SPACE TELESCOPE:
Chandra Celebrates 25 Years
PAGE 12

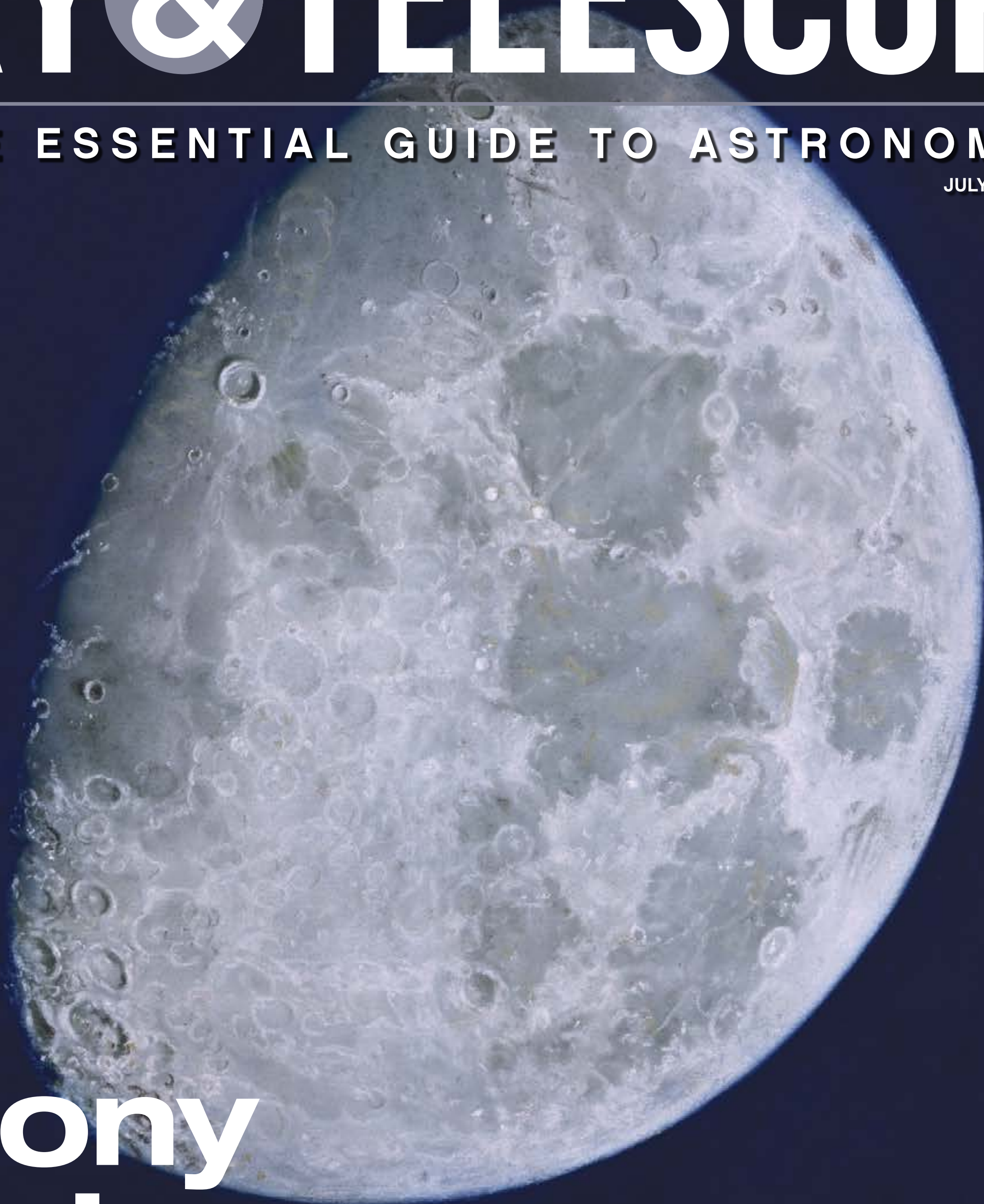
MISSIONS:
The Age of Sample Returns
PAGE 20

TEST REPORT:
The Dwarf II Smartscope
PAGE 66


# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JULY 2024

# Loony for Luna

A Society of "Lunaticks"

Observe Fascinating Features

Watch the Moon Eclipse Spica


skyandtelescope.org

$8.99US $9.99CAN

07

0 71486 02207 7

*The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/*



CONTENTS

# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

July 2024 VOL. 148, NO. 1


X-RAY: NASA / CXC / SAO / E. NARDINI ET AL.; OPTICAL: NASA / STSCI



## ON THE COVER

The Moon by John Russell, pastel, 1797

PHOTO: BIRMINGHAM MUSEUMS TRUST, LICENSED UNDER CC0

## ONLINE

**OUTREACH RESOURCES**
Looking for ideas for your next outreach presentation or event? Check out our collection.
**skyandtelescope.org/outreach-resources**

**ASTRO TOURISM**
Come with us to explore wonders both on Earth and in the sky.
**skyandtelescope.org/tours**

**DIGITAL EDITION**
Use the email connected to your subscription to read our latest digital edition.
**skyandtelescope.org/digital**

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by AAS Sky Publishing, LLC, owned by the American Astronomical Society, 1667 K Street NW, Suite 800, Washington, DC 20006, USA. Phone: 800-253-0245 (customer service/subscriptions), 617-500-6793 (all other calls). Website: skyandtelescope.org. Store website: shopatsky.com. ©2024 AAS Sky Publishing, LLC. All rights reserved. Periodicals postage paid at Washington, DC, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 219, Lincolnshire, IL, 60069-9806. Printed in the USA. *Sky & Telescope* maintains a strict policy of editorial independence from the AAS and its research publications in reporting on astronomy.

# Moonstruck

**IT'S NOT OFTEN** that we feature the Moon on the cover. Aside from solar and lunar eclipses, the last time we did so was in July 2019, five years ago this month. That was a special issue on our planet's satellite, and in a way this one is, too, though it didn't start out that way. It's just that the Moon figures into so much of our reporting, and this month it passed a certain threshold. In short, in this issue you'll find the Moon popping up everywhere.

First and foremost, there's Jerry Oltion's cover story "Go Loony for Luna" (page 34). Illustrated with Cindy Krach's exquisitely rendered sketches, the article showcases Jerry's favorite lunar details to observe with pretty much any optics. (Be sure to keep an eye out for Elvis. Really.)

The Moon plays lesser but still significant roles in two other feature offerings this month: Dave Dickinson's chronicle of sample-return missions, from Apollo 11 to Chang'e 5 (page 20), and Bill Sheehan's spirited look back at the Lunar Society (page 28). This 18th-century band of self-described "lunaticks," which counted luminaries such as Erasmus Darwin and Joseph Priestley among its members, gained its name because it met when the Moon was bright — a helpful beacon in that era before electric streetlights.

You'll also find our nearest neighbor front and center in Sky at a Glance (page 41) and Sun, Moon & Planets (page 46). Both pieces flaunt the many visually arresting pairings that Luna will have this month with assorted planets, stars, and clusters. There's the Moon's usual march across the Northern and Southern Hemisphere sky charts (pages 42–44) as well as its July phases, distances, and favorable librations. And don't miss Bob King's tips on catching the very instant on July 13th when the Moon extinguishes the light of Virgo's brightest star, Spica (page 49).

The Moon makes cameos in Explore the Solar System (page 52) — even though it's not the month for Chuck Wood's bimonthly lunar column on that spread — and in Beginner's Space (page 74). Most sneakily, it shows up, with nary an image, throughout Ákos Bogdán's feature on the 25th anniversary of the Chandra X-Ray Observatory (page 12). (Can you tell how?)

In the end, whether you steer clear of the Moon because its reflected sunlight interferes with your deep-sky observing, or whether you agree with Jerry that "the Moon offers more bang for the buck than any other object in the sky," you can't help but acknowledge the place the Moon holds in all our lives. As in this issue, its presence in the sky is regular as clockwork.

Peter
Editor in Chief

SEAN WALKER

**SKY&TELESCOPE**
**The Essential Guide to Astronomy**

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

**EDITORIAL**
**Publisher** Kevin B. Marvel
**Editor in Chief** Peter Tyson
**Senior Editors** J. Kelly Beatty, Alan M. MacRobert
**Science Editor** Camille M. Carlisle
**News Editor** Monica Young
**Associate Editor** Sean Walker
**Observing Editor** Diana Hannikainen
**Consulting Editor** Gary Seronik
**Editorial Assistant** Sabrina Garvin

**Senior Contributing Editors**
Dennis di Cicco, Richard Tresch Fienberg, Roger W. Sinnott

**Contributing Editors**
Howard Banich, Javier Barbuzano, Jim Bell, Trudy Bell, Ronald Brecher, Greg Bryant, Ken Croswell, Thomas A. Dobbins, Alan Dyer, Tony Flanders, Ted Forte, Steve Gottlieb, Shannon Hall, Scott Harrington, Ken Hewitt-White, Bob King, Emily Lakdawalla, Rod Mollise, James Mullaney, Jonathan Nally, Donald W. Olson, Jerry Oltion, Stephen James O'Meara, Joe Rao, Fred Schaaf, Govert Schilling, William Sheehan, Brian Ventrudo, Mathew Wedel, Charles A. Wood, Richard S. Wright, Jr.

**Contributing Photographers**
P. K. Chen, Robert Gendler, Babak Tafreshi

**ART, DESIGN & DIGITAL**
**Creative Director** Terri Dubé
**Technical Illustrator** Beatriz Inglessis
**Illustrator** Leah Tiscione
**Web Developer & Digital Content Producer** Scilla Bennett

**ADVERTISING**
**Director of Strategic Partnerships** Rod Nenner
**ads@skyandtelescope.org**

**AMERICAN ASTRONOMICAL SOCIETY**
**Executive Officer / CEO, AAS Sky Publishing, LLC** Kevin B. Marvel
**President** Kelsey Johnson, University of Virginia
**President-Elect** Dara Norman, NOIRLab
**Senior Vice-President** Adam Burgasser, UC San Diego
**Second Vice-President** Grant Tremblay, Center for Astrophysics, Harvard & Smithsonian
**Third Vice-President** Dawn Gelino, Caltech/IPAC-NExScI
**Treasurer** Doris Daou, NASA Planetary Science Division
**Secretary** Alice K. B. Monet, U.S. Naval Observatory (ret.)
**At-Large Trustees** Jane Rigby, NASA Goddard Space Flight Center; Louis-Gregory Strolger, Space Telescope Science Institute; B. Ashley Zauderer-VanderLey, National Science Foundation; Lisa Prato, Lowell Observatory

**Editorial Correspondence** (including permissions, partnerships, and content licensing): *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA. Phone: 617-500-6793. E-mail: editors@skyandtelescope.org. Website: skyandtelescope.org. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at skyandtelescope.org.

**Advertising Information:**
E-mail Rod Nenner at: ads@skyandtelescope.org
Web: skyandtelescope.org/advertising

**Subscription Rates:**
U.S. and possessions: $57.73 per year (12 issues)
Canada: $73.18 (including GST)
All other countries: $88.63, by expedited delivery
All prices are in U.S. dollars.

**Customer Service:** Magazine customer service and change-of-address notices: skyandtelescope@omeda.com
Phone toll-free U.S. and Canada: 800-253-0245
Outside the U.S. and Canada: 847-559-7369
Mailing address: *Sky & Telescope* Magazine, P.O. Box 219, Lincolnshire, IL 60069-9806, USA

**Visit shopatsky.com**
Shop at Sky customer service: shopatsky.com/help

**Newsstand and Retail Distribution:**
Marisa Wojcik, mwojcik@i-cmg.com
Comag Marketing Group

## Little Sun Scout

I enjoyed "Make a Solar Finder" by Jerry Oltion (*S&T:* Mar. 2024, p. 72). I thought he might be interested in the method I used. I took a finder mount from Orion that used to hold a pen-light laser. Similar to his technique, I put red tape with a hole in front and white tape with a spot for Sun alignment on the back. The advantage is that it fits on any of my telescopes with a dovetail bracket.

**Rich Tansey • Reno, Nevada**


RICH TANSEY

## Labeyrie Lowdown

In response to Peter B. van der Wal's letter "The Bottle of Labeyrie" (*S&T:* Mar. 2024, p. 6): Yes, I have been aware of their existence for many decades. I believe these two telescopes were proof-of-concept instruments built as prototypes for a more elaborate interferometer project. In this 1993 paper, Antoine Labeyrie and colleagues describe in detail how the instruments work, including tracking: **https://is.gd/GI2TCalern**. The computer tracking system used for these telescopes is extremely complex, much more so than what I came up with in 1994 (*S&T:* Jan. 1996, p. 33). I wonder if the French "Grand Interféromètre à 2 télescopes" prototypes might have benefited from my dual-axis, ball-scope-tracking-platform design had I published it years earlier.

**Pierre Lemay**
**Blainville, Quebec, Canada**

## Tracking T Coronae Borealis

I just read "Get Ready for a Nova's Bright Return" by Bradley Schaefer (*S&T:* Mar. 2024, p. 34) with extreme interest. I've been an avid amateur astronomer since my teens, and as a professional astronomer I work for the Italian Space Agency.

Back in 1992, I wrote a paper (in Italian) in the July and August issue of *Astronomia*, the magazine of the Italian Amateur Astronomers Union. It describes the results of an intensive observing campaign of T Coronae Borealis organized in Europe, resulting in 884 visual estimates by 10 observers over a period of 930 days.

The main result was clear evidence of the orbital motion of the system causing a modulation in luminosity induced by the prolateness of the main star. This effect was shown using photoelectric photometry by H. C. Lines et al. in results published in the May 1988 *Astronomical Journal*, but my analysis has shown that carefully analyzed visual estimates could detect a modulation of +/- 0.16 magnitudes over a period of roughly 230 days.

**Giuseppe Bianco**
**Matera, Italy**

## The Speed of Sound

As someone accustomed to dealing with sound speeds ranging from more than 330 m/sec (in freezing air) to almost 6,000 m/sec (in steel), I was amazed to learn in "100,000-Light-Year Bow Shock in the Milky Way Halo" by Monica Young (*S&T:* Apr. 2024, p. 11) that the speed of sound in the Milky Way halo has a value of 165 km/sec. Could you please explain why this value is so "astronomically" high?

**Robert Janus**
**Hope, Rhode Island**

**Monica Young replies:** *Great question! I'm glad you asked it, because I learned something, too ☺. I asked the astronomers involved in the research your question, and here is their reply:*

*That's a really great question! Robert Janus has correctly identified that one can get quite a bit of variety in the speed of sound in different media, related to how easily compressible a medium is as well as the density of the medium. In the case of an ideal gas like air or the circumgalactic medium surrounding our Milky Way, the math works out that the speed of sound is proportional to the temperature of the gas (specifically, the square root of the temperature).*

*When dealing with room temperature (roughly 300 kelvin) like we experience here on Earth, one calculates values for the speed of sound on the order of a few hundred meters per second. But the circumgalactic medium is a super hostile and hot environment, where the gas is flying around at temperatures more like 1,000,000 kelvin. As a result, the speed of sound can reach incredibly high values like the one quoted in our paper.*

*And because of the enormous gravitational potential of the Milky Way, the Large Magellanic Cloud has been accelerated to a velocity that is almost two times faster than that extremely high sound speed, leading to the supersonic motion that we predict in our simulation.*

## Dazzling Dark Energy

Elizabeth Fernandez's "Dark Energy: A Brief History" (*S&T:* Feb. 2024, p. 26) was the most mind-bending, mind-expanding, thought-provoking article I've read in a long time! Thank you for showcasing such profound science.

**Thomas Tella**
**Wolcott, Connecticut**

The article on dark energy by Elizabeth Fernandez in the February issue of *S&T* was fascinating and set me to thinking. The universe, including time and space, was born in the Big Bang and has been expanding since then, and all galaxies are flying away from each other at ever-increasing speeds. But where was the universe born? Was there nothing before the universe was born? Or were space and time already present and our universe got its birth at some unknown coordinates in an infinite and empty space?

Will such a line of reasoning also explain that dark energy was already there and is tearing us apart now that matter and gravity are dispersed, and matter density is insufficient to fight the negative or vacuum energy we now call dark energy?

**Ven Challa, MD**
**Winston-Salem, North Carolina**

**Camille M. Carlisle replies:** *You are asking questions that people have asked in one form or another for millennia — which is to say that they are fundamental to our growing understanding of the cosmos. Augustine of Hippo, for example, pondered the nature of time in his 4th-century autobiography* The Confessions of Saint Augustine *(see Book XI), and his thoughts wouldn't have been totally foreign to modern cosmologists.*

*To do your questions justice would take several books, and so in lieu of a short, unsatisfying response, I direct you to other more prolific authors. I suggest starting with Brian Greene's* The Hidden Reality, *which discusses the questions you pose in the framework of string theory and multiple universes. (We don't know whether that framework is correct, but it's a useful framework for this discussion.) Matt Strassler's new book* Waves in an Impossible Sea *(*S&T: *June 2024, p. 61), which explores cosmological questions from the particle-physics side of things, also might be of interest.*

## Magnetic Magnetars

Zach Cano's article "Adventures of a Millisecond Magnetar" (*S&T:* Apr. 2024, p. 34) really helped me to understand the possible "lives" of neutron stars, millisecond magnetars, long gamma-ray bursts, and fast radio bursts. I've read articles that refer to them and sort of explain what they are, but his article was so helpful to put it all together.

**Steve Carnes**
**North Oaks, Minnesota**

**Zach Cano replies:** *Thank you for your comments on the recent article in* Sky & Telescope *about the possible ways that neutron stars continue to interact with their environments and other stellar objects long after their progenitor star has suffered its final demise. The article provides the merest of glimpses into a great body of research being undertaken by many talented and knowledgeable astronomers and astrophysicists around the world.*

*I am grateful for the chance to write about these intriguing objects in a way that provides a colorful summary of what we know about them, and I am even more grateful I have managed to share this interest with the public.*

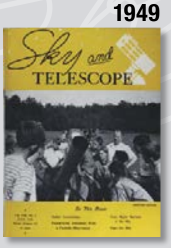
### FOR THE RECORD

● The Crab Nebula is roughly 600 years older than Cassiopeia A, not 1,500 years older (*S&T:* May 2024, p. 19).

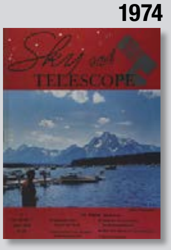
**SUBMISSIONS:** Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

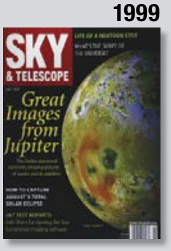
1949




1974




1999




◖ **July 1949**
**Keeping Time** "For many years, at the United States Naval Observatory and other national observatories where time is recorded and dispensed, quartz-crystal-controlled clocks have been used to keep time as accurately as does the earth itself — to about 1/1,000 of a second per day. Nevertheless, quartz-crystal clocks are subject to vagaries that have indicated the need for even more accurate means of control. This has now been found in what is known as the 'atomic clock,' developed at the National Bureau of Standards by Dr. Harold Lyons [and colleagues].

"The frequency of an absorption line [of] ammonia . . . is now used as the 'governor' on apparatus capable of time constancy of one part in 10 million . . . In addition to its obvious astronomical applications, such as furnishing an invariant check of the earth's rotation, the atomic clock will [aid] navigation systems."

*The advent of atomic clocks led to the occasional insertion of leap seconds in the 24-hour day.*

◖ **July 1974**
**Earth Grazer** "The great fireball observed on August 10, 1972, which streaked across the early afternoon skies of the western mountain states from Utah to Montana and over . . . Alberta, was a unique object [see cover shot at left]. It entered the atmosphere at such a small angle with the earth's surface that it did not quite make it to the ground. Instead, after dazzling thousands of astonished spectators for well over a minute, it left the atmosphere to continue its travel around the sun . . . I was one of the astonished spectators . . .

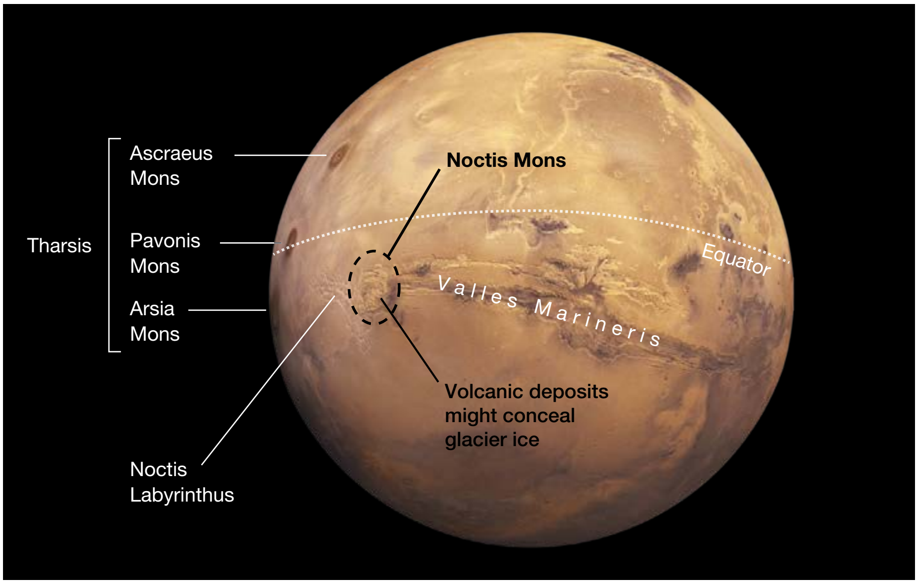
"If it was of magnitude –15 as seen from a distance of 100 kilometers, the mass was 4,000 tons and the diameter 13 meters."

*In a stunning coincidence, Harvard-Smithsonian astronomer Luigi Jacchia, a meteor expert, was vacationing that day at Jackson Lake Lodge, Wyoming. He gave our readers his analysis.*

◖ **July 1999**
**Hypernovae** "What packs more punch than a supernova? Something does, though no one knows for sure exactly what. Northwestern University astronomer Q. Daniel Wang claims to have found the first clear evidence for 'hypernovae': stellar explosions carrying as much as 100 times the energy of a supernova or even more. That's up in the same energy range as cosmic gamma-ray bursts, whose power has awed and confounded astronomers in recent years . . . Many now suspect that hypernovae and gamma-ray bursts are one and the same.

"Wang's evidence consists of two expanding gas bubbles that he discovered in extremely deep X-ray images of the galaxy M101 taken with the Rosat satellite."

*Starting in 2003, some "long" gamma-ray bursts have been definitely connected with hypernovae.*




◀ Noctis Mons is in the Tharsis volcanic province, between the jumbled terrain of Noctis Labyrinthus and the canyons of Valles Marineris. Although more eroded and lower than other nearby volcanoes, it rivals the others in diameter (black dashed circle).

SOLAR SYSTEM

# Giant Volcano Discovered on Mars

**SCIENTISTS HAVE UNCOVERED** the remains of a giant volcano on Mars. Orbiters since 1971 had imaged the formation, provisionally named "Noctis Mons," but extensive erosion concealed its nature until now.

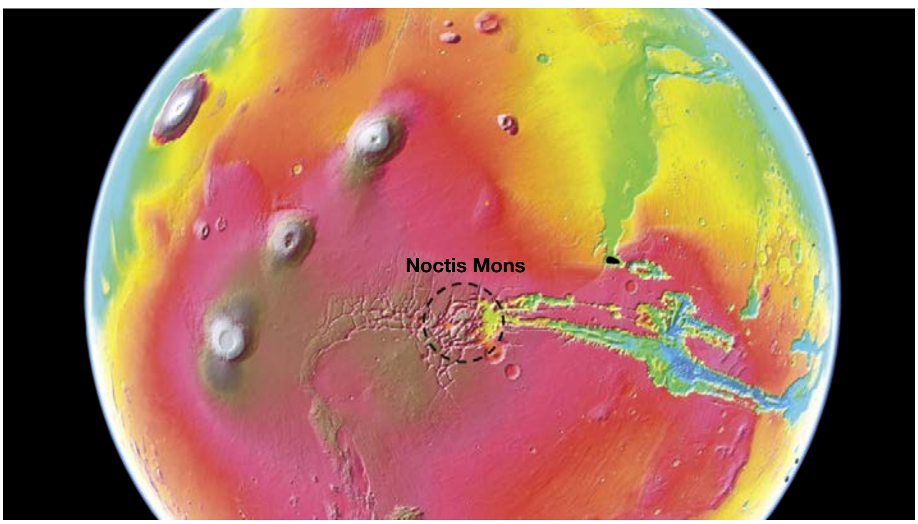
Located near the equator, Noctis Mons is 250 kilometers (160 miles) wide and, even eroded as it is, reaches elevations of more than 9 kilometers (almost 30,000 feet), announced Pascal Lee (Mars Institute and SETI Institute) at the 55th Lunar and Planetary Science Conference in The Woodlands, Texas.

For decades, heavy deterioration prevented the volcano's detection, he adds. A combination of fracturing, thermal erosion, and glacial erosion has produced a jumbled landscape, with a few elevated *mesas* — sandwiches of lava, volcanic fragments, and water ice — cut through by a network of valleys and collapsed areas.

Still, he and collaborators pieced together clues to reveal these formations' volcanic origin. The ridge of mesas curves around an eroded summit, which has the remnant of a *caldera*, a collapsed volcanic crater, in the middle.

"When we saw that arc of high points reaching 9,000 meters and sloping away, that's when we thought: Could this possibly be a volcano?" Lee says. "Now that we know that is there, it's very difficult to unsee it."

▼ Noctis Mons (black dashed circle) is shown on an elevation map of Mars.




The discovery of the volcano ties in with other findings in the region. Lee and Sourabh Shubham (University of Maryland, College Park) previously spotted hints of a glacier buried nearby, underneath the volcanic slopes. Those hints came in the form of a glacier-like sulfate-salt deposit. Lee and Shubham proposed at last year's Lunar and Planetary Science Conference that a layer of volcanic material had landed on top of glacier ice, reacting with the acidic water to form mineral deposits that mimicked the shape of the glacier underneath it. Later erosion removed the upper layers of volcanic material, revealing the salt layers underneath. "The ice is probably still there, but it's protected from disappearing by salt," Lee says.

Lee and Shubham think that the giant Noctis Mons volcano was similarly built like a layer cake, with alternating deposits of ice and volcanic material. This is borne out by the slopes of the mesas, in which salt deposits alternate with layers of volcanic material. Taken together, the eroded volcano and the glacier-like remnant lead Lee and Shubham to speculate that glacier ice might still be concealed beneath the surface near the Martian equator.

Alexis Rodriguez (NASA's Marshall Space Flight Center), who wasn't involved with the study, says other mechanisms, such as uplift caused by magma rising underneath the region, could have formed the eroded dome that Lee and colleagues call a volcano. But he adds that the combination of glaciers and magmatism is tantalizing for the prospect of finding biosignatures. "If it's really true," he notes, "it would be a very important discovery."

■ JAVIER BARBUZANO

MAP OF GIANT VOLCANO'S LOCATION: BACKGROUND IMAGE: NASA / USGS MARS GLOBE; GEOLOGIC INTERPRETATION AND ANNOTATIONS BY PASCAL LEE AND SOURABH SHUBHAM 2024; ELEVATION MAP: BACKGROUND IMAGE: NASA MARS GLOBAL SURVEYOR (MGS) MARS ORBITER LASER ALTIMETER (MOLA) DIGITAL ELEVATION MODEL. GEOLOGIC INTERPRETATION & ANNOTATIONS BY PASCAL LEE AND SOURABH SHUBHAM 2024)

SOLAR SYSTEM
## DART Impact Reshaped Asteroid Dimorphos

**WHEN NASA'S** Double Asteroid Redirection Test (DART) spacecraft whacked the asteroid moon Dimorphos (companion to the larger asteroid 65803 Didymos) on September 26, 2022, the impact was powerful enough to excavate about a tenth of the moonlet's material. That conclusion shakes up our understanding of rubble-pile asteroids.

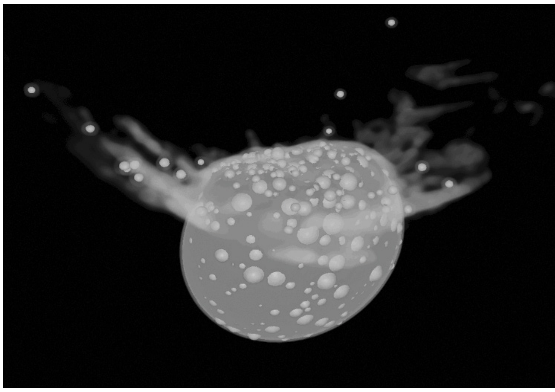
NASA built DART to study what would be necessary to redirect wayward asteroids, by impacting the smaller asteroid of the pair and watching the subsequent change in orbital period (*S&T:* Feb. 2023, p. 9). Dimorphos is a "rubble pile," a jumble of objects ranging in size from boulders to fine grains and, based on Hayabusa 2's much smaller hit on rubble-pile 162173 Ryugu (*S&T:* May 2020, p. 14), researchers had expected the DART collision to produce a crater, says Sabina Raducan (University of Bern, Switzerland). Raducan led a new analysis published on February 26th in *Nature Astronomy.*

Yet, with little holding the rubble pile together, the impact instead blasted material all over. Images from the CubeSat LICIACube, which was released prior to DART's impact and photographed the first few minutes afterward, showed what looked like "a big ball of sand, with very little binding between the grains," Raducan noted.

The team simulated what happened in the following hour based on LICIACube's initial observations as well as on physical models. The simulation calculated the outflying rubble's paths based on the physics of shock propagation.

The team found that DART's hit, at 6 kilometers per second (more than 13,000 mph), blasted 500 million kilograms from the surface — of which 50 million kg or so was wholly ejected from the system.

Other models had suggested rubble piles might contain denser insides, perhaps with clusters of big boulders at their cores, but the simulation instead suggests Dimorphos has a loose interior.



▲ This frame comes from a simulation of the DART impact's effects on Dimorphos.

"They nailed it," says Kevin Walsh (Southwest Research Institute), who was not involved in the study. "It's rubble all the way down."

The next step will be the October launch of the European Space Agency's Hera mission to the Didymos system. Laden with cameras, other sensors, and two CubeSats, Hera will study Didymos and Dimorphos in detail when it arrives in late 2026.

■ **JEFF HECHT**

SOLAR SYSTEM
## New Moons for Uranus and Neptune

**DOZENS OF MOONS** have been found around Jupiter and Saturn over the past two decades. However, since 2003, no new moons had been discovered orbiting Uranus, and only one new moon was officially added for Neptune. Now, three new finds, one for Uranus and two for Neptune, bring their tallies to 28 and 16, respectively.

The International Astronomical Union's Minor Planet Center announced the new finds on February 23rd. They are the faintest moons yet that ground-based telescopes have found orbiting the ice giants. Team lead Scott Sheppard (Carnegie Science) acknowledges, "These objects are at the edge of detectability."

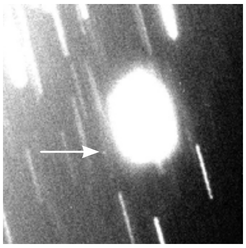
The one orbiting Uranus, provisionally designated S/2023 U1, is only 8 kilometers (5 miles) across, probably the planet's smallest known moon. It has an orbit of 680 days.

The two new moons orbiting Neptune had both been spotted earlier but had not been observed long enough to calculate their orbits. New observations provided a firmer grasp on their trajectories. Provisionally designated S/2002 N5, the bigger and brighter moon measures 23 kilometers across and takes nine years to circle Neptune. The smaller one, provisionally designated S/2021 N1, is about 14 km across and takes almost 27 years to orbit Neptune — the longest orbit known for any planetary moon.

To find these three moons, Sheppard had to stack five-minute exposures, which enabled him to image faint objects while keeping their motion from blurring. These exposures were repeated over a period of up to four or five hours over multiple nights using some of the world's biggest telescopes, such as the Magellan and Very Large telescopes in Chile as well as the Subaru and Gemini North telescopes in Hawai'i.

Each of the three new moons has an orbit that groups it with the orbits of two larger moons. These groupings probably indicate families formed by the breakup of a larger, captured object.

Planetary scientists suspect that the outer solar system may hold the key to understanding the planets' formation and early evolution. Because of that, the National Academy of Sciences has put a high priority on a Uranus Orbiter and Probe concept. Such a mission would also offer close-ups of moons beyond the reach of Earth's biggest and best telescopes.



▲ The new Uranian moon S/2023 U1 appears unblurred in an image from the Magellan Telescope.

■ **JEFF HECHT**

SIMULATION FRAME OF DART IMPACT: SABINA RADUCAN; NEW MOON OF URANUS: SCOTT SHEPPARD

BLACK HOLES

## Strong Magnetic Fields Swirl Near the Milky Way's Black Hole

**THE EVENT HORIZON TELESCOPE** (EHT) collaboration has released another image of our galaxy's central black hole, Sagittarius A* — this time revealing the behavior of the magnetic fields that thread the surrounding gas. The results appear in two papers in the April 1st *Astrophysical Journal Letters*.

The radio images that the EHT produces are reconstructions of the black hole's silhouette, a dark shadow framed by the glow of light that has evaded the event horizon. The radio emission is *synchrotron radiation*, emitted by electrons corkscrewing along magnetic field lines.

This light is *polarized*, the waves oscillating with a fixed orientation: As electrons spiral around magnetic field lines, the particles emit photons that oscillate perpendicular to the field. The amount and pattern of polarization enables astronomers to map the magnetic fields' structure and strength.

▲ Lines around the silhouette of the Milky Way's supermassive black hole trace the light's polarization, which in turn reveals the behavior of magnetic fields close to the event horizon.

The polarization detected in Sgr A*'s emission indicates that the magnetic fields in its accretion flow are strong, twisted, and orderly. Fields like these can control and even choke the gas flowing into a black hole, manipulating the black hole's diet (*S&T:* Dec. 2022, p. 12). They can also serve as a pipeline for outflowing plasma jets.

