, we're looking "sideways" in galactic terms, neither inward toward the center of the Milky Way, nor outward toward the galactic anticenter (*S&T:* Jan. 2019, p. 43), but at least partly along the gap between our own Orion Spur and the Perseus Arm. NGC 6819 is a sort of cosmic landmark, telling us something about our own place in the galaxy — not bad for a "faint fuzzy."

■ **MATT WEDEL** is obsessed by the prospect of using binoculars as a tool of self-discovery.

WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Dusk

*Daylight-saving time



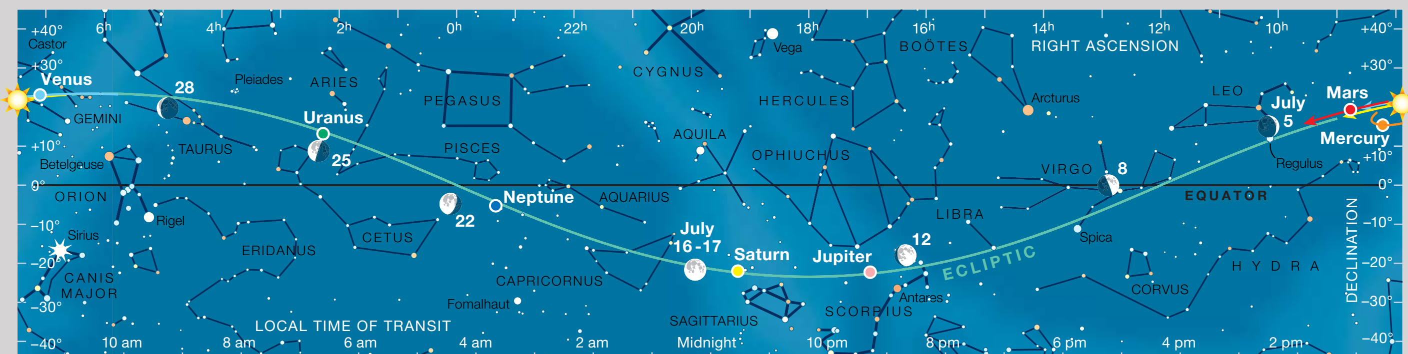
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** hidden in the Sun's glow all month • **Venus:** visible at dawn through the 22nd • **Mars:** hidden in the Sun's glow all month • **Jupiter:** visible at sunset, sets early morning • **Saturn:** visible from dusk to dawn

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$6^h\ 37.6^m$	+23° 09′	—	–26.8	31′ 28″	—	1.017
	31	$8^h\ 38.7^m$	+18° 27′	—	–26.8	31′ 30″	—	1.015
Mercury	1	$8^h\ 17.6^m$	+18° 45′	24° Ev	+1.0	9.4	27%	0.717
	11	$8^h\ 21.3^m$	+15° 59′	16° Ev	+2.6	11.1	10%	0.607
	21	$7^h\ 58.6^m$	+15° 36′	5° Mo	+5.4	11.6	1%	0.580
	31	$7^h\ 39.6^m$	+17° 27′	14° Mo	+2.3	9.9	11%	0.678
Venus	1	$5^h\ 44.8^m$	+23° 12′	12° Mo	–3.9	9.9	98%	1.683
	11	$6^h\ 38.2^m$	+23° 22′	9° Mo	–3.9	9.8	99%	1.703
	21	$7^h\ 31.3^m$	+22° 23′	7° Mo	–3.9	9.7	99%	1.718
	31	$8^h\ 23.5^m$	+20° 19′	4° Mo	–3.9	9.7	100%	1.728
Mars	1	$8^h\ 06.1^m$	+21° 29′	21° Ev	+1.8	3.7	99%	2.564
	16	$8^h\ 45.6^m$	+19° 14′	16° Ev	+1.8	3.6	99%	2.613
	31	$9^h\ 23.9^m$	+16° 29′	11° Ev	+1.8	3.5	100%	2.648
Jupiter	1	$17^h\ 02.6^m$	–22° 15′	158° Ev	–2.6	45.5	100%	4.336
	31	$16^h\ 52.7^m$	–22° 05′	127° Ev	–2.4	42.8	99%	4.607
Saturn	1	$19^h\ 16.0^m$	–21° 57′	171° Mo	+0.1	18.4	100%	9.045
	31	$19^h\ 06.8^m$	–22° 16′	158° Mo	+0.1	18.3	100%	9.098
Uranus	16	$2^h\ 15.6^m$	+13° 04′	77° Mo	+5.8	3.5	100%	20.045
Neptune	16	$23^h\ 18.6^m$	–5° 35′	125° Mo	+7.8	2.3	100%	29.346

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-July; 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.

Orange-gold Antares gleams as the Scorpion's heart.

The Colors of Summer

Look up into July's night sky to see stars tinged with orange, yellow, blue, and possibly even green.

"Everything that lives strives for color."
— Johann Wolfgang von Goethe, as translated in the Dover Publications edition of Minnaert's *The Nature of Light and Colour in the Open Air*

Even in the heart of summer, winter is just a few miles from us. I mean a few miles *upward*, in cirrus clouds where ice crystals can project the circles, arcs, pillars, and patches of often vividly and variedly colored halo phenomena. Summer is also the great season for the abrupt bursts of convective showers and sunlight that late in a day will weave the sky-spanning arc of the magnificent rainbow.

At night, however, beginning amateur astronomers soon learn that the colors seen in visual astronomy are far less intense than those that appear in the images of astrophotography. Even so, there's great beauty in the subtle tints observed in many celestial objects — and a great satisfaction felt by those who learn how to perceive them. This is especially so in summer, when we can see many of our most colorful double stars and traces of color in classic planetary nebulae and supernova remnants — and even globular star clusters. We'll begin to explore them in this, the first of a two-part column.

Tints of the brightest summer stars. Let's start with the brightest single stars of July evenings and what their mostly subtle hues may be.

Arcturus has been described by Senior Editor Alan MacRobert as being the color of ginger ale. The star's combination of spectral type and apparent brightness make its hue truly unique among stars seen with the naked eye. What color would *you* call it?

For many of us the "summer sapphire," Vega, has a vivid hint of blue that brings cool refreshment to the eye and mind after a hot summer day. A sensitive artist friend of mine portrayed Altair as shining an "intense saffron yellow," but most of us will detect at best a touch of pale yellow in its glow. The same friend praised the color of Deneb as the white of the Arctic swan. As for Antares — most of us agree that it glows with a warm campfire orange-gold. Can you see the contrast between the hue of Antares and the white of the brightest star clouds of the summer Milky Way?

The colored doubles of summer. The most famous of all color-contrast double stars is of course Beta (β) Cygni — Albireo, the beak of Cygnus, the Swan. The gold of the magnitude-3.1 primary and blue of the magnitude-5.1 secondary are best seen in telescopes of 4-inch to 6-inch aperture, and the pair can (and should) be split at very low magnifications.

Cygnus has several very famous colorful double stars, but I have to keep reminding people that the orange of Omicron^2 (ο) Cygni shares the same wide-field view of what I see as the gold, delicate green, and even purple of Omicron^1 Cygni (31 Cygni). Tell me what you observe of them and I'll have more about this in a future issue.

Two more overlooked wonders of double-star colors are the orange and blue-green Alpha (α) Herculis (Rasalgethi) and the elusive green companion of Antares. The latter, a magnitude-5.4 star, is 3″ from the 1st-magnitude blaze of Antares and requires only a medium-size telescope to detect — but it also requires truly excellent "seeing," especially in northern lands where Antares suffers more turbulence low in the sky. Is the companion's color really green or just an illusion from contrast with the primary's orange-yellow? Some skilled observers have seen the companion emerge green, all alone before the primary appeared from behind the edge of the Moon.

Next month. In Part 2 of this column we'll cover the colors of summer nebulae, supernova remnants, star clusters, and atmospheric optics effects.

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

AKIRA FUJII

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

Gas Giant Gaze

Three bright planets leave us for a while, but the two that remain accompany us throughout the night.

This is a month when we lose sight of three of the five classic bright planets — Mercury and Mars in the Sun's afterglow and Venus in the solar glare just before sunrise. Our compensation is that the other two bright planets, Jupiter and Saturn, are visible most of the night, at or near their brightest and biggest.

There are also two eclipses viewable in parts of our world (though not North America) during July. One is a total solar eclipse, the other a partial lunar.

DUSK ONLY

Mercury, low in the west-northwest at dusk on July 1st, has dimmed to magnitude 1.1 and is lost from view as it fades rapidly in the following days. The little world reaches inferior conjunction with the Sun on July 21st — the last such event before its rare transit across the Sun's face on November 11th.

Mars shines at its (almost) dimmest magnitude of 1.9 all this month as it descends ever so slowly deeper into the Sun's bright afterglow. In the opening days of July it lies about 4° right of Mercury, and on July 3rd is about 3° upper left of a very thin crescent Moon — all very low in the west-northwest. It will only be visible at more southerly latitudes in North America.

Note that *The Astronomical Almanac* estimates that Mars and Mercury at dusk and Venus at dawn should all be lost from view during, or by about the end of, the second week of July. Mercury will then be out of visibility for a few weeks until it reappears in the morning sky at the end of July, Venus for two months, and Mars for about three months.

ALMOST ALL NIGHT

Jupiter reached opposition back on June 10th. But it begins the month of July still as brilliant, at magnitude –2.6, and still almost as big, at 45.5″ wide. By the end of July the kingly world has faded a bit — to –2.4 — and shrunk a little — to 43″ — but remains a rich and rewarding sight in telescopes. (See pages 50–51 for the best times to observe the Galilean moons and the Great Red Spot.)

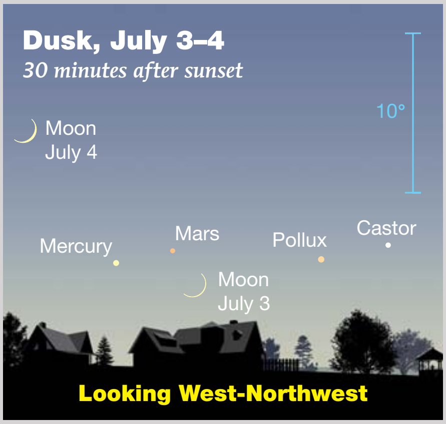
For viewers around latitude 40° north, Jupiter sets as early as about 2 a.m. daylight-saving time at month's end. The time Jupiter culminates (when it's at its highest) backs up from a little before 11:30 p.m. in early July to a little after 9 p.m. local time, in evening twilight, at month's end.

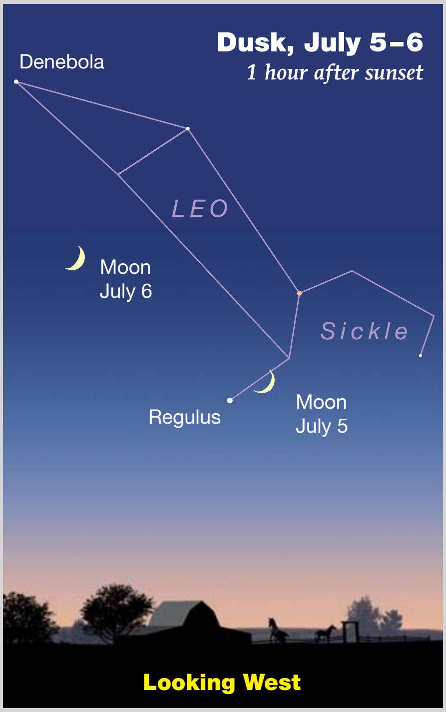
Jupiter continues to retrograde (move westward with respect to the background stars) in July, a little less than 7° separating it from Antares by month's end.

Saturn comes to opposition on July 9th so is visible virtually all night throughout the month. Saturn shines at magnitude +0.1 left of the Teapot asterism of Sagittarius. A closer look finds the ringed planet hanging like a gleaming droplet just spilled from the little Teaspoon asterism.

Saturn's oblate globe reaches an equatorial diameter of 18″. The rings span almost 42″ in your telescope and are tilted more than 24° from edgewise. But viewers around latitude 40° north will see Saturn less than ⅓ of the way up the sky even when at its highest in the south. That time for Saturn occurs a little after 1:30 a.m. daylight-saving time on July 1st but around 11:30 p.m. on July 31st.

Pluto reaches opposition on July 14th — the exact anniversary of the day the New Horizons spacecraft passed closest to it in 2015. Pluto isn't far from Saturn in eastern Sagittarius but you'll





probably need at least an 8-inch telescope (in quite dark skies) and a finder chart (see pages 48–49) to locate and identify Pluto's 14th-magnitude speck of light among the stars.

START OF DAWN

Neptune doesn't reach its highest in the south until morning twilight this month, and **Uranus** trails almost three hours behind it. Finder charts for 8th-magnitude Neptune and 6th-magnitude Uranus are at **https://is.gd/urnep**.

DAWN ONLY

Venus still shines at magnitude –3.9 very low in the bright dawn soon before sunrise, but it becomes lost from view around the 22nd.

EARTH

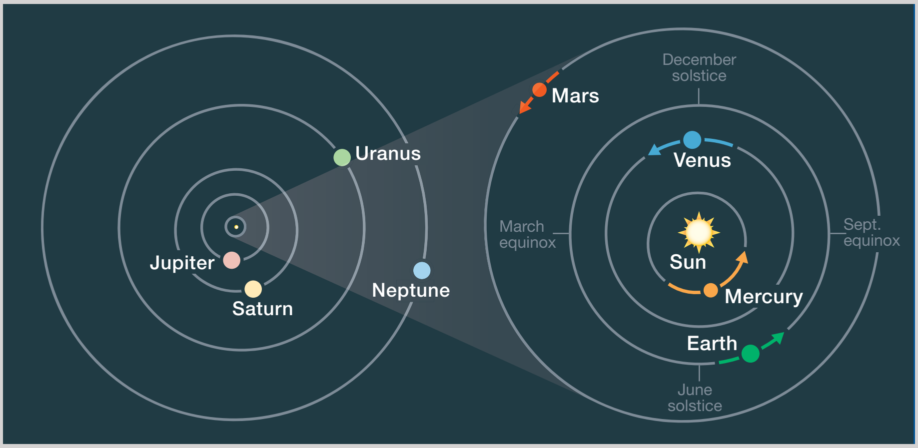
Earth reaches aphelion, its farthest from the Sun for 2019, at 6:11 p.m. EDT on July 4th. At that time our planet is 152,104,285 km (94,513,221 miles), or a little more than 1.1068 a.u., from the Sun.

SUN AND MOON

The Sun is totally eclipsed on July 2nd as seen from limited parts of the Pacific Ocean, Chile, and Argentina (for details on this and the partial solar eclipse in surrounding areas, see page 50).

The Moon is partially eclipsed for most of the Eastern Hemisphere and much of South America on the night of July 16–17 (see page 50 for details). On July 1st, an extremely thin Moon is about 6° right of Venus very low on the east-northeast horizon a mere 30 minutes before sunrise. A thin waxing crescent is less than 3° right of Regulus at dusk on July 5th. A waxing gibbous Moon forms a triangle with Jupiter and Antares at dusk on July 12th, and is only about 4° from Jupiter at the next dusk. The nearly full Moon is in Sagittarius, with Saturn only about 2° left of it at nightfall on July 15th. At the end of the month, the waning crescent Moon is in Taurus some 7–8° upper right of Aldebaran in the early morning hours of July 27th, and a little more than 6° lower left of the red giant the following morning.

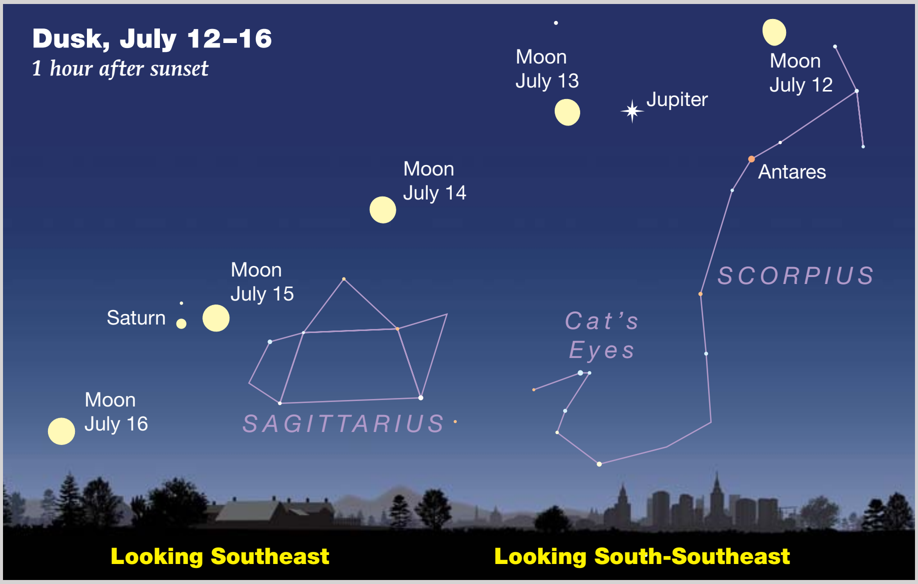
■ **FRED SCHAAF** teaches astronomy at Rowan University and Rowan College, both in southern New Jersey.