EHT astronomers previously found signs of strong, orderly magnetic fields around the black hole in the galaxy M87, too. Yet these two black holes are very different: Sgr A* is a quiet, finicky cat lapping from a trickle of gas; M87* is a roaring lion that shoots out plasma jets thousands of light-years long.

It could be that strong, orderly magnetic environments are a universal feature of the gas that skirts supermassive black holes. Theoretically, such fields should also power jets of plasma that shoot out along the black hole's poles. Observations have yet to find a jet from Sgr A*, but data like these raise hopes that one exists.

Based on comparing the polarization data with simulations and calculations, the researchers suggest that the black hole may be spinning nearly as fast as physically possible and tilts away from us such that we're looking up at its chin. But the team warns that these are inferences, not measurements.

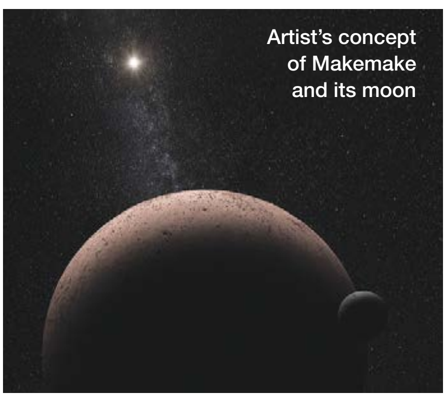
■ **CAMILLE M. CARLISLE**

---

SOLAR SYSTEM

## Webb Spies Evidence of Methane Volcanoes

**ERIS AND MAKEMAKE** are two of the largest *trans-Neptunian objects* (TNOs), denizens of the solar system beyond Neptune. Most TNOs have extremely dark surfaces, the result of being weathered by solar and cosmic radiation for billions of years. However, the biggest TNOs — Eris and Makemake among them — appear brighter thanks to surface methane ice. Now, two teams of scientists, led by Will Grundy (Lowell Observatory) and Christopher Glein (Southwest Research Institute), have obtained James Webb Space Telescope (JWST) observations of these worlds, measuring and analyzing the *isotopic ratios* of hydrogen in their ice. The publications appear in the March 15th and April *Icarus*, respectively.




Both objects formed with at least some methane in their water and rocks, and that methane would have had the same proportion of *deuterium* (heavy hydrogen) as other primordial objects, such as comets. But JWST data showed that Eris and Makemake's methane has less deuterium than expected if the methane were primordial. Instead, the deuterium amount is similar to that of water in other primordial objects, suggesting that "hot" chemical reactions with water generated methane, incorporating the water's lighter hydrogen.

There are two main ways to make methane (without invoking space cows). The first is to heat up rocks to more than 150°C (300°F), so that carbon-rich molecules break apart and loose carbon atoms can take hydrogen from water to make methane. Another way to make methane is to run hot water through rocks containing smaller carbon molecules, such as carbon monoxide and carbon dioxide.

Either scenario suggests Eris and Makemake could have become hot enough in the distant past to form internal oceans. Depending on how hot these worlds became, there could have been some pretty spectacular methane-driven volcanism, generated by the buildup of gas within the deep ocean.

The JWST data suggest Eris and Makemake probably experienced at least some geology and, possibly, explosive methane volcanism in their past. And some of that activity might even still be around, at least on the bigger Eris. The researchers muse that "visits to Eris and Makemake with spacecraft are intriguing to ponder." They sure are.

■ **EMILY LAKDAWALLA**

MAGNETIC FIELDS SWIRLING AROUND SGR A*: EHT COLLABORATION; ARTIST'S CONCEPT OF MAKEMAKE: NASA / ESA / A. PARKER (SOUTHWEST RESEARCH INSTITUTE)

NASA / ESA / CSA

▲ Behind Pandora's Cluster (Abell 2744), imaged here by the James Webb Space Telescope, are eight tiny background galaxies hailing from the early universe.

COSMOLOGY

## Webb Telescope: Dwarf Galaxies Lit Up Early Universe

**FAINT, SMALL GALAXIES** ionized the opaque fog that obscured the early universe, new James Webb Space Telescope (JWST) observations show. The telescope has made the first spectroscopic observations of the faintest galaxies present during the universe's first billion years, offering vital clues about how early events unfolded.

For the first few hundred million years after the Big Bang, in the cosmic dark ages, the universe was a thick soup of hydrogen fog. The fog is thought to have eventually cleared when photons ripped neutral hydrogen atoms apart, a process known as *reionization*. But debate has remained as to whether this reionizing radiation came solely from the first stars that lit up early galaxies or whether material falling into supermassive black holes also played a significant role.

Now, a team of astronomers led by Hakim Atek (Sorbonne University, France) has used JWST to peer at extremely faint and distant dwarf galaxies. These galaxies are only visible because the gravity of the intervening Pandora's Cluster (Abell 2744) — a car crash of galaxies 4 billion light-years away — magnified the more distant galaxies' light.

Atek's team studied eight of these background galaxies, finding that they produced four times more ionizing ultraviolet radiation than theory had predicted. The team published their findings in the February 28th *Nature*.

"It's fantastic to see the pieces fitting together and pointing squarely at tiny galaxies as the culprits," says Sean McGee (University of Birmingham, UK), who was not involved in the study. Astronomers have long suspected that such galaxies were essential to reionization, but McGee adds that "this was becoming more debatable recently, as JWST has been finding more active galactic nuclei than previously expected." The new JWST data put these tiny galaxies back in the limelight.

An upcoming JWST observing program named GLIMPSE will target another massive galaxy cluster — Abell S1063 — in order to see even fainter distant galaxies, which will help verify if the eight galaxies in the current study are typical members of this early time period. Radio data from the Square Kilometer Array, which will map the distribution of neutral (that is, not yet ionized) hydrogen, will also provide essential confirmation of dwarf galaxies' role.

■ COLIN STUART

## IN BRIEF

### Webb Confirms Expansion

A discrepancy in the measurement of the universe's current expansion rate, called the *Hubble constant*, has long mystified cosmologists (*S&T:* June 2019, p. 22). In the February 10th *Astrophysical Journal Letters*, a team of astronomers led by Adam Riess (Space Telescope Science Institute and Johns Hopkins University) used high-resolution data from the James Webb Space Telescope (JWST) to rule out one possible reason for that discrepancy. Riess has been leading a collaboration called Supernova H0 for the Equation of State (SH0ES) that measures the Hubble constant using *Cepheid variable stars*. These stars pulse in a way that reveals their intrinsic brightness, which means astronomers can measure their apparent brightness to figure out their distance. However, Cepheids can be difficult to tease apart from other stars in crowded fields; previous SH0ES studies have accounted for that effect statistically. Now, the SH0ES collaboration has re-imaged in high resolution more than 1,000 Cepheids previously observed by the Hubble Space Telescope, and they found no significant differences in the stars' distance measurements.

■ ARWEN RIMMER

**Read the full story at https://is.gd/WebbCepheids.**

### Icy Impactor Made Martian Moons

Mars's two moons, Phobos and Deimos, have dark surfaces and peculiar orbits, fueling two main theories about their origin: Either they are captured asteroids, or they are coalesced debris, launched to orbit after a giant impactor struck the Red Planet long ago. However, simulations of the latter have problems: A rocky impactor would have launched too much material into orbit, and the debris disk would have been much too hot, altering or destroying the basalts we now observe on the moons' surfaces. In research presented at the 55th Lunar and Planetary Science Conference, Courteney Monchinski (Tokyo Institute of Technology, Japan) suggests the giant impactor was made mostly of water ice. An icy impactor would have put less rock into space, and the vaporization of the ice would have cooled the debris out of which the moons formed. Monchinski suggests that such a large, icy body could have formed in the outer rim of the solar system, beyond the orbit of Saturn or Neptune; instabilities brought on by the giant planets could later have flung the body into the inner solar system.

■ JAVIER BARBUZANO

# Eye on the X-ray Sky

An astronomer shares his highlight reel of revolutionary science drawn from a quarter-century of Chandra X-ray Observatory operations.

When we look up at the night sky with the unaided eye, we see planets, stars, star clusters — and, if we are lucky, the Milky Way itself. Telescopes enable us to explore the wonders of the universe with greater detail and precision: We can resolve details on the surface of the Moon, detect satellites around other planets, explore the remnants of stellar explosions, and study galaxies in the distant universe.

It is important to remember, though, that visible light represents a narrow part of the electromagnetic spectrum. To collect more information, and hence build a comprehensive understanding of astrophysical phenomena, multiwavelength observations are key. Recognizing this, NASA launched a series of Great Observatories between 1990 and 2003 to cover a large part of the electromagnetic spectrum: gamma rays (Compton Gamma Ray Observatory), X-rays (Chandra X-ray Observatory), ultraviolet and visible light (Hubble Space Telescope), and infrared light (Spitzer Space Telescope).

The Chandra X-ray Observatory (Chandra for short) was launched on July 23, 1999, aboard the Space Shuttle *Columbia*. Ever since its commissioning, Chandra has delved into previously hidden aspects of the universe and completely revolutionized many areas of astrophysics.

### Chandra

The Chandra X-ray Observatory was named for Subrahmanyan Chandrasekhar (1910–1995). Known to the world as Chandra, which means “Moon” in Sanskrit, he was a prominent astrophysicist who studied the structure and evolution of stars, for which he received the Nobel Prize in Physics in 1983.

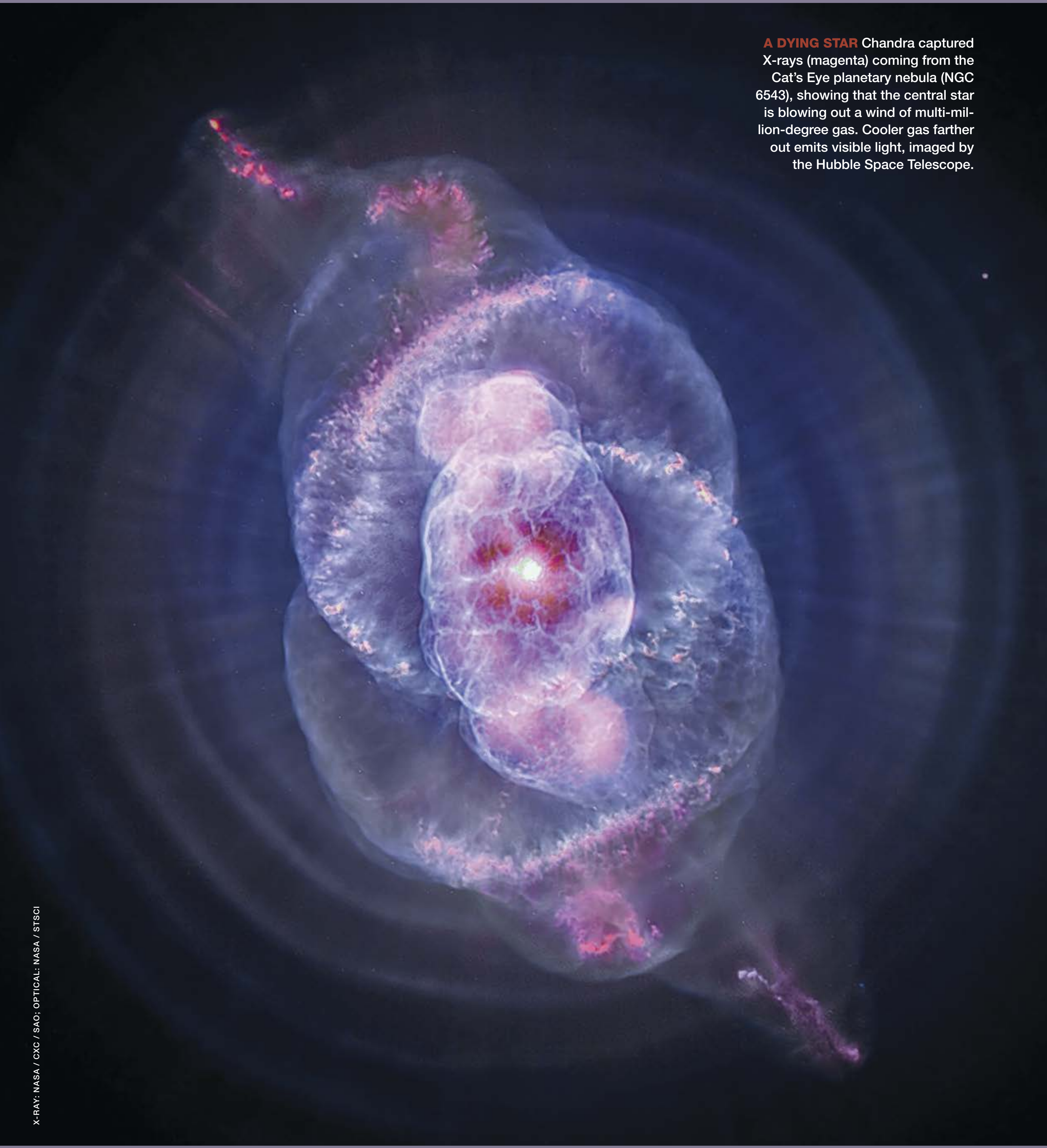
Chandra’s most unique attribute is its 0.5-arcsecond spatial resolution, which results in sharp and detailed X-ray images. This resolution is not as good as Hubble’s (which is 0.1 arcsecond), but it’s nevertheless impressive because X-rays are much harder to catch than visible or infrared light. We therefore need a unique optical design of nested mirrors to guide X-rays to a focus. The unprecedented resolution combines with high sensitivity, mirrors with a large collecting area, and advanced spectroscopic capabilities to create a transformational instrument. It’s unsurprising that Chandra became the powerhouse of X-ray astronomy.

In 2024 we are celebrating the 25th anniversary of Chandra’s launch, which makes it NASA’s longest-operating mission without servicing — and one of only two Great Observatories still running. To honor Chandra’s achievements, I’ve collected some of my favorites among the observatory’s most impactful results.

## From Black Holes to Dark Matter

Studies of black holes are a prime example of where Chandra’s capabilities — in particular its exquisite angular resolution — are best applied. Over the past quarter century, Chandra has painted an amazing picture of black holes near and far, small and large.

X-ray observations are uniquely powerful in identifying growing black holes at the center of distant galaxies. When black holes grow, they gather material from an extensive disk of swirling gas, which can become heated to such extremely high temperatures that it emits X-rays. Chandra not only captures these photons but also produces the sharpest X-ray images available. While the disk itself is too small to resolve, these images enable us to differentiate the black holes’ emission from that of other X-ray sources, either within the host galaxy or in crowded fields of view.



**A DYING STAR** Chandra captured X-rays (magenta) coming from the Cat's Eye planetary nebula (NGC 6543), showing that the central star is blowing out a wind of multi-million-degree gas. Cooler gas farther out emits visible light, imaged by the Hubble Space Telescope.

X-RAY: NASA / CXC / SAO; OPTICAL: NASA / STSCI

More than two decades ago, Chandra found something remarkable in the heart of the star-forming galaxy NGC 6240: not one but *two* supermassive black holes, separated by 3,000 light-years. These giant black holes are orbiting each other and, given their slowly shrinking separation, might coalesce in tens of millions of years. This future merger will release copious amounts of electromagnetic radiation and low-frequency gravitational waves.

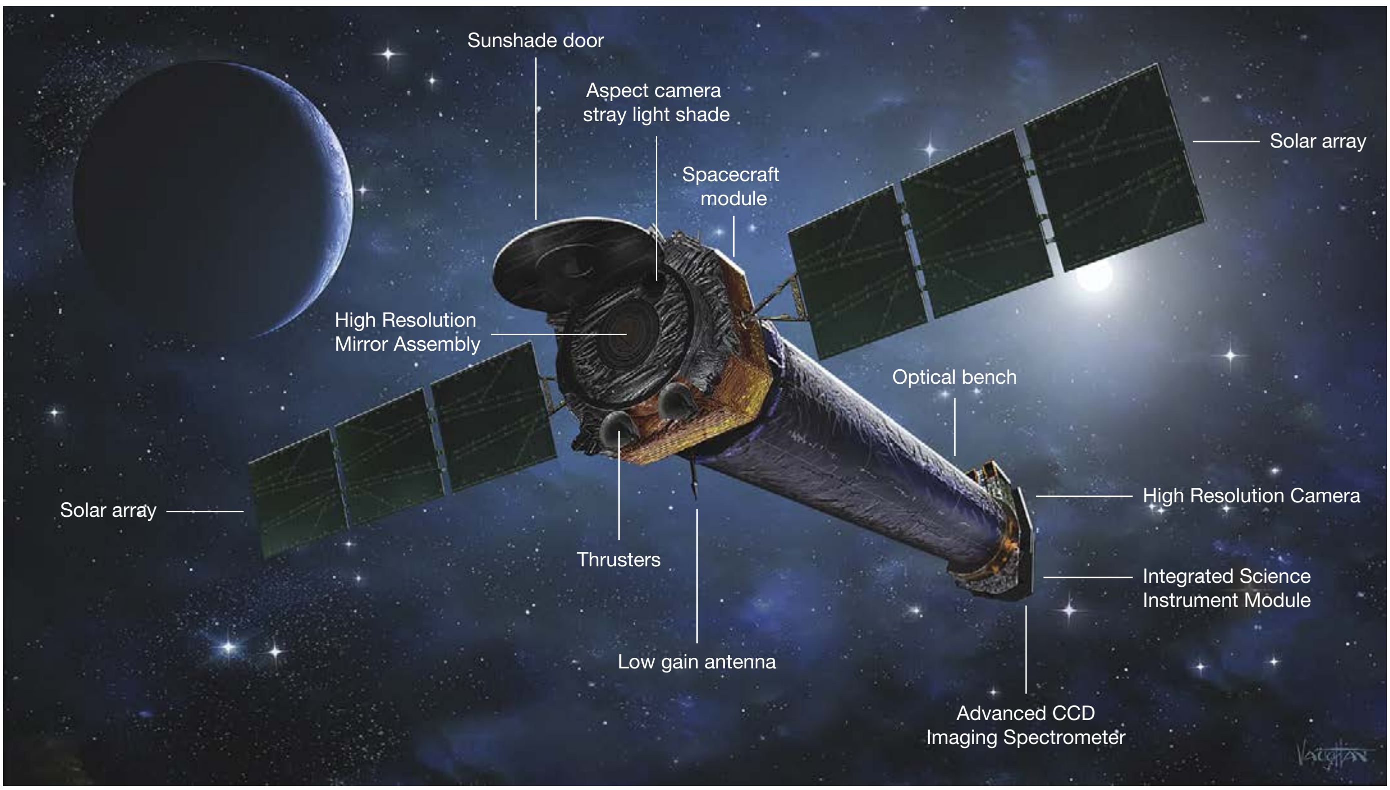
Since this initial discovery, many other such supermassive black-hole binaries have been found in multiwavelength searches. The importance of these discoveries is profound: They support the idea that, not only can supermassive black holes grow through mergers, but also that there are pairs out there converging right now. Such mergers should emit gravitational waves, which we'll be able to observe with the upcoming Laser Interferometer Space Antenna (LISA), set to launch next decade.

Dwarf galaxies, too, held some black hole surprises for astronomers. Nearly every large galaxy (including the Milky Way) hosts a supermassive black hole in its center. But whether black holes existed in the smallest galaxies remained a mystery until 2011, when astronomers published Chandra

## Far Out

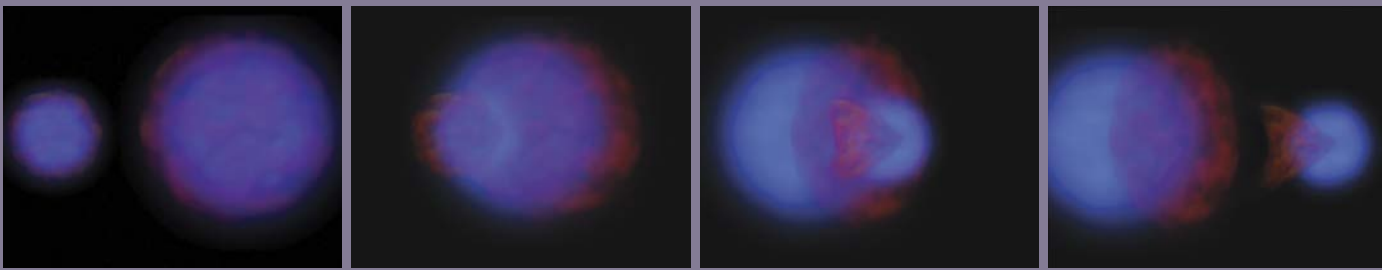
**Chandra's elliptical orbit takes it from 9,660 kilometers (6,000 miles) above Earth's surface out to 139,000 kilometers (86,500 miles). Even at its closest, the X-ray telescope flies about 20 times higher than Hubble. Their respective orbits mean that, while the Space Shuttle could reach Hubble for servicing, it couldn't reach Chandra.**

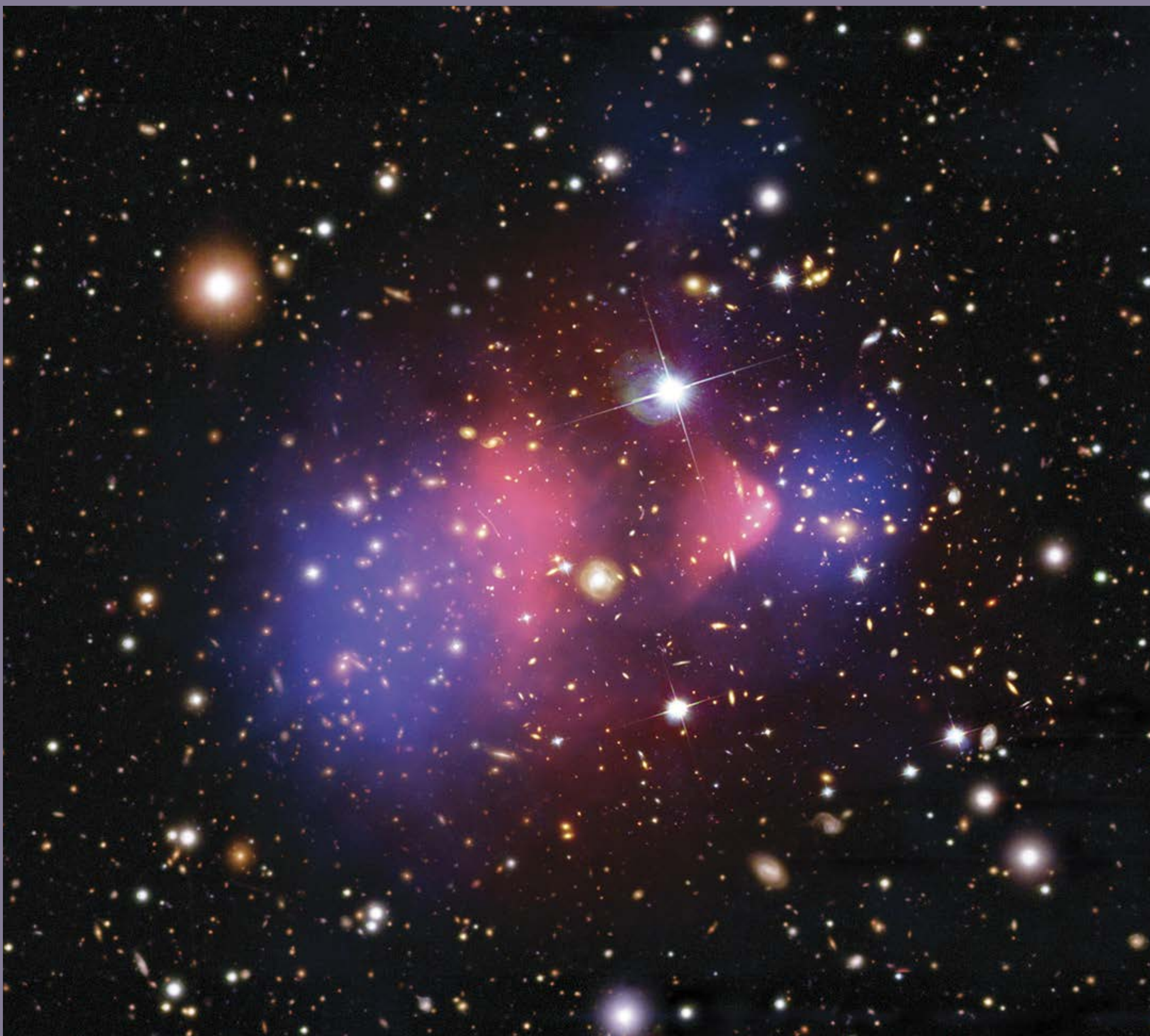

**DEPLOYMENT** Commander Eileen Collins led the deployment of the Chandra telescope from the Space Shuttle *Columbia*, captured here by fellow astronaut Cady Coleman.




▲ **THE OBSERVATORY** The Chandra spacecraft is roughly the size of a school bus. X-rays pass through the side of the telescope facing us in the diagram; the detectors are at the rear. Solar panels provide power, while thrusters maintain the orbit around Earth.

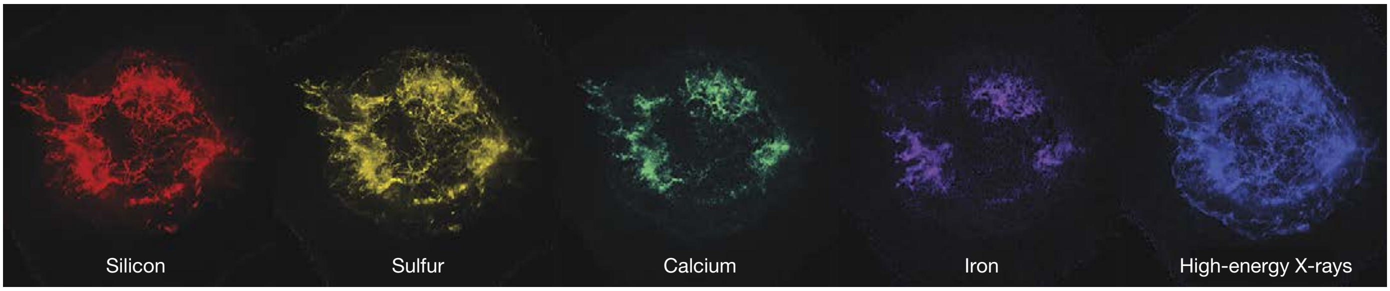
DEPLOYMENT: NASA; ILLUSTRATION: NASA / CXC / J. VAUGHAN





▲ **BULLET THROUGH THE HEART** Chandra captured the heat from gas (pink) associated with two galaxy clusters that have crashed together and passed through each other in what's known as the Bullet Cluster (1E 0657-56). The bullet shape of the gas clump at right comes from its passage through the gas clump at left. The mass of the clusters, as measured by the effect of their gravity on distant galaxies in the background, is marked in blue. Galaxies appear in orange and white. The majority of the mass is not associated with the hot gas, as proposed by alternate theories of gravity; most of the mass of these clusters is thus unseen.

▲▲ **COLLISION** The four artist's illustrations at top demonstrate the collision that created the Bullet Cluster; the final panel mimics the actual data shown in the X-ray image. Hot gas is red and dark matter blue. As the hot gas associated with each of the two clusters collided, a drag force slowed and reshaped it. However, the dark matter passed through unimpeded.




▲ **ELEMENTS OF LIFE** Different chemical elements emit different, narrow ranges of photon energies, enabling astronomers to map their locations. These images show where silicon (red), sulfur (yellow), calcium (green), and iron (purple) are within the Cassiopeia A supernova remnant. The highest-energy X-rays (blue) depict the supernova's expanding blast wave.

observations of a dwarf galaxy called Henize 2-10. This small galaxy, which is forming stars at a prodigious rate, harbors a black hole that already has about 1 million times the mass of our Sun. Because Henize 2-10 is analogous to galaxies in the early universe, this discovery suggests primordial galaxies could host hefty supermassive black holes, already grown to large sizes before the galaxies built up substantially.

While local dwarfs may be analogs of galaxies in the infant universe, to truly understand galactic and black hole formation, we must explore the early universe itself. The detection of such galaxies became possible only recently with the launch of the James Webb Space Telescope. But do any of these early galaxies host a supermassive black hole? Observations from Chandra indicate that yes, some of them do.

I was extremely fortunate to lead a Chandra program that followed up on a sample of JWST-detected galaxies, as we searched for growing black holes in the heart of these infant galaxies. Thanks to nearly month-long observations with Chandra, we found a supermassive black hole in a galaxy called UHZ1, which exists merely 470 million years after the Big Bang, when the universe was barely 3% of its current age.

To everyone's great surprise, the mass of this black hole (tens of millions of solar masses) was already comparable to the stellar mass of the galaxy itself (*S&T:* May 2024, p. 20).


▲ **DWARFED** The dwarf galaxy Henize 2-10 is bursting with new stars and hosts an actively feeding black hole with the mass of 1 million Suns.

For such a black hole to be so massive relative to its host might suggest that it originated from the collapse of a massive gas cloud rather than from the collapse of one of the first stars (*S&T:* Jan. 2017, p. 25).

Chandra can do much more than see black holes: It can actually hear them! Galaxy clusters are filled with gas so intensely hot — between 10 and 100 million degrees — that it emits X-rays. The Perseus Cluster is a prime example. As the supermassive black hole in the central galaxy of the cluster accretes matter, it launches jets of material into the surrounding gas, creating pressure waves. Deep Chandra observations have revealed these waves as ripples in the X-ray-emitting gas.

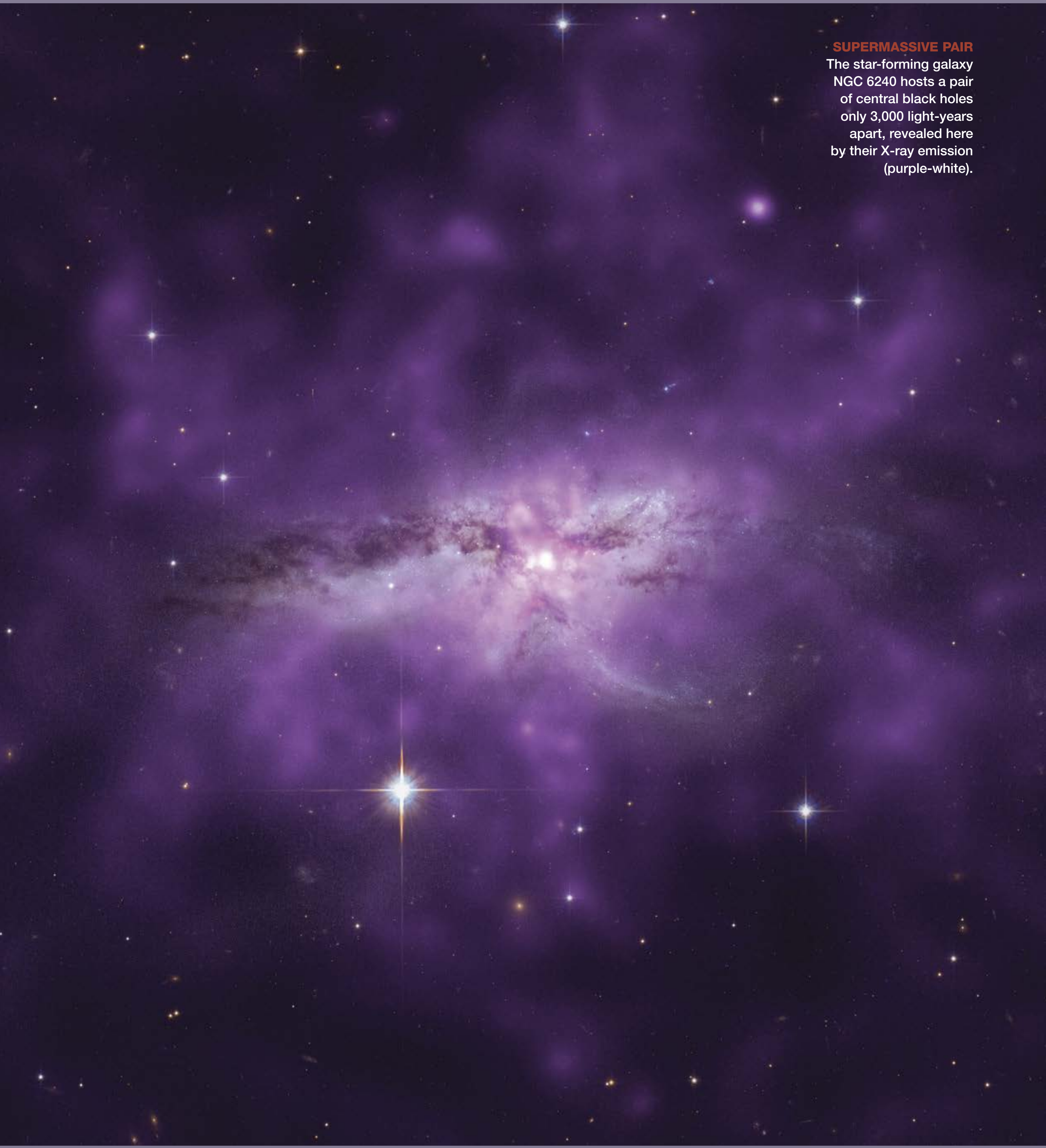
Sound waves are also pressure waves. If we were to convert these ripples in the Perseus Cluster into a note, it would be 57 octaves below middle C, which the human ear cannot hear. However, by scaling the sound waves of Perseus to be within the range of human hearing, Chandra's sonification project (called Universe of Sound) made it possible for anyone to now listen to the sound of the cluster — as well as that of many other astrophysical objects (*S&T:* Mar. 2024, p. 26).

The vast amount of hot, X-ray-emitting gas that fills galaxy clusters makes them prime targets for Chandra. A wide range of studies explore cluster evolution and dynamics as well as the interaction between supermassive black holes and large-scale gas. Perhaps the most intriguing application of an X-ray observation of galaxy clusters, though, is that it can provide evidence for the existence of dark matter.