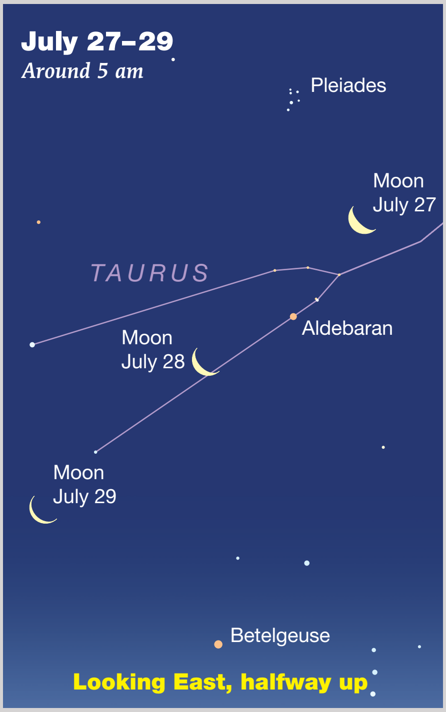


ORBITS OF THE PLANETS

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

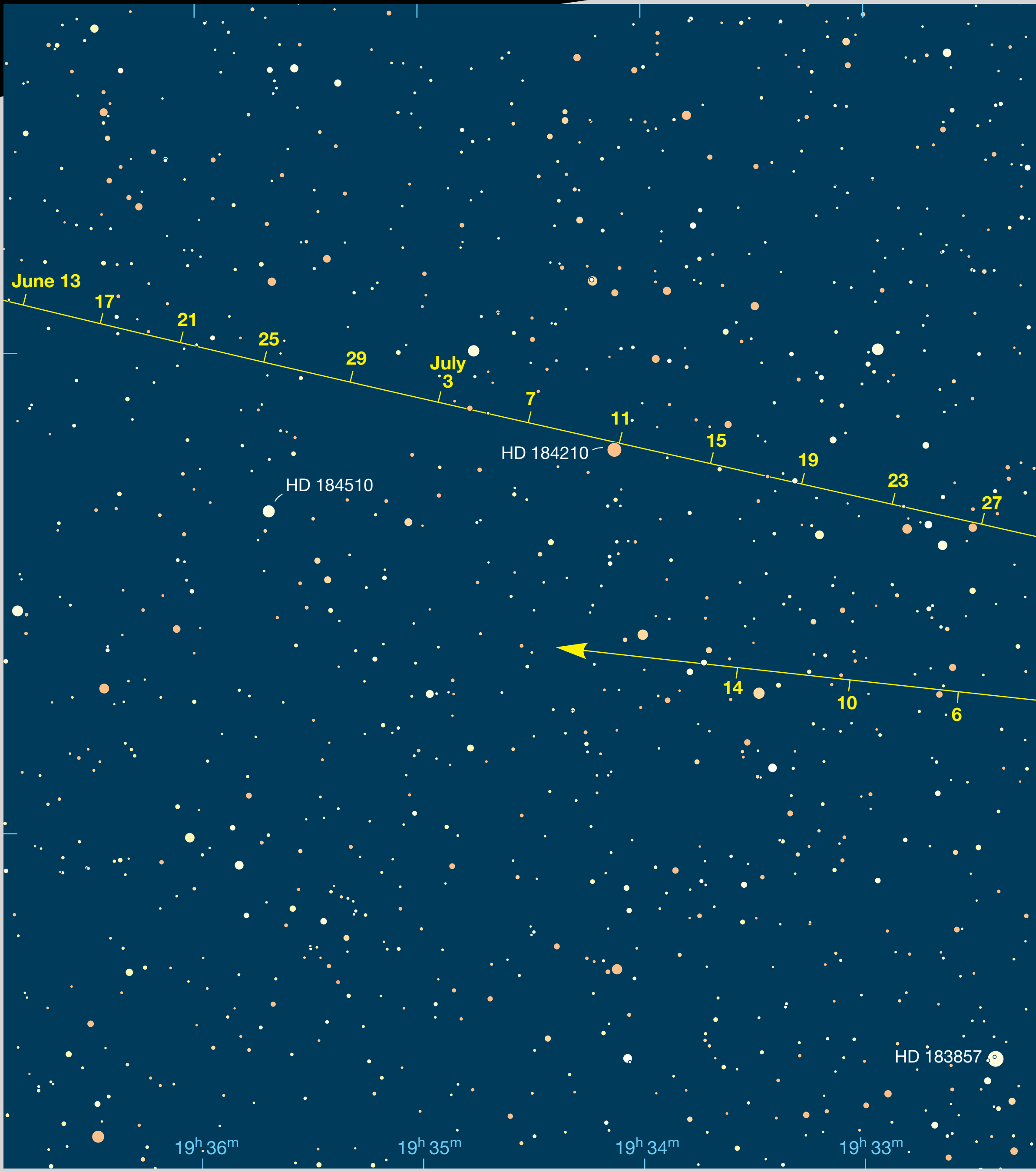
◀▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your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





Finding Pluto

All it takes is planning and patience to find the most beloved dwarf planet.

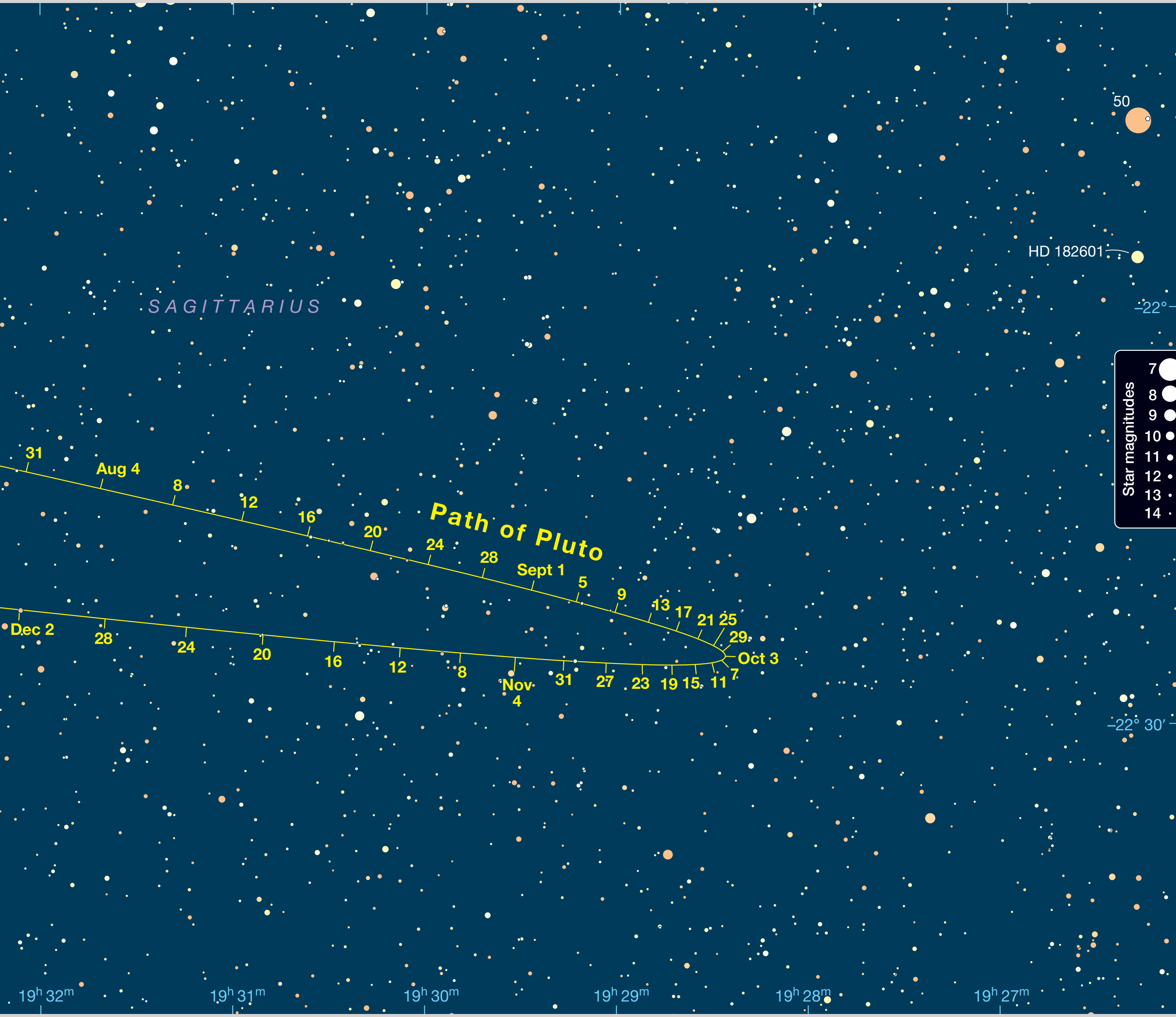


As you read this, the Johns Hopkins Applied Physics Laboratory Kossiakoff Center, in Laurel, Maryland, is revving up for the "Pluto System After New Horizons" conference, scheduled to begin on the date the dwarf planet reaches opposition, July 14th (not coincidentally the anniversary of the New Horizons Pluto flyby). Press releases on fresh findings and theories about Pluto and the Kuiper Belt are sure to fly fast and furious after the meeting, but we can also look forward to a new book based on the conference proceedings (*The Pluto System After New Horizons*, projected publication 2020).

In the meantime, amateur astronomers can turn (or return) their ground-based telescopes to the small speck and contemplate its place in the solar system's history. Many of us have never seen Pluto. It's something of a challenge target, not only because it's dim, but because it takes at least two observations and supporting documentation (a sketch or image) to confirm a sighting. The best approach is to seek it out on the first clear night of a star party. Grab a few buddies (or strangers) to share the view, and bring the same group back to the scope the next clear night. No matter how bad the sketches, if you have a few versions of the same view, you'll be able to confirm that the object labeled "Pluto" in them has indeed shifted to a new position.

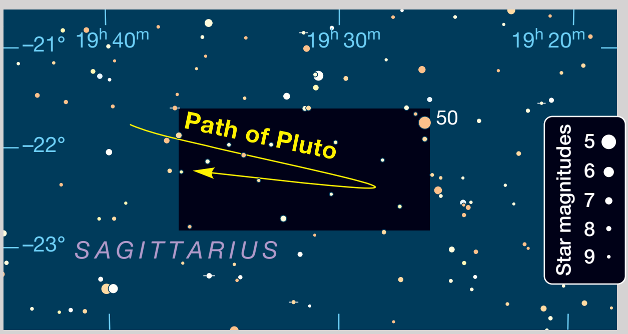
Pluto admittedly doesn't look like much in the eyepiece, appearing as an unremarkable 14.2-magnitude star. In 2018, 50 Sagittarii lay right in Pluto's path. That same star will land you in the general area for observing this year, but easier star-hops begin from HD 184210 or possibly HD 184510. Pluto and 8th-magnitude HD 184210 (HIP 96233) are just two arcseconds apart on July 11th.

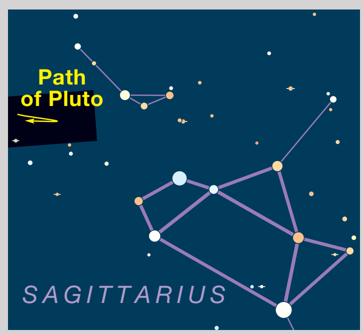
Pluto isn't impossible to find, but its current –22° declination does add a degree of difficulty to the hunt. On the night of opposition, Pluto stands around 28° above the horizon at its highest for observers near latitude 40° north. That's low enough to increase the chances of poor seeing, but still high enough to get



a good look on a good night. A 10- or 12-inch scope should capture the view, although if you're fortunate enough to have access to more aperture, use it. I find Pluto mostly takes time and patience. The star-hop moves slowly, and looking away from the eyepiece to sketch and back again slows things down even more.

Use the charts here to plan your search. Black rectangles on the small key charts at right show the area covered by the next larger chart. The large chart above covers a bit more than 1° of declination and shows the stars to magnitude 14.5. The date ticks on the large chart are for 0^h Universal Time, which translates to late afternoon or evening hours of the date before for North America.





A Pair of Eclipses

THERE WILL BE A TOTAL solar eclipse on July 2nd, but if you're a resident of North America, you'll need to travel to see it. The path of totality, only about 200 km wide, falls mainly on the Pacific Ocean, but also crosses northern Chile and central Argentina. Large parts of the rest of South and Central America will be treated to a partial eclipse. First contact, the moment the Moon's shadow is first cast on Earth, is at 16^h 55^m UT (12:55 p.m. Chile Standard Time). The shadow abandons our planet at 21^h 51^m UT (5:51 p.m. CLT). Although the entire event, from first contact through the partial phases and totality to last contact, is long, lasting around five hours, totality itself is brief. For observers in the ideally located Chilean city La Serena, darkness will last only 2 minutes and 13 seconds, with eclipse maximum falling at 20^h 39^m UT (4:39 p.m. CLT).

Two weeks after this total solar eclipse comes a partial lunar eclipse. On July 16–17, viewers in South America, Europe, Africa, most of Asia, and Australia will see about 65% of the Moon darkened by Earth's shadow. Europe and Africa see the event on the evening of July 16th, with the Moon exiting the penumbral shadow after midnight. Australia sees the action begin early on the morning of July 17th.

July Meteors

THE NEW MOON FALLS ON the night of July 31st–August 1st, so the sky should be dark for this year's Delta Aquariids, which are predicted to peak on July 30th. At its best, this shower can produce as many as 25 meteors per hour. Many will be faint, so find your darkest sky. The shower is fairly long-lived, stretching from about July 12th to August 23rd, so there should be plenty of chances to catch at least a few of the brighter meteors.

As the name suggests, the shower's radiant lies in the constellation Aquarius at the time of peak (it's still in Capricornus in mid-July), so viewing is best from southern locales. Indeed, this is often the best shower of the year for southern observers. However, those at mid-northern latitudes can scout the sky for shower meteors in the early morning hours, when the radiant will be about halfway between the southern horizon and Alpha (α) Pegasi.

Saturn at Opposition

Resplendent Saturn, gleaming gold at magnitude +0.1, arrives at opposition at 17^h UT on July 9th. The great ringed planet will be visible from dusk to dawn, provided the weather cooperates and you have a clear view of the southern horizon. Saturn remains low in the south, shining at declination –22° in Sagittarius. The planet stands around 28° at its highest this month, but that's high enough if the seeing is good. The waxing gibbous Moon encroaches on Saturn's golden light on July 15th, but soon flees the scene.

Action at Jupiter

JUPITER REACHED OPPOSITION in June and remains visible for most of the night in the dim southern reaches of Ophiuchus. Look for it in the southeast at nightfall on July 1st, when its –2.6-magnitude fire blazes about 8½° east of Antares. The gas giant culminates earlier each night; by month's end, it stands highest at nightfall and sinks lower through the evening.

Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. In binoculars, the moons are all but indistinguishable from one another. They orbit Jupiter at different rates, changing positions along a straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time.

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

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.)

These times assume that the Great Red Spot will be centered at System II longitude 308°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 308° and 1⅔ minutes later for each degree more than 308°.

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

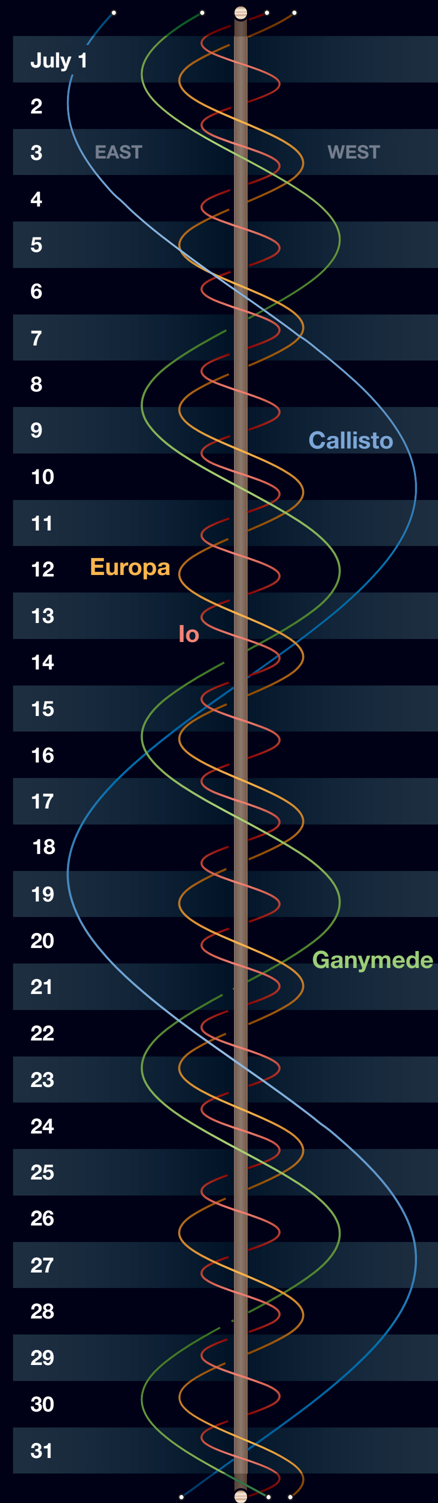
July 1: 7:55, 17:50; **2:** 3:46, 13:41, 23:37; **3:** 9:33, 19:28; **4:** 5:24, 15:20; **5:** 1:15, 11:11, 21:06; **6:** 7:02, 16:58; **7:** 2:53, 12:49, 22:45; **8:** 8:40, 18:36; **9:** 4:32, 14:27; **10:** 0:23, 10:18, 20:14; **11:** 6:10, 16:05; **12:** 2:01, 11:57, 21:52; **13:** 7:48, 17:44; **14:**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

Phenomena of Jupiter's Moons, July 2019

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 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.

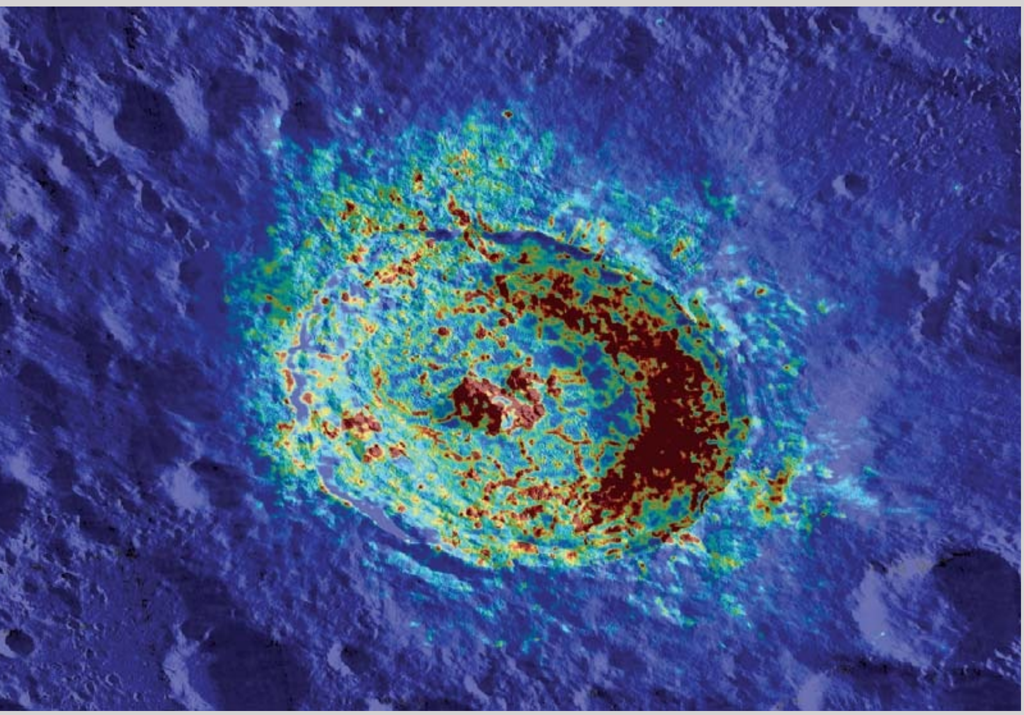
How Old Is That Crater?

A new crater-dating technique yields new insights into what you see on the Moon.

When you observe the Moon, do you ever wonder how old the crater you're looking at is? Wondering is about all you could do for most craters, with the exception of a handful that were dated by studying samples brought back during the Apollo missions that had been shocked or melted during impact. But the formation date of the vast majority of craters was almost entirely unknown . . . until now.

Sara Mazrouei, her advisor Rebecca Ghent of the University of Toronto, and their colleagues have developed an ingenious new technique for estimating the ages of lunar craters based upon the rockiness of their ejecta (*S&T:* May 2019, p. 8). When an impact excavates a new crater, large boulders are thrown out around its rim. The Diviner Lunar Radiometer Experiment infrared thermal sensor, onboard NASA's Lunar Reconnaissance Orbiter, detects such boulders in crater ejecta based on their heat signature. Once night falls on a crater, large boulders cool more slowly than the surrounding *regolith* (soil), appearing as warm spots in a sea of coldness. Over millions of years, these boulders are slowly broken down and covered by dust created by micrometeorite bombardment and by the baking and freezing cycle of each lunar day. It takes about a billion years for boulders to be reduced to dusty rubble and cool as fast as the regolith.

▼ The crater Tycho is seen with LRO Diviner instrument measurements. Red depicts the highest concentration of rocks versus soil and dust. More rocks are seen inside crater rims due to downslope movement exposing new boulders. The rock abundance measurements used to determine crater ages are made *outside* crater rim crests.

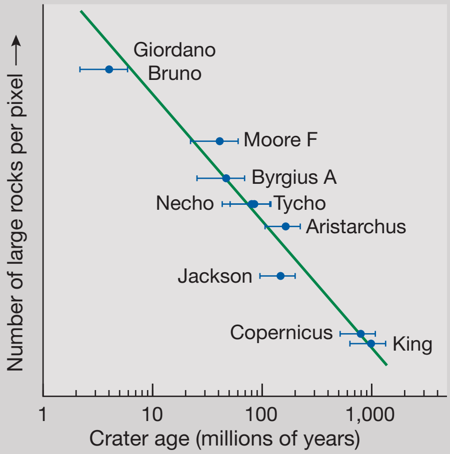


NASA / LUNAR RECONNAISSANCE ORBITER

Using this knowledge, Mazrouei and her colleagues have determined the ages of 111 young lunar craters 10 km and larger. They applied a rock-abundance vs. age calibration published in 2014 by Ghent and colleagues using Diviner-derived rock abundances, in addition to the reasonably well-known absolute ages of nine lunar craters: **Copernicus**, **Tycho**, **King**, **Jackson**, **Aristarchus**, **Necho**, **Moore F**, **Giordano Bruno**, and **Byrgius A**. None of these age estimates is based on laboratory measurements of samples directly from the crater. Instead, most are derived from counting craters superposed on their ejecta and calibrated by the crater counts of mare areas with accurately dated lava samples from Apollo landing sites. These are the best ages available until many more lunar samples can be radiometrically dated by future lunar landers or in terrestrial labs.

An unanticipated discovery from this new dating technique is its discovery that 290 million years ago, the rate of lunar impacts abruptly increased by a factor of 2.6. Terrestrial impact craters show the same increase. For hundreds of millions of years before that, the impact cratering rate for Earth and the Moon was roughly constant.

Mazrouei's coauthor, Bill Bottke of the Southwest Research Institute, speculates that a large collision in the asteroid belt could have sent a surge of asteroid fragments into the inner solar system to cause the upswing in impacts. In fact, he suggests that a col-

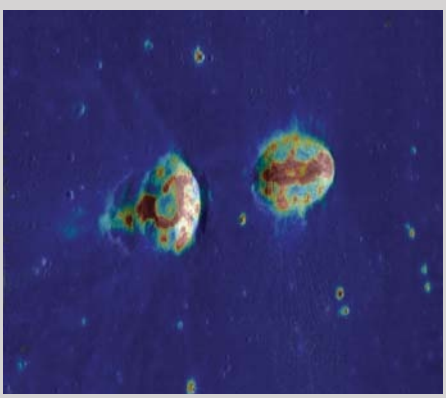


▲ Crater ages plotted by size vs. rock abundance. The bars represent the range of uncertainty of each crater's age.

lision about 300 million years ago that produced the Baptistina asteroid family is a possible source for the increased cratering.

For students of the Moon, the ages of observable craters are of great interest. A list of rock-abundance-derived ages for 19 rocky nearside craters observable with backyard telescopes is included at right. All are younger than 1 billion years old, which, by lunar standards, is quite recent. They are younger than any mare and are about 3 billion years younger than the period of basin formation and intense cratering that ended about 3.9 billion years ago (the "late heavy bombardment").

These craters are good targets to examine for hints of degradation, increasing from the youngest to the oldest. First of all, look to see if younger craters (like **Furnerius A**) have more conspicuous ray systems, which fade with time and usually disappear after a billion years. Young craters should also have fewer subsequent impact pits on their rims, floors, and ejecta. For example, compare nearly pristine Tycho with Copernicus, whose outer walls are pierced by several 2- to 4-km-wide newer craters.



▲ Both Messier (right) and Messier A have rocky interiors but only slight rocky ejecta (red), consistent with their age of 128 million years.

GRAPH: *S&T* DIAGRAM, SOURCE: S. MAZROUEI ET AL. / *SCIENCE* 2019; CRATERS: NASA / LUNAR RECONNAISSANCE ORBITER

Each of these rocky craters has interesting features. Furnerius A, the youngest named large crater on the nearside, is one of two bright rayed craters on either side of **Stevinus**. I call them "The Headlights" because near full Moon they appear as nearly side-by-side bright beacons near the east limb. The other Headlight is **Stevinus A**, which is not included in the list because it is only 8 km wide. Because Diviner data show more boulders around it than for Furnerius A, it's probably even younger.

It's intriguing that both Aristarchus and nearby Bessarion are about the same age. Forty-km-wide Aristarchus is famous for its brightness and widespread ray system, while Bessarion is neither bright nor the center of rays. Has it lost its youthful characteristics because erosion degrades brightness much faster for small craters? Bessarion is only 10 km wide.

Glushko is a bright rayed crater often overlooked because it's near the limb. Look limbward from Reiner Gamma to see this foreshortened feature during a favorable libration under high illumination. Notice that one of its rays streaks across Oceanus Procellarum, bends toward Seleucus, and continues all the way to the north side of the Aristarchus Plateau. The existence of such a long ray is probably due to the crater's youthful age of about 200 million years; its kinky bending is unexplained.

Also consider the distribution of rocks around the famous **Messier** crater pair. The projectile that formed these craters is thought to have come in at just 5° above the eastern horizon, excavating first the elongated Messier, and then, like a stone skimming across a pond, dug out Messier A. Messier A has two nearly parallel narrow rays running like a railway track to the west, whereas Messier's rays are wide and extend north and south.

Finally, let's consider a crater that didn't make the list due to its location on the farside just around the eastern limb from Gauss. Giordano Bruno is a very bright, 22-km crater with long rays (including one reaching just east of Mare Crisium). It is dated by crater counts and rock abundance at only about 4 million years old. The uncertainties of this estimate include the possibility that it formed as recently as 1178, when English monks observed a bright flash at Bruno's location. Keep observing the Moon, for no one can predict what you may see!

■ Contributing Editor **CHUCK WOOD** has studied the Moon for more than five decades and has never seen a new crater form.

Crater Ages

Crater Name	Diameter (km)	Age (millions of years)
Furnerius A	12	29
Byrgius A	19	47
Euclides C	11	50
Thales	32	61
Tycho	86	85
Messier A	11	128
Aristarchus	40	164
Bessarion	10	164
Glushko	43	196
Petavius B	34	224
Proclus	28	253
Aratus	11	421
Dawes	18	454
Cauchy	12	489
Dionysius	19	492
Lalande	24	495
Anaxagoras	53	586
Copernicus	97	797
Kepler	32	930

▲ Alexander Jamieson's *Celestial Atlas*, from which this depiction of Hercules is drawn, included 26 plates covering more than 100 constellations with stars shown to 7th magnitude.

ALEXANDER JAMIESON, *CELESTIAL ATLAS* (1822) / UNITED STATES NAVAL OBSERVATORY LIBRARY / PUBLIC DOMAIN

Heavenly Hero

Hercules strides across the summer sky, carrying with him an abundance of deep-sky wonders.

So when Alcides mortal mold resign'd,
His better part enlarg'd, and grew refin'd;
August his visage shone; almighty Jove
In his swift carr his honour'd offspring drove;
High o'er the hollow clouds the coursers fly,
And lodge the hero in the starry sky.
—Ovid, *Metamorphoses*

To celebrate 20 years of Sue French's stellar contributions to *Sky & Telescope*, we will be sharing the best of her columns in the coming months. We have updated values to current measurements when appropriate.

Here, the Latin poet Ovid chronicles the celestial ascent of the mythological hero Hercules (Alcides), son of the god Jupiter (Jove) and a mortal woman. When Hercules' earthly life ended, his godly half was given a place of honor among the stars. Great in death as he was in life, Hercules lays claim to the fifth-largest constellation. His starry head, Rasalgethi, is near the head of Ophiuchus, Rasalhague, as though our hero is offering help with the monstrous serpent that Ophiuchus is wrestling.

Rasalgethi, Alpha (α) Herculis, is a red-giant star 400 light-years away and large enough, if it replaced our Sun, to extend beyond the orbit of Mars. It's also a variable star ranging between magnitude 2.7 and 4.0 during a 6-year period that underlies a complex cycle of smaller oscillations over shorter intervals. Through my 4.1-inch (105-mm) refractor at a magnification of 127×, deep-golden Rasalgethi closely nuzzles a 5th-magnitude companion to the east-southeast. The fainter star is white, but comparison with its yellow-orange partner often seems to lend it a blue or green tint. With components too tight to be split with a telescope, the companion consists of a yellow giant in close proximity to a white star perhaps twice as massive as our Sun.

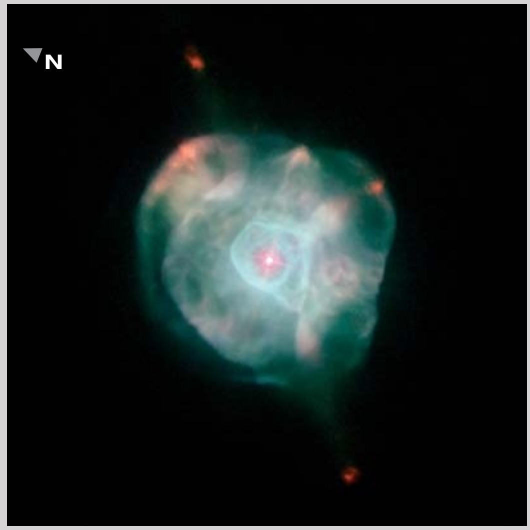
At low power, Rasalgethi shares the field with **Dolidze-Dzimselejsvili 7**, a little knot of faint stars 1.3° northwest. Boosting the magnification to 87×, I see a loose collection of several stars in a shape that Finnish observer Jere Kahanpää likens to a sailboat. Six 10th- to 12th-magnitude stars form a curved hull with its open side facing west-southwest. A sailless mast juts out in that direction, topped by a 10th-magnitude star. Data from proper-motion surveys indicate that these stars are moving in different directions through space and do not form a true, gravitationally bound cluster.

In a dark sky, a naked-eye splash of stars can be seen a few degrees west of Rasalgethi. Astronomy author Tom Lorenzin calls this asterism **Sudor Ophiuchi** (Sweat of Ophiuchus) and writes, "Hey! If you were wrestling with a giant snake, you wouldn't care where your sweat splashed, either!" In my 8×50 finder, I see eight stars in the shape of an integral sign (∫) about 2½° long with a boxy extension at its northwestern end. Through my little refractor at 17×, the bright star near the center of the integral sign is prominently orange. South of it, the distinctive double star **Struve 4033** (Σ4033) displays a nearly matched pair of white and gold suns, which are easily split in binoculars.