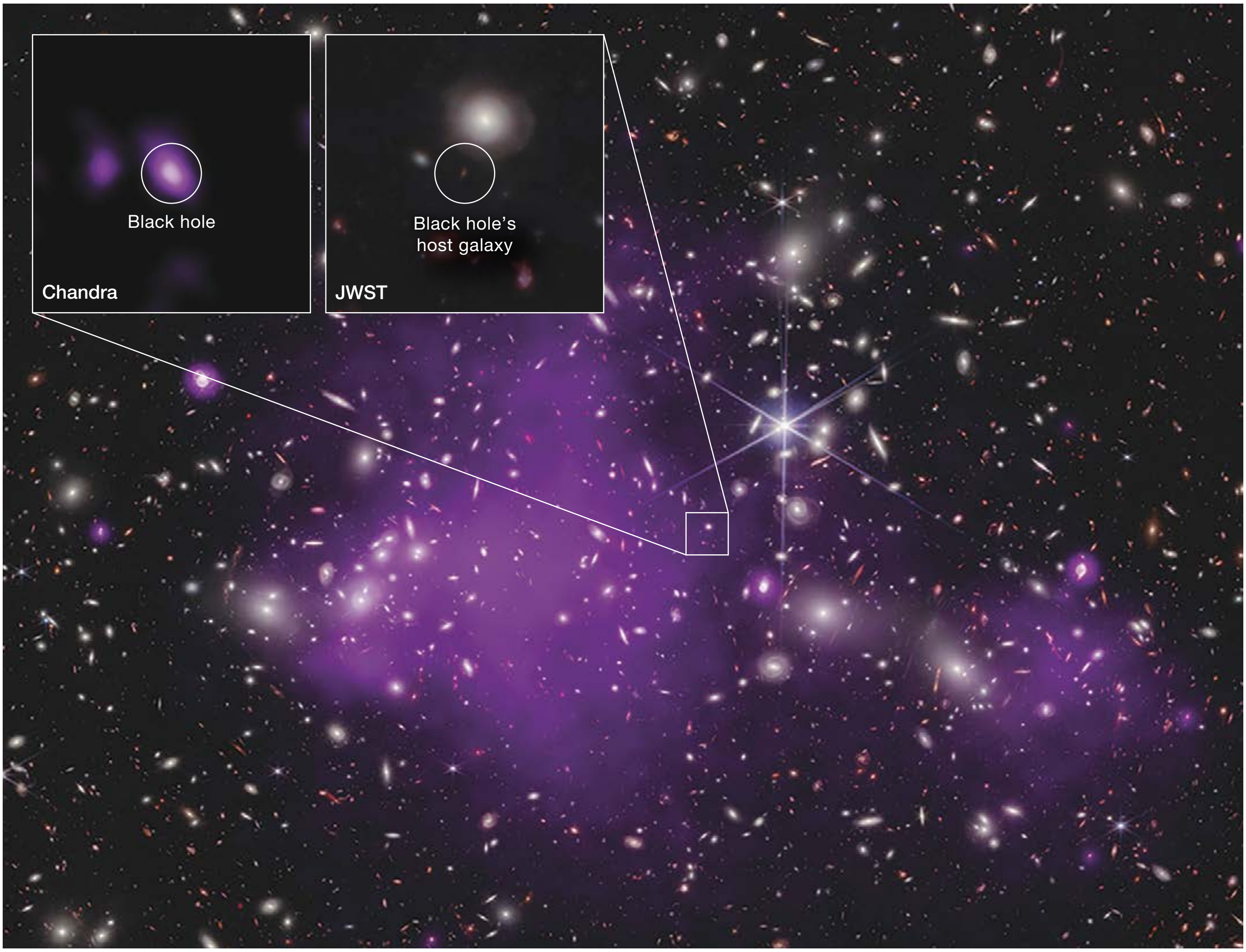
There's no better example of this than the Bullet Cluster, a merger of two galaxy clusters whose light has traveled 3.4 billion years to reach Earth. When astronomers observed the cluster both with Chandra and in visible light, they discovered an offset between the hot, X-ray-emitting gas and the location of most of the cluster mass. This mass, most of it "dark," is measured through the effect of gravitational lensing, in which its gravity distorts the visible light of distant background galaxies.

Why was there an offset? The X-ray-emitting gas from one cluster interacts with that of the other, slowing it down and resulting in the characteristic bullet-like feature. However, the non-interacting dark matter didn't slow down and instead kept moving forward. Stars within the cluster's galax-

ELEMENTS: NASA / CXC / SAO; HENIZE 2-10: X-RAY: NASA / CXC / VIRGINIA / A. REINES ET AL; RADIO: NRAO / AUI / NSF; OPTICAL: NASA / STSCI; NGC 6240; X-RAY: NASA / CXC / SAO / E. NARDINI ET AL; OPTICAL: NASA / STSCI



**SUPERMASSIVE PAIR** The star-forming galaxy NGC 6240 hosts a pair of central black holes only 3,000 light-years apart, revealed here by their X-ray emission (purple-white).




▲ **RECORD-BREAKER** One of the most distant black holes lies in the galaxy UHZ1, which existed 470 million years after the Big Bang. The background image shows both infrared (white and red) and X-rays (purple). The black hole in the galaxy's core reveals itself in X-rays (top left inset).

NASA / CXC / SAO / ÁKOS BOGDÁN; INFRARED: NASA / ESA / CSA / STSCI; IMAGE PROCESSING: NASA / CXC / SAO / L. FRATTARE & K. ARCAND

ies are also visible in multiwavelength images (they, too, are non-interacting, passing right by each other), but they do not nearly account for the total mass. This set of observations was the first to provide direct evidence that the bulk of a cluster's mass is some form of unseen matter.

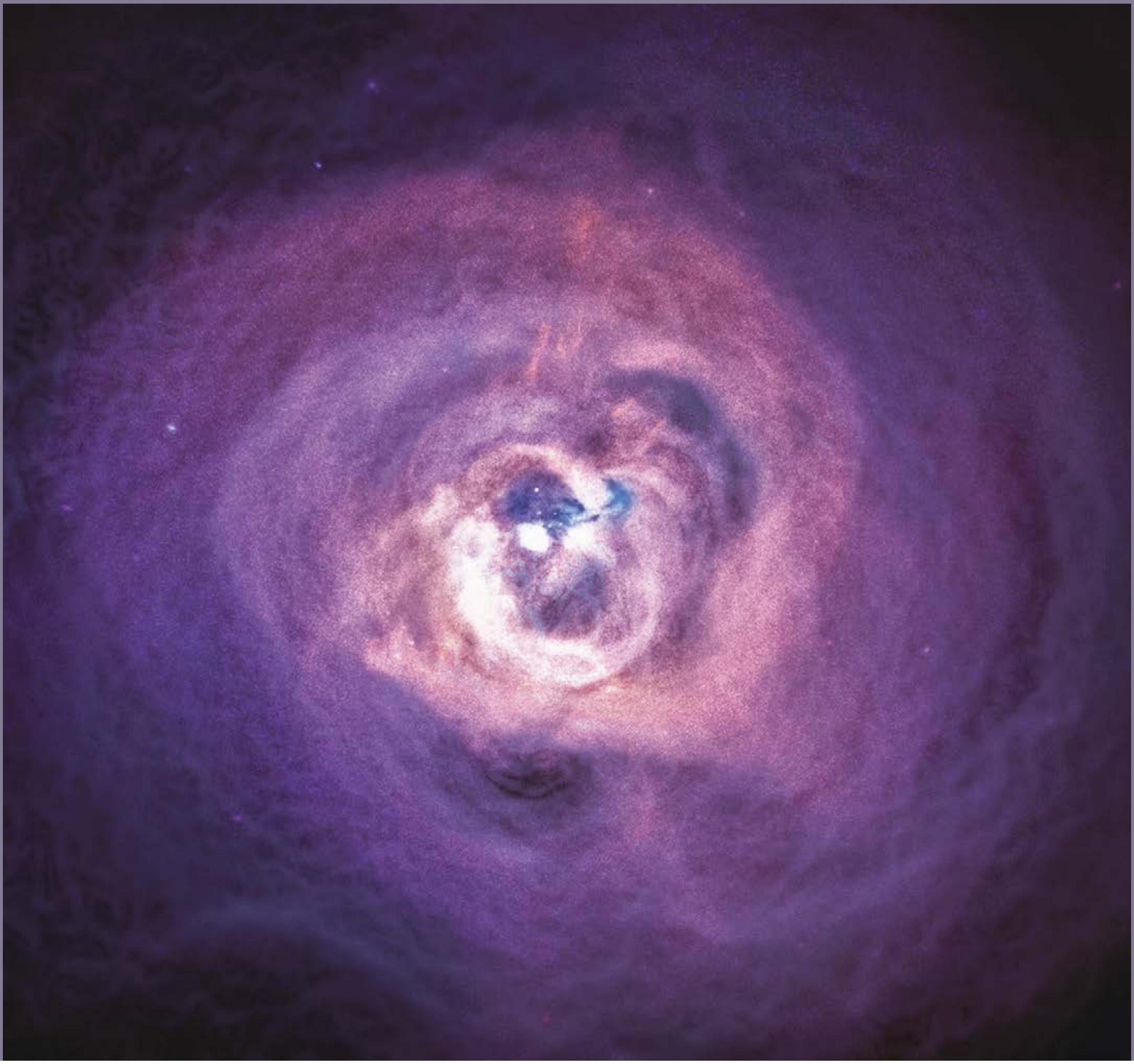
## Cosmic Death and Life

So far, we have looked at the larger-scale universe through the eyes of Chandra. However, Chandra's first-light image, and perhaps its most iconic observation, was something much closer to home: the Cassiopeia A supernova remnant. The 0.5-arcsecond angular resolution of Chandra revealed the neutron star created in the supernova explosion and, on larger scales, unveiled never-before-seen structures in the tossed-off stellar layers that wreathe this tiny star. Studying supernova remnants allows astronomers to understand how stars produce, and then disseminate, chemical elements, such as the sulfur, iron, and oxygen atoms that are essential for life on Earth (*S&T:* May 2021, p. 34).

What is even more fascinating is that over more than two decades, Chandra regularly observed this supernova remnant and captured changes in its appearance. Since Cassiopeia A is expanding so fast, at some 5,000 kilometers per second (10 million mph), we can actually see it grow from image to image. By stitching together many individual observations from Chandra's first light to the present day, we can generate a movie of its expansion, which lets us observe the physics of a supernova remnant from a "front-row" seat.

On even smaller scales, Chandra has explored numerous planetary nebulae in concert with the Hubble Space Telescope, creating beautiful images of the aftermath of stellar death. In these systems, Chandra detects the diffuse X-ray emission that results when a wind from the hot stellar remnant rams into the star's ejected atmosphere.

Chandra reaches even smaller scales, down to that of planets. Planets may not be the first objects that come to mind when it comes to X-rays; however, Chandra has successfully detected several planets and minor bodies in the solar system



▲ **PERSEUS CLUSTER** The galaxies of this cluster aren't visible in this X-ray image, which instead highlights the ripples in the hot gas suffusing the cluster. Giant jets shooting out of the central galaxy have created overlapping bubbles in the gas, providing a record of the jet's activity throughout cosmic time.

NASA / CXC / SAO

— including the dwarf planet Pluto. While Pluto itself does not emit high-energy radiation, the collision of solar wind particles with the gases in Pluto's tenuous atmosphere generates X-rays. It fascinates me that Chandra can detect such a small, faraway world — one smaller even than our Moon.

Needless to say, the above examples provide a subjective glimpse into Chandra's achievements over the past 25 years. When we think about these and other discoveries, we should remember that it takes a large and dedicated team to make the Chandra project a success. I am lucky to be part of this team, and I am extremely proud to say that I have contributed to the success of Chandra. As we celebrate the telescope's 25th anniversary, I am not only looking at the past, but I am also excited for the future — and I'm curious to see what secrets of the universe Chandra will reveal tomorrow.

■ **ÁKOS BOGDÁN** is an astrophysicist at the Center for Astrophysics, Harvard & Smithsonian, working at the Chandra X-ray Center. He is enthusiastic about the wonders of the universe and often seeks to perceive them through the eyes of Chandra.

# The Age of Sample Returns

The science gained from sample-return missions has turned remote dots of light into real worlds.

I remember my first look at the solar system as a kid. As a child of the early 1970s, I dove into books that often showed off blurry images of the major planets taken by professional observatories, ones that astrophotographers could easily top today. Finally, a short paragraph would mention the asteroids, perhaps with a photo of a dot in a star field, and a "?" on a table next to mass, rotation, etc.

Fast forward to today, and these places have become real worlds: locales of rock, mud, and rubble that we can actually discuss in terms of their geology and chemistry — often on a microscopic level.

A pivotal development that enabled this sea change has been sample-return missions: the intentional retrieval of material from planets, asteroids, comets, and the space between them.

For sure, we've long had samples come to us accidentally in the form of meteorites, and to date, we've identified specimens from the Moon, Mars, and the dwarf planet 4 Vesta. We've even found interstellar dust samples linked to ancient supernovae, preserved in recent snowfalls in Antarctica. But these incidental samples are contaminated the moment they hit Earth's atmosphere.

So scientists send out spacecraft (and sometimes astronauts) to retrieve pristine material and bring it back to Earth for study. By doing so, they deepen our understanding of the science and formation of the solar system.

◀ **ALIEN RUBBLE** A look inside the head of the OSIRIS-REX sampling instrument, with the lid removed and the asteroid material revealed. The largest rocks are about 1 cm (0.4 inch) wide.

## A Brief History of Sample-Return Efforts

The dream of returning pristine samples from distant worlds to the laboratory for study goes back to the early Space Age. The very first samples collected were the contingency samples scooped up by astronaut Neil Armstrong immediately after setting foot on the lunar surface. This was an assurance that, had Apollo 11 needed to leave the lunar surface quickly, at least some lunar samples would still make it back to Earth.

Ultimately, the Apollo program would bring back 382 kilograms (842 pounds) of lunar samples, over the span of six missions. Apollo 11 collected mainly basalts and breccias, but it was the unique composition of the fragments of ancient lunar highland crust that led scientists to conclude that the Moon had once been a *magma ocean* (*S&T:* July 2019, p. 14).

The Soviet Union completed the first robotic sample return, when Luna 16 retrieved 101 grams (3.56 ounces) of lunar soil and brought it to Earth on September 24, 1970. Over three missions, Russia returned a total of 300 grams of lunar samples. These were initially curated at the Russian Academy of Sciences' Vernadsky Institute in Moscow, with small samples eventually distributed to international partners. Small amounts were even exchanged between the U.S. and the Soviet Union.

But later sampling attempts met with failure. One ill-fated try was Russia's Phobos-Grunt mission, launched in late 2011, which failed to leave Earth orbit. In fact, Russia has yet to field a successful lunar or interplanetary mission since the breakup of the Soviet Union. Its most recent attempt, Luna 25, succumbed to "litho-braking" in 2023 when (in the

▲ **APOLLO ERA** Researchers carefully handle a Core Sample Vacuum Container from the Apollo era at NASA ARES.

SAMPLING INSTRUMENT: NASA / ERIKA BLUMENFELD & JOSEPH AEBERSOLD; APOLLO SAMPLE CHAMBER: NASA / JSC words of the space agency Roscosmos) it "ceased to exist as a result of a collision with the surface of the Moon."

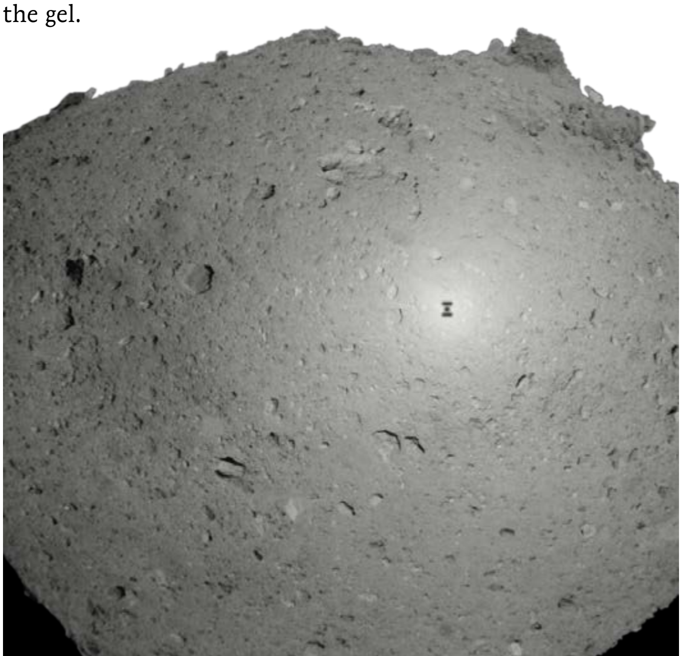
## Trials and Triumphs

But planets and moons aren't the only targets for sample-return missions. Comets, asteroids, and even the solar wind make good sources as well.

The first in situ collection of micrometeoroids (along with human-made debris) used *aerogel*, an ultra-lightweight, porous, and solid silica gel. The aerogel was lodged in NASA's Orbital Debris Collector placed outside the Russian *Mir* space station, which collected interplanetary dust for 18 months starting in 1996.

Next up, NASA dispatched the Genesis mission in 2001 to catch solar-wind particles. Genesis used an innovative array of collectors composed of materials such as sapphire, gold, and silicon. Team members feared that the mission was a loss after it slammed into the Utah desert at the end of its journey on September 8, 2004, but researchers were later able to salvage shards of the detector plates — with their precious solar-wind samples — from the crash.

NASA fared better with the Stardust mission, which also used aerogel to trap particles as it passed through the coma of Comet Wild 2. It returned samples to Earth on January 15, 2006. The mission team made use of the large citizen-science project Stardust@home to identify dust-grain tracks through the gel.



▲ **ALIEN VISITOR** Hayabusa 2 took this selfie of its shadow on the asteroid Ryugu from an altitude of about 240 meters, as it was approaching the surface. The "wings" are the spacecraft's solar panels.

◀ **CRASH LANDING** Sent to collect solar wind particles, NASA's Genesis spacecraft crashed in Utah upon return. Scientists were still able to salvage samples from the debris.

More recently, Japan's Tanpopo experiment on the International Space Station, mounted on the exterior of the Japanese Experiment Module, Kibo, also collected cosmic dust from 2015 to 2019.

Although the amounts gathered in each of these cases were tiny, these projects have given us insights into the chemical composition of interplanetary dust, the solar wind, and cometary comae. The grains from Comet Wild 2, for example, contain a hodgepodge of materials that suggests that large-scale mixing in the early solar system mingled stuff made closer to the Sun with that in the distant reaches.

## Japan's Intrepid Hayabusa Missions

The Japan Aerospace Exploration Agency (JAXA) has had its own sample-return woes. Its first dedicated retrieval mission to an asteroid, Hayabusa, had to overcome several problems on its journey to asteroid 25143 Itokawa and back to Earth. These included a large solar flare, reaction-wheel failures (the bane of many a mission), and communication issues. Mission controllers weren't even certain at the time that the collection mechanism fired properly when it touched the asteroid. (Spoiler alert: It didn't.)

Still, after team members recovered the Hayabusa capsule in the Australian outback in 2010, JAXA researchers discovered about 1,500 dust grains caught in the inner collection chamber, kicked up from the spacecraft's touchdown on Itokawa. Despite its setbacks, Hayabusa was the first successful sample return from an asteroid.

As is often the case in spaceflight, the failures of the past became lessons that enabled the successes of the present. JAXA scored the first full-scale success with the Hayabusa 2 sample-return mission. Its 3½-year journey saw the mission rendezvous with asteroid 162173 Ryugu in June 2018.

Ryugu turned out to be of special interest as an example of an Ivuna-type carbonaceous (CI) chondrite, a specimen that's only rarely seen in meteorite form. Such asteroids are representative of the chemical composition of the early solar nebula. CI chondrites are also rich in *organic molecules* — carbon- and hydrogen-containing compounds, especially amino acids, which are the precursor building blocks for life. Ryugu samples have given scientists a chance to study CI chondrites in pristine, uncontaminated condition.

"The finding that Ryugu properties are consistent with CI-group [chondrites] was quite surprising, because the spectra of CI meteorites were very different from that of Ryugu," says Seiji Sugita (University of Tokyo). "What *was* expected is that we found a large amount of carbon in Ryugu. This was expected from its very dark appearance."

Hayabusa 2 was a resounding success, returning in 2020

CRASHED SPACECRAFT: USAF 388TH RANGE SQUADRON; RYUGU: JAXA / UNIV. OF TOKYO / KOCHI UNIV. / RIKKYO UNIV. / NAGOYA UNIV. / CHIBA INST. OF TECHNOLOGY / MEIJI UNIV. / UNIV. OF AIZU / AIST with 5.4 grams of samples (including sample gas trapped in the canister). Today, those samples reside at the Extraterrestrial Sample Curation Center located in the city of Sagamihara on the outskirts of Tokyo (see sidebar on page 24).

"More than 100 peer-review papers have been published since the capsule return in 2020," says Sugita. Among the results was the discovery that, based on their chemical makeup, the rocks that Ryugu is built of are remnants of an older body that originally formed in the outer solar system, much farther from the Sun than the asteroid belt.

"It may have been near Saturn or beyond," Sugita explains. The evidence, he says, comes from signs that carbon dioxide condensed on Ryugu's materials when they first came together, which would only happen in very cold conditions. "This requires an orbit much farther away than Jupiter."

Today, Ryugu lies within the orbit of Mars, having moved there recently from the main belt. Its composition shows that some asteroids did indeed migrate from outside the *snow line* of the solar system, perhaps due to the giant planets' movements (*S&T:* Mar. 2021, p. 22).

What's more, samples from Ryugu show evidence of tiny *melt splashes*, created when organic-bearing cometary dust bombarded the asteroid. This finding could provide clues as to the transport of organics across the solar system.

## OSIRIS-REX Vindicates NASA's Know-How

NASA's Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer (OSIRIS-REX) followed on Hayabusa 2's heels. OSIRIS-REX met up with asteroid 101955 Bennu in December 2018 and, after a thorough reconnaissance, retrieved samples two years later.

At first, the sampling process seemed to have worked too well: an examination of the instrument's head after the touch-and-go maneuver showed material spilling out beyond the collection flap. The team decided to simply stow the container rather than perform the planned rotation maneuver to assess the mass gained.

The trip home also had a close call. The craft's drogue chute failed to deploy properly upon return in 2023, leaving the main parachute to do all the braking on its own. Then, the team revealed that screws on the capsule were stuck, necessitating the creation of a custom tool to pry it open. Standard carbon-steel tools cannot be used around carbonaceous samples. Instead, a tool of a specific grade of surgical stainless steel was specially fabricated to work in the tightly confined glove box.

But OSIRIS-REX brought home the mother lode. Mission planners had hoped to collect 60 grams of material from Bennu. They collected more than twice that: OSIRIS-REX brought back a final tally of 121.6 grams from the asteroid, about the weight of two tennis balls. Early analysis shows a diverse mix of organic-bearing and carbonaceous rocks, ranging in size from fine dust to particles the size of a grain of rice. These include water-bearing clays and minerals rich in sulfur and iron.

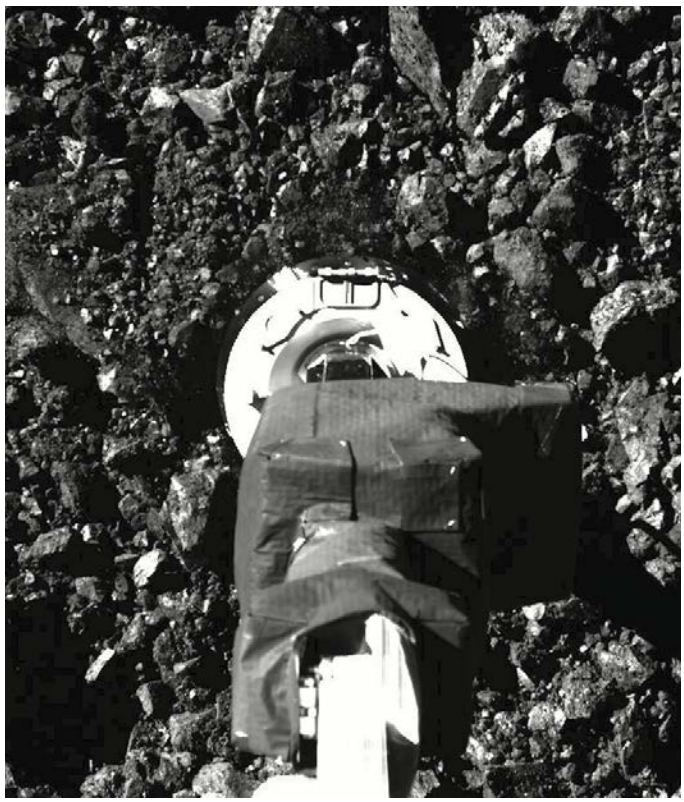
### Samples from the Moon and Asteroids

| Mission/ Project | Country | Target | Years | Amount Returned |
|---|---|---|---|---|
| Apollo | U.S. | Moon | 1969–1972 | 382 kg |
| Luna | USSR | Moon | 1970–1976 | 300 g |
| Hayabusa 1 | Japan | 25143 Itokawa | 2003–2010 | ~1,500 dust grains |
| Hayabusa 2 | Japan | 162173 Ryugu | 2014–2020 | 5.4 g |
| OSIRIS-REX | U.S. | 101955 Bennu | 2016–2023 | 121.6 g |
| Chang'e 5 | China | Moon | 2020 | 1.7 kg |

Amounts collected by other projects are much smaller — for example, NASA's Stardust spacecraft collected a total mass of about 1 mg in cometary and deep-space particles.

Bennu's rocks are also exceptionally porous. "If you look at [the sample] in the electron microscope, the grains are just stuck together," says Sara Russell (Natural History Museum, UK). "That means that, even though it's a tiny amount in mass, it sort of occupies more [space] than you think."

Preliminary examination has already revealed the unexpected. "One of the big surprises was evident just as soon as we opened up the capsule," says Russell. "We just thought it would all be black rock, but there are lots of white bits as



▲ **TOUCHDOWN** In October 2020, the OSIRIS-REX spacecraft unfurled its robotic arm and briefly touched the asteroid Bennu, collecting dust and pebbles from the surface.

NASA / GSFC / UNIVERSITY OF ARIZONA

▲ **IN THE LAB** Curation scientists work on the OSIRIS-REX sample canister. First they collected asteroid dust from the canister's base *(left)*, then they worked to open the canister itself. Stuck screws required the creation of a special stainless-steel tool *(right)* in order to open the canister and access the long-awaited samples.

LEFT: NASA; RIGHT: ROBERT MARKOWITZ / NASA JSC

well, and the white bits turn out to be mostly phosphate, which is quite rare." They're still trying to work out why Bennu has so much of the stuff, she adds. "It probably formed by the action of water."

Scientists know that Bennu's rocks were transformed by hydrothermal activity early in solar system history, thanks to the spacecraft's observations during its visit. But putting the pieces together to fully understand what all this means will take time.

"We're at this new era of things exploding in sample-return missions," says Russell. "I think in 200 or 300 years' time, these are going to be so precious, because they're going to be used to answer questions that we can't even think about."

### China's Lunar Sample-Return Program

China has also been busy in the sample-return game with the Chang'e program (named after the Chinese Moon goddess). In late 2020, Chang'e 5 became the country's first all-in-one sample-return mission, featuring an orbiter, lander, ascent vehicle, and sample-return capsule. From launch at Wenchang Space Launch Site, to landing at the Mons Rümker site on the Moon, to the capsule's landing in Inner Mongolia, the Chang'e 5 mission took only 23 days to complete. It returned

## Safekeeping

Decades after their return, Apollo samples are still providing scientific insights (*S&T:* Aug. 2018, p. 26). While some samples were studied immediately, others were preserved for later study with future technology. The curators at NASA's Astromaterials Research and Exploration Science (ARES) division in Texas are anticipating future analysis techniques as well as new material returned by the crewed Artemis missions.

"Our role here is really to take care of the samples, and for the last couple years a lot of that has been preparation for the samples [from OSIRIS-REX]," says Nicole Lunning (NASA ARES). "We are focused on making sure that we prevent all contamination that we possibly can before it gets to them."

Because organics are such an important part of the scientific return for OSIRIS-REX, curators have added additional constraints to protect the lab as well as the sample, says Lunning. "There was careful contamination control throughout its assembly and testing so that the spacecraft wasn't exposed to unknown organics" in the lab.

In addition to NASA's ARES and JAXA's Extraterrestrial Sample Curation Center for Hayabusa material (mentioned in the main text), other sites worldwide that maintain and study extraterrestrial material include China's Extraterrestrial Sample Curation Center and Russia's Vernadsky Institute of Geochemistry and Analytical Chemistry in Moscow. Canada is developing a curation facility for its share of the OSIRIS-REX sample at the John H. Chapman Space Centre in Saint-Hubert, Quebec. French and German scientists are also planning their own facilities.

▶ **CURATION CENTERS** Scientists preserve and study samples from other worlds at several centers (blue labels), and they're developing more facilities (white).

▲ **LUNAR DUST** A researcher holds a sample from the Chang'e 5 mission, which brought back regolith from the Moon in 2020. Study of the samples revealed lunar volcanism existed about 2 billion years ago, more recently that previously thought.

1.7 kg of lunar regolith, brought up from a depth of 1 meter.

Early science results from the returns include confirmation that the basaltic lava in the region is about 2 billion years old — young in terms of solar system formation. These materials could fill in a crucial rung on the geological ladder used to calibrate the ages of other regions on the Moon. Such results are vital because our dating estimates of much of the solar system rely on studies of how old different lunar terrains are.

In an unprecedented move, China has announced that it will allow international researchers — including those at NASA — to apply to study samples collected by Chang'e 5. Although tiny, these samples represent a significant and separate site in Oceanus Procellarum, which was also visited by NASA's Surveyor 1 and 3, Apollo 12, and the Soviet Union's Luna 9 and 13 missions. For its part, NASA has certified its intent to allow NASA-funded researchers to apply for access to Chang'e 5 samples. This cooperation represents a break from the usual exclusion of China from U.S. space science efforts, due to the 2011 Wolf Amendment.

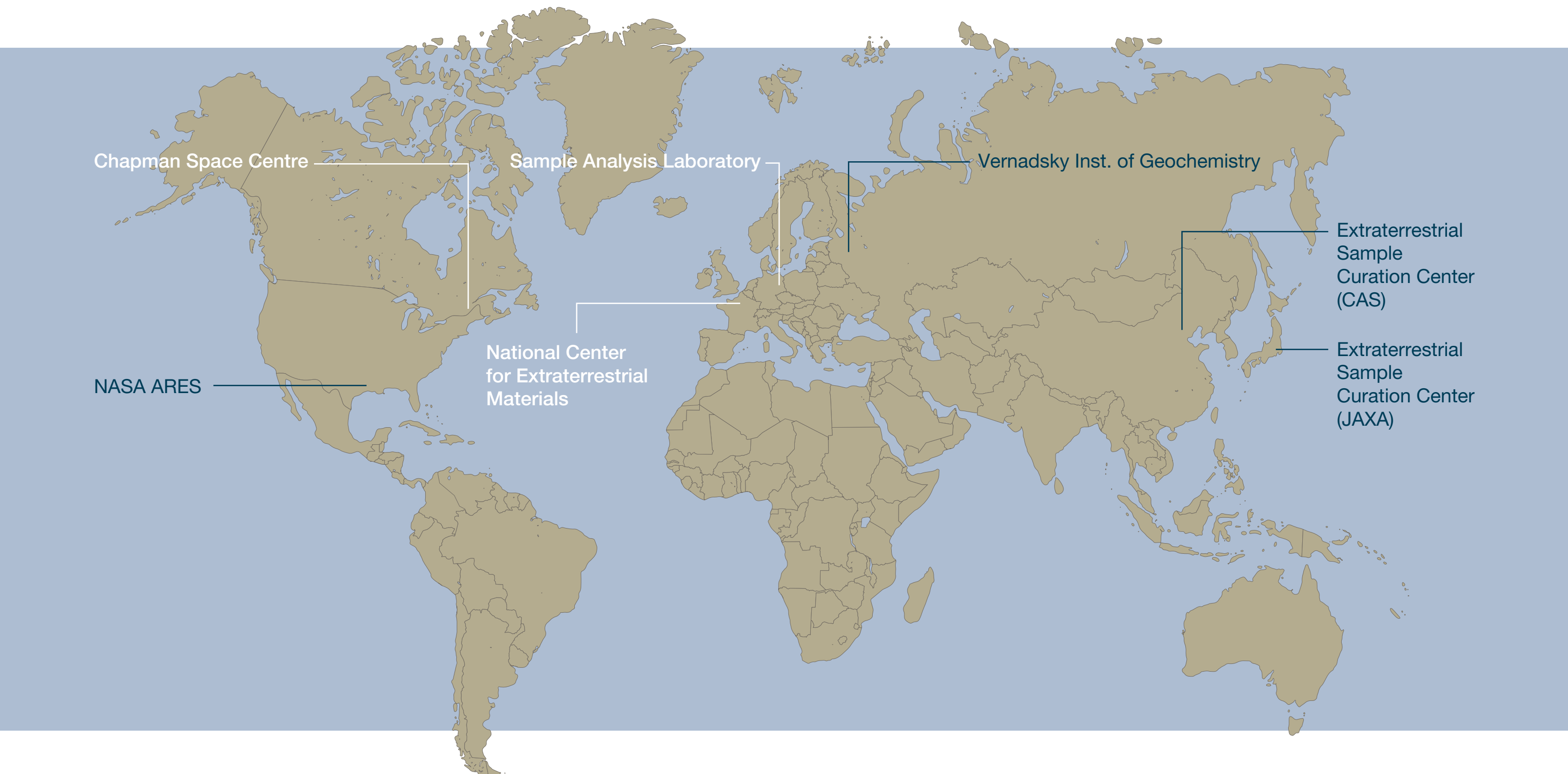
But the heady success of these missions represents just a small sample (pun intended) of what's to come.