Harrington 7, a large asterism 2° west-southwest of Omega (ω) Herculis, is a wonderful group for dot-to-dot games. My 4.1-inch scope at 28× shows a score of 8th- to 10th-magnitude stars in a 1.3° zigzag leaning north-northwest. It's 14′ wide in the south and tapers to a point in the north. Writer Phil Harrington calls it the Zigzag Cluster. It reminds me of the Chinese dragons carried in parades. The brightest star (third from the tip of the dragon's tail) is gold, so I call it the Golden Dragon. However, the view through my 10-inch reflector at 44× gives a different impression. A spray of stars at the southern end seems to outline a flower, perhaps an iris, whose stem winds northward. Another twist of the imagination turns the asterism into a lit fuse with a sparking end.

A white, 7th-magnitude star lies 1¼° west of the dragon's head. Drawing a line from it to a golden 8th-magnitude star 13′ south-southwest and continuing three times that distance takes you to the double star **Σ2016**. The white, 8.5-magnitude primary has a yellow, 9.6-magnitude companion 7.4″ south-southeast. Planetary nebula **IC 4593**, sometimes called the White-eyed Pea, dwells 11′ north-northwest of this pair. The nebula's 10.7-magnitude central star makes it easy to locate. My little refractor at 28× reveals a very small, gray-green glow around the star. The nebula shows up better at 47× with an O III filter. Large scopes render a more striking hue, variously reported as green, blue-green, or blue. At high power the nebula is oval and appears to grow with averted vision. Look for a brighter patch in the northwest.

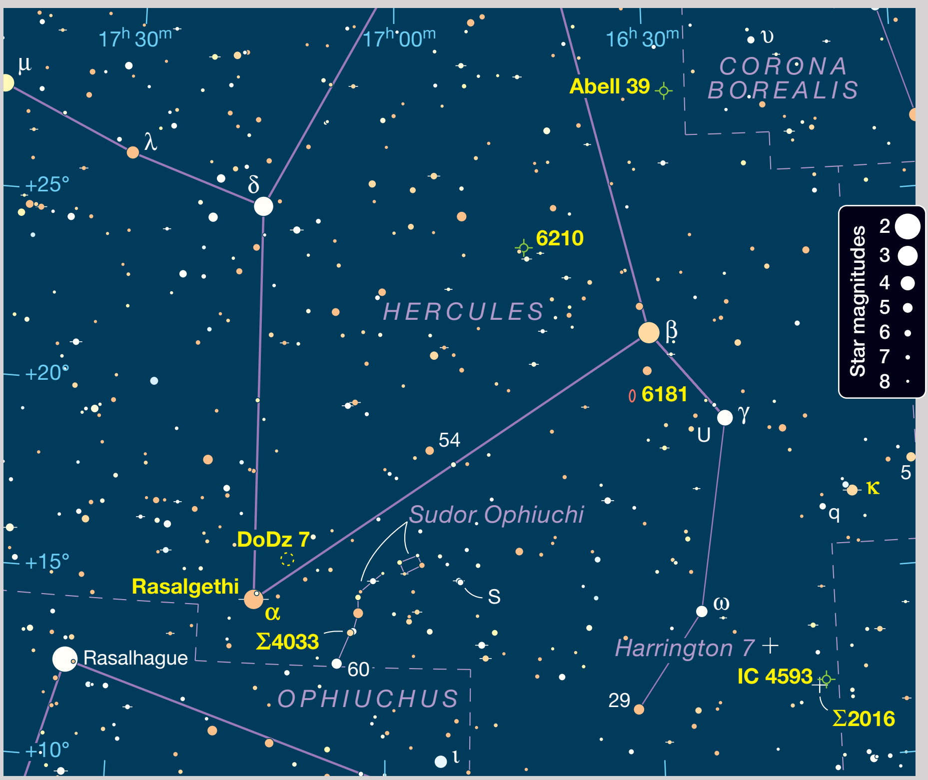
Let's move a bit more than 5° north and pay a visit to the attractive double star **Kappa (κ) Herculis**, whose bright components are easily split at low power. They appear a lovely deep yellow and gold to me, which agrees fairly well with their cataloged spectral classes of *G*8 and *K*1.



▲ A 10th-magnitude star centers the planetary nebula IC 4593. Nicknamed the White-eyed Pea by amateur astronomers, this bubble represents an advanced stage in the life of a planetary nebula. Its gas clouds of hydrogen and oxygen, lit up by ultraviolet light from the dying star, have expanded dramatically.

IC 4593: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

Hercules plays host to many galaxies, none dazzling. **NGC 6181**, near Beta (β) Herculis, is one of the brightest. Drop 1° south from Beta to a yellow 5th-magnitude star, and then slide 47′ south-southeast to the galaxy. Just a few arcminutes east of an 11th-magnitude star, NGC 6181 is faintly visible in my little refractor at 47×. Boost-

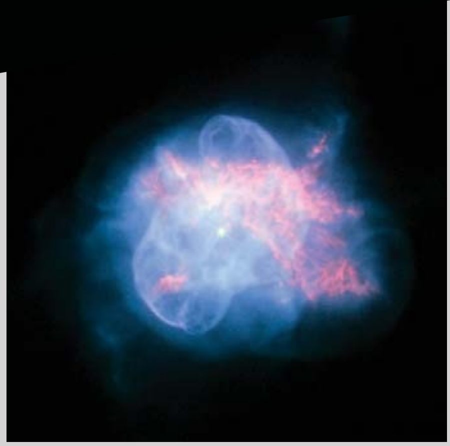


ing the magnification to 87×, I see a small north-south oval with a broadly brighter core.

A pair of 7th-magnitude stars spaced 17′ apart lies two-thirds of the way from Beta to 51 Herculis. The bright planetary nebula **NGC 6210** sits 9′ west-northwest of the duo's northeastern star. I can spot the nebula even at 17× through my 4.1-inch refractor. At 87× this pretty, blue-gray nebula almost overpowers its 12th-magnitude central star. A faint halo rims the planetary. NGC 6210 looks greenish blue through my 10-inch reflector, and at high power it's elongated east-west. Deep images of NGC 6210 show unusual projections that earn this planetary its nickname, the Turtle Nebula.

Our final target is another planetary nebula, a very challenging one: **Abell 39** (PK 47+42.1). The nearest star with a Bayer designation is Upsilon (υ) Coronae Borealis. From Upsilon, hop 1.7° east-southeast to a golden 7.5-magnitude star, the brightest in the area, and then drop 39′ south-southeast to an 8.6-magnitude star. Next sweep 26′ due east to a 9.8-magnitude star at the northern corner of a 15′ trapezoid formed with three slightly brighter stars. A line drawn from the trapezoid's western star through its northern one and continued for the same distance again will take you right to Abell 39.

When I first visited Abell 39 with my 10-inch reflector, I could spot it only using averted vision and an O III filter. Since familiarizing myself with it, I've been able to view the nebula while gazing directly at it. Abell 39 is round, vaguely annular, and moderately large for a planetary — almost 3′ across. A magnification of about 70× gives me the best view. Other observers have managed to nab this elusive planetary with 8-inch scopes. Can you?



▲ Higher magnifications reveal NGC 6210 to be elongated east-west. This high-resolution image taken by the Hubble Space Telescope reveals the true complexity of the planetary nebula's structure. The central star is surrounded by a burgeoning gas bubble, behind which filaments and pillars of excited hydrogen gas appear.

▲ The planetary nebula Abell 39 is a ghostly haze in even large-aperture scopes like the 32-inch Ritchey-Chrétien used to capture this image. Averted vision and an O III filter may help improve the view for smaller scopes.

■ Contributing Editor **SUE FRENCH** shared this Deep-Sky Wonders column in the July 2007 issue of *Sky & Telescope*.

Harbored in the Hero

Object	Type	Mag(v)	Size/Sep	RA	Dec.	*MSA*	*U2*
Rasalgethi	Double star	3.5, 5.4	4.7″	17^h 14.6^m	+14° 23′	1251	87L
DoDz 7	Asterism	–	10′	17^h 11.4^m	+15° 29′	1251	87L
Sudor Ophiuchi	Asterism	–	~3½°	17^h 01.1^m	+14° 13′	1251	87L
Σ4033	Double star	5.9, 6.2	305″	17^h 03.7^m	+13° 36′	1251	87L
Harrington 7	Asterism	–	100′ × 15′	16^h 18.1^m	+13° 03′	1254	87R
Σ2016	Double star	8.5, 9.6	7.4″	16^h 12.1^m	+11° 55′	1254	87R
IC 4593	Planetary nebula	10.7	13″ × 10″	16^h 11.7^m	+12° 04′	1254	87R
κ Herculis	Double star	5.1, 6.2	27″	16^h 08.1^m	+17° 03′	1230	87R
NGC 6181	Spiral galaxy	11.9	2.5′ × 1.1′	16^h 32.4^m	+19° 50′	1229	69L
NGC 6210	Planetary nebula	8.8	20″ × 13″	16^h 44.5^m	+23° 48′	1204	69L
Abell 39	Planetary nebula	13.0	170″	16^h 27.6^m	+27° 55′	1181	69L

Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0. The columns headed *MSA* and *U2* give the appropriate chart numbers in the *Millennium Star Atlas* and *Uranometria 2000.0 Deep Sky Atlas*, respectively. All the objects this month are in the area of sky covered by Charts 54 and 55 of *Sky & Telescope's Pocket Sky Atlas*.

NGC 6210: ESA / NASA / HUBBLE SPACE TELESCOPE; ABELL 39: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA / CC BY-SA 3.0

The Nebulae of Ophiuchus

Visit the Serpent Holder to snare a collection of dark and bright nebulae with just a few sweeps of your scope.

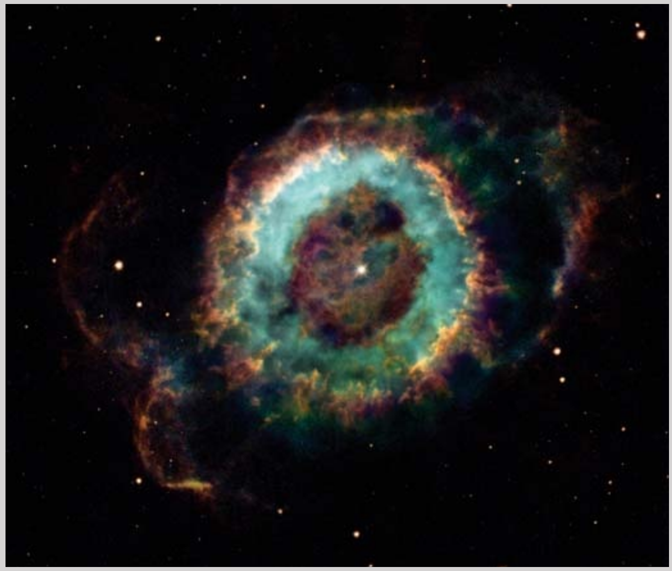
BABAK TAFRESHI

The region of the sky in and around Ophiuchus fascinated William Herschel; E. E. Barnard repeatedly returned to it in an attempt to understand the structure of the Milky Way. If you spend a little time with the constellation, then you'll begin to understand some of the historical misunderstandings that arose here. Observing this region, Herschel reacted with shock as he swept past such objects as the globular star clusters M80 and M4 only to enter what would become known as the dark nebula Barnard 42 and the bright nebulae IC 4603 and IC 4604. He proclaimed that he'd discovered a "hole" in the sky without a star to be seen. William's sister, Caroline, wrote to her nephew, John, warning him to take care when observing this region — her brother thought it might contain clues to the understanding of the entire heavens. Indeed, until the 20th century the Herschel family and the majority of the scientific community held to the theory that Herschel's "holes" came about during the formation of the nearby globular clusters. The theory proposed that somehow stars in regions such as Ophiuchus had been gathered up into these wonderfully beautiful globular star clusters, leaving only "vacancies" to be viewed and pondered.

In fact, Herschel's conclusions were the beginning of Barnard's journey toward realizing that what he was observing weren't "vacancies" at all, but were bright and dark nebulae that filled the area, much like in other parts of the Milky Way. It would be left to others in the early decades of the 20th century to show that rather than globular star clusters forming by gathering large numbers of stars out of "vacancies," it was the dark nebulae (and other sources of absorbing dust) that had the effect of hiding the globular clusters from our view.

▲ **THE GREAT NEBULA OF RHO OPHIUCHI** A cornucopia of celestial objects appears in this image. Nebulae, both bright (IC 4603 and IC 4604) and dark (Barnard 44), multiple-star systems (Rho Ophiuchi itself), and globular clusters (the most prominent being M4) all contribute to the wonders of this particular region of sky.

M80 and M4 are just over the border in Scorpius, but **Barnard 42**, **IC 4603**, and **IC 4604** are solidly in Ophiuchus. The three objects make for a wondrous sight, worthy of a location in the sky where scientific history would be repeatedly made in order to understand the universe. Barnard made this threesome famous, calling them collectively the Great Nebula of Rho Ophiuchi. Just a little more than 3° north-northeast of Antares, the heart of the Scorpion, you will slew into the darkness of B42 — this dark nebula will dominate your view. A little less than 1° south of Rho Ophiuchi, you'll find IC 4603 surrounding the



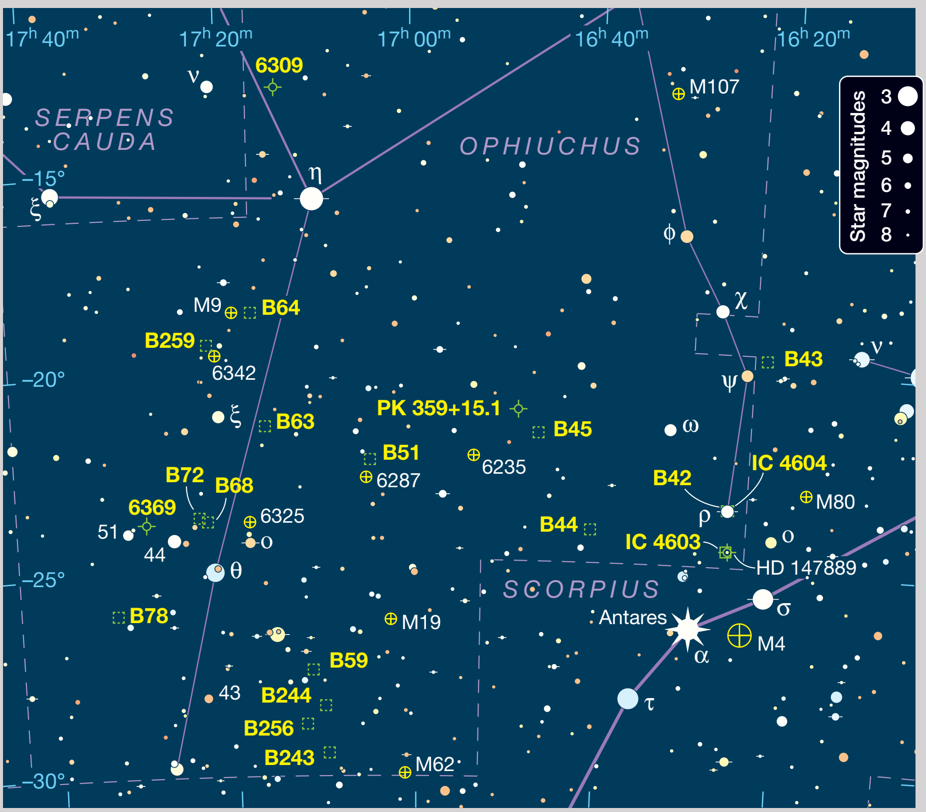
▲ *Left:* The Pipe Nebula, or Barnard 59, is a perfect example of how William Herschel and others mistook dark nebulae for "holes" in the sky. The stars superimposed on the inky blackness of the nebula are foreground stars. No starlight from background objects makes it through the dark cloud. *Right:* NGC 6369 is often dubbed the "Little Ghost Nebula" — can you make out the ghostly ring of stellar matter blown off the dying star in your scope?

8th-magnitude star HD 147889. The nebula, described by Barnard as a 20′ (arcminute) brightening around and north of the star, was discovered just in time to be included in the *Second Index Catalogue* (published in 1908). Turn back north, and you'll cross over a dark channel of Barnard 42 to find the 5th-magnitude multiple star Rho Ophiuchi surrounded by IC 4604, a bright nebula somewhat larger than IC 4603.