## The Future

The next decade may see a new batch of extraterrestrial material brought to Earth from the Moon, Mars, and the small Martian moon Phobos, as sample-return capabilities mature.

First comes China's Chang'e 6, scheduled to launch in May 2024 for a farside lunar sample return — the first ever. Like Chang'e 5, it will be a quick, all-in-one package of an orbiter, lander, surface launch vehicle, and return capsule. To operate on the lunar farside out of sight from Earth, China will also launch the Queqiao 2 orbiter beforehand; it will act as a communications relay. Chang'e 6 is set to sample a site in the South Pole-Aitken Basin region. The terrain on the lunar farside site is expected to be basalt exposed by the original impact that formed the basin.

China also plans to launch Tianwen 2 in 2025 to return a sample of asteroid 469219 Kamoʻoalewa. After an Earth flyby, the probe will then head onwards to main-belt comet 311P/PanSTARRS. Another proposal, named Tianwen 3, would see a two-ship mission head to Mars sometime later this decade, for a return to Earth as early as 2031.




LUNAR DUST: JIN LIWANG / XINHUA NEWS AGENCY / GETTY IMAGES; MAP: BEATRIZ INGLESSIS / S&T

▲ **TO PHOBOS** A future Japanese-led mission aims to land on the Martian moon Phobos — shown in this illustration, with the Red Planet looming behind — and collect samples to bring to Earth.

JAXA

The Artemis initiative to return humans to the Moon, meanwhile, promises to fetch a hoard of lunar samples. Crewed missions are roomier than robotic ones and can carry more rocks back to Earth. Trained human geologists are also more flexible and can make decisions on the fly regarding what to collect while in the field.

Artemis 3 will make the first crewed landing in the lunar south polar region, now scheduled for late 2026 at the earliest. NASA plans to launch two more missions (Artemis 4 and 5) before 2030. Planners are targeting the polar regions because they appear to harbor water ice inside permanently shadowed craters. Water ice, if accessible, could provide a vital in situ resource for future astronauts on the Moon (*S&T:* Jan. 2021, p. 34).

An enterprising project coming up is the joint Martian Moons Exploration (MMX) mission, led by JAXA. MMX will explore Mars's moons Phobos and Deimos and then land on and collect a sample from Phobos. The mission is set to launch from the Tanegashima Space Center in 2026, arrive in orbit around the Red Planet and Phobos in 2027, and return to Earth with its precious cargo in 2031. The mission is an international effort, with participation from the French, German, and European space agencies as well as NASA.

Scientists hope that MMX will answer a key question in planetary science: Are the moons captured asteroids or the result of an ancient impact on Mars? Either case could yield fascinating results, both in understanding the origin story of Mars and the solar system as a whole (*S&T:* Apr. 2021, p. 34).

"One of the key ways to discriminate between these theories is to measure the elemental composition of the moons," says David Lawrence (Johns Hopkins University Applied Physics Laboratory).

To this end, in addition to helping with the sampler hardware, NASA is contributing the Mars-moon Exploration with Gamma Rays and Neutrons instrument (MEGANE; "eye glasses" in Japanese). MEGANE will measure Phobos' composition from orbit. "Ultimately, the MMX mission is planning to grab a sample from Phobos, bring it back to Earth, and fully quantify the composition of the sample," Lawrence adds. "MEGANE's composition measurements will get a good down payment on this information."

Heck, it will be amazing to see images from the surface of Phobos, with the gigantic Red Planet hanging in the sky about 40° across — 80 times larger than the full Moon we Earthlings see.

## Mars Sample Return

NASA's Mars sample-return (MSR) mission is probably the most ambitious sample-return mission of all. The current schedule would see a 2027 launch for the orbiter and a 2028 launch for the lander, with sample arrival on Earth in 2033.

U.S. planetary scientists have talked about such a sample-return mission for decades. The Jet Propulsion Laboratory completed the first MSR study in 1967, as a response to a 1966 NASA study that explored a piloted Mars flyby mission with a robotic sample retriever, says author and spaceflight historian David S. F. Portree. "JPL sought to prove that a wholly robotic sample retriever would be as effective as and less complex (and less costly) than the planned piloted/robotic hybrid sample return."

NASA's Perseverance rover is the first step in the MSR process. The rover landed inside Jezero Crater sky crane–style in 2021 and has been meticulously collecting samples from various sites, depositing them in tubes on the Martian surface for return to Earth at a later date.

Pristine samples of Mars are vital for understanding the history and formation of the Red Planet. Jezero samples would be especially valuable, as the crater floor shows signs of both flowing and standing water early in the planet's history. Perseverance has had to navigate a jumble of boulders and what looks like an ancient mudflow.

Right now, the plan is that a future spacecraft will land, collect the lightsaber-like sample tubes, and load them on a return vehicle. This will then rendezvous with a vehicle provided by the European Space Agency, which would be waiting in Mars orbit. That vehicle would carry the capsule back to Earth in a manner similar to the maneuver OSIRIS-REX performed.

It's a complicated mission for sure. In fact, MSR may ultimately cost in excess of $10 billion, well over the original $4.4 billion estimate cited in 2020 by an independent review board — if it survives the budget axe, that is. As of this writing, the mission could suffer a federal budget cap that reduces its 2024 budget to about one-third that of the previous year. Congressional delays in approving a larger budget led JPL to lay off more than 500 employees in early February.

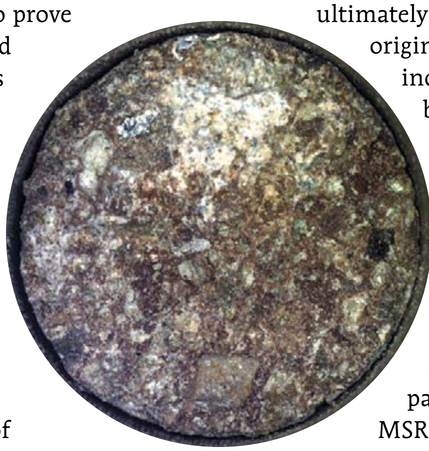
Other missions have faced financial crises before and still made it to the launch pad — and produced great science. What MSR's fate will be remains unclear, but the sample tubes will always be there, waiting.

## What a Ride

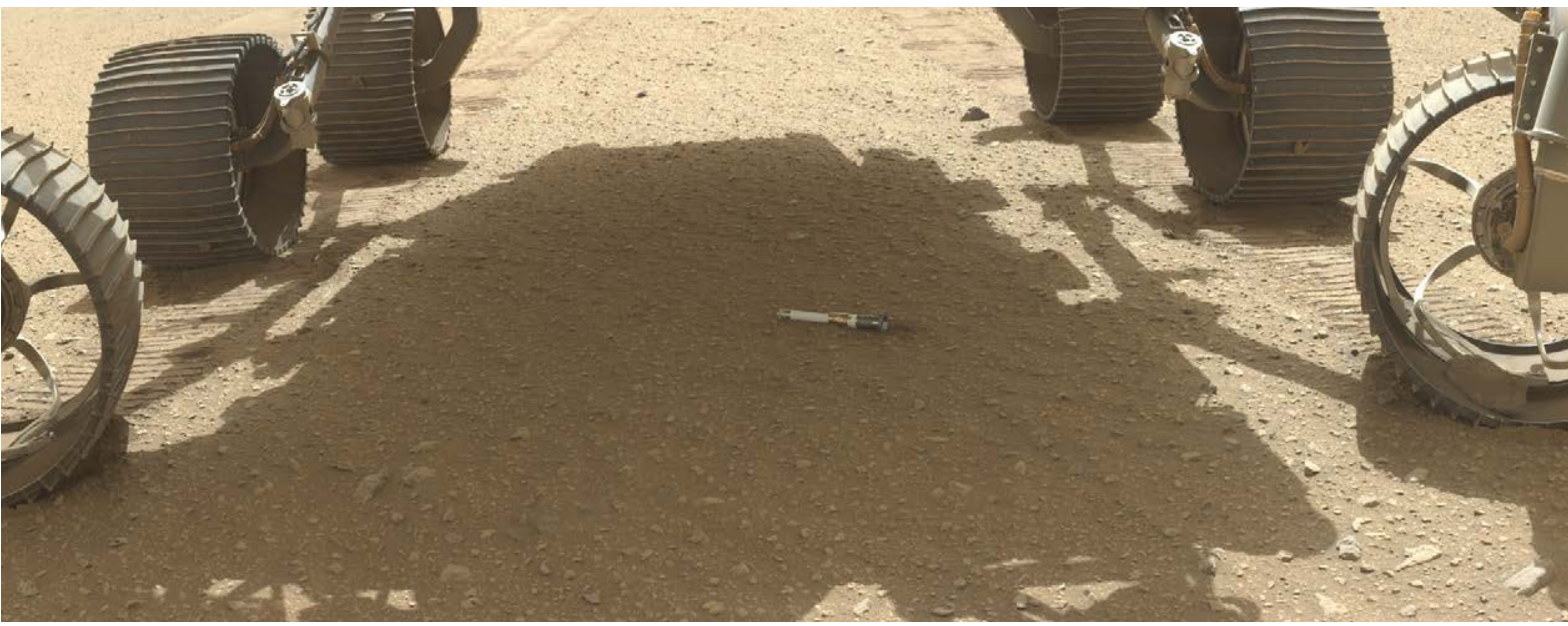
There are also a few potential missions in the works by other countries. The Indian Space Research Organisation (ISRO), for example, plans to carry out a lunar sample-return mission with its next Chandrayaan 4 mission, launching sometime around 2028.

It has been a long journey — especially for the spacecraft and the researchers involved! But it has been great to see these tiny dots of light in the sky turn into real worlds that we can finally reach out and touch.

■ **DAVE DICKINSON** has covered the spaceflight beat for *S&T* for nearly a decade and would love to one day see Mars from the surface of Phobos.



▲ **ROCK CORE** An image of the rock core nicknamed Otis Peak, collected by Perseverance on June 12, 2023. The varied colors come from individual minerals and rock fragments.



▼ **SAMPLE DROP** The Perseverance rover stands over the first of the sample-bearing tubes that it has left on Mars's surface. They await pickup by a future spacecraft. Each tube is about 18 cm long.

SAMPLE: NASA / JPL-CALTECH; ROVER ABOVE TUBE: NASA / JPL-CALTECH / MSSS

# The Rise *and Fall* of the Lunar Society

A small circle of learned friends helped launch the Industrial Revolution and modern astronomy.

DERBY MUSEUM AND ART GALLERY / PUBLIC DOMAIN

William Herschel is now remembered as one of the greatest observational astronomers of all time, but his early days included a walk on the wild side. On May 28, 1776, Herschel — then a busy, professional musician, with a hobby interest in astronomy — had just completed several homebuilt Newtonian reflectors. Like most beginners in the same situation, he first trained a new 9-inch on the Moon and recorded in his observing logbook:

> *It has hitherto been supposed that those seas, as they are called, consisted of a different kind of soil, which reflected light less copiously than the Hills and Mountains. I conclude them to be Woods or Forests . . . These Forests . . . cast shadows all along the side opposite the Sun . . .*

On July 30th, he logged another comment inspired by his observations:

> *Perhaps conclusions from the analogy of things may be exceedingly different from the truth, but . . . we have no other way to come at knowledge . . . [W]ho can say that it is not extremely probable, nay beyond doubt, that there must be inhabitants on the Moon of some kind or other? Moreover it is perhaps not altogether so certain that the Moon is out of the reach of observation in this respect. I hope, and am convinced, that some time or other very evident signs of life will be discovered on the Moon.*

Herschel was then living in the dazzling spa town of Bath, England, whose gleaming buildings were made of local, golden-colored Bath stone. Among the famous structures were the Octagon Chapel, where Herschel performed concerts, and the famous Circus consisting of three long curved terraces that is regarded as the masterpiece of the English architect John Wood, the Elder. In Herschel's observing log, he referred to lunar craters as "circuses," and in addition he made out what he thought was a canal — a reminder that this was the age of England's first great industrialization. Clearly, the inhabitants of the Moon were advanced, and Herschel declared, "Were I to chuse between the Earth and moon I should not hesitate a moment to fix upon the moon my habitation."

**18TH-CENTURY ENLIGHTENMENT** In a moment evoking wonder, a philosopher demonstrates an orrery to a group of children. The central figure is probably meant to represent James Ferguson, who demonstrated such a machine in Birmingham in 1761. Painting by Joseph Wright of Derby.

He continued to hold to his views about lunar inhabitants for a few years but realized that not everyone would share his enthusiasm. Nevil Maskelyne, Astronomer Royal at the time, later advised him to temper his claims of the Moon's habitability. In a letter written in June 1780, Herschel beseeched the Astronomer Royal to "promise not to call me a Lunatick" if he continued to unguardedly express such views.

In 1781, Herschel discovered Uranus — an event that established his reputation in astronomy. Henceforth he became more conservative and no longer talked openly about the inhabitants of the Moon, though he later published his belief in solar inhabitants!

## A Gathering of Lunaticks

Herschel's reference to "lunaticks" referred to the patients kept (and regularly exhibited like zoo animals for the general public's amusement) in London's Bethlem Royal Hospital, otherwise known as Bedlam. However, he was also punning on the name of a group to which he belonged as a peripheral member. This so-called Lunar Circle was an informal association of a dozen or 20 remarkable men who constituted an informal research society in the Midlands of England, around Birmingham. Fired by Enlightenment ideals, broadly democratic in politics, and believers in progress and technology, they made up a kind of Institute for Advanced Study for the early Industrial Age. However, far from being self-absorbed dreamers, they were practical men, interested in business, experimental science, and technology — not simply in knowledge for its own sake.

They called themselves lunaticks because they held meetings at the time of the full Moon. In an age in which artificial lighting was almost nonexistent and cross-country travel on uncertain roads was hazardous at best, the light provided by a bright Moon was essential. Even in cities like Bath and metropolises like London, concerts and assemblies were crammed between the first and last quarters of the Moon to take advantage of the extra illumination.

The Lunar Circle grew by an accretive process, beginning in the 1760s, largely through the efforts of Birmingham-based Matthew Boulton. After his father's death in 1759, Boulton took over the family toymaking business — where "toys" were luxury goods consisting of buttons and silver buckles, brass candlesticks, clocks, and enameled snuff boxes. Funded by an inheritance from his father and through marriage to a well-to-do cousin — and after her death, to her sister — he acquired the means to greatly expand his factory and build a luxurious residence called Soho House.

Boulton had a singularly expansive, gregarious personality, which made him one of the century's great networkers. He counted among his friends many of the leading figures of the Midlands, including the physician Erasmus Darwin and John Michell. Michell had been Darwin's tutor at St John's College, Cambridge, where he lectured aspiring scholars in arithmetic, geometry, Greek, Hebrew, and philosophy. Rapidly becoming a legend in his own time, he was named to the college's Woodwardian Chair of Geology. However, he then stalled in his ascent. A quirk in the Woodwardian bequest required the holder to be celibate, but Michell wanted to marry and so had no choice but to leave Cambridge. Within a few years he had drifted into a position as Rector at St. Michael's Church at Thornhill, near Leeds.

During a quiet quarter century there, Michell kept himself busy. He built a monstrous, 30-inch-aperture reflecting telescope for his own use (which Herschel later acquired); designed the torsion balance later used by his friend Henry Cavendish to measure the mass of Earth; suggested that double stars were gravitationally bound to each other (a proposition Herschel later proved); and suggested the existence of "dark stars," whose mass was so great that light couldn't escape. Of course, we now know they do exist and today call them black holes.

Michell's genius was forgotten in his own time and was only rediscovered toward the end of the 20th century. In 2009 he was described in a publication of the American Physical Society as "one of the greatest unsung scientists of all time . . . so far ahead of his scientific contemporaries that his ideas languished in obscurity until they were re-invented more than a century later."

It was Michell who put Boulton in touch with the aforementioned Erasmus Darwin, who would become one of the Lunar Circle's best-known members. Darwin was one of the great polymaths of the century, though he has been utterly eclipsed by his famous grandson, Charles Darwin, the co-originator of the theory of evolution by natural selection. According to historian Andrew P. B. Lound, Erasmus was "by far the more interesting and eclectic [member] of the Darwin family. Although a physician his interests ranged wide and included electricity, education, chemistry, botany, engineering, poetry, canals, geology, aviation and of course astronomy."

Perhaps Erasmus Darwin's most important contributions were to botany. The vast numbers of new plants and animals that Captain James Cook and others brought back from places they visited led to a veritable mania for classification. Not only did plants and animals need to be classified but also eventually the nebulae in the heavens, Herschel's domain.

Darwin translated the great Swedish classifier Carl Linnaeus's seminal works into English and popularized the biologist's ideas in verse, writing poems augmented with extensive commentary that included the possibility that plants might evolve over time. Today Darwin's poetry strikes one as rather eccentric, but the notes that he added to explain the science behind his verses remain remarkable. For all his powers as a versifier, Darwin proved once and for all that prose is the proper medium for scientific exposition.

## The Sun-and-Planet Wheel Rolls into Motion

The beginnings of the Lunar Circle may have been spurred by visits to Birmingham by the self-educated, itinerant Scottish lecturer and showman James Ferguson. Ferguson was the author of the extravagantly titled *Astronomy Explained* *upon Sir Isaac Newton's Principles, and Made Easy to Those Who Have Not Studied Mathematics* (1756). Among the book's future readers would be Herschel, who, when he was still mainly involved in giving concerts and music lessons, had not yet embarked on his frenzy of telescope-making and had not yet begun his intense passion for observing the Moon. In Ferguson's book, Herschel would have read, "From what we know of our own System, it may be reasonably concluded that all the rest are with equal wisdom contrived, situated, and provided with accommodations for rational inhabitants." It was a short step from this to the forests, canals, and circuses on the Moon.

Perhaps the most dramatic of Ferguson's exhibits consisted of an *orrery* — a machine for demonstrating the motions of the Moon and planets. The simplest models included only Earth's annual movement around the Sun, the phases of the Moon, the oscillation of the Moon's orbit, and the advance of its apogee. A more elaborate version elucidated the motions of the other planets and even the satellite systems of Jupiter and Saturn. In addition, Ferguson was handy with electrical apparatuses and experiments, then all the rage. Indeed, at about the same time Ferguson passed through Birmingham, a future Founding Father of the United States, Benjamin Franklin, already famous for his electrical experiments, visited in order "to improve and increase Acquaintance among Persons of influence." Michell introduced Franklin to several other lunaticks, including William Small, a Scottish medical doctor who served as Boulton's physician. Small's interests ranged beyond medicine into optics, electricity, and sound. He had recently returned from America, where he had been Professor of Natural Philosophy and Mathematics at the College of William and Mary in Williamsburg, Virginia. Among his pupils was a young Thomas Jefferson, another future Founding Father.

Small's interest in optics brought him into contact with James Watt, a maker and repairer of scientific instruments in Glasgow, Scotland. Watt was a somewhat obsessive,

▼ **LEARNED CONVERSATION** This 19th-century artist's rendering shows a typical Lunar Society (formerly, Lunar Circle) meeting in progress. The individual figures are difficult to identify, but James Watt is probably represented on the far side of the table.

▲ **LUNAR MAN ABOUT TOWN** A leading manufacturer and inventor in Birmingham, Matthew Boulton had an intellect and gregarious personality that drew kindred spirits into the Lunar Society, where they discussed ideas, experiments, and inventions — including the achromatic refractor, which Boulton tried unsuccessfully to develop.

▲ **THE OTHER DARWIN** A leading member of the Lunar Society, Erasmus Darwin was a physician, philosopher, poet, inventor, and abolitionist. His botanical writings contain hints about a theory of evolution, which his grandson Charles Darwin later brought to full realization.

▲ **A MAN FOR ALL SEASONS** The dissenting minister, liberal political theorist, natural philosopher, and chemist Joseph Priestley, who experimented with electricity, discovered what he called "dephlogisticated air" (oxygen) and invented carbonated water. Soon after arriving in Birmingham, Priestley became one of the Lunar Society's most active members.

perfectionistic, morose individual. At the time, he was busy trying to improve the quality of flint glass for use in achromatic lenses, which were just being developed. Unfortunately, the material was difficult to cast without introducing streaks and veins, which compromised the lenses' optical quality. Even more discouraging, an exclusive patent for achromatic telescopes had been granted to Peter Dollond of London, which effectively gave Dollond right of first refusal on the best optical flint glass available. Dollond's patent and the scarcity of good optical glass made achromatic telescopes at the time prohibitively expensive. As a result, a great deal of experimentation went into the development of speculum-mirror reflectors, such as those made by Michell and Herschel. Even Boulton performed experiments, successfully demonstrating a new method for making speculum mirrors in 1778.

In a few years, Watt migrated from working with lenses and telescopes to steam engines, and in 1774 he moved to Birmingham to develop his ideas with the aid of Boulton's capital. Although he didn't invent the steam engine, Watt introduced various improvements. One involved a "sun and planet gear," which converted vertical motion into rotatory motion. It was so-called because it resembled Ptolemy's description of planetary motion in the *Almagest* but also — and perhaps this was its real inspiration — some of the gear mechanisms Ferguson employed in his orrery. Although the sun-and-planet gear was actually invented by the Scottish engineer William Murdoch, Watt recognized its importance and was first to patent the idea.

## The Circle Expands

Through their mutual interest in building a canal to connect the Trent and Mersey rivers, Darwin collaborated with Josiah Wedgwood, who was in the process of developing a large pottery factory at Etruria, in what is now Stoke-on-Trent, Staffordshire. Wedgwood's factory lay directly in the path of the proposed canal, which would provide a crucial connection to the markets for his pottery.

▲ **THE ANGER OF THE MOB** Priestley's liberal views about politics and religion were widely seen as subversive in England after the excesses of the French Revolution and led to his home being looted and set on fire by an angry mob in July 1791.

Yet another force of nature joined the group when Michell introduced Darwin and Wedgwood to Joseph Priestley, then serving as minister to Mill Hill Chapel, in Leeds. Sharing the other Lunar Circle members' fascination with electricity, Priestley frequently traveled from Leeds to Birmingham to attend meetings mostly held at Boulton's home, Soho House.

By 1775, the informal association of learned friends adopted the name Lunar Society. Their only real goal was to convene to engage in stimulating conversation and brainstorm new ideas. In addition to Watt, Priestley also relocated to Birmingham and quickly became the Society's most active member, replacing Boulton, who was increasingly preoccupied with developing Watt's steam engine. Among Priestley's many achievements were the independent discovery of oxygen in its gaseous state (which he called "dephlogisticated air"), extensive writings on electricity and — perhaps his greatest boon to humankind — the invention of carbonated water, which Johann Jacob Schweppe later developed into what was to become a multibillion-dollar soft-drinks industry.

The Lunar Society members engaged in numerous activities, which frequently overlapped. For example, the problem with imperfections in flint glass caught the attention of Wedgwood, though his interest was only secondarily astronomical. Much more important to him was the material's use in ceramics. For several years, beginning in 1779, he carried out a series of experiments that eventually led to an important discovery: By constantly stirring the molten flint glass, the streaks and veins that affected its use in optics could be eliminated. Unfortunately — possibly because he wanted to avoid paying a large excise duty on the quantities of glass he had used in his experiments — Wedgwood never published the paper he wrote on the subject. And so, the secret of making high-quality flint glass for achromatic lenses remained unknown until the Swiss glassmaker Pierre Louis Guinand independently discovered it 15 years later. Guinand's glass, combined with the lens-designing genius of the Munich-based optician Joseph von Fraunhofer, would revolutionize observational astronomy in the 19th century. But for the excise tax and Dollond's patent, the British rather than the Germans might well have taken the lead in introducing the age of the refractor!

## A Society on the Wane

The Lunar Society inspired widespread interest, even among those who weren't part of the group's core membership. In the society's outer orbit was the artist Joseph Wright of Derby, who specialized in dramatic scenes in which moonlight often provided the illumination. Another was artist John Russell of London, who borrowed a Herschel reflector and used it to produce numerous precise sketches of the Moon, including the one presented on the facing page. Appropriately, one of his pastels hangs today in the study of Soho House.

**A LUNAR BEAUTY**
Now in Soho House, this magnificent pastel is called *The Face of the Moon*. John Russell painted it in 1797 based on his observations with one of William Herschel's telescopes.



By the time Russell made his arresting depiction of the Moon, the Lunar Society was on the wane. The ideals of its members had sprung from the Enlightenment. Most of the group (especially Priestley and Darwin) had enthusiastically supported what was perceived as the overthrow of despotism during the French Revolution of 1789. As the Revolution turned to Terror, however, "fierce Radicals and Dissenters," which included many members of the Lunar Society, were regarded as dangerous. Priestley, especially, came into the sights of conservative politicians and churchmen and, in July 1791, they stirred up a mob to attack Priestley's home and several other buildings in what became known as the Birmingham Riots of 1791. Although Priestley himself escaped, he emerged a sadder but wiser man. He emigrated to the United States in 1794 and died in Pennsylvania 10 years later.

Despite the changing social tides, the Lunar Society tried to carry on even as its charter members aged and eventually passed away. A new generation of Watts, Boultons, and Wedgwoods tried to take up the cudgel for a remnant of the former society, but the moment had passed. What had once been a blazing full Moon of ideas and invention was now a waning sliver. Meanwhile, Boulton's and Wedgwood's progressive factories, which they once hoped would give dignity and meaning to work, were replaced by the "dark Satanic mills" of the unbridled free market. Even the Moon lost some of its luster and romance as the prospects of lunar life that had once stirred William Herschel faded in the wake of observations made by Wilhelm Beer and Johann Mädler. In 1837, these German astronomers, wielding a Fraunhofer achromatic refractor, produced a detailed lunar map and pronounced that the Moon was "No copy of the Earth."

Gone forever were the fanciful lakes, seas, rivers, and inhabitants of a more innocent era.

**WILLIAM SHEEHAN** became a "lunatick" when he first looked at the Moon with a 60-mm refractor in September 1964. He co-authored (with Tom Dobbins) the classic book on the history of selenography, *Epic Moon*, available at **shop@sky.com**.

# Go Loony for Luna!

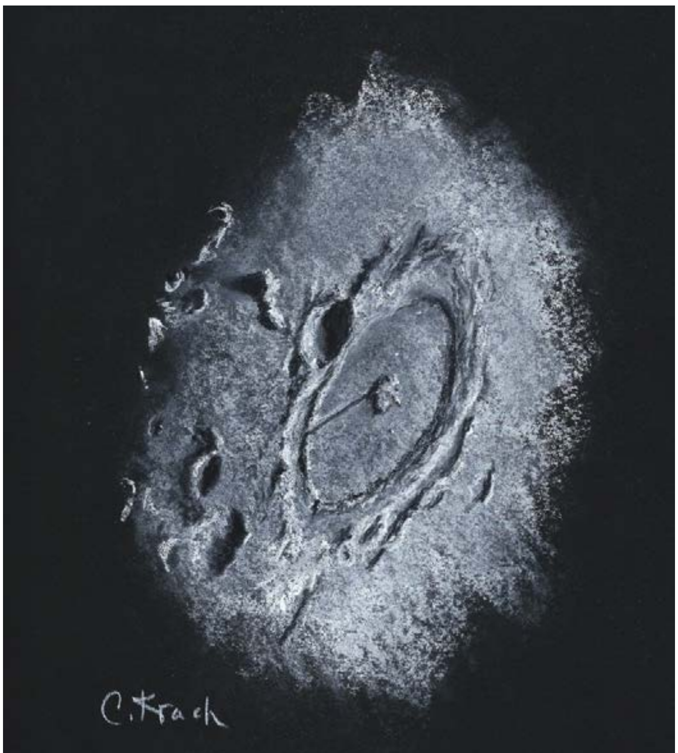
Look into the light for a change.

Amateur astronomers love to disparage the Moon. It's nature's own glare-bomb, casting its spotlight glow across the sky to drown out galaxies, nebulae, and any hope of dark-adapting our eyes. We often put our scopes away as the Moon reaches first quarter and leave them untouched until last quarter, only observing during the dark phase.

That's a sad waste of photons, because the Moon offers more bang for the buck than any other object in the sky, bar none. In fact, if the Moon were the only thing we could see with a telescope, amateur astronomy would still be the coolest hobby in the world.

I'm something of a Moon nut, and by the end of this article I hope you will be, too. There are so many neat things to see! I can't cover a tenth of what's up there, but I'll describe some of my favorite sights, illustrated with Cindy Krach's amazing sketches.

Before we start, let's take a moment to talk about equipment. For lunar observing, you don't need much. The Moon is a big, bright rock hovering out there in space close enough that you can see features with your naked eye. Even a modest telescope, the kind we often call a "hobby killer" (*S&T:* Dec. 2019, p. 36), will show you tons of detail on the Moon. Binoculars are great, too. But the more scope you can throw at it, the more details you can see.




**RILLEY NEAT!** Petavius sports a radial rille that's best viewed when the terminator is near the crater.

If you have much aperture, you'll need one piece of vital equipment: a filter to reduce the brightness. The Moon can be uncomfortably bright to look at directly. It won't hurt you, but it will be unpleasant, especially in a modestly large scope. I recommend a variable-polarizing filter, which lets you dial in the amount of dimming you want, because the Moon changes brightness as it waxes and wanes.

Okay, now that we're equipped, what can we look for?

## Chiaroscuro World

The Moon is tidally locked in its orbit around Earth, which means the same side always faces us. There's a little wobbling about — called *libration* — due to its inclined and somewhat eccentric orbit, but even with the effects of libration we only get to see 59% of the Moon's surface.

That's plenty! There are an estimated bazillion craters visible on the 22.3 million square kilometers (8.6 million square miles) of lunar terrain that we can see. Plus there are volcanic features, stress fractures, fault lines, and *lunarisms* (features that look like something familiar to the human eye) galore. You won't run out of stuff to look at.

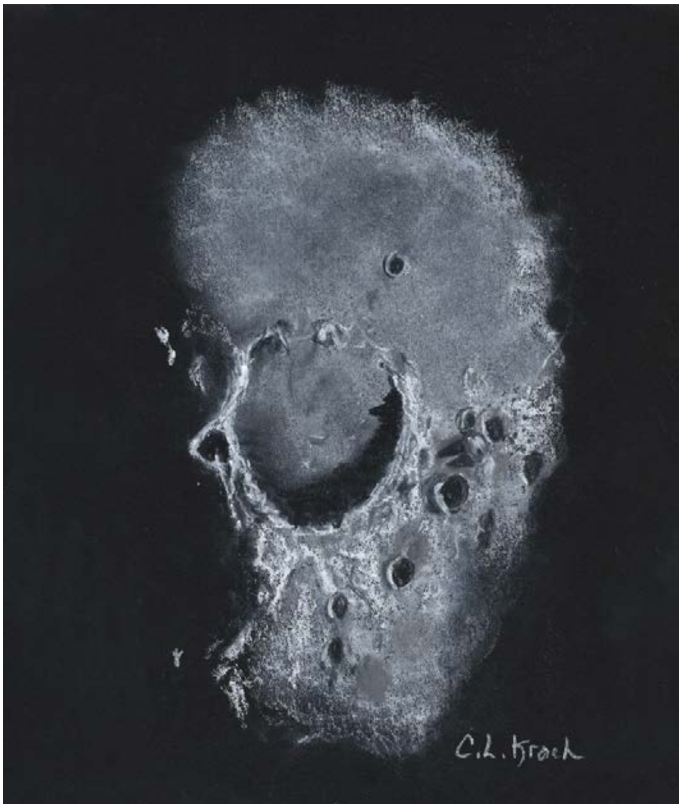
So where to start? It depends on the phase, but at any time other than full or new Moon, look for the *terminator*, the band of high-contrast features where light gives way to darkness. That's where sunlight comes in at a shallow angle and casts long shadows, highlighting differences in terrain. Often you'll find craters along the terminator that are completely filled with shadow, yet the rims and a central peak will be brightly sunlit. Watch for a few hours during the Moon's waxing phase and you can see sunlight work its way down the central peak, eventually reaching the crater floor. You might even see individual peaks along crater rims even farther out into the dark side, standing like lone sentinels at the edge of dawn.

The location of the terminator changes dramatically from night to night. It takes the Moon 29.5 days to cycle through all its phases (the *synodic month*), so the sunrise terminator takes roughly two weeks to sweep across from limb to limb, followed by the sunset terminator as the


**BEAUTIFUL SPOTLIGHT** Don’t curse the Moon. It’s the most wonder-filled object in the entire sky.

The craters and other features discussed in this article are listed below, along with their diameters or dimensions in kilometers.

1: Petavius (177)
2: Vendelinus (147)
3: Langrenus (133)
4: Theophilus (101), Cyrillus (98), Catharina (101)
5: Fracastorius (124)
6: Mare Nectaris (350)
7: Ptolemaeus (154), Alphonsus (118), Arzachel (98)
8: Elvis & Ukert (23)
9: Rima Hyginus (220 × 4)
10: Purbach Cross (crater 118)
11: Plato (101)
12: Clavius (225)
13: Mare Nubium (750) & Straight Wall
14: Sinus Iridum (400 × 260)
15: Mare Imbrium (1,250)
16: Copernicus (93)
17: Oceanus Procellarum (700 × 500)
18: Schiller (179)
19: Gassendi (111)
20: Mare Humorum (380)
21: Aristarchus (40)
22: Schröter’s Valley (160 × 10)
23: Mare Serenitatis (650)
24: Mare Tranquillitatis (700)
25: Tycho (86)
26: Kepler (31)



**FLOODED HORSESHOE** Fracastorius was flooded when Mare Nectaris to its north filled with lava, leaving it with just the ghost of a northern wall. The small crater Rosse stands alone within Mare Nectaris.