Leave Rho Ophiuchi by moving 3° north to see **Barnard 43**, another large and well-defined dark nebula. However, after the Rho Ophiuchi field, the real treat is to start about 1° southeast of IC 4603 and slew east. Follow the truly dark path of **Barnard 44** for some 6° or so until you arrive at **Barnard 51**, which marks a somewhat sharp end to the extensive dark lane. Along the way you'll also find the globular clusters NGC 6235, NGC 6287, and NGC 6325 (you may spot several more bordering on either side of the dark lane).

Just 2° north of Barnard 44 you'll find **Barnard 45**. This nebula looks to me to be about 2° long, with the very faint planetary nebula **PK 359+15.1** (Abell 40) at its eastern end (and the 9th-magnitude star HD 151451 some 10′ northwest of the planetary).

Back at B51 you can proceed by slewing 3° east-northeast to get to the curved dark nebula **Barnard 63**. Continuing a little more than 3° north brings us to comet-shaped **Barnard 64**. The globular cluster M9 is on the nebula's eastern side. Turning ½° southeast brings you to the dark nebula **Barnard 259**, with the globular cluster NGC 6342 on its southwestern edge. All these associations between globular star clusters and dark nebulae suggest that we should easily forgive the scientists of old for having made a mistaken connection between the two.



BARNARD 59: ESO; LITTLE GHOST NEBULA: NASA / ESA / THE HUBBLE HERITAGE TEAM / AURA

Returning to B63, slew south about 5° to run into the large dark nebula **Barnard 59**. B59 marks the beginning of the famous Pipe Nebula that empties into the massive **Barnard 78**, a dark nebula so large you should probably first seek it with the naked eye. However, you can also appreciate it with binoculars or small rich-field telescopes at low power. This is a dark nebula that must be seen to be understood. Also in this region is **Barnard 72**, or the Snake Nebula, rendered famous through photographs. However, it's much more of a challenge visually than photographically. Just to its southwest, though, is a much more accessible dark nebula — **Barnard 68**. Easy to spot in any telescope, B68 has become famous in university astronomy classes where students learn that the "hole" in the sky is actually a cloud. (A series of photographs progressively deeper in the infrared brings out more and more stars from behind the cloud until the cloud virtually disappears.)

Moving about 8′ east you'll find the planetary nebula **NGC 6369**, discovered by William Herschel in 1784 and listed as the 11th object in his catalog. It's a nice, ringed object just north of a line drawn from 44 Oph to 51 Oph. The ring has a bright arc on its northern side that shows more detail with greater magnification on good quality nights.

Sliding several degrees down to 43 Oph and then heading southwest you'll find the large dark nebula **Barnard 256**. Around 3° west of Barnard 256 are two similar nebulae, **Barnard 243** and **Barnard 244**, at approximately the same right ascension.

Let's conclude our tour by making a foray into the more northern reaches of Ophiuchus. Sweeping northward some 16° brings us to the planetary nebula **NGC 6309**, discovered by John Herschel in 1830. You'll find NGC 6309 a little more than 1° west of 4th-magnitude Nu (ν) Serpentis. With a larger scope, you should see a greenish oval elongated in the north-south direction and a 13th-magnitude central star. The northern end of the nebula, brighter than the southern end, has a 12th-magnitude star to its north.

JOSEF PÖPSEL / STEFAN BINNEWIES

Our next slew will give you an idea of how large the constellation is: We're continuing northward to declination +6° in order to find **vdB 111** (and remember that before our visit to NGC 6309 we were lurking near declination –30°). This reflection nebula, centered on HD 156697 and a sprinkling of stars that includes a 10th-magnitude orange star, along with a number of fainter 13th-magnitude stars, is smaller than most of the Barnard objects you've viewed.

There are many more nebulae, both dark and bright in this part of the sky, but hopefully this will have given you a taste of some of the wonders here.

◀ **REFLECTION NEBULA** The ethereal nebulosity vdB 111 surrounds HD 156697 and is well worth the effort to observe. If you manage to do that after studying the dark nebulae in the southern parts of the constellation, you'll be aware of how large Ophiuchus is after your sweep northward to it.

■ **RICHARD P. WILDS** is the author of *Bright and Dark Nebulae: An Observer's Guide to the Clouds of the Milky Way Galaxy* (CreateSpace, 2017), and a member of the AAS (DPS and HAD).

Nebulae in Ophiuchus

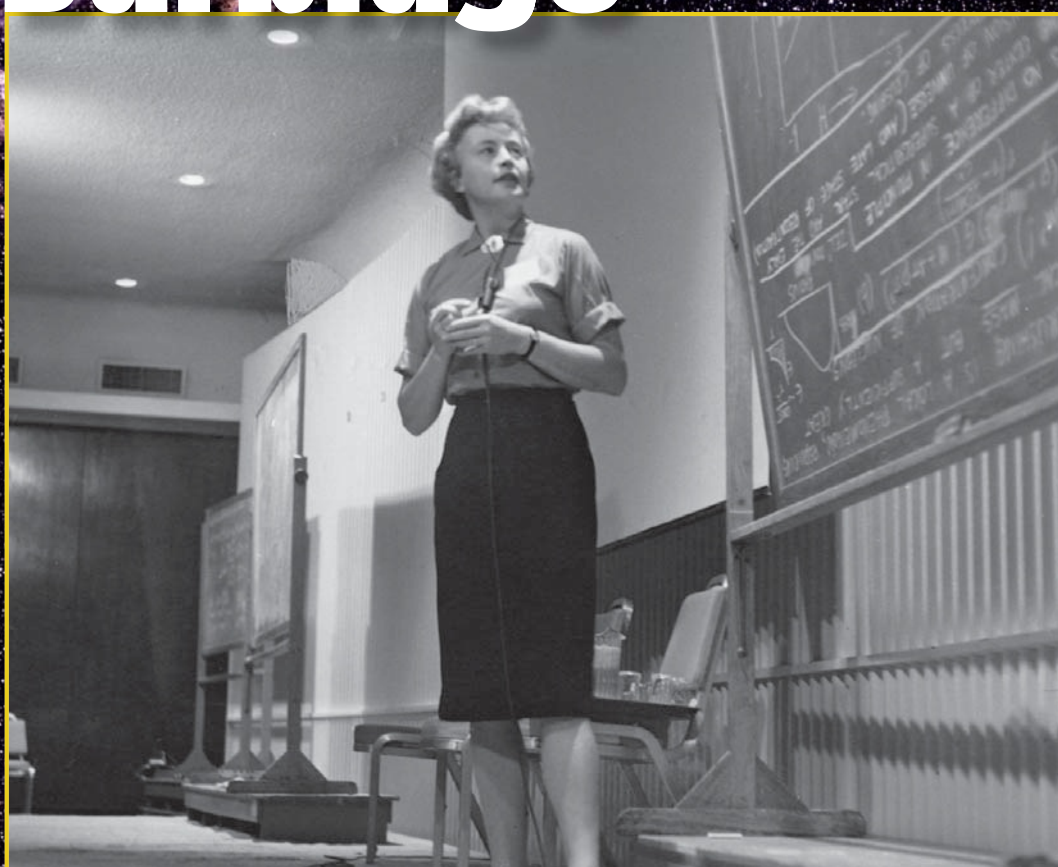
Object	Type of Nebula	Opacity/ Mag(v)	Size	RA	Dec.
Barnard 42	Dark	6	20′ × 6′	16^h 25.5^m	–23° 26′
IC 4603	Reflection	—	35′ × 20′	16^h 25.6^m	–24° 28′
IC 4604	Reflection	—	60′ × 50′	16^h 25.6^m	–23° 26′
Barnard 43	Dark	4	—	16^h 30.3^m	–19° 47′
Barnard 44	Dark	5	—	16^h 40.6^m	–24° 04′
Barnard 51	Dark	6	20′ × 20′	17^h 04.7^m	–22° 16′
Barnard 45	Dark	5	—	16^h 46.4^m	–21° 36′
PK 359+15.1	Planetary	—	34″	16^h 48.6^m	–21° 01′
Barnard 63	Dark	3	100′ × 20′	17^h 16.5^m	–21° 29′
Barnard 64	Dark	6	20′ × 20′	17^h 17.3^m	–18° 29′
Barnard 259	Dark	4	30′ × 30′	17^h 22.0^m	–19° 18′
Barnard 59	Dark	5	60′ × 60′	17^h 11.4^m	–27° 30′
Barnard 78	Dark	4	200′ × 140′	17^h 32.7^m	–25° 36′
Barnard 72	Dark	6	4′ × 4′	17^h 23.6^m	–23° 37′
Barnard 68	Dark	6	4′ × 4′	17^h 22.6^m	–23° 47′
NGC 6369	Planetary	11.4	38″	17^h 29.3^m	–23° 46′
Barnard 256	Dark	5	50′ × 10′	17^h 22.2^m	–28° 50′
Barnard 243	Dark	3	25′ × 25′	17^h 09.8^m	–29° 35′
Barnard 244	Dark	5	30′ × 20′	17^h 10.9^m	–28° 25′
NGC 6309	Planetary	11.5	19″	17^h 14.1^m	–12° 55′
vdB 111	Reflection	—	9′ × 6′	17^h 18.9^m	+06° 05′

Angular sizes and separations are from recent catalogs. Opacity estimates (with 1 the least opaque, 6 the most) come from the Lynds Dark Nebulae catalog. 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.

 by Benjamin Skuse

Happy Birthday, Margaret Burbidge

The astronomer who taught us we are all made of stardust will celebrate her 100th birthday on August 12, 2019.



CYGNUS LOOP: ESA / DIGITIZED SKY SURVEY / CALTECH; BURBIDGE: *S&T* ARCHIVE

LADY STARDUST Margaret Burbidge, who celebrates her 100th birthday in August, had a long and stellar career in multiple fields of astrophysics. One of her most significant achievements was formulating our understanding of nucleosynthesis in stars. Among positions she held in her lifetime were director of the Royal Greenwich Observatory and president of the American Astronomical Society, both the first time that a woman filled the post. The photograph shows Burbidge in Dallas, Texas, in February 1964.

"You can't give telescope time for this junk science! Who does she think she is?" blustered a young upstart upon hearing that an elderly astronomer wanted half a night with one of the brand-new Keck telescopes to observe objects that might disprove the Big Bang theory.

Observatory Director Joe Miller was quick to put the youngster in his place: "You just look up Margaret Burbidge, *the* Margaret Burbidge, and you'll know who she is," he said. "If Margaret Burbidge wants half a night to draw up pictures of Mars, I'll give it to her — whether we think it's crazy or not, we're going to show respect to one of the greatest astronomers of the 20th century."

Though the night turned out to be cloudy and she wouldn't have found evidence to support an alternative to the Big Bang anyway, this mid-1990s episode — when Burbidge was already in her 70s — is but one of many in a career spanning more than 60 years that highlight a determination to push the frontiers of human knowledge.

Born Eleanor Margaret Peachey in Davenport, UK, to chemist parents, Burbidge caught the astronomy bug early. "She became interested in the stars when she was three or four years old," explains her daughter, Sarah Burbidge. "Her family took a night ferry crossing to France for a holiday, and for the first time the stars were clearly visible to her, and she was smitten."

This fascination, combined with a talent for mathematics, developed to the point where she was reading the books of astronomer and mathematician Sir James Jeans, a distant relative on her mother's side, by the age of 12. She went on to study astronomy at University College London, graduating in the summer of 1939 with little ceremony due to the looming cloud of war.

Over the next few years, the fresh graduate split her time between maintaining the University of London Observatory at Mill Hill in the absence of the many scientists and technicians

▶ **THE QUARTET** Margaret and Geoff teamed up with Willy Fowler (third from left) and Fred Hoyle (at right) to write one of the seminal papers in all of astrophysics. They not only worked together, they also played together — here they're celebrating Fowler's 60th birthday in July 1971, admiring his model train engine.

Triumph Over Obstacles

In her largely quiet and undemonstrative way, Burbidge's handling of the many moments of discrimination she encountered during her career inspired other female astronomers to pursue and achieve their own ambitions.

1945

With World War II ending, Burbidge saw an opportunity to gain "access to larger telescopes, better instruments and clearer skies" in the U.S. through an advertisement for a Carnegie Fellowship at Mount Wilson Observatory. However, her hopes were immediately dashed when her application was denied — simply on account of her gender. "A guiding operational principle in my life was activated," she said in her 1994 memoir. "If frustrated in one's endeavors by a stone wall . . . one must find a way around." Ten years later, Geoff submitted another application, which was accepted. The couple stayed in a separate summer cottage on the mountain away from the exclusively male dormitory, and Margaret was officially only there as Geoff's assistant. In reality, Geoff conducted the dark room work and smoked cigars, while Margaret finally got to observe the heavens from Mount Wilson.

1971

The Annie Jump Cannon Award was the American Astronomical Society's (AAS) oldest prize and the only one exclusively for women. It had been awarded to luminaries such as Cecilia Payne-Gaposchkin and Helen Sawyer Hogg, so it wasn't at all surprising when the AAS wanted to award Burbidge with the accolade. What was surprising, instead, was the rejection letter Burbidge wrote in response. In it, she said "it is high time that discrimination in favor of, as well as against, women in professional life be removed, and a prize restricted to women is in this category." Her refusal led to the creation of the first working group on the status of women in astronomy, and increased awareness of discrimination against women and other minority groups in astronomy.

1972

Just a year later, Burbidge became the first female astronomer to become a member of the National Academy of Sciences, and the first female director of the Royal Greenwich Observatory — but wasn't elected Astronomer Royal, the first and only time in the organization's history this occurred. Instead, Martin Ryle was given the position. Whether this was pure gender discrimination or a symptom of political shenanigans in the British astronomical community remains unclear. What was clear was that Burbidge didn't want to be involved in the turmoil within British as-

QUARTET: MASTER AND FELLOWS OF ST JOHN'S COLLEGE / CAMBRIDGE / DONALD CLAYTON; STARDUST TEXTURE: WRIT-ERFANTAST / ISTOCK / GETTY IMAGES PLUS sucked into the war effort, fabricating optical instruments for the armed forces, and graduate studies.

For her PhD thesis, she analyzed spectra of the variable star Gamma Cassiopeiae. She observed in the harshest of conditions, often alone at night in a cramped space under a cold open dome, sometimes with the fear-inducing sounds of flying bombs going off around her. Yet she never complained, offering the first hint of the steely determination and thirst for knowledge that would later define her: "Those nights, standing or sitting on a ladder in the dome of the Wilson reflector . . . fulfilled my early dreams," Burbidge later recalled in a 1994 memoir.

The years immediately following World War II would turn out to be career-defining for the young astronomer. Alongside giving classes on practical astronomy on the observatory roof — to students that included an enthusiastic undergraduate named Arthur C. Clarke — she also attended graduate lectures in physics. There, she immediately hit it off with "an interesting person" called Geoffrey (Geoff) Burbidge who she would go on to marry just six months later.

From the outside, the pair made an unlikely couple. Geoff was a large man with a truculent, impatient character, while Margaret was so demure and quiet that Miller claims, "My wife always used to say 'If Queen Elizabeth ever needed a stand-in, Margaret could do it'."

But appearances can be deceiving. Though Geoff had strong scientific views and a penchant for a heated argu-

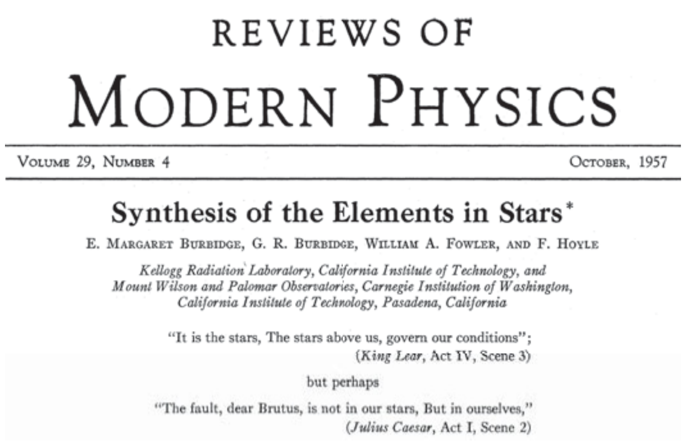
tronomy at the time, and she tendered her resignation just a year and a half later.

1976

Despite, or perhaps because of, the Annie Jump Cannon Award rejection, Burbidge was elected the first woman president of the AAS. At the time, the U.S. Equal Rights Amendment — guaranteeing the same rights for all American citizens regardless of gender — had been ratified by all but three states. Burbidge put forward to the membership the idea of banning annual AAS meetings from being held in the three dissenting states. She received highly polarized responses, but it narrowly passed, offering a signal of support from the AAS for women in science.

1983

B²FH was a transformative paper deserving of the highest accolades. And in 1983 this was recognized when Fowler was awarded the Nobel Prize in Physics. Yet even Fowler was shocked by the omission of his colleagues. Hoyle could have been left out for various reasons: his stance on the Big Bang theory, the various outlandish ideas he put forward in later life, or for heavy criticism of the committee in 1974 for awarding Antony Hewish and failing to recognize Jocelyn Bell Burnell's contributions in discovering the first pulsar. Various commentators have since posited that Bell Burnell's and Burbidge's Nobel omissions were but two of many examples of sexism in astronomy. Burbidge remains characteristically reserved on the subject.



REVIEWS OF

MODERN PHYSICS

VOLUME 29, NUMBER 4 OCTOBER, 1957

Synthesis of the Elements in Stars*

E. MARGARET BURBIDGE, G. R. BURBIDGE, WILLIAM A. FOWLER, AND F. HOYLE

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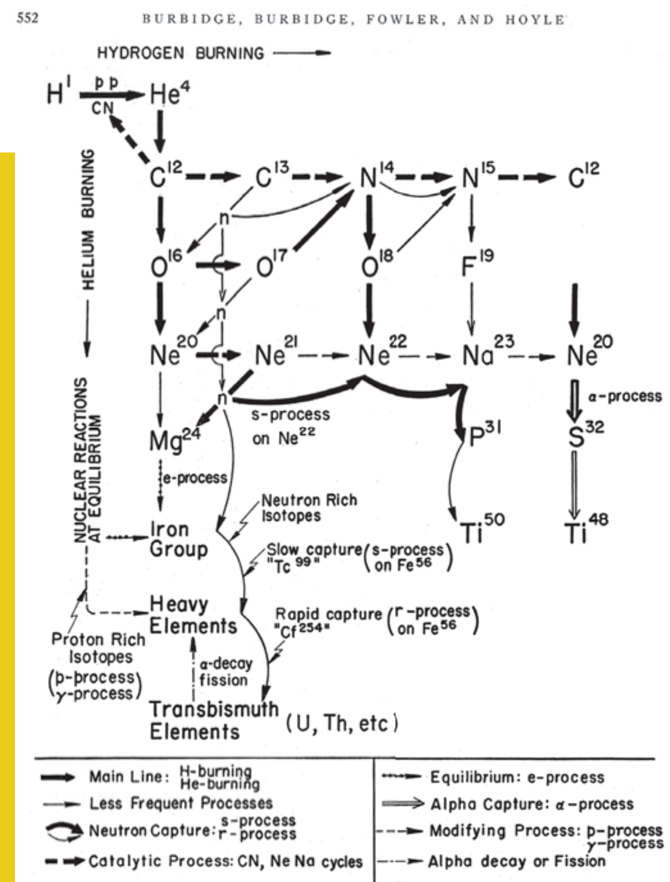
"It is the stars, The stars above us, govern our conditions";
(*King Lear*, Act IV, Scene 3)

but perhaps

"The fault, dear Brutus, is not in our stars, But in ourselves,"
(*Julius Caesar*, Act I, Scene 2)

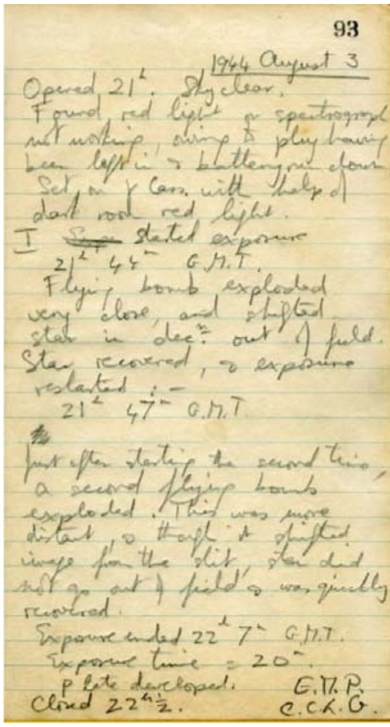
552 BURBIDGE, BURBIDGE, FOWLER, AND HOYLE



▲ **THE B²FH PAPER** This seminal paper on stellar nucleosynthesis, headed by Margaret Burbidge, was cited so often that the authors were referred to as "B²FH." Above is a schematic diagram of the nuclear processes by which the synthesis of elements in stars takes place. This tour de force is 108 pages long.

E. M. BURBIDGE ET AL. / *REVIEWS OF MODERN PHYSICS* VOL. 29, NO. 4, P. 547 (1957) / AMERICAN PHYSICAL SOCIETY

▶ PAGE FROM AN OBSERVING LOGBOOK – AUGUST 3, 1944 Burbidge conducted her PhD research during the World War II years. Between wartime duties, she observed Gamma Cassiopeiae at the University of London Observatory in Mill Hill Park. The telescope was donated by J. G. Wilson, and it's not to be confused with the Mount Wilson Observatory in California. While observing on the night of August 3rd, Burbidge was twice interrupted by bombs exploding nearby, but neither incident rattled her, as is clear from her notes.



1944 August 3

Opened 21^h. Sky clear.
Found red light on spectrograph not working, owing to plug having been left in & battery run down.
Set on γ Cass. with help of dark room red light.
I started exposure
$21^h\ 44^m$ G.M.T.
Flying bomb exploded very close, and shifted star in decⁿ out of field.
Star recovered, & exposure restarted:
$21^h\ 47^m$ G.M.T.

Just after starting the second time, a second flying bomb exploded. This was more distant, & though it shifted image from the slit, star did not go out of field & was quickly recovered.
Exposure ended $22^h\ 7^m$ G.M.T.
Exposure time = 20^m
Plate developed.
Closed $22^h½$.

E.M.P. was Eleanor Margaret Peachey.

C.C.L.G. was Christopher Clive Langton Gregory, first Director of the Observatory.

UNIVERSITY COLLEGE LONDON OBSERVATORY

ment, he was honest, loyal, and carried on friendships with colleagues with whom he disagreed, and even promoted them. And as for Margaret, "It was the classic iron fist under her velvet glove," says Miller. "She knew what she knew and believed strongly, and she would stick to her principles."

Fruitful Collaboration

In fact, it was Margaret's passion for and knowledge of astronomy and spectroscopy — the analysis of starlight by wavelength — that prompted Geoff to switch from physics soon after they married, spawning a winning collaboration that led to numerous new insights into chemically peculiar stars. In one study, they performed the first detailed spectral analysis of Alpha^2 Canum Venaticorum, now considered the prototype of a class of variable stars that harbor strong magnetic fields. Among numerous seminal results in the paper, published in 1955, they also showed that the star had, on average, an overabundance of rare earth metals of about 800 times that of the Sun. This finding piqued the interest of distinguished experimental nuclear physicist William (Willy) Fowler. At the time, Fowler was spending a year in Cambridge, UK, working with Fred Hoyle. In 1946 and 1954, Hoyle published the first-ever papers in which he theorized how stars might forge hydrogen and helium into the heavier elements found throughout the universe, a concept now known as *stellar nucleosynthesis*. This went against the established notion that the elements were all derived from the Big Bang.

Seeing how the Burbidges' research and expertise could help in proving Hoyle's stellar nucleosynthesis idea, Fowler invited Geoff and a pregnant Margaret to join them in Cambridge. They immediately clicked: "You can't imagine how much fun they all had working together," says Sarah Burbidge. The next year and a half was a flurry of intense activity.

Though Margaret was so far along in her pregnancy that "Willy said he was worried she would 'pop'," says Sarah, it didn't deter her from making key observations that helped identify all the processes within stars that form the elements populating the periodic table (except for the very lightest). This included expanding on Hoyle's earlier work to show how elements up to iron could be created by the successive stages of nuclear fusion as a star evolves. They also illuminated how fast and slow neutron capture, the *r*- and *s-processes*, could explain the observed abundances of elements heavier than iron.

The result of all these efforts was a 108-page paper written by Margaret and Geoff along with Fowler and Hoyle, and published in *Reviews of Modern Physics* in October 1957. It showed how elements are formed at various stages of the stellar life cycle, and perhaps most importantly how most of the elements that make up everything around us — and ourselves — originate from stars. "This one paper just completely laid the foundation for what is going on in terms of the formation of the chemical elements," summarizes Miller.

"Synthesis of the Elements in Stars," as it was titled, quickly popularized the idea of stellar nucleosynthesis in the scientific community. The article was referenced so often that it was later simply referred to as B^{2}FH (after the first letter of each author's surname) for short. It became and remains a landmark contribution to nuclear astrophysics.

Yet the paper was not without controversy. Hoyle and Geoff were key proponents of the Steady State theory of the universe. Unlike the Big Bang theory, in which the observable universe had a definite beginning, the Steady State concept maintained that the universe has and always will exist. Importantly, it claimed that the universe could generate new matter, which B^{2}FH demonstrated. However, this victory for the Steady State community would soon be drowned by a tsunami of evidence in favor of the Big Bang picture, in particular the discovery of a faint glow coming from all directions. It soon became clear that this glow was relic radiation left over from the early universe that today we know as the *cosmic microwave background*.

From a historical perspective, that Hoyle and Geoff remained stubborn adherents to Steady State cosmology — long after the consensus deemed it had been disproved — somewhat overshadowed the light they both illuminated on numerous scientific mysteries throughout their careers. The memory of Burbidge's contributions to astronomy, in contrast, remains unfettered by the controversy.

Cleverly, she rarely offered her opinion publicly on theoretical matters, either leaving Geoff to slug it out or, if he were absent, astutely contributing to the debate by starting her argument with: "If Geoff were here, he would say . . . " Sarah feels the reason for this was simple: She was never a theoretician. "I don't think Mum ever worried about where Fred's theories might lead," she says. "Remember that she was an observational astronomer, focused on her observations and reducing spectra."

A New Astronomical Mystery

Having wielded these formidable observational skills in B^{2}FH, Burbidge needed a new scientific mystery to get her teeth into. After 10 years working with Geoff measuring the rotation of stars and gas in disk galaxies and studying peculiar galaxies and galaxy clusters, she eventually found it in the newly discovered puzzling objects we now call quasars — or, as they were termed at the time, *quasi-stellar objects*.

The first positively identified quasar to be observed and identified as such, 3C 273, caused a tremendous commotion in the astronomical community in 1963. Barring any new physics, it was shining 40 times more brightly than the brightest known galaxies. Plus it had a *redshift* — meaning its light is shifted toward the red end of the spectrum because of its motion away from the viewer — that placed it far beyond our own galaxy, around 2.5 billion light-years away.

With only a few telescopes around the world that could obtain spectra of quasars, Burbidge was ideally placed to join the race to find more quasars with even bigger redshifts, given her access to the Shane 3-meter (120-inch) telescope at Lick Observatory. This she did — with a reputation as "a rather formidable driver," she would quite literally speed to the observatory in their Jaguar. She discovered tens of examples, including OQ 172 at redshift 3.53 in 1973, a quasar that remained the farthest known for nearly a decade.

Though fascinating, quasars presented a problem for

SARAH BURBIDGE (2)

◀ **COLD NIGHTS IN THE CAGE** An overhead photo taken around 1970 shows Burbidge sitting in the "cage" of the Shane 3-meter (120-inch) telescope at Lick Observatory owned and operated by the University of California. Nowadays, observers operate telescopes from comfortably heated control rooms, sometimes miles away from the actual dome.

▲ **THE JAGUAR** Margaret still owns the 1961 Jaguar Mark II, shown here behind the Burbidges. Although she doesn't drive it anymore, she loves being driven around by Sarah and her grandson, Connor.

Hoyle, Geoff, and their dwindling band of fellow Steady State universe supporters. Unless some new physics peculiar to quasars could be mustered or observations of blueshifted quasars made, these redshifts were cosmological, indicating that the universe is expanding everywhere and that this expansion had to come from the Big Bang. As it became clear that neither of these would be forthcoming, Burbidge's quasar observations turned out to be yet another nail in the coffin of the Steady State universe. However, Burbidge herself never saw it that way, keeping "an open mind always."

The latter years of Burbidge's scientific career were spent probing the spectra of galaxies, determining galaxies' rotations, masses, and chemical composition, and, of course, investigating quasars. She also played a major role in moving observational spectroscopy into the heavens, helping to develop the Faint Object Spectrograph (FOS) aboard the Hubble Space Telescope. The FOS was one of the original Hubble instruments, designed to detect the physical state and chemical composition of very faint objects such as quasars. Her last major scientific contribution was leading the FOS data analysis team. Among other findings, this team provided evidence for the presence of a massive black hole at the center of nearby elliptical galaxy M87 (see page 10 for more on M87).

As Hubble's FOS was churning out new astronomical insights in 1995, Fowler died. Hoyle followed in 2001, with Geoff sadly passing away in 2010 at the age of 84. As a result, for almost a decade Margaret has remained the sole living member of B^{2}FH. On the eve of her 100th birthday, it's a good time to reflect on and applaud what she and the other members of B^{2}FH achieved, as well as all the triumphs she can rightly claim are hers alone.

"You've made me look back over her 100 years — starting with observations from that little telescope in Mill Hill in the 1940s all the way to the development of the Faint Object Spectrograph on the Hubble Space Telescope — and it is really quite remarkable," reflects Sarah. "She simply wanted to be very good at her work as an observational astronomer, and I would say she was probably the best of her generation."

■ **BENJAMIN SKUSE** is a science writer based in Somerset, United Kingdom.

Lumicon's New Oxygen III Filter

Lumicon improves a helpful visual accessory.

Lumicon's new 1¼- and 2-inch Generation 3 O III filters.

Lumicon Generation 3 Oxygen III Filter

U.S. Price: $100 (1¼-inch), $200 (2-inch)

farpointastro.com

What We Like

Improved contrast over classic O III filter

What We Don't Like

Nothing

A LOT HAS CHANGED during the 50 years I've been observing the night sky. Much of that change has been in the equipment we use to view it with. Typical amateur telescopes are bigger and undeniably better, mounts are more precise, and modern eyepiece designs make the older ones look like antiquated magnifying glasses.

For the amateur interested in viewing nebulae, however, light-pollution-reduction (LPR) filters are the innovation that's perhaps brought the most profound change. For observers under urban and suburban skies, one of these filters can make the difference between seeing many objects and not seeing anything at all.

A standard for me has been the filters from long-time accessory maker Lumicon (now owned by Optical Structures Incorporated). Recently, the company announced a "new and improved Generation 3" oxygen III filter, but I was skeptical. I've been using Lumicon O III filters since 1995, and they have performed admirably. While nothing in life is perfect, there didn't seem to be much room for improvement.

What is an O III filter? It's a filter that mainly passes the light emitted by the so-called "forbidden lines" of doubly ionized oxygen (O III for short) at 495.9 and 500.7 nanometers, while blocking light pollution that brightens our urban skies. Oxygen III is generally the dominant light emitted by planetary nebulae, and those are the objects an O III filter is best suited for observing.

A cursory inspection of the filters (I received both 1¼-inch and 2-inch formats for this review) left a positive impression. The coatings were uniform, and the filter cells are machined better than earlier models — each screwed smoothly into all of my eyepieces' filter threads. Both come in padded plastic storage boxes. Held up to the light, the new Generation 3 filters have a blue-green tint, unlike some older ones that impart a pinkish color.

A data sheet is included with a plot of the filter's transmission characteristics and a table showing the percentage of light blocked or transmitted at various wavelengths. The transmission percentages for the two spectral lines of doubly ionized oxygen are an impressive 97.7% and 98.2%, respectively. Equally impressive is the percentage of "bad" light blocked. For example, at 583 nm, near the 589-nm wavelength of sodium vapor streetlights, the report states the filter passed a mere 0.29% of the light.

While the filters looked good indoors, the real test is their performance under the stars. I didn't have the test equipment necessary to quantify the figures given in the report, but I did have my eyes, which have never failed me when it comes to evaluating astronomy products.