**ROCK AND ROLL** When the light is just right, Elvis appears, but only for a few hours every other lunation. Note that South is up in this sketch. (In other words, Elvis is upright in a Newtonian telescope view.)

Moon wanes. That means you get a new set of features to examine every night. And because of that extra half day in the synodic month, the following month you'll have a whole different set of interesting sights as the terminator splits the difference between what you saw on successive nights the previous month.

## Waxing Crescent

As we go from a thin crescent Moon toward first quarter, one of my favorite features to look for is **Petavius**, a fairly large, rugged crater at about latitude 25° south. It's at its best about three days after new Moon. Petavius looks a bit oblong due to the perspective of seeing it partway around the curved lunar surface, but you can still note its extensive *ejecta blanket* splashing outward on all sides from the crater's floor, which is flat because lava filled it, as with many other large craters. Petavius has a neat additional feature: a wide *rille* (a long, channel-like groove) that runs southwest from the central peak to the crater rim. It's basically a big, 3-kilometer-wide (2-mile-wide) stress fracture in the lava bed. Photos show that the rille even extends right over the flank of the central peak.

North of Petavius lie two more large craters that are at their best on the same night: **Vendelinus** and **Langrenus**. Vendelinus is an old, battered, lava-flooded crater with no central peak left, while Langrenus is much like Petavius, minus the rille.

In these early days when the Moon is still only a thin crescent, look for a pale glow that reveals the dark side, which can be seen by naked eye and in binoculars as well as in telescopes. That's light bouncing off the sunlit face of the Earth and illuminating the shadowed side of the Moon. Not surprisingly, it's called *earthshine*. It's easiest to see early in the lunar cycle when the Moon is a thin crescent and gets progressively harder each night as the Moon waxes. From the Moon's perspective, Earth is waning, exposing less and less sunlit surface to cast its light on the Moon. But in the early days, if you avoid looking at the bright part of the Moon and let your eyes dark-adapt, you can see quite a bit of detail by earthshine.

Two to three days after Petavius's best showing, the terminator reaches three more distinctive craters: **Theophilus**, **Cyrillus**, and **Catharina**. Theophilus and Cyrillus, the northern two, overlap, with Theophilus clearly newer than Cyrillus because its rim intrudes into Cyrillus and not the other way around. Both have well-defined rims and central peaks. Theophilus has some lava flooding on its floor, but Cyrillus is all impact debris. To their south, Catharina is the oldest of the three, with another crater, Catharina P, overlying almost half of it. Several other impacts have wrecked the northeastern rim, and the erosion of countless tiny meteor strikes has eliminated the terraces commonly seen on newer crater rims. This triplet is a good place to contemplate the immense age of some of the Moon's features.

While you're in the neighborhood, check out **Fracastorius**, a beautiful lava-flooded crater on the southern end of **Mare**

▲ **ROUND AND RUGGED** Langrenus (top) is a classic, large crater with a central peak, while Vendelinus (bottom) is, well, seriously messed up.


▲ **THREE GENERATIONS** Theophilus, Cyrillus, and Catharina have widely differing ages. Theophilus (top) is youngest, while Catharina (bottom) is oldest.


▲ **VANISHING PEAKS** Arzachel (bottom) has a classic central peak. Alphonsus (middle) has just a nub remaining after lava partly filled the crater. Ptolemaeus is completely flat, with just one visible crater (Ammonius) marring its smooth floor.

▲ **X MARKS THE SPOT** Like Elvis, the Purbach Cross (left center) is only visible for a few hours every other lunation. It's fun to watch sunlight reveal more and more of the crater walls, wiping out the X in a single night.

**Nectaris** (the Sea of Nectar). Its northern wall was wiped out by the advancing lava, leaving a horseshoe-shape remnant.

## First Quarter and Beyond

At first quarter, when the Moon is half-lit and half-dark, we get a bonanza of great features. The most obvious is probably another crater trio: **Ptolemaeus**, **Alphonsus**, and **Arzachel**. They're different sizes and have vastly different histories. Ptolemaeus, the largest one, is fully flooded with lava, leaving no central peak at all. Alphonsus, in the middle, is partially flooded but still has a central peak, while Arzachel, the southernmost of the three, is a classic large impact crater with slumped walls and a ragged central peak.

There's a smaller feature visible at first quarter that is quite possibly my favorite feature on the Moon. It's the lunarism I call **Elvis**, the lunar guitarist. It's a trick of the shadow that pools into a V-shaped pair of ridges next to the crater **Ukert**. When the light is just right — and it's only right for a few hours every *other* lunar cycle — the shadow looks like the rock 'n' roll guitarist with his feet wide apart and guitar held straight out. You can even see the crook of his arm around the body of the guitar.


**ICE CREAM SPLAT** Copernicus looks rugged when near the terminator, but when fully sunlit it looks like nothing so much as a scoop of ice cream that landed with a splat on hot pavement.

While you're in the neighborhood, check out **Rima Hyginus**, a volcanic caldera with collapsed lava tubes radiating outward to the southeast and northwest.

At the same time when Elvis is visible, there's another lunarism called the **Purbach Cross** (or the Lunar X) that appears down in the *southern highlands*, a large swath of ancient, rugged terrain blanketed with craters. The X is formed by the overlapping walls of Purbach and three or four other craters and is only visible for a few hours. When sunlight first touches the crater rims, you see a luminous X surrounded by darkness on all sides, but a few hours later encroaching light reveals the lower parts of the craters and the X fades.

A day after first quarter, look for **Plato**, a distinct, flat-bottomed crater at the northern edge of Mare Imbrium. Plato has been completely flooded with lava, and its floor is as smooth as a baby's bottom . . . until you crank up the power and look for craterlets. Plato has several distinct craters on its flat floor, including four that range from 2.0 to 2.4 km across (1.2 to 1.5 miles), which makes them just barely visible with a medium-size telescope on a night of good seeing. When the light angle is low and Plato's floor is lit but the craters are filled with shadow, it's fun to see if you can spot them.

At about the same time, in the southern highlands, look for **Clavius**, a crater that holds an interesting mystery. Within Clavius lies a perfect arc of smaller craters, diminishing in size as you work your way counterclockwise around the arc. There are six craters in the arc (five of them obvious), and they're so perfectly spaced that there's no doubt in my mind that they're related. It seems clear to me that they must have all happened at the same time as an asteroid approached the Moon and was torn apart by tidal forces, the asteroid's rotation flinging the smaller pieces outward farther than the larger pieces. That's the only explanation that fits, except craterlet counts within the individual craters indicate that they aren't all the same age. They're apparently randomly timed and not-so-randomly placed. No, I can't believe that either.

Near the time that Plato and Clavius are looking good, so is the **Straight Wall** to the north in **Mare Nubium** (the Sea of Clouds). It's actually a long fault scarp, but at low light angles it draws a straight line of shadow that stands out easily against all those circular craters elsewhere.

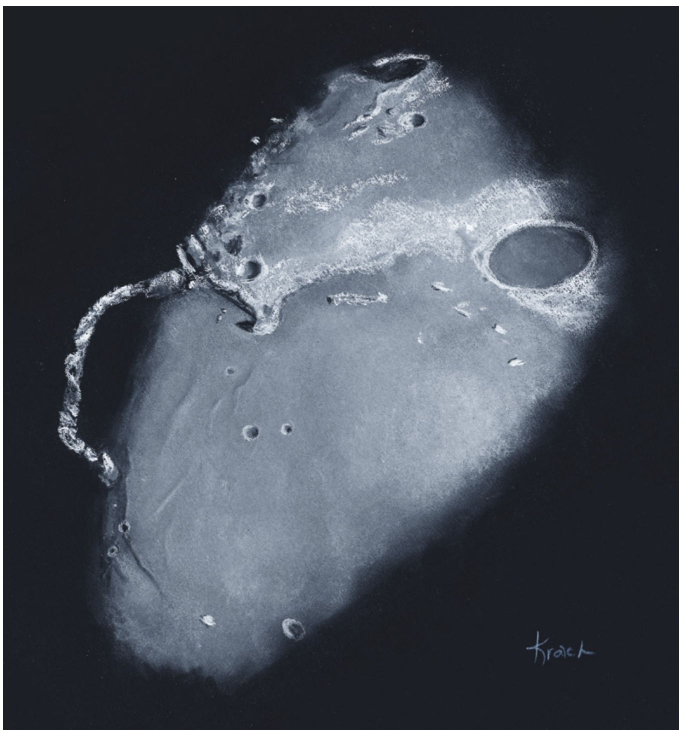
A day or two later, look for the "Golden Handle" of **Sinus Iridum** (the Bay of Rainbows) that sticks out northwest of **Mare Imbrium** (the Sea of Rains). When the light is just right, Iridum's rim is sunlit but the floor is still in darkness, making this huge feature stand out like the handle on an enormous celestial coffee cup.

## Fattening to Full

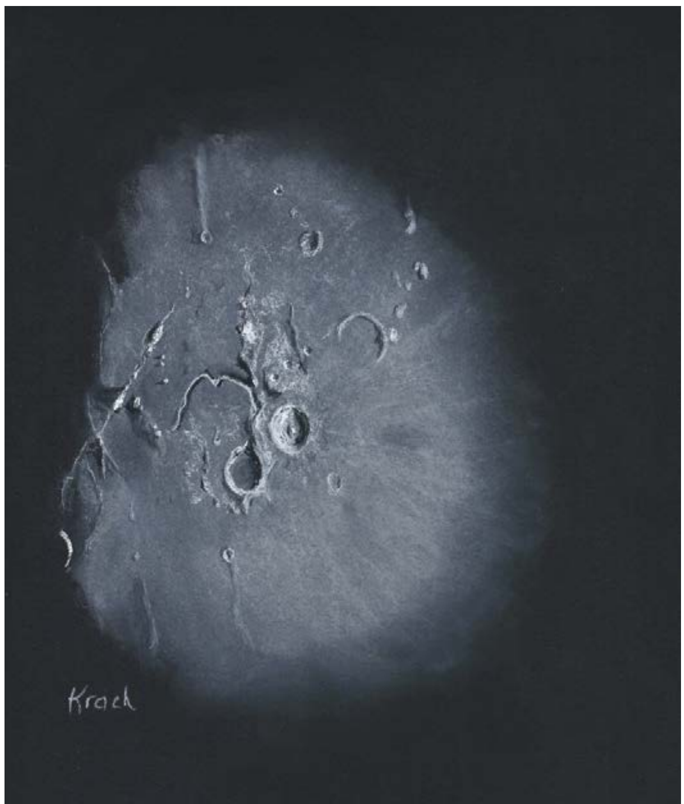
Later on in the waxing gibbous phase, look for **Copernicus**, a beautiful crater in the **Oceanus Procellarum** (the Ocean of Storms). It's fiercely rugged when it's on the terminator, but I like it even more when it's fully sunlit. Copernicus is relatively fresh, and thus the rays of debris scattered outward from the asteroid impact that created it are still quite conspicuous, along with the ejecta blanket of material that splashed down just beyond the rim. To me, Copernicus looks like a scoop of ice cream that fell off a cone and landed with a splat on the sidewalk.

About four days past first quarter, when the Moon is around three-quarters lit, look along the southern terminator for a crater that isn't circular. **Schiller**, my very favorite crater of all, is a long, skinny thing. Even the central peak is long and drawn out. Almost every crater on the Moon is circular, because when an asteroid strikes it's vaporized almost instantly and the explosion spreads out in a spherical blast. But Schiller is different. The object that gouged it out had to have just skimmed the surface, blasting a shallow trench and vaporizing from the bottom up as it did so. The elongated explosion created an elongated central peak, and the final fireball blasted the even wider but still quite elongated secondary lobe. Then lava poured in, forming a long, narrow lake. At least, that's what it looks like to me. Some lunar scientists disagree, saying it took two or even three separate impacts, but even if that's the case, they had to be at an extremely shallow angle to create that stretched-out central peak on the northwestern end. However it happened, Schiller is a unique crater.

**MOON NUT'S FAVORITE** Schiller Crater is a mystery wrapped in an enigma wrapped in a hot dog bun.



**HANDLE OF LIGHT** The rim of Sinus Iridum, the Bay of Rainbows, stands out in brilliant light well before the crater floor emerges from darkness, giving it the look of a handle big enough to lift the Moon. To the right, Plato presents a flat pool pocked by tiny craterlets that will challenge your optics.



**COBRA'S HEAD** Schröter's Valley meanders like a snake to the west of Aristarchus, one of the brightest craters on the Moon.


▲ **STEREO MYSTERY** Clavius sports a perfect arc of diminishing craters. Could this have happened by accident? Your humble author says "Naaaah." Cindy Krach captured the curve of the Moon's southern region so well that we made this a stereo image. To try this, cross your eyes so you're looking at the left image with your right eye and the right image with your left eye. The third image that forms in the middle will be in 3D. If you're more comfortable going wall-eyed for stereo images, you can view that version at **https://is.gd/Clavius_3D**.

When Schiller is looking good, so is **Gassendi**, on the northern end of **Mare Humorum** (the Sea of Moisture). Gassendi is what Fracastorius would have looked like if it hadn't been flooded with lava.

And not long after the above, **Aristarchus** Crater and **Schröter's Valley** come into view. Aristarchus is a relatively young (and thus bright) crater, and Schröter's Valley is a sinuous rille that shows up very well at low sun angles.

As the lunar phase moves onward toward full, you'll notice that the details you saw when objects were near the terminator vanish. Instead, you see a brightly lit surface with no shadows. There's still plenty of detail, though. Now is the time to look at the *maria* and the rays.

Start with the maria. These are the big, dark splotches that cover about half the Moon's Earth-facing surface. Notice that most of them are round. That's because they're craters left behind by truly enormous asteroid impacts that occurred back when the solar system was young. Asteroids dozens of miles in diameter slammed into the Moon, gouging out huge basins that later filled with lava leaking upward from the mantle. The maria are darker because the lava is darker than the material that makes up the surrounding highlands. Look carefully and you'll see that some of the lava flows are darker than others. The contrast is particularly evident at the junction between **Mare Serenitatis** (the Sea of Serenity) and **Mare Tranquillitatis** (the Sea of Tranquillity).

During full Moon you'll also see bright rays extending outward from some of the more prominent craters, most notably **Tycho** in the southern hemisphere. Tycho's rays stretch all the way up to the Moon's northern limb, and possibly beyond. One ray cuts straight through Mare Serenitatis. These rays are the ejecta from the violent impact that created Tycho Crater. Rays tend to be eroded away by micrometeorite impacts over time, so any crater you see with obvious rays will be fairly young, geologically speaking. Tycho is about 100 million years old, we figure. Copernicus is about 800 million (still young, in crater terms). **Kepler**, another bright-rayed crater west of Copernicus, is somewhere in between.

I've run out of space and have still barely scratched the surface. There's so much to see on the Moon, you'll never go without a new target even if that's all you look at from now on. And you can see everything above in reverse order as the terminator advances across the Moon's face during its waning phase! I'll leave you with one final thought: You can't see the Apollo hardware itself (it's too small to show up in an amateur telescope), but you can see the landing sites.

Next moonrise, don't curse nature's spotlight. Go have a look at it instead!

## More on the Moon

See this magazine's Explore the Solar System column every other month for more detailed information on the many lunar wonders.

■ Contributing Editor **JERRY OLTION** says you're a Moon nut when you have a favorite crater. **CINDY KRACH** is coordinator of the Astronomical League's Sketching Observing Program. She created all her sketches at the eyepiece.

# OBSERVING
## July 2024

**1** **DAWN:** Face east to see the waning crescent Moon hanging some 4° above Mars. Jupiter at lower left, flanked by Aldebaran and the Pleiades, completes the scene. Turn to page 46 for more on this and other events listed here.

**2** **MORNING:** The lunar crescent and the Pleiades rise above the east-northeastern horizon separated by about 4°. They're closely followed by Jupiter, then Aldebaran.

**3** **MORNING:** A thin sliver of the Moon shepherds Jupiter with some 4½° between them as they climb in the east-northeast, while Aldebaran twinkles lower right.

**5** **EARTH** is at aphelion, farthest from the Sun for the year, at a distance of 152.1 million kilometers (94.5 million miles).

**7** **DUSK:** The two-day-old Moon and Mercury grace the west-northwestern horizon with 3° between them. You'll need binoculars to enjoy the view.

**8** **DAWN:** Jupiter blazes slightly less than 5° upper left of Aldebaran. Turn to the east-northeast to take in this sight before the Sun rises.

**9** **EVENING:** The waxing crescent Moon trails Regulus, in Leo, by 6° as they sink in tandem toward the western horizon.

**13** **EVENING:** The first-quarter Moon eclipses Virgo's brightest star, Spica, for much of North and Central America (see page 49 for full details).

**17** **EVENING:** In the south, the waxing gibbous Moon gleams around 3½° left of the Scorpion's heart, the red supergiant Antares.

**24** **EVENING:** Look toward the east-southeast to see the waning gibbous Moon following Saturn as they climb above the horizon. The gap between the pair is about 5°.

**29, 30, 31** **MORNING:** As with the start of the month, a pretty picture greets early risers: The waning crescent Moon, Jupiter, Mars, Aldebaran, and the Pleiades gather above the eastern horizon. Watch as the thinning Moon drifts across the tableau from upper right to lower left.

**30–31** **ALL NIGHT:** The Southern Delta Aquariid meteor shower, which favors viewers at southerly latitudes, is expected to peak. The waning crescent Moon rises in the predawn hours and won't spoil the show.
—DIANA HANNIKAINEN

▲ The *terminator*, the line that divides night and day on the lunar surface, helps highlight features on the Moon as seen in this photo. To learn more about what you can see as the Moon waxes from new to full phase, turn to page 34. SEAN WALKER

## 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 5
22:57 UT

**FIRST QUARTER**
July 13
22:49 UT

**FULL MOON**
July 21
10:17 UT

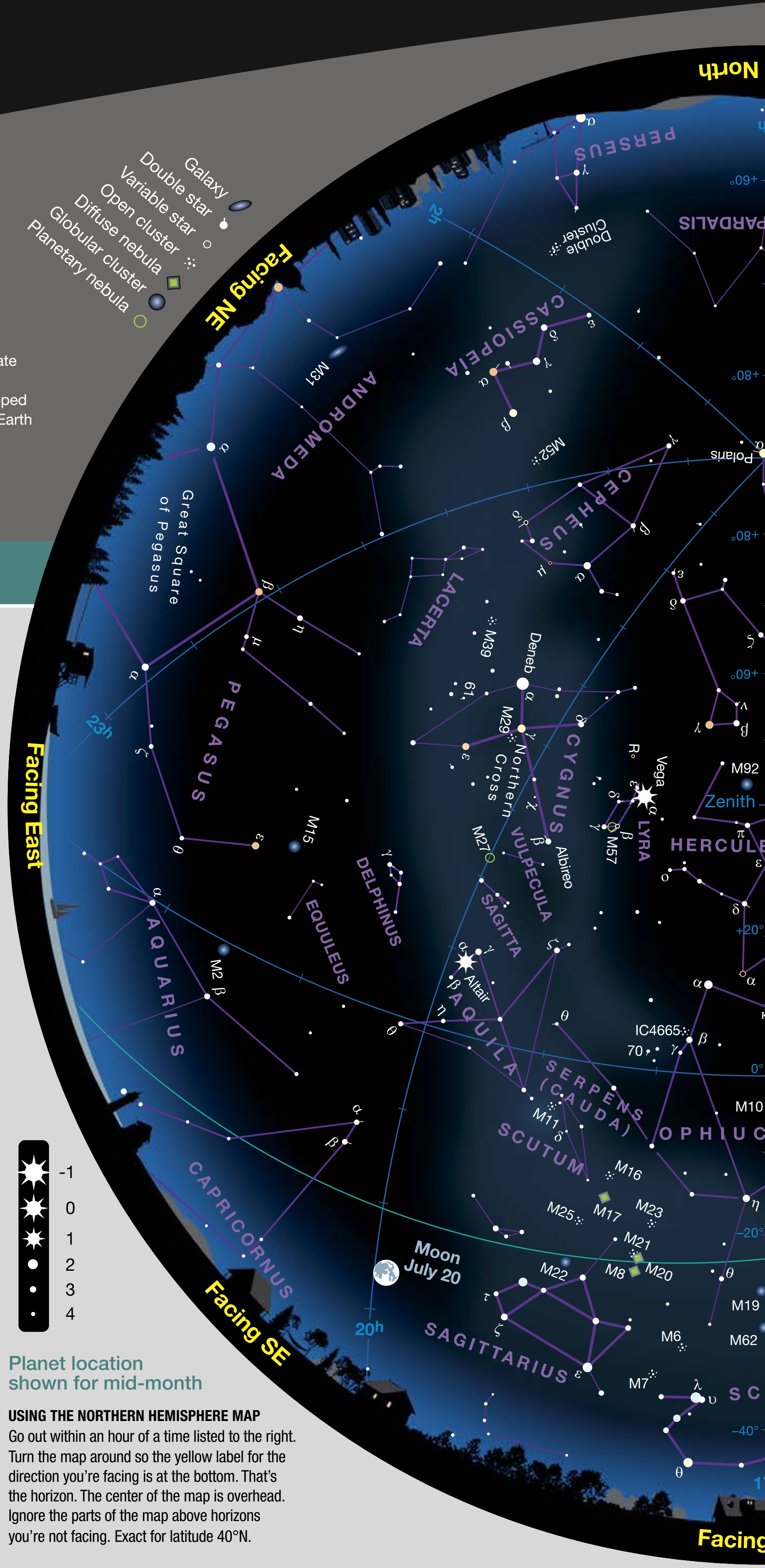
**LAST QUARTER**
July 28
02:52 UT

### DISTANCES

| | |
|---|---|
| Apogee | July 12, 8[h] UT |
| 404,361 km | Diameter 29′ 33″ |
| Perigee | July 24, 6[h] UT |
| 364,918 km | Diameter 32′ 45″ |

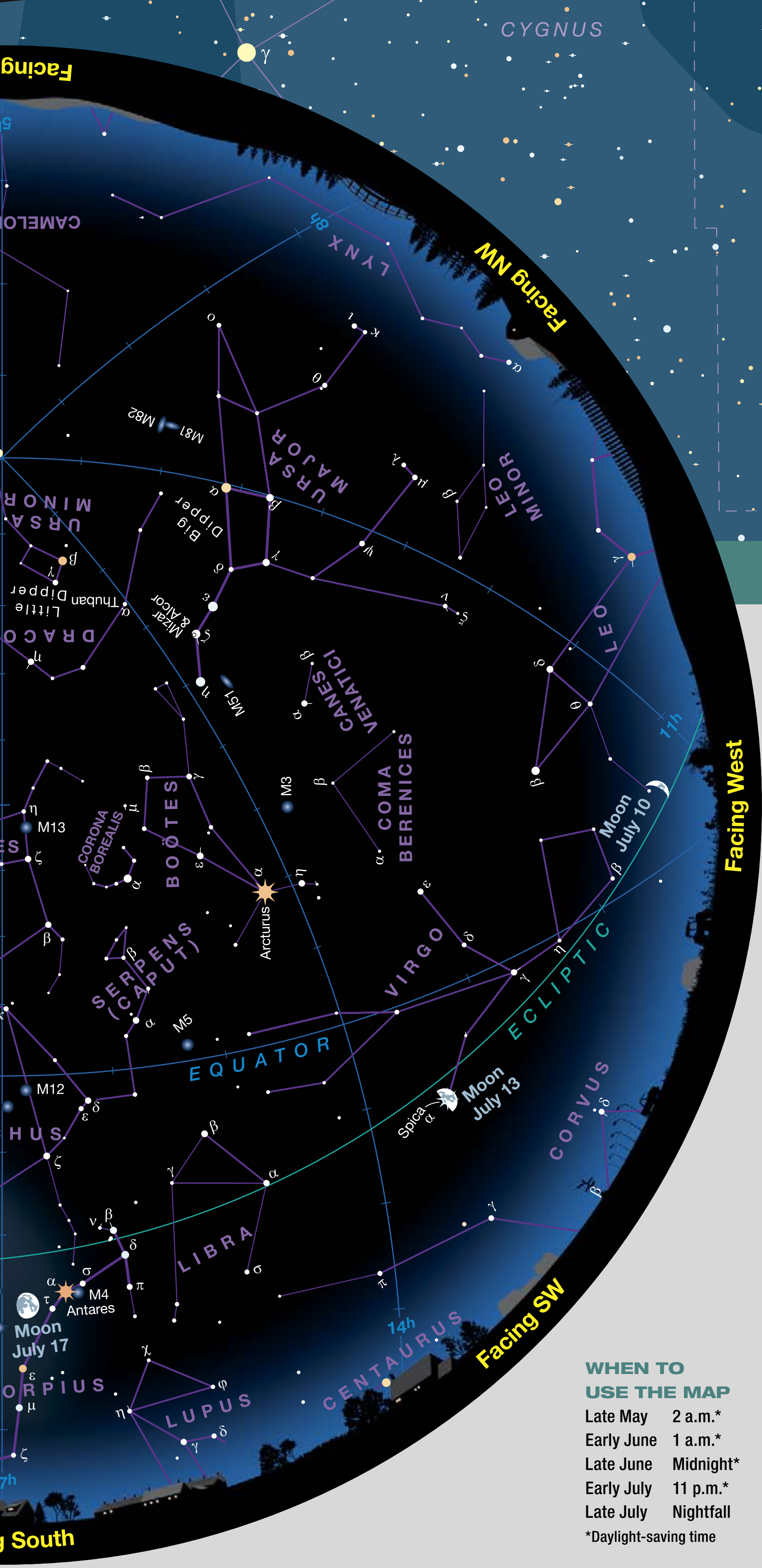
### FAVORABLE LIBRATIONS

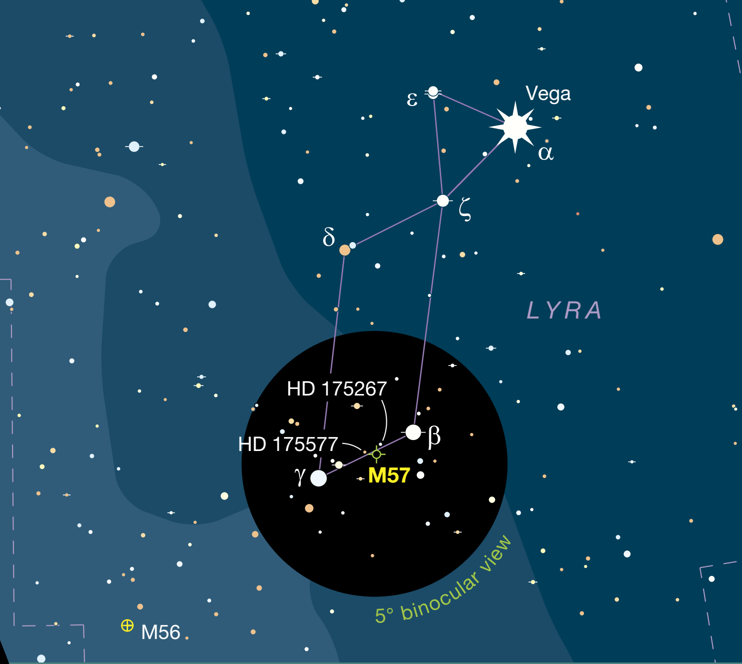
| | |
|---|---|
| • Jeans U Crater | July 9 |
| • Volta Crater | July 21 |
| • Xenophanes Crater | July 22 |
| • Cremona Crater | July 23 |




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. Exact for latitude 40°N.




**Binocular Highlight** by Mathew Wedel

# The Reclusive Ring

Our target this month is the Ring Nebula, **M57**, in the constellation Lyra, the Lyre. I haven't done anything like a scientific survey, but I'll bet that the Ring Nebula is one of the half-dozen most famous deep-sky objects, up there with the Orion Nebula, the Andromeda Galaxy, and the Pleiades. Unlike those other celestial gems, all of which are visible to the naked eye, M57 offers a bit more of a challenge. You'll need binoculars, and even then, it may push you.

M57's 8.8-magnitude glow is concentrated in a small space, just a little more than 1′ in diameter, which gives it a reasonably high surface brightness. The challenge comes in seeing the Ring as a non-stellar object. Or, perhaps it would be better to say as a "more-than-stellar" object, since the nebula is a torus of gas blown off by an aging star. In practical terms, that means trying to detect the "fuzz" that distinguishes M57 from nearby field stars.

It helps to know precisely where to look. Start on the southern edge of the Lyra parallelogram, with the 3rd-magnitude stars Sheliak, or Beta (β) Lyrae, and Sulafat, or Gamma (γ) Lyrae. M57 lies about 40% of the way from Beta to Gamma, and just south of the line connecting them. The closest objects of comparable magnitude to the Ring are the stars HD 175267 and HD 175577 (both north of the Gamma–Beta line), which form an isosceles triangle with M57.

Once you're on target, all the usual tricks apply, like good dark adaptation and averted vision. Other observers have detected M57 as more-than-stellar in 7× binoculars, but I need 10×50s at least, and I appreciate the extra power of 15×70s. If you have multiple binoculars, try running through them and see how low you can go with the magnification. Happy hunting!

■ **MATT WEDEL** has only fair-to-middling visual acuity, but he still likes to push his eyes as far as they can go on the night sky.

**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 | Nightfall |

*Daylight-saving time

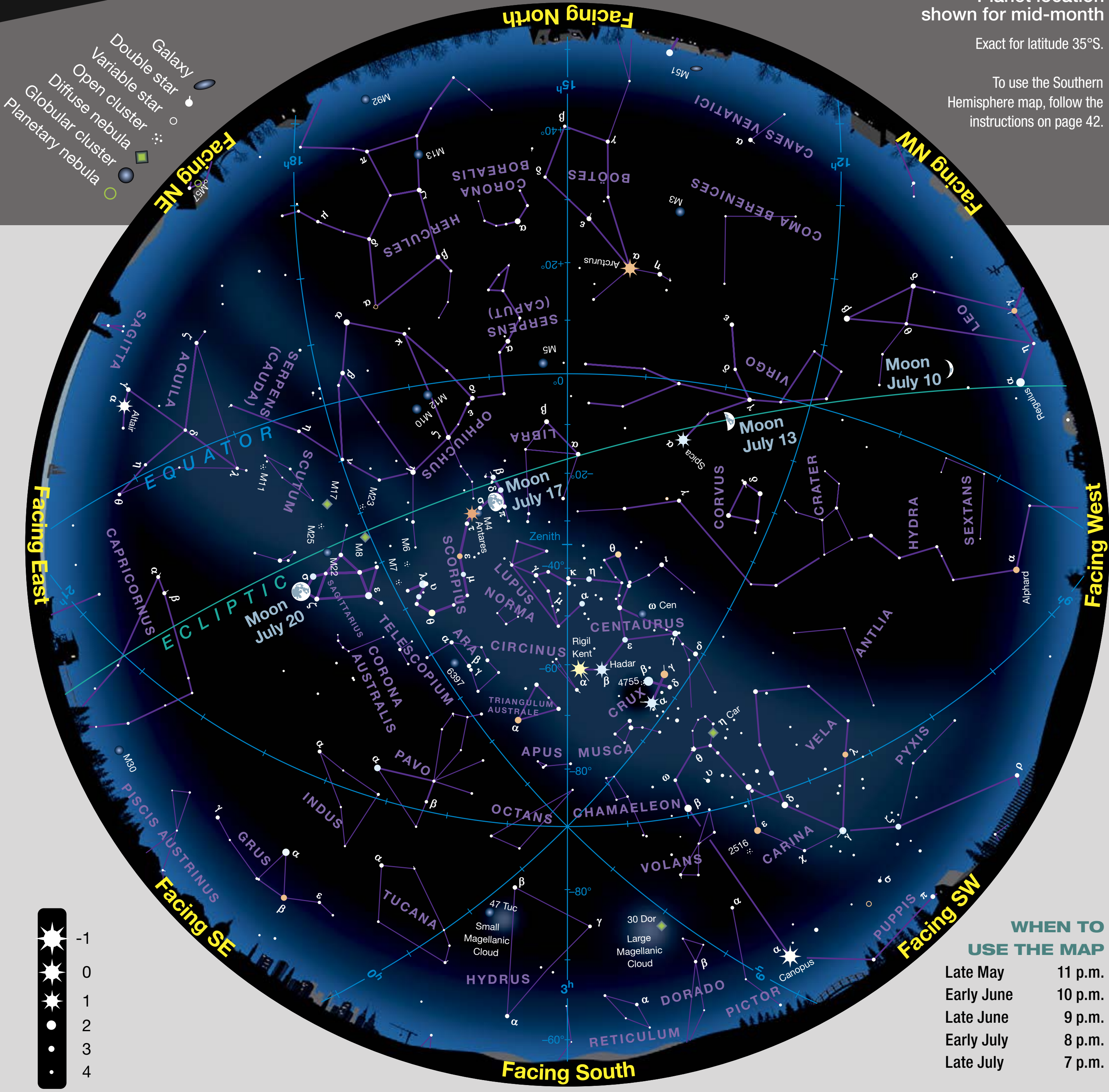
## Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

To use the Southern Hemisphere map, follow the instructions on page 42.




**WHEN TO USE THE MAP**

| | |
|---|---|
| Late May | 11 p.m. |
| Early June | 10 p.m. |
| Late June | 9 p.m. |
| Early July | 8 p.m. |
| Late July | 7 p.m. |

**JULY MARKS THE** middle of winter in the Southern Hemisphere, and that means one of the sky's most famous and easily recognizable constellations is riding high: **Crux**, the Southern Cross. Even though Crux is the smallest of the 88 officially recognized constellations, it stands out among the rich star fields of the southern Milky Way due to the prominence of its four main stars.