ALL IMAGES BY THE AUTHOR

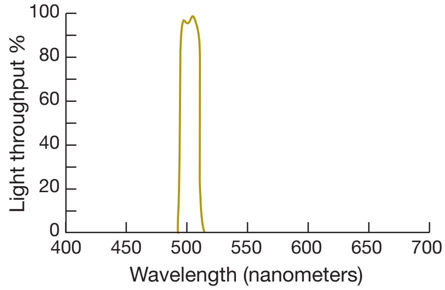
I was lucky to be experiencing a lull in winter storms and was able to get into my suburban backyard with my 10-inch f/5 Dobsonian reflector one hazy evening immediately after receiving the filter. The first target was one of the best planetary nebulae in the sky, Messier 27, the Dumbbell Nebula.

After a few minutes hunting around at 50× without the filter, I swept up a faint, round glow in the field of the 25-mm wide-field eyepiece. Adding my older 2-inch Lumicon O III filter to the ocular confirmed the telescope was on the correct spot. With the filter in place, the nebula went from barely visible to showing hints of its apple-core shape. There wasn't much other detail visible, but the view was impressive considering the conditions, which now included a full Moon rising in the east.

I didn't expect much improvement when I replaced the original O III with the new Generation 3 filter. However, the view was undeniably better! The sky background was noticeably darker, and the nebula wasn't any dimmer than it had been looking through the older filter. In fact, it was more prominent, and as I stared, I began to see detail the original O III filter hadn't revealed.

Although the dumbbell shape was detectable with the older Lumicon filter, it wasn't easy. Most of the time M27 looked more like a rectangle. With the Generation 3 filter, however, curved arcs of nebulosity at either end of the nebula came into view, and the rectangle's center began to look narrower than its ends. There was also subtle dark detail within the nebula that was invisible with the older filter.

Lumicon Generation 3 O III Bandpass



▲ The report supplied with the Generation 3 O III filter shows a roughly 10-nanometer-wide passband that includes both the 496- and 501-nm wavelengths emitted by doubly ionized oxygen in planetary and other nebulae.

GRAPH: S&T ILLUSTRATION

How would the new filter perform on smaller planetary nebulae? Rising in the east was NGC 2392, Gemini's well-known magnitude-9.7, 48-arcsecond-diameter nebula. After locating the object with the 25-mm eyepiece, I switched to a 1¼-inch 4.7-mm ocular that yielded 266× in hopes of seeing some details. Adding an older Lumicon O III manufactured in the 1990s made the nebula easy to see, but it was lacking detail beyond that visible in the unfiltered view. It was a slightly oval gray ball with a brighter center.

The difference between the Generation 3 and the older Lumicon filters was even more readily visible here than it had been when viewing M27. With the new O III filter, not only was the sky background considerably darker, details that completely eluded the original Lumicon were visible.

Like all light-pollution blocking filters, the new O III filter dims the stars in the field. It's an unavoidable consequence, since their total light spans the spectral range, including the wavelengths of light pollution the filter is designed to block. The nebula's bright central star was still prominent, however. Despite the presence of the full Moon a mere 15° away, I also detected signs of the inner ring and dark detail that make the nebula resemble a face. These features are easy to see in long-exposure images but difficult to spot in an eyepiece.

While O III filters work best on planetary nebulae, they can help us see other nebulae as well, most notably supernovae remnants. The Veil Nebula in Cygnus was really too close to the horizon to observe when I tested the filter, but I could at least see traces of it with the Generation 3 filter. The 25-mm eyepiece alone or equipped with the older 2-inch O III filter didn't show a sign of it.

An oxygen III filter belongs in the accessory case of every serious deep-sky observer. One can dramatically improve views of planetary nebulae, not just under city or suburban skies, but also under dark skies. I've used many O III filters over the years, but the Lumicon Generation 3 Oxygen III filter exceeded the performance of any of them. It's one of those rare instances where "new and improved" really *is* "new and improved."

■ **ROD MOLLISE** can be found enjoying deep-sky observing at several star parties each year.

▶ The Dumbbell Nebula, M27, was just visible in the author's 10-inch Newtonian under light-polluted skies *(left)*. Adding an older Lumicon O III filter began to bring the shape of the inner part of the nebula into view *(middle)*, while the outer arcs were only visible when using the Generation 3 filter *(right)*.

▲ Optolong's 2-inch City Light Suppression (CLS) filter blocks most of the unwanted wavelengths of light caused by streetlights, signs, and other artificial sources while passing the light of most astronomical targets unimpeded. This comparison of IC 434, the Horsehead Nebula, was captured through an 8-inch f/5 Newtonian reflector. The left image was recorded with no filter, the right with the CLS filter in place.

ALL IMAGES BY THE AUTHOR

Optolong CLS Light-Pollution Filter

This inexpensive accessory can improve your observing under suburban skies, both visually and photographically.

Optolong CLS Filter

U.S. Price: $55 (1¼-inch), $85 (2-inch), and DSLR clip-in ($115)

Available in the U.S. at Oceanside Photo & Video

Optcorp.com

What We Like

Inexpensive and effective

Perfect for color cameras

What We Don't Like

Nothing

DEEP-SKY ASTROPHOTOGRAPHY from suburban locations can be a real challenge. As light pollution increases year after year, imagers are forced to consider additional methods to get the most out of their brightening skies, particularly astrophotographers who use one-shot-color cameras. Fortunately, there's an ever-increasing selection of effective and reasonably priced options in broadband, light-pollution-rejection filters.

The latest company to enter the market in North America is the Chinese manufacturer Optolong. The firm specializes in filters for many types of astronomical and scientific imaging. Because of increasing light pollution in my neighborhood, I was particularly interested in Optolong's City Light Suppression (CLS) filter that's offered in 1¼- and 2-inch formats.

This coated-glass filter suppresses the light produced by common sources of light pollution, including mercury-vapor lights, high- and low-pressure sodium-vapor lights, and natural airglow. The CLS filter does this while passing the majority of wavelengths of light from nebulae, such as the emission lines of doubly ionized oxygen (495.9 nm and 500.7 nm), hydrogen beta (486 nm), hydrogen alpha (656.3 nm), and S II (672 nm). I decided to order a 2-inch version for use with my DSLR and color astro-cameras.

When I received the filter, a quick look through it just holding the filter to my eye revealed a generally neutral-color-balanced scene; I couldn't conclusively determine if the filter imparted any obvious color bias despite looking carefully at several high-contrast scenes. This neutral color balance bodes well for the filter's use for astrophotography.

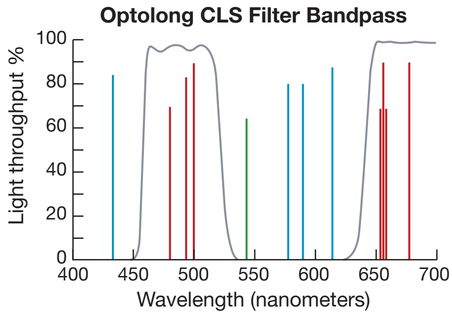
The 2-inch Optolong CLS filter is mounted in a 48-mm threaded cell that is 5 mm thick (not including the cell's male threads) and has a clear aperture of 44 mm.

Optolong states that the filter is equally helpful for imaging and visual observing, so I first gave it a night under the stars attached to several 2-inch eyepieces used with my 12½-inch reflector and 71-mm refractor.

The contrast was slightly greater on emission and planetary nebulae when using the filter visually, allowing me to see the outer wisps of nebulosity in M42 very well compared to the view without a filter. The background sky was noticeably darker in views of nebulosity around the Pleiades (M45) and even when observing several small galaxies, much to my surprise.

I used the CLS filter photographically with my telescopes by screwing it directly into the 48-mm threads on my coma-corrector (for the reflector) and field-flattener (for the refractor). I also have a T-thread adapter that accepts Nikon lenses and includes internal threads for 48-mm filters. It lets me mount a filter between my off-axis guider's pick-off prism and the camera so I can guide on unfiltered stars.

GRAPH: S&T ILLUSTRATION; SOURCE: OPTOLONG



▲ The filter scan of the Optolong CLS shows it blocking most light-pollution sources while passing light produced by emission nebulae essentially unhindered.

Using the Optolong CLS filter with a stock Nikon D750 DSLR and a ZWO ASI071MC one-shot-color CMOS camera produced images showing a marked increase in contrast in emission nebulae compared to images made without the filter. Star colors appeared accurate, and there weren't any additional bright-star reflections compared to unfiltered photographs. No obvious differences in color balance were apparent in the images taken through the filter, and processing the data was noticeably easier as opposed to the work necessary for addressing light-pollution gradients in unfiltered images taken from the same location.

The Optolong CLS filter's ability to block light pollution also helped with aiming my scope and composing images since faint nebulosity that was not visible in short, unfiltered exposures became detectable with the filter. When imaging with the CLS filter in place, I could make exposures about twice as long before the sky-background levels in images became objectionably high.

Optolong also offers a CLS-CCD filter, which is more expensive, for use with CCD cameras that do not have an integrated infrared-blocking filter. The CLS-CCD filter is designed to block near-infrared wavelengths while still passing the astronomically important wavelengths, including Hα (656.3 nm) and S II (671.6 nm).

In addition to images made with my telescopes, I also attempted photos with the filter attached to the front of a 105-mm f/2.5 Nikon lens on my full-frame Nikon D750 camera. The results were encouraging, but there was a noticeable color-shift at the corners of the frame. As such, I wouldn't recommend this combination, though it should work well with cameras using smaller APS-format detectors and short telephoto lenses. On the downside, front-mounting the filter with my wide-angle Nikon 35-mm lens produced a radial gradient of decreasing filter effectiveness and dramatic color balance changes between the center and edge of the field.

The Optolong CLS filter should be attractive to astrophotographers using one-shot color cameras and stock DSLRs shooting from moderately light-polluted sites. The noticable increase in image contrast, especially on emission nebulae, with relatively little shift in overall color balance can significantly improve results. Even under dark skies, the CLS filter produces a noticeable boost in image contrast when targeting fainter emission objects.

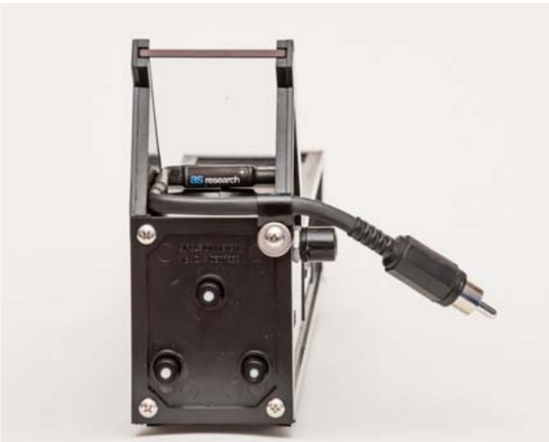
▶ *Top:* The filter's 48-mm thread is compatable with most 2-inch eyepieces and accessories, including coma-correctors and field-flatteners. *Bottom:* The CLS filter can also be positioned between CMOS or CCD cameras and camera lenses with certain lens adapters, like those marketed by ZW Optical, which include internal filter threads.

■ **JOHNNY HORNE** welcomes any accessory that makes it easier to shoot from his backyard observatory under the increasing glow of Stedman, North Carolina.

▼ TELRAD ANTI-DEW HEATER

Apache-Sitgreaves Research Center now offers an integrated Telrad Dew Heater ($30). The device fits snugly at the base of your Telrad unit-finder's optical window and is powered with any standard dew controller on the market today that connects using an RCA-style plug. Each purchase includes a cable clip that attaches to one screw on your Telrad. A 6-foot RCA extension cable is also available for an additional $10.

Apache-Sitgreaves Research Center
apache-sitgreaves.org



▲ 5-INCH APO

Stellarvue announces the SVX130T Premium Apochromatic Triplet Refractor ($4,995). This 5.1-inch apo features an air-spaced f/7 triplet objective that uses a combination of extra-low-dispersion and Lanthanum elements to produce sharp, color-free views at the eyepiece. Its 5½-inch diameter, fully baffled tube assembly is 29½ inches long with dew shield retracted and weighs in at 16.8 lbs. The telescope's 3½-inch dual-speed focuser can accommodate heavy payloads and includes both 1¼-inch and 2-inch eyepiece adapters, as well as an integrated dovetail shoe for mounting an optional finder scope. Each purchase includes a lens cap, two heavy-duty CNC-machined tube rings, and a C130L padded carry case.

Stellarvue
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stellarvue.com

▶ PORTABLE PRECISION

iOptron introduces the latest addition to its series of portable, center-balanced, equatorial Go To mounts, the CEM40 ($1,998). The mount head weighs just 15.8 lbs yet can support loads of up to 40 lbs. It features precision stepper motors and 216-tooth aluminum in both axes. The CEM40 advertises permanent periodic error correction (PPEC) to produce smooth tracking during long-exposure astrophotography. Alignment is simple with the CEM40's integrated iPolar electronic polar finder, and users can quickly swap telescopes on the mount with its Universal Self-Centering Saddle plate, which accepts both Vixen and Losmandy-style dovetail bars. The CEM40 is controlled via the Go2Nova 8407+ hand controller, which includes a database of more than 350,000 objects. The mount comes with a heavy-duty stainless steel tripod, counterweight shaft, and DC power supply.

iOptron
6F Gill St., Woburn, MA 01801
866-399-4587; ioptron.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.

Slumping and Grinding

Making thin, fast mirrors is an idea whose time has come.

▲ *Left:* David Davis holds one of his pie pan mirrors, which proved that thin glass, properly supported, could make a fine mirror. *Right:* David removes a slumped blank from his homemade kiln. The slumping mold is just a carefully shaped pile of sand.

WHEN CANADIAN AMATEUR Tom Otvos decided to build a large-aperture, fast telescope, the first thing he did was get a kiln. Why? Because of David Davis.

David is the guy who got me started grinding mirrors. I met him when I first joined my astronomy club, and I watched him make mirrors out of unlikely stuff like a granite paving stone and a Pyrex pie pan. He was my kind of crazy, so when he offered a mirror-making class I jumped at the opportunity. I wound up grinding a 10-inch f/3.8 mirror at a time when that was considered insanely fast, but David was already into new territory.

He realized early on that fast mirrors had an inherent problem: The sagitta, the depth of the curve you grind into them, becomes a substantial fraction of the mirror thickness. In order to keep from grinding through the center, you need a thick blank, which is heavy and expensive. A honeycomb structure lightens up the glass, but "expensive" becomes "hideously expensive" in a hurry.

David is all about cheap alternatives to expensive problems. When telescope maker Dan Gray handed him a 16″-by-⅜″-thick piece of glass that had been slumped in a kiln, David realized he was looking at the future of large, fast mirror making. A mirror could be pre-formed with heat rather than with grinding, and because the slumped glass has the same thickness throughout, the result would be just as strong as a flat slab ground into a bowl. Stronger, actually, since the weight of the outer zones would be significantly reduced.

As Mel Bartels puts it: "Others, including me, saw meniscus mirrors as cellular mirrors without the glass support structure. David saw meniscus as a replacement for rough grinding."

▶ Tom Otvos slumped, ground, and finished the 14-inch f/2.6 mirror in his new scope — only the second telescope he's built.

David took the concept and ran with it. He built an enclosure out of firebrick and ceramic wool, wired it with heating coils, then ". . . bought a controller from Ortin Ceramic and started learning how to break glass."

If you heat or cool glass too quickly, internal stress will overcome the glass's tensile strength and it will shatter. But David learned how to slowly heat glass to just the right temperature to let it sag onto a curved mold, then lower the temperature gradually through the annealing range until it's well below the stress point where it can be cooled faster without damage.

Then he started learning how to fine-grind and polish his creations. Until this point, most large mirrors were worked with subdiameter tools on top, but David learned that thin glass is flexible glass, and any deviation in the support structure would deform the mirror. If you got a high spot and polished it down, when you took the mirror off the stand you would have a low spot.

JERRY OLTION (2); TOM WITH TELESCOPE: TOM OTVOS

That meant putting the mirror on top, just like amateurs have been doing since Jean Texereau published his seminal book *La Construction du Télescope d'Amateur*. And it worked.

Mel was so impressed with David's results that he ground 10″, 13″ and 25″ meniscus mirrors — the latter two featured in our January 2012 and February 2019 issues, respectively — and he had David slump a pair of 30″ blanks and a pair of 42″ blanks for eventual big binoscopes. (Yes, Mel is crazy, too.)