The base of the Cross is marked by Alpha (α) Crucis, or Acrux, a multiple-star system with a combined magnitude of +0.8. The left star is Beta (β), or Mimosa (magnitude 1.3); the top star is Gamma (γ), or Gacrux (1.6); and the 2.8-magnitude right-hand star is Delta (δ). Once seen, you quickly realize why the Southern Cross appears on the flags of many countries, including Australia, New Zealand, and Brazil. ■

# Listen to the Stars

## When you look at the night sky, can you perceive the sound of starlight?

The night sky is more than a purely visual tapestry — the stars can speak to us. Not that we should expect to hear them. Yet, in a way, we do. In his poem "Footsteps of Angels," American poet Henry Wadsworth Longfellow (1807–1882) likens the stars to a divine messenger's eyes — its voiceless prayer "Uttered not, yet comprehended."

There are several instances in Longfellow's 1839 debut book of poetry, *Voices of the Night*, in which he reveals how he heard the stars. For example, the opening verse of his poem "Hymn to the Night" evocatively begins with:

*I heard the trailing garments of the Night*
*Sweep through her marble halls!*

Ever since humankind first pondered the night sky, we have found meaning in the stars. They have told us when to plant or sow, or when to expect the long nights of winter or the joyous coming of spring. Some of my most memorable nights under the stars haven't been those mired in telescopic research, but instead those when I simply looked up in wonder as if for the first time. When you gaze at the night sky, what do you hear?

The ancients invoked the sound of starlight in the names of certain stars and constellations. The most important constellation to the Phoenicians was *Doube* (Ursa Minor, the Little Bear), which, in his *History of the Heavens*, the French astronomy popularizer Camille Flammarion translated as "the speaking constellation." As the Greek poet Aratus explains in *Phaenomena*, "By her [Ursa Minor's] guidance, then, the men of Sidon [Phoenicians] steer the straightest course."

There is another sound that reaches us from the east. On the Northern Hemisphere star chart on pages 42 to 43, we see Pegasus, described in the 1849 *Dictionary of Greek and Roman Biography and Mythology* as the "thundering horse of Zeus," lifting its neck and forelegs above the eastern horizon. In ancient China, the star Zeta (ζ) Pegasi, which is near the base of the Horse's neck, was known as *Luy Tien*, which means "thunder." Now, try to imagine Pegasus's hooves clacking like thunder against what Longfellow called "the marble halls of night." This characterization contrasts with the original Arabic name for the star: *Al Hammām*, meaning "whisperer." Unlike today's horse whisperers who communicate with their equine charges, Al Hammām, one could say, speaks to us.

Our star chart also shows 1st-magnitude Antares, the reddish Alpha (α) star of Scorpius, the Scorpion, cresting above the southern horizon. Antares is another "noisy" star. Its rapid-fire twinkling — a trait that bright stars near the horizon often exhibit — could almost be perceived as chattering. In ancient China, warnings from chattering stars played an important role in state politics — an emperor wouldn't make an important decision before consulting with a court astrologer.

Hovering high in the west-southwest on July evenings is the glorious, zero-magnitude Arcturus, the brightest star of Boötes, the Herdsman. One may wonder just *what* is Boötes herding? The answer dates to an ancient Babylonian star list that includes a star (likely Arcturus) known as *Sibzianna*, which translates to "Shepherd of the Life of Heaven," referring to its proximity to the north celestial pole. Certainly, Boötes is not shepherding the Bears. On the contrary, as Richard Proctor imagines in his 1878 *Myths and Marvels of Astronomy*, "He was of old 'a fine figure of a man,' waving aloft his arms, and, as his name implies, shouting lustily at the retreating bear."

▲ This engraving of an angel of the night in trailing garment accompanies Longfellow's poem "Hymn to the Night" in the 1857 edition of *The Poetical Works of Henry Wadsworth Longfellow*.

Indeed, the name Boötes may have derived from a Greek word meaning "clamorous," which could describe the hollers a shepherd makes when ordering his dogs to scare away any potentially dangerous animals. In the celestial case, Boötes holds the leashes of Canes Venatici, the Hunting Dogs, in one hand as they help him drive away the Great Bear. These shouts follow the Bear around the north celestial pole in an endless pursuit, which is why sometimes the constellation was also known as "Vociferator."

So, as you look up at the night sky this month, try to remove all obstacles from your mind and listen to the stars.

■ Contributing Editor **STEPHEN JAMES O'MEARA** has been studying the stars and their lore for more than 50 years.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

# A Busy Dawn

Mars, Jupiter, and the Moon dance among the stars of Taurus.

## MONDAY, JULY 1

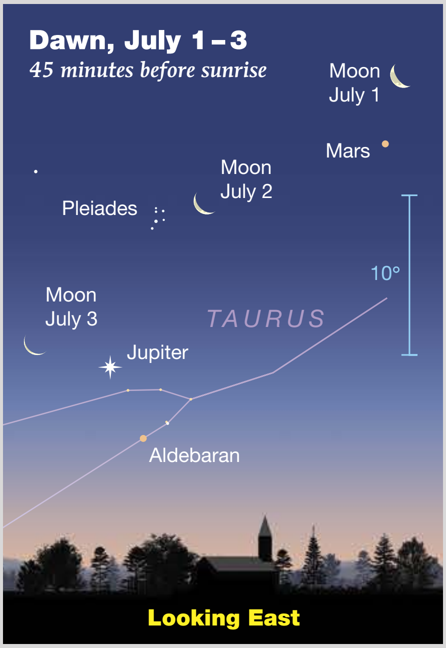
There's a lot happening at dawn as this month kicks off, thanks to the presence of a couple of planets. First up is the **Moon** visiting **Mars**. You can take in this lovely pairing by facing east at around 3:30 a.m. local daylight time. That's when you'll be presented with a 23%-illuminated, waning lunar crescent perched a bit more than 4° above Mars. The Red Planet presently shines at 1st magnitude and, thanks to its steady eastward drift, will continue to hang around at dawn for a few months to come. That means you can look forward to regular morning conjunctions featuring Mars and the Moon.

## TUESDAY, JULY 2

It's **Pleiades** season once again, and at dawn today the **Moon** has its first observable encounter with the cluster since early April. The two meet twice this month — this morning, and on the 29th. However, today's event is the closer of the two, as the attractively earthlit lunar crescent approaches to within 1½° of the cluster's periphery, as seen from the West Coast. Nevertheless, this is a lovely sight all across North America. Be sure to have a look with your binoculars, which will make the earthshine illuminating the "unlit" side of the Moon's face even more obvious and add many more cluster stars to the scene. But the most rewarding way to enjoy this morning's sky is to take in the whole vista with your eyes alone. The Moon is neatly situated between Mars and Jupiter, with added luster provided by the nearby bright stars Aldebaran and Capella. It's a sight worth getting up for!

## WEDNESDAY, JULY 3

The third and final act of our early-July dawn show features an even thinner (7%-illuminated) crescent **Moon** sitting roughly 4½° upper left of **Jupiter**. The giant planet is near the start of its current apparition, which will climax on December 7th when it reaches opposition. Jupiter gleams at magnitude –2.0 about 5° from 1st-magnitude **Aldebaran**, in Taurus. Scattered to the right of the pair are the stars of the **Hyades** — one of the most conspicuous naked-eye clusters in the sky. Jupiter has taken up temporary residency on the outskirts of the cluster but over the course of the coming weeks will drift farther and farther from Aldebaran and the Hyades.

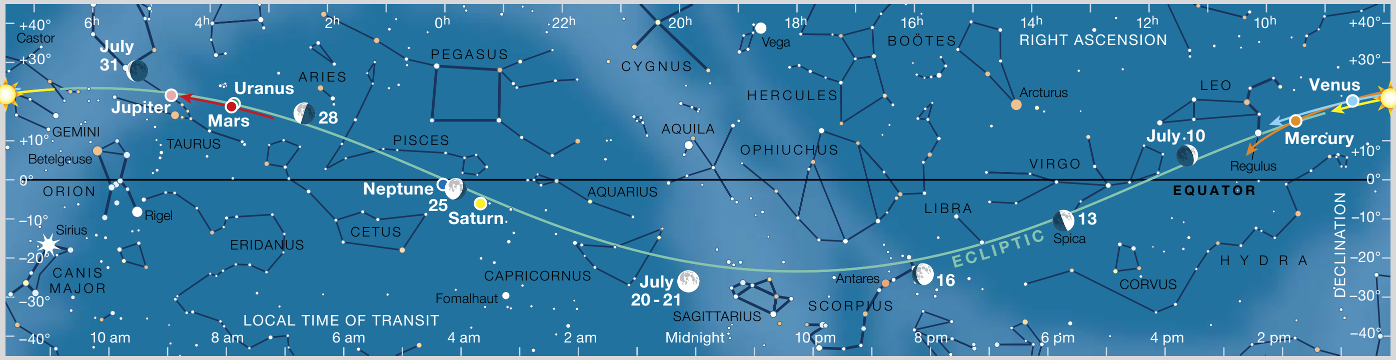



## SATURDAY, JULY 6

Here's a real horizon-hugger for you. At dusk today you have a chance to see a very thin **Moon** sitting between the innermost planets, **Venus** and **Mercury**. All three are going to be tricky to spot, but for different reasons. Although it shines brilliantly at magnitude –3.9, Venus sits very low in the west-northwest and sets just half an hour after the Sun. The Evening Star is only now reappearing after it was lost to the Sun's glare at dawn in early April. It's at the start of a favorable evening apparition that lasts through to the end of the year and well into next spring. So, don't be dismayed if you can't see it today — you'll get plenty of chances in the weeks ahead.

As for the Moon, this evening it suffers from being very young — it's just a bit more than one day past new and is only 1.4% illuminated. Half an hour

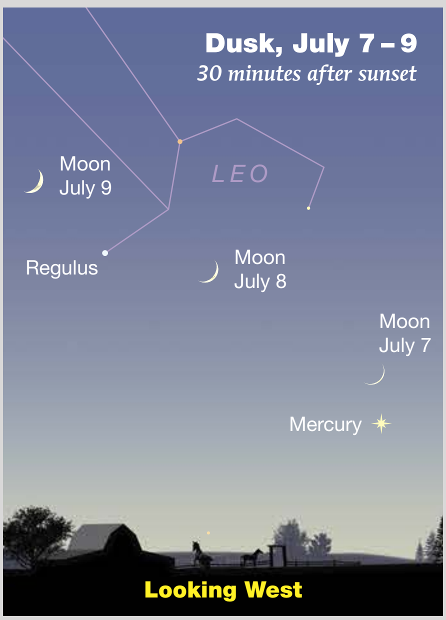

▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your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




▲ 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 illuminated). "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.

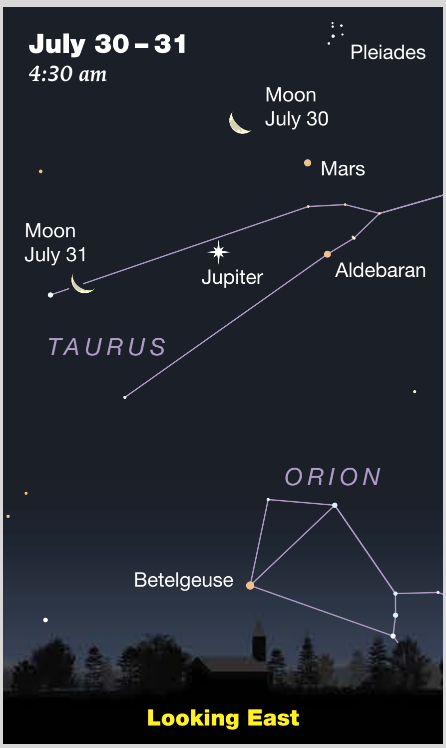
after sunset it's a mere 5° above the horizon and roughly 4¾° above Venus. Highest of all is Mercury, which is 8° up at that time and about 9° above left of the Moon. The challenge when it comes to sighting the third member of our low-down dusk trio is that the planet struggles to shine through bright twilight. Yes, at magnitude –0.2 it's not exactly faint, but it's still going to be a tough find. For all three, binoculars are your friend. Try to sight each one with optics first, then see how you make out with your eyes alone. Will you score a perfect three out of three?

If Mercury eludes you, try again tomorrow when the slightly fatter crescent Moon sits 3° above the planet and guides you to it. Binoculars will show both in the same view. And keep an eye on the speedy little planet in the coming week. Although it doesn't reach greatest elongation until the 22nd (when it lies 27° east of the Sun), owing to the relatively shallow angle the ecliptic makes with the evening horizon at this time of year, Mercury will achieve its greatest altitude on the evening of the 12th for observers at mid-northern latitudes.




## SATURDAY, JULY 13

The **Moon** has several close encounters with bright stars as it makes its way along the ecliptic during July. By far the most interesting is this evening's meet-up with **Spica**. That don't-miss-it event is described in detail on page 49. Less interesting (but still noteworthy) is the Moon's conjunction with **Antares** on the evening of the 17th, when it sits roughly 3½° left of the 1st-magnitude ember.




## TUESDAY, JULY 30

July winds down with the **Moon** returning to the same stretch of sky where it began the month. Cast your gaze eastward just as the first blush of morning twilight begins to brighten the dawn and you'll see the waning lunar crescent, **Jupiter**, **Mars**, and **Aldebaran** arranged in a compact, lopsided square. That's lovely enough on its own, but what makes the scene even more delightful are the cast of secondary players. Directly above the box and a bit more than 7° from the Moon are the Pleiades, while a scattering of Hyades stars fills the gap between Aldebaran and Mars. Expanding our view to take in the bigger picture, we have zero-magnitude Capella 25° left of the box, and the bright collection of stars making up the constellation Orion below the luminous quartet. The view on the following morning will be similarly attractive, but the Moon will now be a slightly thinner crescent and forms part of a ragged line with Jupiter and Aldebaran.

■ Consulting Editor **GARY SERONIK** plans to forgo sleep and rise early this month to see the dawn sights.

# Dwarf Planets at Opposition

Pluto and Ceres are at their best this month, though one is far easier to see than the other.

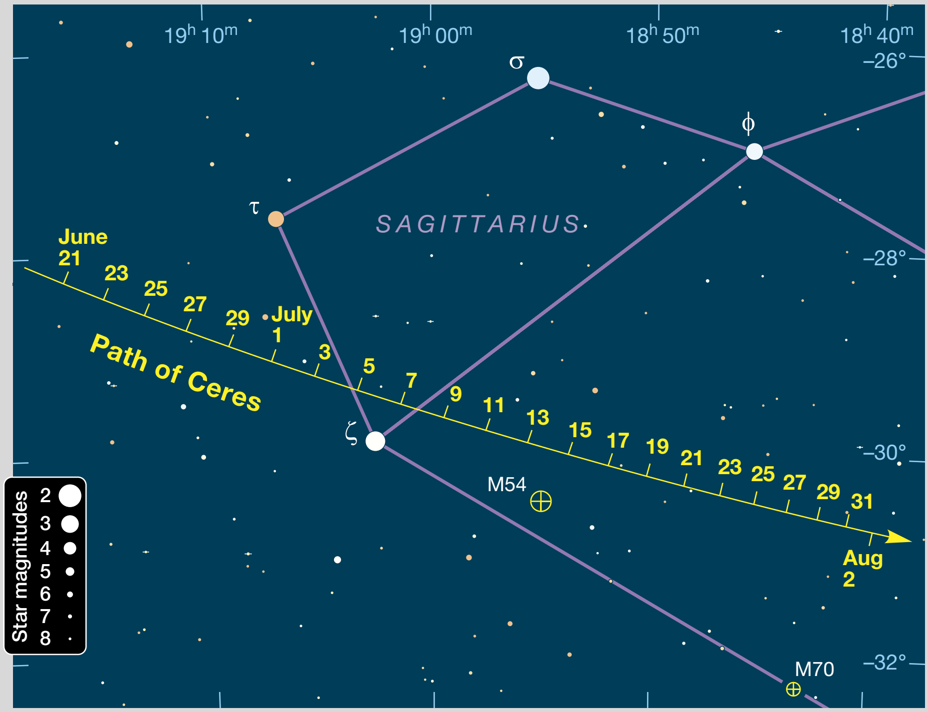
If someone asked you to name the most amazing thing about the dwarf planet Ceres, how would you answer? For me it's the fact that this single, 939-kilometer-wide (583-mile-wide) object possesses some 25% to 40% of the mass of the entire asteroid belt. To put that in perspective, NASA estimates there are between 1.1 and 1.9 million asteroids larger than 1-kilometer diameter, mostly orbiting between Mars and Jupiter.

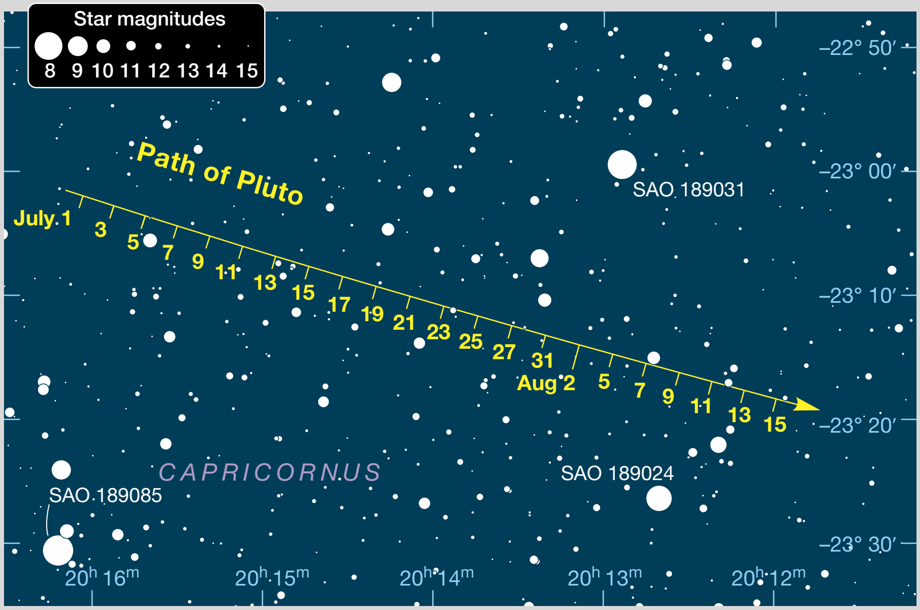
You can see this marvelous little world at its best when it reaches opposition on the night of July 5th. At magnitude 7.3, the starlike object is easy to pick out in binoculars as it tracks westward in retrograde motion across the handle of the distinctive Sagittarius Teapot asterism.

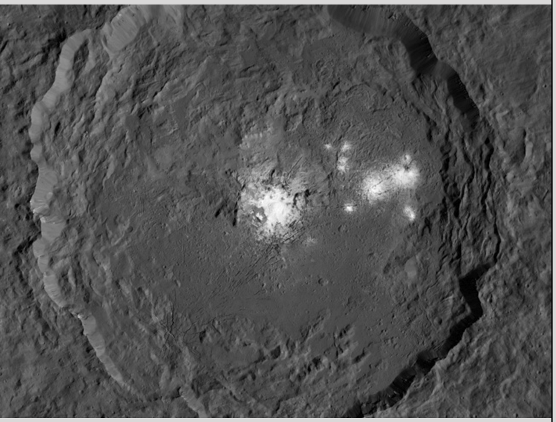
The object's declination on opposition night is nearly −30°, which is ideal for spotting at nightfall from tropical and southerly latitudes. Northern observers will have to wait until around midnight local daylight time for it to clear the horizon haze for a good view.

During its July run, Ceres passes a bit less than ½° north of 2.6-magnitude Zeta (ζ) Sagittarii on the night of July 7th. This makes for an easy opportunity to locate the dwarf planet and detect its movement from night to night. Then on the 14th and 15th, you can watch it toddle a similar distance north of the 7.7-magnitude globular cluster M54.

There are many notable things about Ceres, including the fact that when Pluto was downgraded from planet to dwarf planet in 2006, Ceres was upgraded from asteroid to dwarf planet. In the realm of official nomenclature, you win some, and you lose some.





▲ Occator Crater on Ceres is 92 km (57 miles) across and 3 km deep. It contains the dwarf planet's brightest spots — features rich in highly reflective sodium carbonate likely deposited after briny water percolated to the surface and vaporized. Data from NASA's Dawn probe indicate Ceres has a subsurface reservoir of salt-enriched water about 40 km deep and hundreds of kilometers wide.

Arguably as complex and multi-faceted as any planet, Pluto reaches opposition on July 23rd at a distance of 5.2 billion kilometers from the Sun. With Pluto's diameter only about two-thirds that of the Moon, it's remarkable that amateur telescopes can show the dwarf planet at all. Nitrogen, carbon monoxide, and methane ice are the reason why — they jacket Pluto's surface and excel at reflecting light.

Pluto's eccentric, 248-year-long orbit causes its distance and brightness to vary significantly. With an apparent magnitude range of 13.7 to 16.3, it sits during this opposition at 14.4. An experienced observer under ideal conditions might spot it in a 6-inch scope, but most of us will find this remote object difficult enough to require an 8- or 10-inch instrument. Next opposition Pluto will be farther away and slightly fainter.

After slow-jamming across Sagittarius since 2006, the dwarf planet crossed into Capricornus at the start of 2024. You'll find the frostbitten orb about 2¼° southeast of the 8.6-magnitude globular cluster M75 — a great place to begin your summer Plutonian odyssey.

CERES CRATER: NASA / JPL-CALTECH / UCLA / MAX PLANCK INSTITUTE FOR SOLAR SYSTEM STUDIES / GERMAN AEROSPACE CENTER / IDA / PLANETARY SCIENCE INSTITUTE; SIMULATED OCCULTATION: STELLARIUM

Skywatchers in Miami Beach, Florida, can see a spectacular occultation of Virgo's brightest star Spica at the Moon's dark limb on July 13th at 11:48 p.m. EDT. The star will flash back into view on the bright limb a little more than an hour later, as the Moon sets.

# Spica Occultation Season Gets Underway

**SPICA IS THE 16TH-BRIGHTEST** star in the nighttime sky and one of only four 1st-magnitude stars periodically occulted by the Moon. (The other three are Regulus, Antares, and Aldebaran.) Each one has its own occultation season, during which the Moon eclipses it monthly (or, sometimes, twice a month) for up to several years. However, since some events occur in daylight or favor specific geographic locations, individually each of us is privy to just a fraction of the total possible occultations. So, don't let a good occultation opportunity pass you by!

Spica began its current occultation season in June, and it continues through to November 17, 2025. The first event visible in the Americas occurs on the night of July 13th. Observers across much of the U.S., Canada, Mexico, and Central America can watch the dark limb of the first-quarter Moon creep closer and closer to Alpha (α) Virginis until the star's light is extinguished in the blink of an eye.

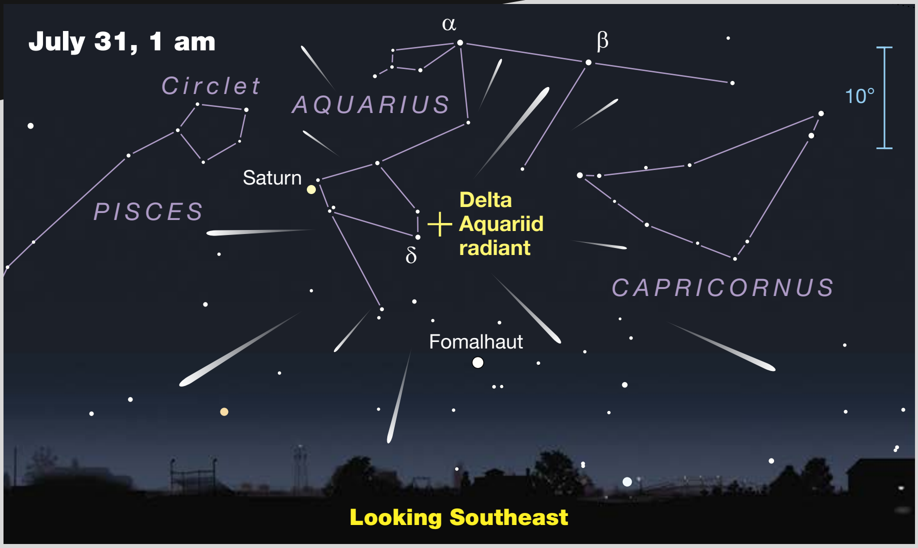
From the Eastern Seaboard, disappearance takes place around 11:30 p.m. EDT, with the Moon low in the west-southwestern sky. Viewing circumstances improve in the southern states, where the Moon is higher up in steadier air. Midwesterners can witness the occultation in late evening twilight at around 10 p.m. CDT, while across the Mountain states it occurs in early twilight at around 9 p.m. MDT.

Although Spica vanishes in broad daylight an hour or more before sunset on the West Coast, I suspect that under clean, haze-free skies the star might still be visible in a telescope given that we'll know exactly where to look — right next to the Moon. It'll be a challenging find, however.

Located about 250 light-years from Earth, Spica is a fascinating spectroscopic binary. The primary and secondary stars orbit each other so closely they're stretched into egg shapes as they whirl about their center of mass once every four days. The primary packs a mass at least 11 times that of the Sun, but the secondary is no lightweight either, containing more than 7 solar masses. We hear a lot about the possibility of Betelgeuse going supernova one day, but Spica's primary star is also massive enough that it will likely suffer this fate. Don't set your alarm just yet, though — the blast isn't expected for several million years.

Besides the close pair, the Spica system may have two more distant companions, though it's uncertain if either is physically bound to the main pair. The Washington Double Star Catalog also lists a third, 7.5-magnitude member separated by just 0.5″, but its nature is unclear. Perhaps someone with a high-sensitivity, high-frame-rate video camera and large telescope might succeed in resolving the issue during the upcoming occultation.

For a list of cities and occultation times, stop by the International Occultation Timing Association's website: **https://is.gd/july2024spica**.




# Southern Delta Aquariid Meteor Shower Paves Way For Perseids

**THE SOUTHERN DELTA AQUARIID** meteor shower shares summer's slow-and-easy vibe. Active from mid-July to late August, this display is expected to max out with around 25 medium-fast meteors per hour on the night of July 30–31. The luminous streaks appear to emanate from a radiant in southern Aquarius, about 3° west of 3.3-magnitude Delta (δ) Aquarii. That's 16° below the celestial equator, which means observers in the tropics and Southern Hemisphere have the best view. However, northern meteor watchers will still see some activity, though at a reduced rate.

Be on the lookout as early as 10 p.m. for *earthgrazers* — meteoroids that strike the atmosphere at a very shallow angle and take several seconds to completely vaporize as they cross the sky. The peak viewing time occurs from 11 p.m. until around 2 a.m. local daylight time, when the waning crescent Moon rises in Taurus.

One of the benefits of watching the Southern Delta Aquariids is the chance to also catch some early Perseids, which are active at the same time. You may want to tally meteors from both showers to see which display comes out ahead. They'll be easy to tell apart — Perseids point back to Perseus in the northeastern sky, while Aquariids point back to Aquarius, in the south. As far as which way to face, I'd say pick the direction that's darkest and has the least amount of light pollution.

## Mercury Visits the Beehive

**CONJUNCTIONS BETWEEN** deep-sky objects and planets are common, but it's unusual for a planet to pass *directly* in front of a galaxy, star cluster, or nebula. On the evening of July 6th, skywatchers in the southern U.S. and the tropics will find zero-magnitude Mercury in the northwestern quadrant of the Beehive Cluster, M44, in Cancer. Look low in the northwestern sky about an hour after sunset. You'll probably need binoculars or a telescope to battle twilight and get a good view. Unfortunately, bright solar glow engulfs the duo for observers in the northern half of the country.

# Action at Jupiter

**NOW ENTERING THE THIRD** month of its current apparition, Jupiter is at last becoming a rewarding telescopic sight. On July 1st, it stands better than 15° above the east-northeastern horizon half an hour before sunrise. By month's end that figure improves to nearly 40°. On the 15th Jupiter shines at magnitude –2.1 and presents a disk spanning 34.4″. From the perspective of observers at mid-northern latitudes, this apparition promises to be a fine one, with the planet favorably positioned on the northern reaches of the ecliptic in Taurus. As July begins, Jupiter's declination is +21°. It'll remain north of this mark for a little less than just two years.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost 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 the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. 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.)

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

**July 1:** 9:46, 19:42; **2:** 5:38, 15:34;

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

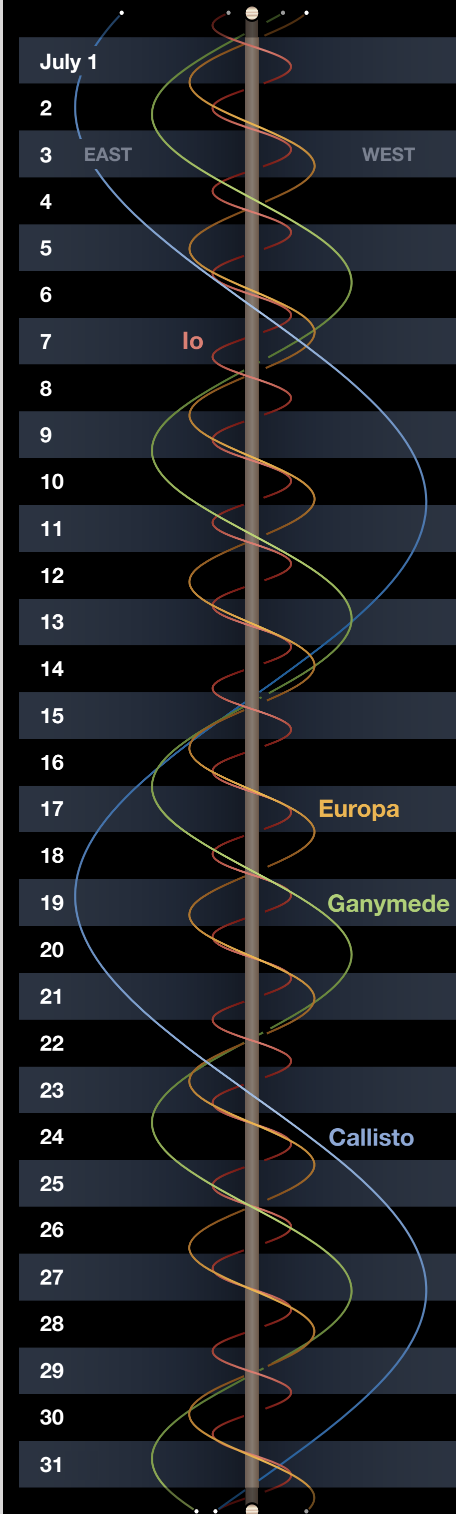
These times assume that the spot will be centered at System II longitude 60° on July 1st. If it has moved elsewhere, it will transit $1^{2}/_{3}$ minutes earlier for each degree less than 60° and $1^{2}/_{3}$ minutes later for each degree more than 60°.

## Phenomena of Jupiter's Moons, July 2024

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

## Jupiter's Moons




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

# Seeing Straight

## The limits of vision for solar system targets are better than you may think.

At the dawn of the 20th century, a heated debate was raging about a network of canals crisscrossing the globe of Mars, first reported by the Italian astronomer Giovanni Schiaparelli in 1877. Percival Lowell, the most fervent and eloquent advocate that the canals were real and not some sort of optical illusion, described them as "little gossamer filaments."

One of the arguments that canal skeptics advanced was that the purported features — at least in the form of the exceedingly fine lines Lowell reported — were far too narrow for his telescope to resolve. Some cited the oft-quoted Dawes limit, which states that one can calculate the resolving power of a telescope in arcseconds by dividing 4.56 by the telescope's aperture expressed in inches (see page 76). Keen-eyed British amateur William Rutter Dawes published this empirical formula in 1867 following an extensive series of observations of similar-brightness double stars using a variety of modest but optically excellent refractors.

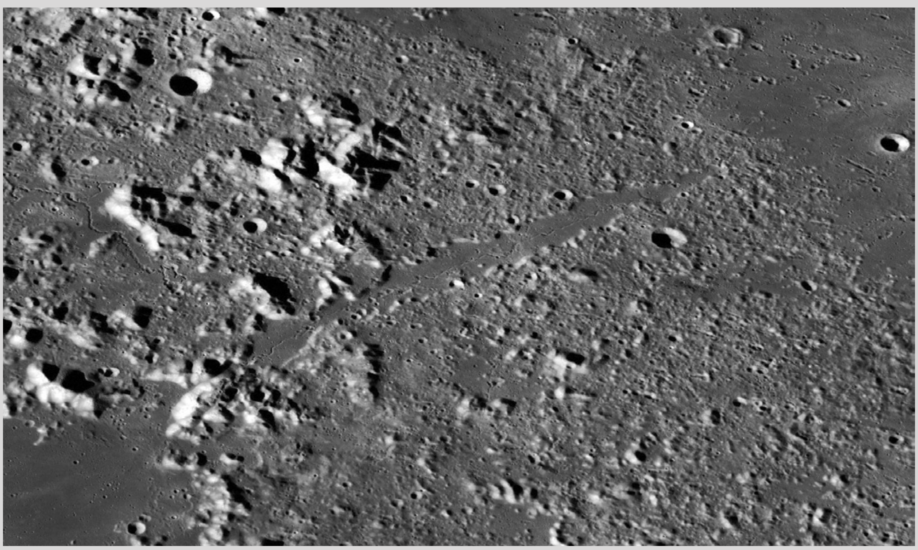
Lowell and his allies countered that this was a case of comparing apples and oranges. Granted, the Dawes limit might be valid for point sources of light, such as double stars seen against a dark background, but the eye's ability to resolve dark linear objects against a bright background is far greater.

Lowell conducted experiments using telegraph wires silhouetted against the daytime sky and determined that they could be glimpsed when their apparent diameter was only 0.7 arcsecond — 1⁄50 of the Dawes limit. Harvard astronomer William H. Pickering found that he could detect a human hair through an 11-inch refractor from a distance of nearly a quarter mile, when its apparent width was reduced to only 0.03 arcsecond — 1⁄14 of the Dawes limit — even when handicapped by moderate atmospheric turbulence.

If there had actually been canals on Mars, they could have been resolved through surprisingly modest telescopes. And there are very real "little gossamer filaments" to be seen elsewhere in the solar system, such as the fine divisions in the rings of Saturn.

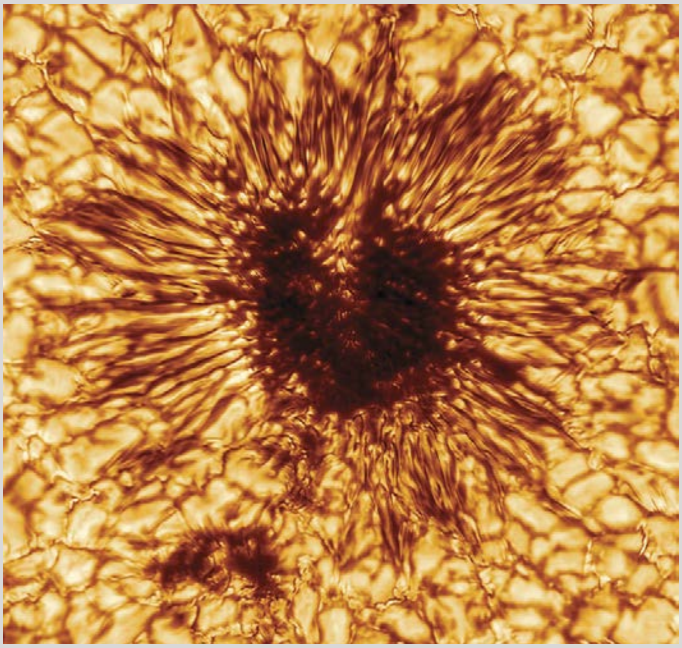
Gian Domenico Cassini discovered the most prominent of these ring divisions in 1675 using an unwieldy, non-achromatic refractor of about 2½-inches (64-millimeters) aperture and a focal length of 20 feet (6 meters)

▲ Dark linear features surrounded by bright backgrounds, such as the divisions in Saturn's rings, easily defy the resolution limits that William Rutter Dawes described more than 150 years ago.



▲ Narrow lunar rilles like the slender, sinuous lava channel that runs along the floor of the Alpine Valley (Vallis Alpes) are also visible with much smaller apertures than predicted by Dawes' limit.

SATURN: DAMIAN PEACH / CHILESCOPE TEAM; ALPINE VALLEY: NASA / GSFC / ARIZONA STATE UNIVERSITY



▲ *Left:* The radial striations in the penumbrae of sunspots are another type of linear feature visible through small telescopes. *Right:* Black shadows cast by the Galilean moons onto Jupiter's cloudtops are easy to spot even through small apertures.

SUNSPOT: NSO / NSF / AURA; JUPITER: SEAN WALKER

that magnified 90×. The 4,800-kilometer-wide Cassini Division subtends a span of only 0.7 arcsecond at the mean opposition distance of Saturn, so Cassini managed to achieve a 2.6-fold improvement over the Dawes limit.

A quarter century ago Nebraska amateur David Knisely found it difficult to surpass Cassini's feat, even with modern telescopes. Curious about the minimum aperture required to discern the Cassini Division, on a night of steady seeing Knisely experimented with a series of off-axis aperture stops fitted over the tube of his 250-mm (10-inch) Newtonian reflector. Holding the magnification constant at 141×, he gradually reduced the aperture in 10-millimeter increments from 80 mm to 50 mm. With a 60-mm aperture, he could detect the division only in the *ansae* (handles) of the rings, but with the aperture reduced to 50 mm he could no longer make it out with certainty.

In 1888, Lick Observatory astronomer James Keeler discovered a far narrower division near the outer edge of Saturn's A Ring. Only 325 km wide, it was officially named the Encke Gap by the International Astronomical Union during the 1980s. More than 14× narrower than the Cassini Division, this feature has an apparent width of only 0.05 arcsecond, yet it's often glimpsed through 8-inch telescopes in very steady seeing when the ring plane is favorably tilted. That's about 11× narrower than the closest double star that an 8-inch aperture can split according to Dawes limit.

The solar system offers other dark linear features against bright backgrounds, notably rilles on the Moon, festoons and streaks in Jupiter's atmosphere, and radial striations in the penumbrae of sunspots. As with the gaps in Saturn's rings, the visibility of these features defies conventional wisdom about the resolution limits based on point sources of light.

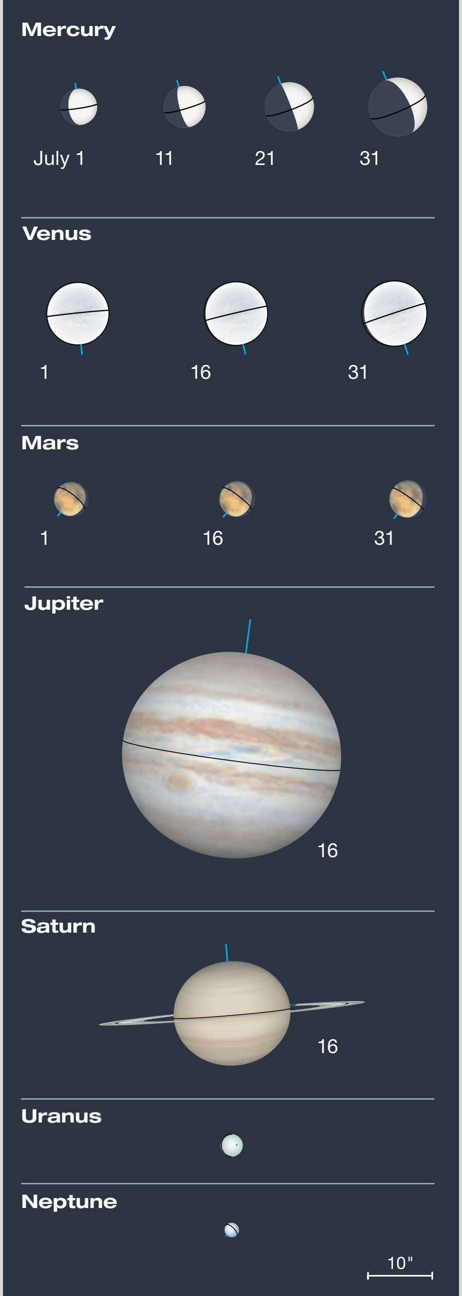
Some observing guides provide values for the smallest craters on the Moon discernible through telescopes of various apertures that are incorrectly based on the Dawes limit. In fact, the visibility of circular black spots on a bright background, such as sunspots, shadow-filled craters on lunar maria, and the shadows of Jupiter's Galilean satellites, surpass Dawes' limit, though not nearly to the extent that linear features do. Pickering found that he could perceive craterlets 2.3× smaller than the Dawes limit, while British amateur William Herbert Steavenson cited a value 3× smaller.

In his classic work *Amateur Astronomer's Handbook*, J. B. Sidgwick explained:

> *The definition — i.e. sharpness, and smallest detail visible — of an extended surface . . . is composed of the overlapping diffraction patterns formed by light emanating from every point in the object . . . the low intensity of the light, compared with that of stars, reduces their effective size, and the Dawes criterion therefore cannot be applied to the resolution of detail in extended images.*

Even moderate atmospheric turbulence will seriously impair the performance of any telescope. But when the seeing momentarily steadies to provide those fleeting moments of clarity that Percival Lowell called "revelation peeps," patient observers of the Moon and planets are rewarded with glimpses of surprisingly delicate features.

■ Contributing Editor **TOM DOBBINS** co-authored *Epic Moon: A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.




▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

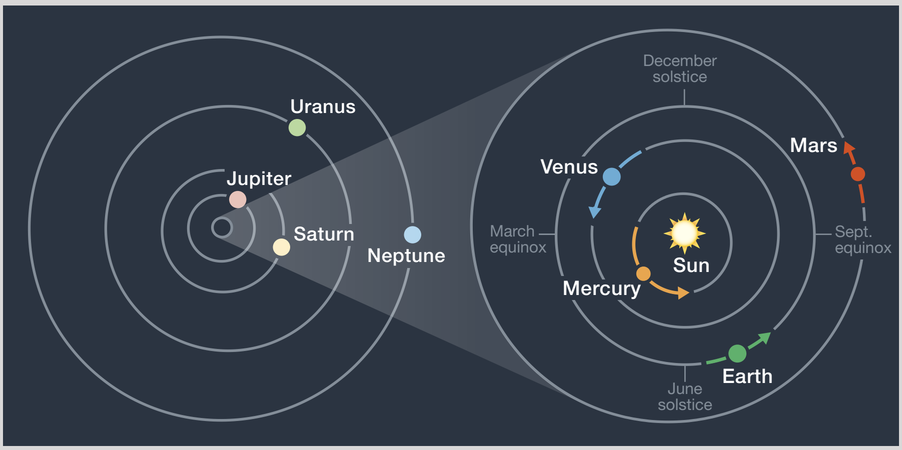
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during July. The outer planets don't change position enough in a month to notice at this scale.

**PLANET VISIBILITY** (40°N, naked-eye, approximate) **Mercury** visible at dusk until the 25th • **Venus** visible at dusk starting on the 2nd • **Mars** and **Jupiter** visible at dawn all month • **Saturn** rises before midnight and is high in the south-southeast at the start of morning twilight.

## July Sun & Planets

| | Date | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | $6^h$ $40.6^m$ | +23° 07′ | — | –26.8 | 31′ 28″ | — | 1.017 |
| | 31 | $8^h$ $41.5^m$ | +18° 17′ | — | –26.8 | 31′ 31″ | — | 1.015 |
| Mercury | 1 | $7^h$ $57.6^m$ | +22° 35′ | 18° Ev | –0.6 | 5.7″ | 78% | 1.183 |
| | 11 | $9^h$ $03.1^m$ | +17° 50′ | 24° Ev | –0.1 | 6.5″ | 62% | 1.031 |
| | 21 | $9^h$ $49.3^m$ | +12° 27′ | 27° Ev | +0.3 | 7.7″ | 47% | 0.877 |
| | 31 | $10^h$ $14.4^m$ | +7° 58′ | 25° Ev | +0.9 | 9.1″ | 30% | 0.735 |
| Venus | 1 | $7^h$ $12.2^m$ | +23° 19′ | 7° Ev | –3.9 | 9.7″ | 99% | 1.715 |
| | 11 | $8^h$ $04.9^m$ | +21° 34′ | 10° Ev | –3.9 | 9.8″ | 98% | 1.697 |
| | 21 | $8^h$ $55.9^m$ | +18° 46′ | 13° Ev | –3.9 | 10.0″ | 97% | 1.673 |
| | 31 | $9^h$ $44.9^m$ | +15° 07′ | 16° Ev | –3.8 | 10.1″ | 96% | 1.644 |
| Mars | 1 | $2^h$ $53.8^m$ | +15° 36′ | 54° Mo | +1.0 | 5.4″ | 91% | 1.739 |
| | 16 | $3^h$ $36.6^m$ | +18° 33′ | 57° Mo | +0.9 | 5.6″ | 90% | 1.673 |
| | 31 | $4^h$ $19.5^m$ | +20° 49′ | 61° Mo | +0.9 | 5.8″ | 89% | 1.603 |
| Jupiter | 1 | $4^h$ $24.9^m$ | +20° 56′ | 31° Mo | –2.0 | 33.6″ | 100% | 5.866 |
| | 31 | $4^h$ $50.4^m$ | +21° 47′ | 54° Mo | –2.1 | 35.4″ | 99% | 5.564 |
| Saturn | 1 | $23^h$ $23.0^m$ | –6° 09′ | 110° Mo | +1.1 | 17.9″ | 100% | 9.287 |
| | 31 | $23^h$ $20.3^m$ | –6° 34′ | 140° Mo | +0.9 | 18.7″ | 100% | 8.881 |
| Uranus | 16 | $3^h$ $35.0^m$ | +19° 00′ | 58° Mo | +5.8 | 3.5″ | 100% | 20.107 |
| Neptune | 16 | $0^h$ $00.4^m$ | –1° 22′ | 114° Mo | +7.9 | 2.3″ | 100% | 29.470 |

**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. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



# Great Balls of Fire

## Globular clusters in Hercules come in three sizes: small, medium, and large.

Pity poor Hercules. It wasn't his fault that he was the undesired result of an extramarital union between Zeus and a mortal woman. Strong but ill-fated, Hercules survived the notorious Twelve Labors, only to suffer a grisly end (don't ask), after which Zeus gave the hard-luck hero asylum in the heavens.

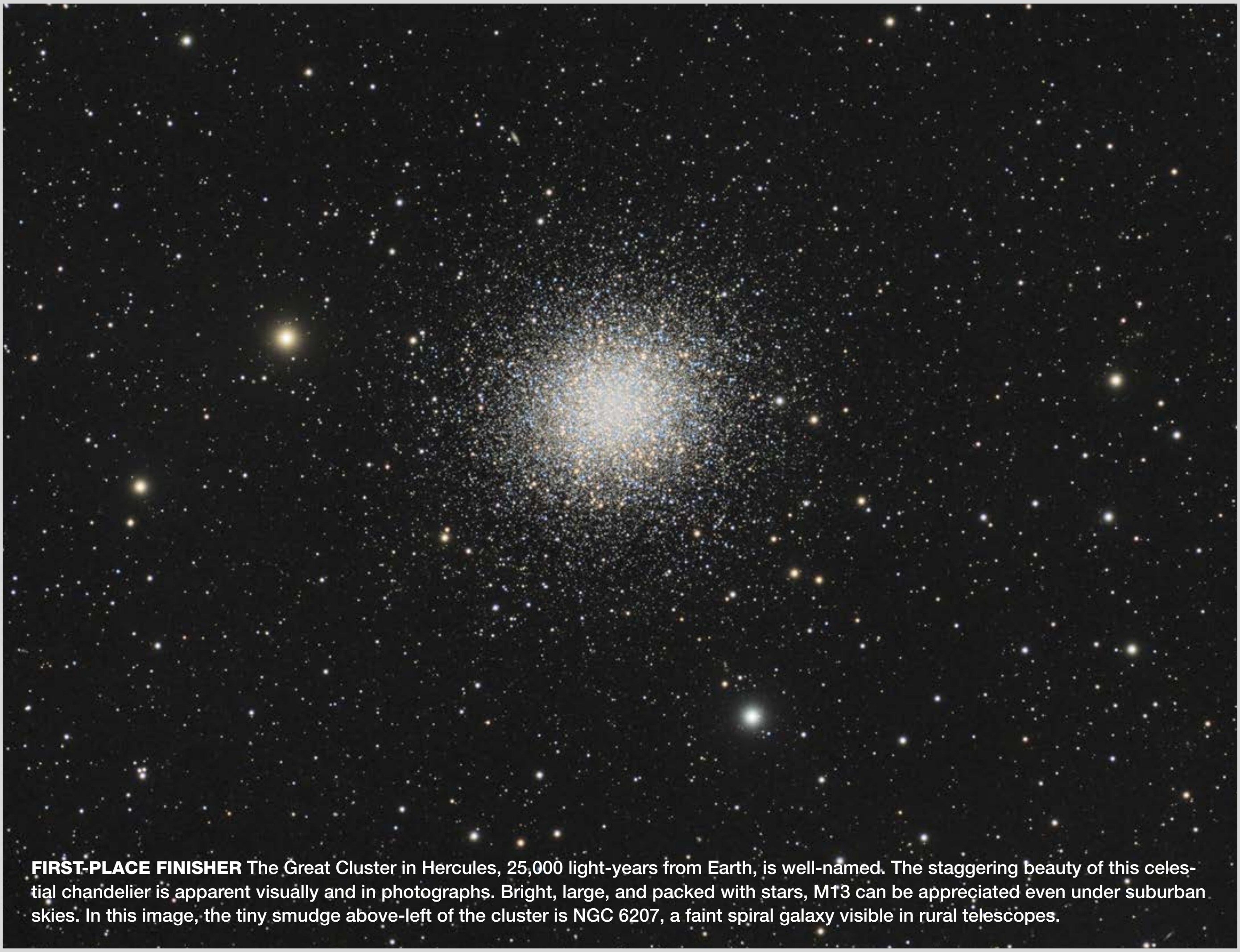
Today, stargazers appreciate Hercules as a sprawling constellation (5th largest of the official 88 groups) that hangs high on summer nights. The big guy stands on his head (a neat trick), his muscular torso outlined by the attractive Keystone asterism formed by a quartet of 3rd- and 4th-magnitude stars.

Where I live, in a small city generously endowed with urban lighting, the only safe direction to point my telescopes is straight up. The light pollution isn't fatally bad up there in the high half of Hercules. Hooray, because the region from the Keystone northward is home to three globular star clusters. Included in that stellar trio is the finest globular north of the celestial equator, the celebrated Great Cluster, **M13**.

Let's start there, then find the other two globulars. I've got a couple of reflectors — a 4¼-inch f/6 Newtonian and a 10-inch f/6 Dobsonian — set up for Ken's Three Labors.

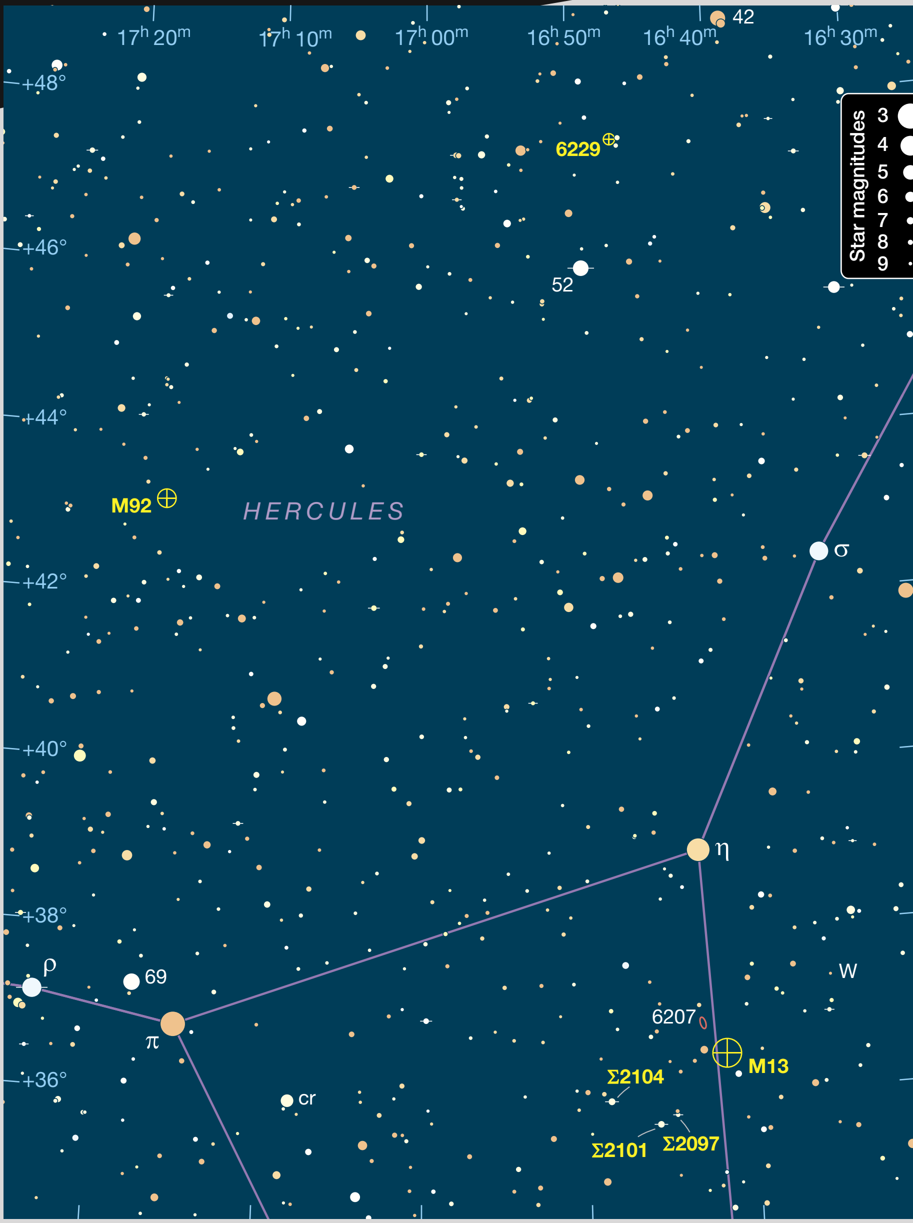
### The Great One

Start your quest by identifying the roughly 7°-tall Keystone asterism, which sits about two-thirds of the way from Arcturus to Vega. M13 resides on the west side of the asterism, which is



**FIRST-PLACE FINISHER** The Great Cluster in Hercules, 25,000 light-years from Earth, is well-named. The staggering beauty of this celestial chandelier is apparent visually and in photographs. Bright, large, and packed with stars, M13 can be appreciated even under suburban skies. In this image, the tiny smudge above-left of the cluster is NGC 6207, a faint spiral galaxy visible in rural telescopes.

RON BRECHER




▲**GLOBULARS OF HERCULES** M13 and M92 are both well-known globular star clusters, but try also for NGC 6229, a diminutive globular in the northwestern part of the constellation. And don't miss the three binary stars located just southeast of M13.

marked by 2.8-magnitude Zeta (ζ) at the Keystone's southwest corner, and 3.5-magnitude Eta (η) Herculis on the northwest corner. M13 is found two-thirds of the way from Zeta to Eta. Glowing at magnitude 5.8 and 20′ in diameter, you should see the globular readily in your finderscope.

M13 is a cosmic hive of several hundred thousand ancient suns. Fabulous. But our ability to resolve a globular into stars depends on both the size of your scope and the luminosity of the brightest cluster members. The leading lights of M13 shine at magnitude 11.9, and with good sky conditions, a 4-inch telescope can detect stars down to magnitude 12.7. My sky conditions aren't even close to good, but let's see what I can do.

In the 4¼-inch reflector at 27×, M13 is a diffuse sphere with a broad, bright middle. As shown in the photo on page 55, the cluster is flanked by two guardians — a 6.8-magnitude orange star 15′ to the east and a 7.3-magnitude white star a similar distance to the southwest. The guardians are handy for re-focusing different eyepieces. My patient use of averted vision and magnifications between 93× and 108× teases out 12th-magnitude flecks of light across the cluster, turning it into a grainy sphere. Not bad for a small scope.

The 10-inch does way better. At 48×, M13 grows smoothly brighter from the edge to the middle. An eyepiece yielding 64× resolves the surrounding halo into stars; doubling to 128× adds numerous pinpoints throughout the interior. At 169× to 218×, the glittering sphere displays irregular clumps of stars separated by narrow voids. The patchy effect becomes stronger with increased magnification. And to my eye, several long chains of stars curve southwestward, in the general direction of the 7.3-magnitude guardian.

Bonus time: Three double stars lie just southeast of M13. **Struve (Σ) 2104** has 7.5- and 8.8-magnitude components 5.7″ apart. Less than 40′ west of that duo is **Σ2101**, which offers 7.5- and 9.4-magnitude stars spanning 4.1″. Both tandems resolve at around 100×. The third binary, **Σ2097**, stands 14′ northwest of Σ2101. This one is tough. The 9.4- and 9.6-magnitude components, separated by only 1.9″, barely split in my 10-inch at 169×. The dim dots are too tight for my smaller scope.

## Midsize Marvel

M13's less famous cousin lies almost 10° northeastward. **M92** is w-a-a-a-y up there. Observers near the latitude of Denver, Colorado, can watch M92 climb to a point just north of the zenith. From my home at around 49° North, I have to crane my neck to sight M13 — M92 is even worse!

Get ready for one big star-hop. M92 is located roughly two-thirds of the way from Eta Herculis to 3.8-magnitude Iota (ι), a lonely light in northeastern Hercules. Eta and Iota are about 12° apart — too widely spaced to fit in a finderscope field. No problem. I place Eta in my finder, then shift northeastward until Iota swims into view. There's no other star as bright as Iota to distract me along the way. M92 is less than 5°

**AND SECOND PLACE GOES TO . . .** In the contest of competing Hercules globular star clusters, M92 places a solid second to M13. About 4,000 light-years farther away, M92 is smaller than the Great Hercules Cluster and not quite as bright. However, M92 has strong visual appeal because of its angular outline and compressed core.

RON BRECHER

southwest of Iota. Working from my suburban yard, I can spot the cluster as a fuzzy "star" in the finder field, provided I don't overshoot Iota.

M92 is certainly less prominent than M13. However, at magnitude 6.5 and sporting a diameter of 14′, it's still a substantial target. M92's brightest members are magnitude 12.1, only two-tenths dimmer than those of M13. Even so, all the little differences add up. Those dimmer, smaller aspects pose a challenge for my 4¼-inch when it comes to resolving M92 into stars. Moreover, the core of the cluster is extremely concentrated. It's a brilliant but singular mass. Maintaining sharp focus is crucial for teasing out any detail. A 9.8-magnitude star immediately east of M92 is handy for checking focus, though it's much less bright than the guardians of M13.

In my smaller scope at 93×, the globular's periphery is salted with very faint stars, but the strongly condensed interior resists resolution. In the 10-inch Dob, that compact core packs a punch since M92 is more strongly packed in the middle than M13. Even at 218×, the central region yields very few individual points, but the halo resolves nicely. The whole cluster is outlined by dim outliers that give the cluster a slightly squarish appearance. It's a pretty sight.

## Faint Fuzzy

The last — and admittedly, least — of the Hercules globulars is 9.4-magnitude **NGC 6229**. This third entry is no prize-winner — but, hey, it's one that most casual observers don't even know about, so why not give it a try? Though relatively dim, the little fellow is easy to find. Well, sort of. You might be tempted to make a right-angle turn at M92 and head northwest for 7°, hoping you'll bump into NGC 6229. I tried that once — and veered way off-course.

I think it's wiser to retreat to M13. A line drawn from M13 through Eta Herculis, aimed 7° north-northeastward, passes less than 20′ west of a handy finderscope star: 4.8-magnitude 52 Hercules. A further 1.6° onward, the line runs a mere 10′ east of NGC 6229. The key part of the star-hop is 52 Hercules, which is plainly visible in any finderscope. I center that star in my telescope then, using a low-power eyepiece, carefully nudge my way the required extra distance to NGC 6229.

There's no hiding it: NGC 6229 is a wimp. It's almost three magnitudes dimmer than M92, and its diameter of 4.5′ is about three times smaller. The brightest stars of NGC 6229 are magnitude 15.5 and not visible in city-based scopes like mine. Still, the feeble fuzzball can at least be detected using backyard instruments. In my 4¼-inch at 54×, NGC 6229 appears much the way M92 looks in 10×50 binoculars. Viewed at 93× it now resembles M13 in the same binos. In my 10-inch at 200×, the cluster grows in size just enough to reveal a brightening towards the middle. I can't resolve any part of the cluster. Two 8th-magnitude stars lined up north-south immediately west of NGC 6229 aid high-power focusing.

Okay, you've seen what my scopes reveal. Give these light Labors a go. That strongman, Hercules, will thank you for it.

■ Contributing Editor **KEN HEWITT-WHITE** first sighted M13 in the summer of 1967 with his 4.5-inch Tasco reflector.

## Hercules Hits

| Object | Type | Mag(v) | Size/Sep | RA | Dec. |
|---|---|---|---|---|---|
| M13 | Globular cluster | 5.8 | 20.0′ | $16^h$ $41.7^m$ | +36° 28′ |
| Σ2104 | Double star | 7.5, 8.8 | 5.7″ | $16^h$ $48.7^m$ | +35° 56′ |
| Σ2101 | Double star | 7.5, 9.4 | 4.1″ | $16^h$ $45.8^m$ | +35° 38′ |
| Σ2097 | Double star | 9.4, 9.6 | 1.9″ | $16^h$ $44.8^m$ | +35° 44′ |
| M92 | Globular cluster | 6.5 | 14′ | $17^h$ $17.1^m$ | +43° 08′ |
| NGC 6229 | Globular cluster | 9.4 | 4.5′ | $16^h$ $47.0^m$ | +47° 32′ |

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

# Cool Neighbors

Help astronomers find challenging dim objects.

**BIG THINGS COME IN SMALL PACKAGES** Brown dwarfs may be small and dim, but they pack a punch when it comes to the information they provide on the evolutionary processes of both stars and exoplanets.



You may have heard the phrase "failed star." It's a term often bandied about for *brown dwarfs*, a class of object intermediate to planets and stars. But brown dwarfs represent much more than their moniker implies, as they hold clues to the evolutionary histories of both planets *and* stars.

**Cool Neighbors.** Brown dwarfs are much less massive than regular, main-sequence stars, weighing in at 1% to 8% the mass of the Sun. In planetary terms, that's around 10 to 80 Jupiters. They're not massive enough to sustain nuclear fusion in their cores (hence their nickname), but they do emanate a pale infrared glow thanks to residual heat from their formation process. All this means that they're generally cooler and smaller than regular stars, making these dim targets extremely challenging to find.

Nevertheless, astronomers persist at seeking them out for a variety of reasons. One is that brown dwarfs can give us insights into exoplanets. Their atmospheres exhibit signatures of water and methane, compounds that are also present in gas-giant exoplanets. But there's one rather vexing feature of exoplanets: They orbit blindingly bright host stars. Brown dwarfs, on the other hand, often wander through space alone, their feeble light not drowned out by a companion. So, by studying the chemical composition of large numbers of brown dwarfs, researchers may gain insight into exoplanets. (See *S&T:* Mar. 2022, p. 34.)

Astronomers identified the first brown dwarf in the 1990s and have subsequently found a few thousand, but there should be many more lurking out there. Space missions — such as NASA's Wide-field Infrared Survey Explorer (WISE), which received a second lease on life as the near-Earth object hunter NEOWISE — are spewing out reams of data that may contain the imprints of these elusive targets. Professional astronomers are turning to you for help mining this mother lode via a Zooniverse project called Backyard Worlds: Cool Neighbors.

**From the comfort of your desk.** Because brown dwarfs are so dim, the only ones we have hopes of detecting are those that are relatively close to our solar system. Their apparent motion in space should stand out against the more distant background stars (see, e.g., *S&T:* Dec. 2023, p. 74). So to find them, you can employ the same technique that Clyde Tombaugh used to discover Pluto in 1930: Compare images of the same field of sky taken at different times and see if anything moved.

Getting involved is easy: Head to the project homepage (**https://is.gd/cool_neighbors**), click on the "Classify" button at top right, and you're good to go! (Do also take a look at their tutorial, though, for helpful tips.) Amateur Dan Caselden, co-investigator of Cool Neighbors, says, "It's a simple yes-or-no process — either you see something move, in which case you hit YES, or you don't, and you hit NO."

What happens if you think you stumble upon what's known in the lingo as a *mover*? First thing to do is to crosscheck with SIMBAD (**https://is.gd/astro_simbad**), the go-to database for professional and amateur astronomers alike. If you find your target listed, move on to the next field in the project. If your target *isn't* listed, upload your info — and get excited. (But not too excited: The research team has to verify that your finding is indeed a brown dwarf and not an artifact.) Don't despair if you don't find anything the first few tries — or even tens of tries. Cool Neighbors' excellent FAQ page notes that it takes about 60 tries to spot a *known* object and a wee while longer for something unknown.

Caselden himself has reported hundreds of discoveries, some still awaiting confirmation. He urges you to give it a try: "You'll be working with a lovely and inspiring community, and you'll contribute directly to science." He would know: Caselden won this year's AAS Chambliss Amateur Achievement Award thanks to his work with Backyard Worlds.

■ Observing Editor **DIANA HANNIKAINEN** is delighted brown dwarfs are getting the attention they deserve.


### ▲ SOLAR WEDGE

Starfield Optics announces a solar-observing accessory for refracting telescopes up to 4 inches in aperture. The Starfield 1.25″ Solar Wedge (CAN$280.45) uses a prism to divert a small percentage of sunlight to the eyepiece, while heat-absorbing materials disperse the diverted solar energy from the back of the unit. The wedge replaces the star diagonal in your refractor's 1¼-inch focuser and secures your eyepieces with a non-marring compression ring. Its anti-reflection-coated prism has a clear aperture of 26.5 mm, which will fully illuminate any 1¼-inch eyepiece. The wedge incorporates a built-in, circular-polarizing filter positioned below the eyepiece, with an adjustment arm that lets you quickly dial in a comfortable brightness level. The focuser includes M42 threads, allowing users to connect cameras with T-thread adapters.

**Starfield Optics**
670 Hardwick Rd., Unit 5, Bolton, Ontario, Canada L7E5R5
store.starfieldoptics.com

### ▲ CONTROL CENTER

Chinese manufacturer ToupTek introduces a smart Wi-Fi controller for astrophotographers. The ToupTek AstroStation Wi-Fi Smartphone Controller for Photography ($399) lets you power and control your DSLR or astronomy camera, autoguider, and Go To mount with your smart device. The AstroStation is a mini-computer with expandable storage housed in a CNC-machined casing that attaches directly to your telescope or mount. It includes four female 5.5 × 2.1-mm 12-volt DC outputs, two USB 2.0 and two USB 3.0 ports as well as an ethernet port to connect and power all your imaging equipment without the need for a bulky laptop computer. The unit connects to your smart device via a dual-network 2.4G and 5G Wi-Fi antenna and is controlled with the free *AstroStation* app for Android or iOS. Images are saved on a user-provided SD card, which can then be offloaded via a USB-C connection.