Enter Tom Otvos. All he wanted was a medium-big, portable scope. Portability meant fast, to cut down on the overall length, and fast meant a meniscus mirror. So even though he had only ground one 8″ mirror before, Tom retrofitted a ceramics kiln with a computerized controller, slumped a blank, and set to work. Because he was enamored of Mel's "Zipdob" design (*S&T:* Jan. 2012, p. 62), he consulted Mel on the grinding and polishing particulars, confessing that "Mel made it look easy. Kinda naïve on my part."

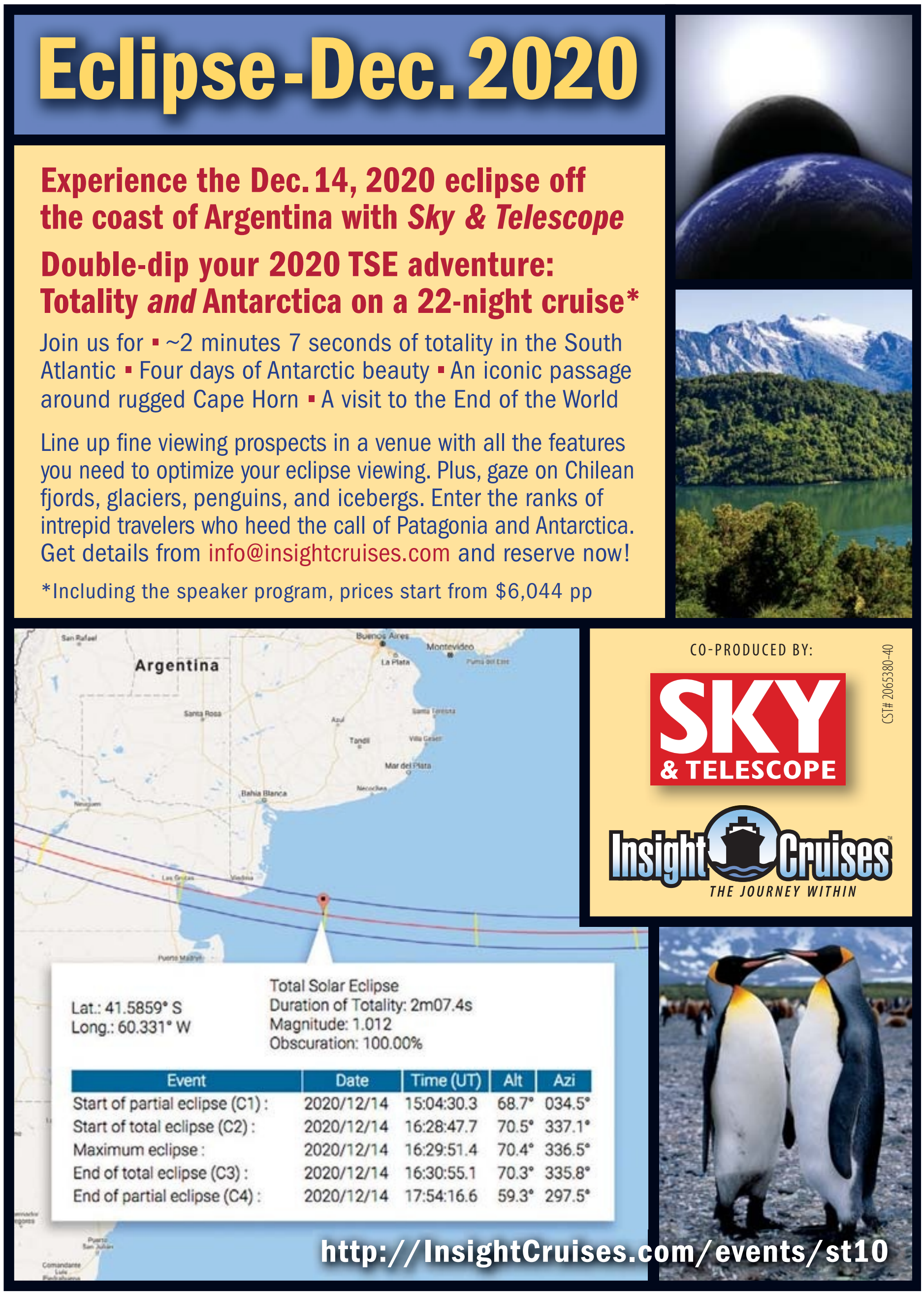
Indeed, fast, thin mirrors are no picnic, but they're doable with patience and attention to detail. Despite a tragic tip-out accident during star-testing that broke his first attempt into two pieces, Tom completed a second 14″ f/2.6 mirror in about seven months and turned it into a fabulous rich-field telescope. He even silvered his own mirror, which will be the subject of a future column.

My point in telling you all this is that the technology has matured. David (and, to be fair, several others as well) did the pioneering, Mel (and, again, others) did the proving out, and Tom is the demonstration that kiln-slumped meniscus mirrors are ready for prime time.

You want a big, fast, yet lightweight scope? Start with a kiln.

For more information, contact David at **prepitious@gmail.com**, and Tom at **tom.otvos@gmail.com,** or visit his website at **astronomy.tomotvos.ca**, as well as Mel's website at **bbastrodesigns.com**.

■ Contributing Editor **JERRY OLTION** believes you don't have to be crazy to grind an ultrafast mirror, but it helps.



NOT SO COLORLESS

Jamie Cooper

While often overlooked, large patches of subtle bluish and brownish hues are seen in the dark lunar mare regions.

DETAILS: *8-inch Sky-Watcher Newtonian reflector with Canon EOS 6D DSLR camera. Total exposure: 1⁄160 second at ISO 200.*

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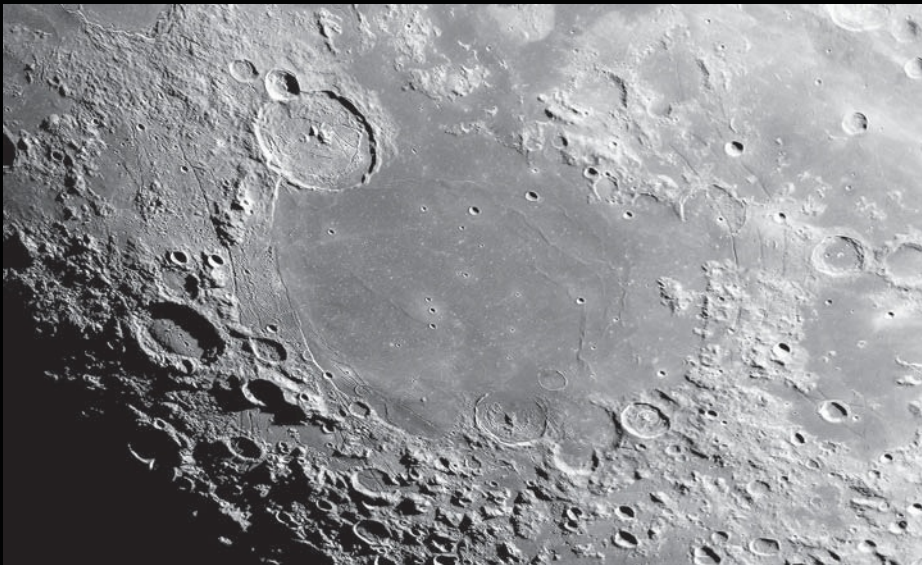


◁ SEA OF MOISTURE

Robert Reeves

The fractured crater Gassendi (top left) borders circular Mare Humorum. This plain displays many mare ridges (center), as well as several long rilles along its eastern and western borders. North is up.

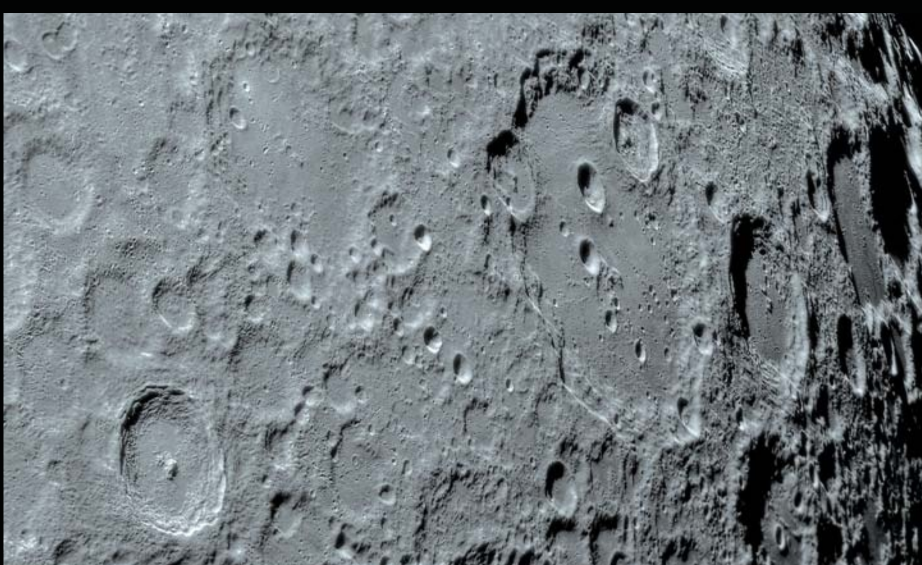
DETAILS: *Celestron C8 with an Imaging Source DMK 41AU02.AS video camera. Mosaic of four panels, each consisting of a stack of multiple video frames.*

◁ LUNAR ALPS

Howard Eskildsen

Seen about two days after first quarter, tall peaks within Montes Alpes cast jagged shadows across the floor of Plato (top left). The mountain range continues to arc toward the southeast, terminating just before the flooded crater Cassini at bottom right. North is up.

DETAILS: *Explore Scientific ED152 refractor with an Imaging Source DMK41AU02.AS video camera. Stack of multiple video frames recorded through a Wratten 8 yellow filter.*



◁ TYCHO TO CLAVIUS

Michael Wirths

Two popular craters dominate the southern lunar highlands. Tycho, seen at bottom left, is a relatively young crater with terraced walls, while the weathered appearance of much larger Clavius (middle right) with its many overlapping craters hints at its older formation date. North is to the left.

DETAILS: *18-inch Starstructure Dobsonian with a ZW Optical ASI174MM video camera. Stack of 1,200 video frames.*

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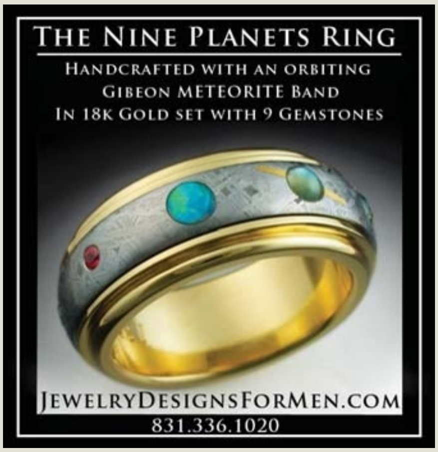

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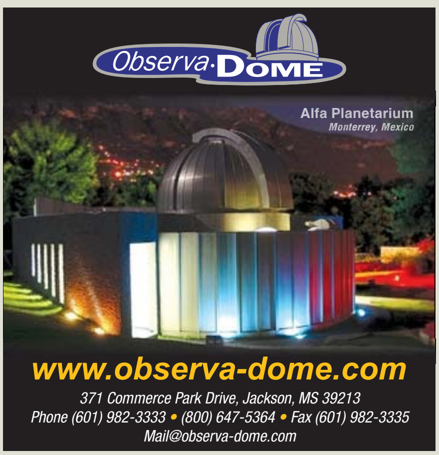

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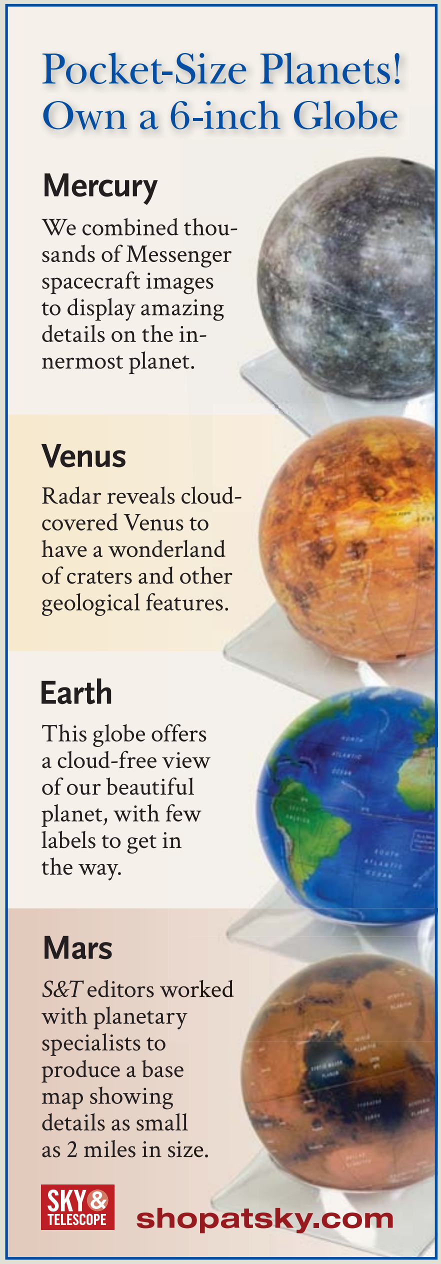

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Still as Bright

During an emotional crisis, the author rediscovers the visual wonders of our Moon.

EACH MONTH, when the Moon returns, the first "sea" I routinely observe is Mare Crisium — the Sea of Crises — and the first "lake" I look for is the limb-foreshortened Lacus Temporis — the Lake of Time.

The Moon is always there, at least in our lives, lit or dark, seen or not, a frigid or scalding rocky globe of pits and rubble, of mountains and scars, our companion in gravity and evolution, symbol, territory, night light, and silent siren for predators, mythic werewolves, lovers, geologists, and, soon again, astronauts. For me, until recently, as for other stargazers, the Moon was a bane bleaching out fainter, far-flung gray-green galaxies and nebulae.

Not long ago, I found myself questioning, if not everything, then quite a bit — mortality, happiness, profession. I'd run my hand along the spines of philosophy titles in a used bookstore in Tucson, Arizona, tip one out, and purchase it to read at home in a certain silence. I'd sit down to meditate, trying to focus on breath instead of mistakes. I'd talk with my wife in a gravelly yard behind our old adobe house beneath mesquites or the giant tamarisk.

Too tired, too low, I couldn't bring myself to haul the telescope to where skies darken and the Andromeda Galaxy blossoms enough for me to see with my naked eye. Ever since moving to Tucson from four riverside acres in rural Utah, I'd spent far less time under night skies than I used to — one of several touchstones I'd slowly lost in my recent clotted, frantic city years.

So I began to do something different: pay attention to the Moon. Using my 10-inch Dobsonian, I spent evenings sweeping across landscapes that made me gasp at dramatic gouges, sunlit peaks and sharp shadows, white sprays of ejecta.

With a growing array of maps and atlases, I memorized features — their names, their topography, their history — and realized that I needed more direction to the sublime and often confusing lunar surface, its craters upon craters, wrinkle ridges, lava plains obvious or demure. I found an observing program from the apparently defunct American Lunar Society (ALS), whose website once included a plan to observe nearly 100 features.

So for several lunations I stayed up late, got up early, and exclaimed at low volcanic domes, pumped my fist at crater chains, and smiled at just-noticed notches in crater rims.

When I went ahead and sent my observing log to the ALS contact anyway, he wrote back with a kind letter — and my "diploma," the Lunar Study and Observing Certificate, which made me unreasonably happy.

Now I plan on doing another observing project using the Royal Astronomical Society of Canada's list. I can start a separate one for Charles Woods's Lunar 100, and there's the RASC's even more ambitious Lunar 1,000 Challenge — observing 1,000 named features on the Moon. When I'm more comfortable with sketching and calculating colongitude, I'll pursue certification with the Association of Lunar and Planetary Observers.

In *The Moon Observer's Handbook*, Fred Price writes that "personal cares and problems are best not brought to the telescope . . ." Yet those sent me to the Moon. Now its beauty, history, and science engender an equanimity both curious and satisfying. I fly over the Moon with my eyepiece. I walk there with my maps. I get lost less often.

■ CHRIS COKINOS is co-editor of the anthology *Beyond Earth's Edge: The Poetry of Spaceflight*, due out in 2020.

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