**ToupTek**
touptek-astro.com

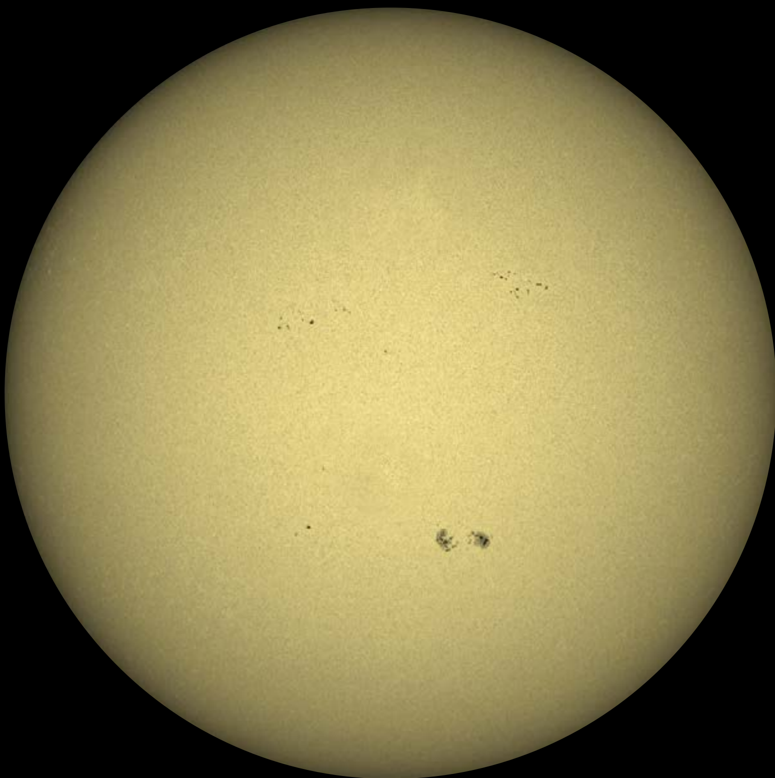

### ◀ STURDY MOUNT

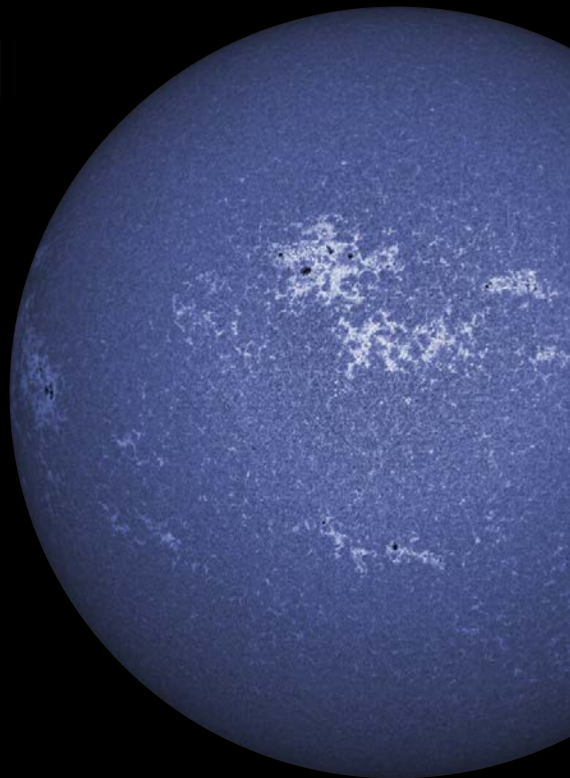
ZWO now offers a small telescope mount for travelling astrophotographers. The AM3 Harmonic Equatorial Mount (starting at $1,499) features strain-wave gear drives in both axes, with a periodic error of ±15 arcseconds. The mount weighs just 3.9 kilograms (8.6 pounds) yet boasts a load capacity of 8 kg without counterweights, and 13 kg after installing an optional counterweight and shaft. The mount operates in both equatorial and alt-azimuth modes from any latitude. It is controlled with a joystick and is plug-and-play compatible with the company's ASIair telescope control computers thanks to its several interfaces including USB, Wi-Fi, and Bluetooth. The AM3 accepts standard ST-4 autoguider commands to produce sub-arcsecond guiding, and its dual-compatibility saddle plate accepts both Vixen- and Losmandy-style dovetails. Base model includes a joystick controller and a DC power cable, and it requires 12V DC power at 5 amps.

**ZWO**
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: 0-51265923102; zwoastro.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.org. Not all announcements can be listed.*

# Solar Image Processing





ALL IMAGES COURTESY OF THE AUTHOR

**Use these helpful tips to make your Sun images shine.**

April's total solar eclipse drew the attention of many observers, turning many of us into solar imagers, at least temporarily. And though the big event has come and gone, it's still a great time to continue the focus on our nearest star. The peak of the 11-year solar cycle is due to occur this year, with numerous sunspots, active regions, prominences, and flaring events that make the Sun such an exciting target.

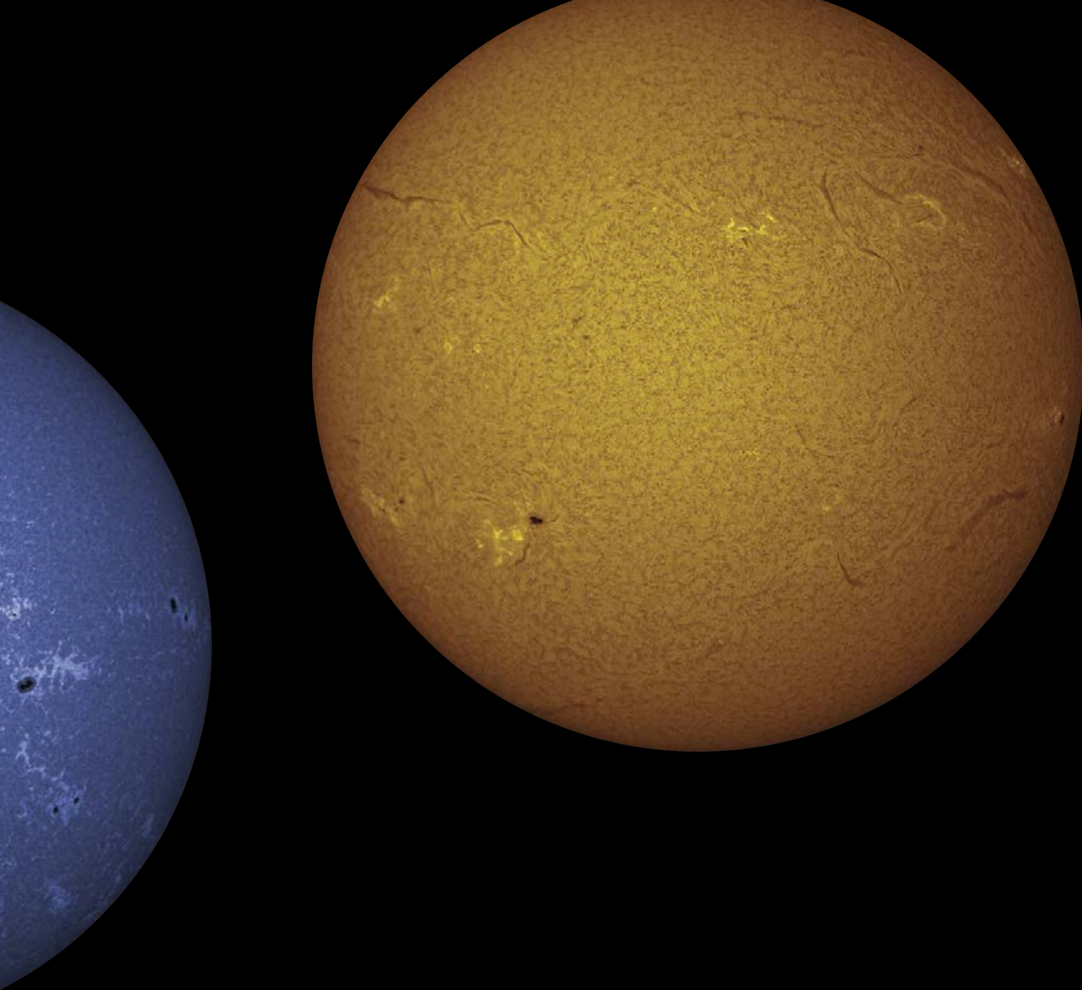
The Sun is a continually churning ball of plasma, and its appearance can change dramatically day to day and even within minutes. Solar imaging is pretty easy, and unlike deep-sky photography, it can only be accomplished during daylight hours, so you won't lose sleep recording solar photons. But like all forms of astrophotography, capturing the Sun requires special considerations during the processing stage in order to produce the best images with your particular gear.

Here are some of the techniques I use to get the most of my solar imagery through a variety of filters.

## Which Wavelengths to Shoot

The Sun transmits across many wavelengths, but the three most accessible to amateurs are white light, calcium K (Ca-K), and hydrogen alpha (Hα).

White light encompasses the entire visible spectrum from about 380 to 750 nanometers. You only need a simple solar filter that reduces the Sun's brightness to a safe level in order to see the *photosphere*, where sunspots, faculae, and solar granulation are visible (see the May issue, page 52). The Ca-K filter passes light near the ultraviolet end of the spectrum at 393.4 nanometers, where one of the two strong absorption lines of calcium are found in the solar spectrum (the K and H lines). This filter reveals part of the *chromosphere*, a region of the solar atmosphere just above the photosphere, and displays large areas of supergranulation. Prominences are also faintly visible in Ca-K. The third region of the solar spectrum of interest to imagers is the Hα line centered at 656.28 nanometers, and it is



**SOLAR ATMOSPHERE** Photographing the Sun is an exciting and rewarding experience. Author Chris Schur shares many of the techniques he uses to produce colorful, detailed images at white-light (far left), calcium-K (middle), and hydrogen-alpha (Hα) wavelengths (near left).

perhaps the most exciting. In Hα you'll see bright prominences, active regions, flares, and spicules. Such a filter also shows the chromosphere but at a higher level where the most action occurs.

## Stacking and Pre-processing

Regardless of which wavelengths you choose to image, the capture techniques are the same: Avoid overexposure, focus carefully, and record multiple frames to combine later with software. The Sun is so bright that you can image it without tracking, though having the scope follow it allows for longer captures. This is particularly necessary under poor seeing conditions, when you'll need longer videos in order to acquire enough sharp frames for stacking. A monochrome camera is preferable since the Sun is essentially monochrome through each of the aforementioned filters — the Ca-K and Hα only transmit in very narrow slivers of the blue and red spectrum.

Once you have your images or videos, you'll then need to stack the results to ensure a smooth image with a high signal-to-noise ratio before performing any sharpening or contrast adjustments. Until recently, solar imagers usually stacked images with a freeware program called *Registax* (**astronomie.be/registax**) and then enhanced them with the program's wavelet sharpening function. These days there are several superior options. My preferred stacking program is *Autostakkert!* (**autostakkert.com**), the use of which is well documented in the November 2022 issue, page 59.


**GAMMA CURVE** Unprocessed solar images typically appear low-contrast and require setting both the black point and mid-tone contrast. This is easy to do in *Adobe Photoshop* using the ***Curves*** tool. Set the black point by moving the bottom-left point of the curve to the right until just before it meets the rise in the histogram (left). Increase the mid-tone contrast by picking a point in the middle of the curve (seen at right) and pulling it down slightly.

So how many frames should you stack? This has always been a hot topic of discussion. A common rule of thumb used to be to stack the best 25% to 50% of frames to make the raw image for later sharpening. This methodology came about from the early days of using inexpensive webcams. These cameras had fairly noisy CCD sensors that required stacking many frames in order to achieve a satisfactory signal-to-noise ratio. Today, state-of-the-art CMOS video cameras used for planetary imaging have excellent sensitivity and noise characteristics. The old rules simply do not apply anymore. In many cases, the more frames you stack, the blurrier the image becomes because you're simply adding bad frames. Personally, I stack no more than 50 of the typically 2,400 frames per video I record.

Before processing your picture, it's important to consider the final target audience. The steps you take and the final appearance of the resulting images may be quite different depending on the requirements of the intended recipient. For example, if your primary goal is to submit images to organizations such as the Association of Lunar and Planetary Observers (ALPO), a crisp black-and-white image is mandatory. However, most of us prefer to share our pictures online with friends and family or present them on popular websites like Astronomy Picture of the Day (**apod.nasa.gov/apod/astropix.html**) that tend to favor colorful imagery. Some magazines also generally prefer color, but it's advisable to keep the saturation low in order to stay within the more limited color gamut of the high-volume printer's inks.

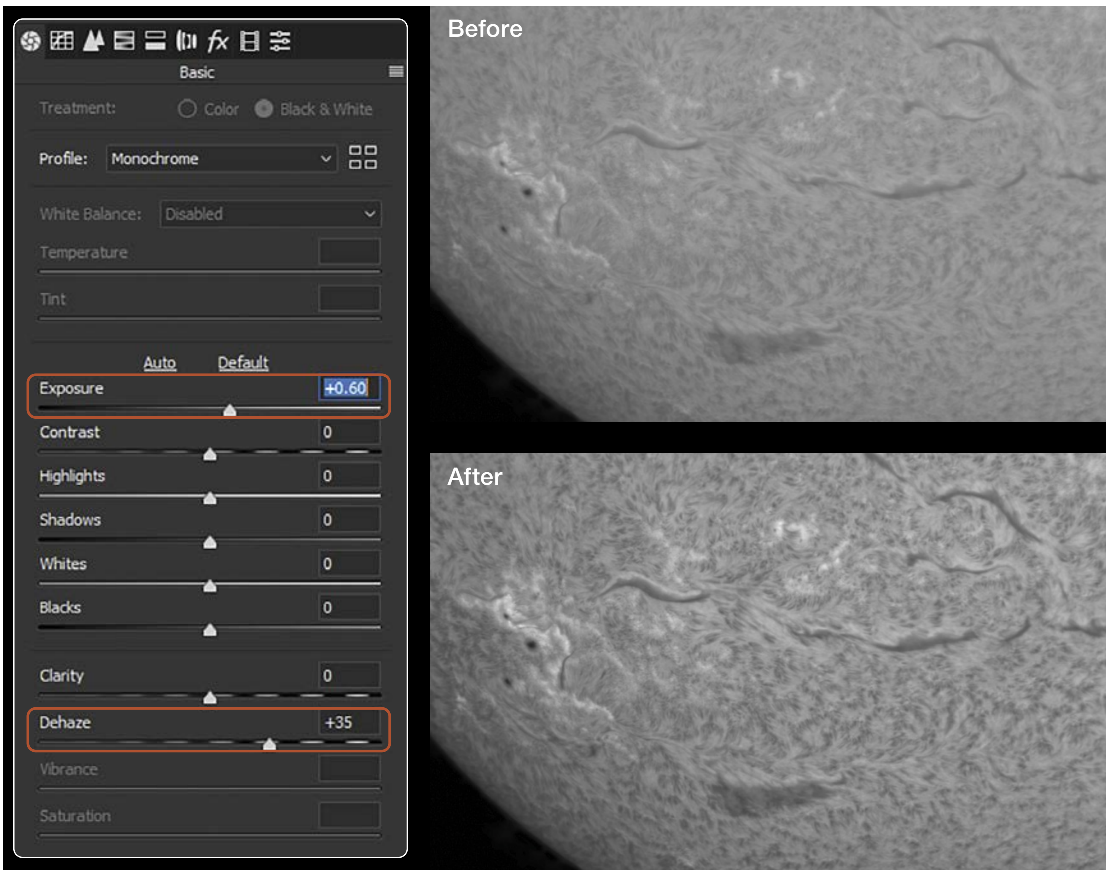
## Beginning the Workflow

The same general processing techniques are the same no matter the type of solar filter used. Once you've determined your audience and created raw images ready for enhancement, there are several programs you can employ to get the most out of your data. I use *Adobe Photoshop* (**adobe.com**), *PixInsight* (**pixinsight.com**), *Images Plus* (**mlunsold.com**), and *Maxim DL* (**diffractionlimited.com**). Most of these programs have a lot of overlap and can perform the same processes, though some do certain tasks better than others. I often bounce among *Photoshop*, *PixInsight*, and *MaximDL*, and then return to *Photoshop* for the final tweaks before declaring an image to be complete.

An important first step if you use a solar telescope with a built-in diagonal mirror (found in many Coronado and Lunt scopes) is to correct your image so that it's not mirror-reversed. This is important because you'll want your images to be directly comparable to others, particularly if you're concentrating on a small region of the solar disk. In *Photoshop*, the steps are: ***Image > Image Rotation > Flip Canvas Horizontal***.

Depending on the camera settings you used, you may need to set the black point and gamma, or midtone. Each is adjustable with the Curve tool located within the ***Camera Raw Filter*** in *Photoshop* (***Filter > Camera Raw Filter***). Nearly all the fine details on the Sun are in the midtones, so pull the middle of the curve downward to boost midtone contrast or pull upward in order to reduce image contrast. Typically, you want to slightly boost the contrast at this stage, so decreasing midtones a bit will greatly benefit the next steps of processing. Before hitting the ***OK*** button, set the black point in the image by moving the lower-left end of the curve slightly toward the right.

There are several excellent enhancement tools found within the ***Camera Raw Filter***. Among my favorites is ***Dehaze***, located in the ***Effects*** section seen along the right of the filter window. This is an almost magic adjustment that

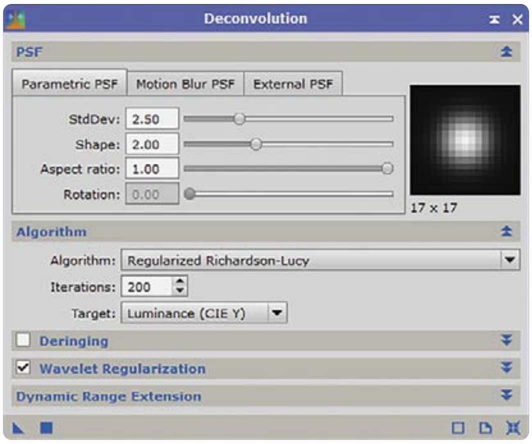



▶ **RAW CONTROLS** *Adobe Camera Raw* contains many tools to improve your solar images. The ***Exposure*** slider increases the brightness in your image much like increasing the gain or ISO in your camera. The ***Dehaze*** slider is designed to reduce haze in landscape photos but works well to increase the contrast in the mid-range values.

can make or break your solar images! ***Dehaze*** uses artificial intelligence to judge where to apply local contrast and was designed to only target areas of low contrast while avoiding highlight regions. The filter is normally used to remove atmospheric haze from landscape pictures, making it the perfect filter for solar processing since (with the exception of sunspots) most features on the Sun's face are fairly low-contrast. I prefer to increase the ***Dehaze*** setting to between +25 and +50 to boost granulation or filaments visible across the solar disk in Hα. So dramatic will be the change that it's tempting to go overboard. When you're just starting out, I suggest limiting to around +25.

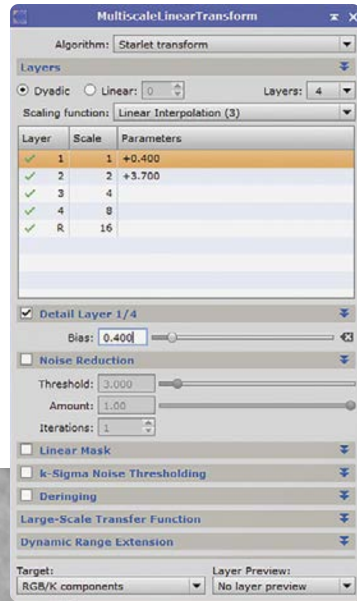
## Deconvolution and Wavelets

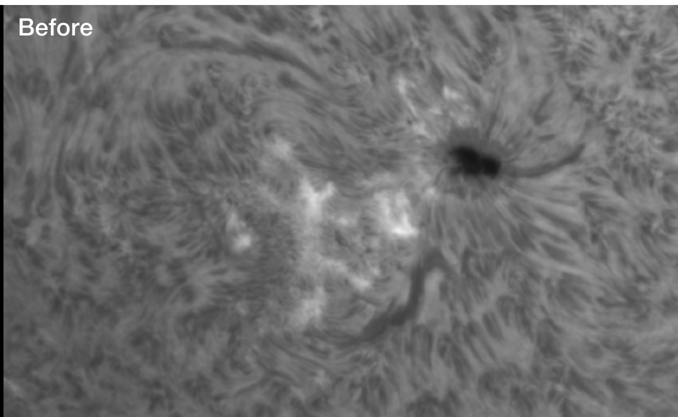
At this point I save the image before moving it into a program that contains a deconvolution- or wavelet-restoration filter. There are two paths here, depending on the quality and general look I want in the final result. Solar images tend to be taken under fair to poor seeing conditions because the daytime Sun heats the ground, producing turbulence that blurs the view. You can recover seeing-softened details by using either Richardson-Lucy deconvolution or a wavelet algorithm. Note that these tools aren't sharpening filters. The filters in *Photoshop* like ***Unsharp Mask***, ***Sharpen***, and ***Edge Enhance*** increase noise and are far less effective at recovering blurred

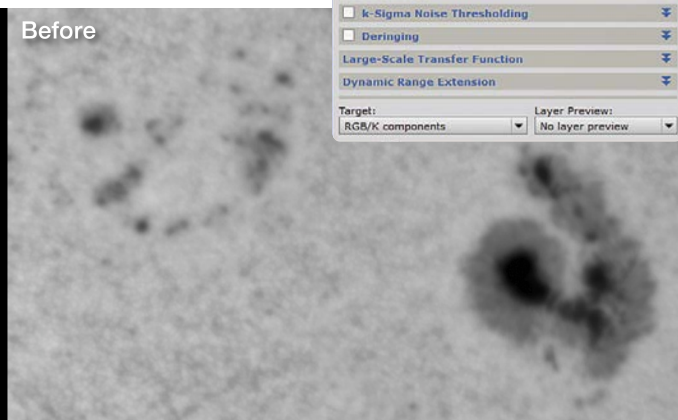


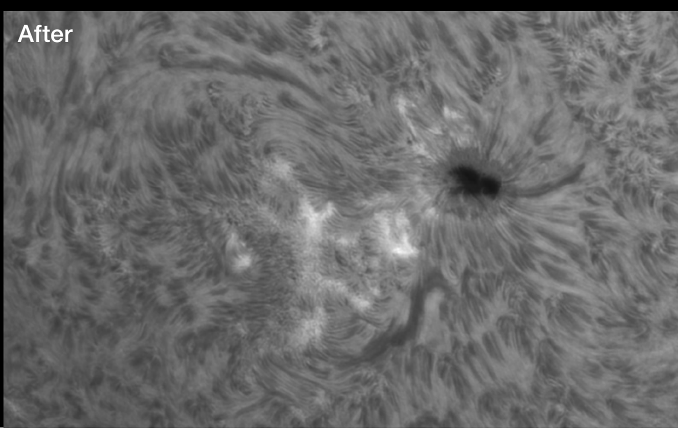

◀ **RETRIEVING DETAIL** Unlike most sharpening tools, deconvolution uses a process called the *point spread function* (PSF) to recover blurred detail. By using the ***Deconvolution*** process in *PixInsight*, the author was able to improve many small-scale details in the Hα close-up seen in the bottom-left image.

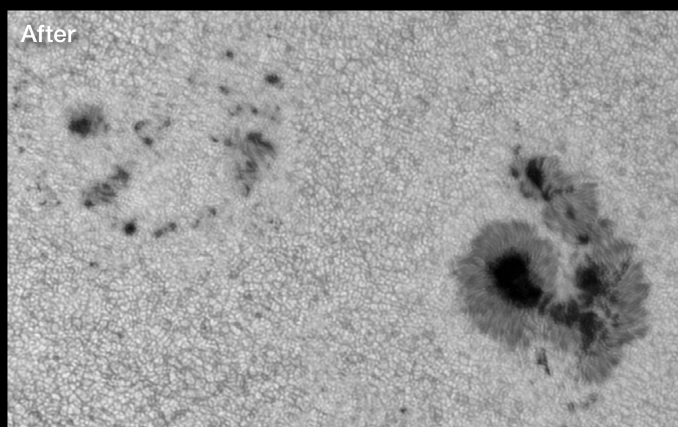
▶ **PIXINSIGHT WAVELETS** Wavelets can also bring out a staggering amount of detail in your solar pictures. This white-light photo (below right) appears soft and blurry, but after applying two levels of ***Wavelets*** in *PixInsight* (bottom right), granulation surrounding several sunspot groups come into sharp focus.



detail than true deconvolution and wavelet filters.

Most astronomical image-processing software includes some form of deconvolution. These processes use small, iterative steps to restore detail by setting the *point spread function* (PSF), an estimate of the blur radius, and limiting the number of iterations it performs. In *PixInsight*, I usually use the ***Regularized Richardson-Lucy*** deconvolution (found in the pulldown menu ***Process*** > ***Deconvolution***) and set the ***StdDev*** to around 1 when processing full-disk shots, and to 2 or more for close-ups, with iterations set to anywhere from 10 to 200. Experiment to find what works best.

Wavelet algorithms work in a very different way from deconvolution. Wavelets increase what is called the high frequency "bias" — how visible the fine details are by superimposing these details directly onto the original image. I prefer the wavelet function in *PixInsight* over those available in *MaxIm DL* and *RegiStax*. It's found through the dropdown menu ***Process*** > ***Wavelets*** > ***MultiscaleLinearTransform***. If you're working on a full-disk image, click on ***Layer 1*** in the tool window and then adjust the ***Detail Layer ¼ Bias*** slider up slightly, say, to 0.4. Now drag the caret in the bottom left of the window onto your image to activate the process. If you're working on a high-magnification close-up, click on ***Layer 2*** and raise its parameter slightly higher to about 2, and then apply this to your image. I rarely activate both layers on the same close-up field.

If you don't have *PixInsight*, the wavelets in *RegiStax* are still quite serviceable. Move the top two sliders to the right to enhance the small-scale details in your photo. It's like magic watching how much hidden detail these tools can reveal! However, there can be too much of a good thing. Stop increasing the levels of the wavelet sliders when either the noise becomes objectionable or the details start to have a bright outline. When you're satisfied with the result, be sure to save your changes.

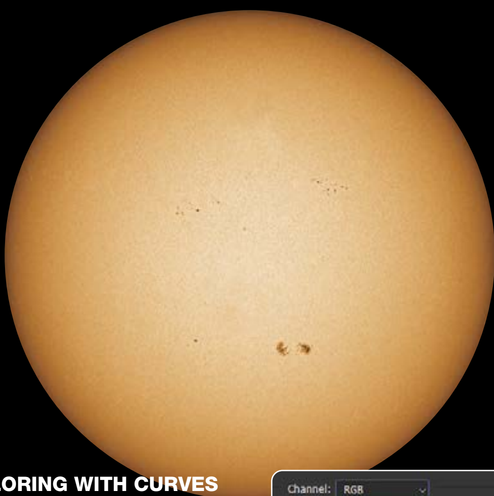
Deconvolution often raises the black level of an image, so reopen the picture in *Photoshop* and use the levels tool (***Image*** > ***Adjustments*** > ***Levels***) to readjust black level if needed (the left end of the histogram). While you have the tool open, you can adjust the overall brightness by moving the right slider to the left. Be careful not to clip the brightest areas — stop a little before the left end of the histogram. At this point, the monochrome version of the image is complete.

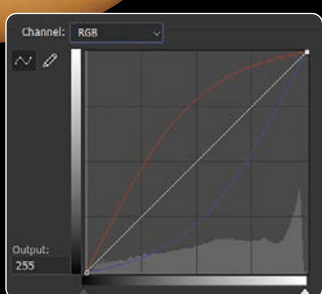
If you're assembling a high-magnification mosaic from a set of processed panels, *Photoshop* can automate the process. Select ***File*** > ***Automate*** > ***Photomerge***. In the command window, click the ***Browse*** button, select the panels you're stitching, then choose ***Reposition*** from the options in the left of the window. In a few moments, you'll have your assembled mosaic ready.

## Introducing Color

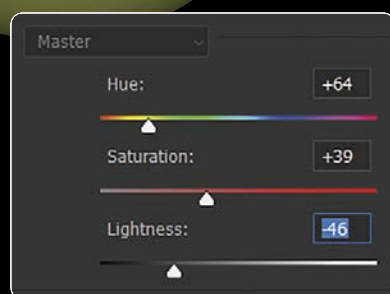
You now have an excellent black-and-white image of the Sun. Endowing your solar portrait with fiery reds, oranges, or electric blues and violets will garner more attention.

An easy way to colorize your pictures in *Photoshop* is to






▲ **COLORING WITH CURVES** The Sun is essentially colorless, so imagers typically photograph it with monochrome cameras and add color to the final result. One easy method is to open the ***Curves*** tool (right) in *Adobe Photoshop* and adjust the red, green, and blue channels separately to achieve the desired result, like the result seen above.




▲ **SELECTING HUE** Another easy technique for adding color to your monochrome images is to use *Photoshop's* ***Hue/Saturation*** tool. Simply move the slider until it's positioned below the color you want your image to appear and increase the saturation slider as desired.

first convert the grayscale image to RGB by selecting ***Image* > *Mode* > *RGB*** from the dropdown menu. Next, open the Curves tool (***Image* > *Adjustments* > *Curves***), select Red in the ***Channel*** section, and pull up on the center of the curve, but don't hit ***OK*** yet. Select Blue in the ***Channel*** section and pull down from the center point about the same amount. The green channel can be adjusted slightly if necessary to get more of an orange shade. You'll need to experiment here, but once you're satisfied with the coloration, the curve can be saved on disk for future use on other images by clicking the gear icon and selecting ***Save Preset***.

An alternate method for colorizing your picture is to open the Hue/Saturation tool (***Image* > *Adjustments* > *Hue/Saturation***) and select the ***Colorize*** checkbox. Move the ***Hue*** slider to the desired color shade and increase the ***Saturation*** slightly. Although you can tint your image any way you'd like, I personally prefer my images to resemble the wavelengths captured. So, I typically colorize my Hα as orange and my Ca-K pictures with a blue hue.

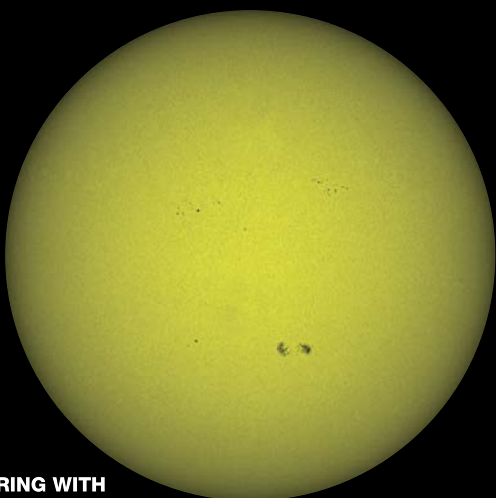
An additional method for colorizing your image in *Photoshop* is to use the ***Color Picker*** tool located at the bottom of the tools palette (the overlapping squares). Click on the top (foreground) box and select the color you want to colorize your image with. Next, open the Layers window (***Window* > *Layers***) and add a new, blank layer to the image (***Layer* > *New* > *Layer***). Click on this new layer and select everything in the window (***Select* > *All***) and then click on the paint bucket tool in the tool palette and click on your image. The new layer will be filled with that color, hiding your image. Now simply change the Layer Blending Mode in the Layer window from ***Normal*** to ***Darken***. Instantly your image is colorized with your chosen hue. Each of these methods produces a view very similar to observing the Sun through a colored filter.

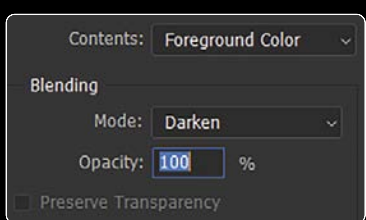
## Final Considerations

With your processed Sun images at hand, the last step is to prepare for submission, distribution, or posting. Typically, you can save your images in JPEG format with the quality set to maximum. Some publications and websites might prefer other formats such as PNG, which incorporates lossless compression. However, such files are much larger than JPGs and can take a long time to upload. Magazines and book publishers may also require that you send a full-resolution version of the image. If you're posting your image to social media or other online forums, it's best to shrink your photos to around 1,200 to 1,600 pixels wide, which shows plenty of detail without overspilling the screens of most of your audience.

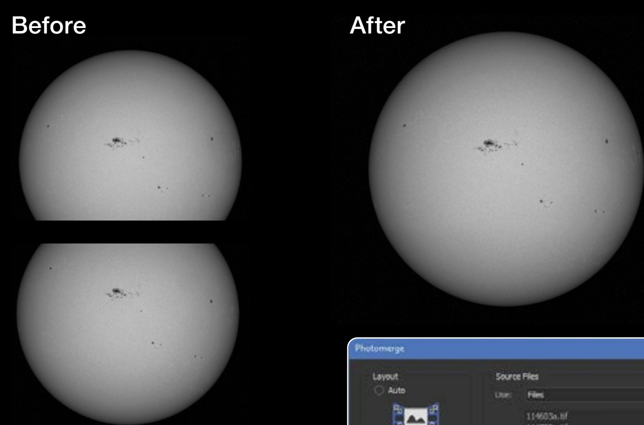
The Sun is an immensely rewarding target for imaging. Capturing the ephemeral beauty of the solar atmosphere presents unique challenges, but if you put some of these tips to use, you'll be able to make this solar maximum the most memorable you've experienced yet!

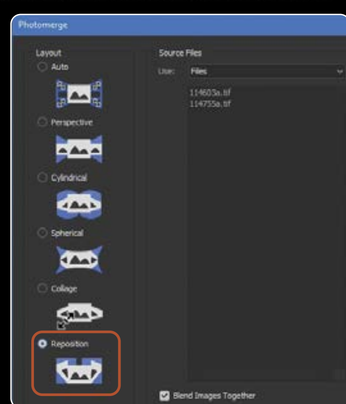
■ **CHRIS SCHUR** images the Sun in multiple wavelengths from the high mountain Ponderosa pine forests of northern Arizona.






▲ **COLORING WITH LAYERS** There are several easy methods for colorizing black-and-white images in *Photoshop*. This technique requires adding a new layer, filling it with the desired color, then changing the ***Blending*** to ***Darken*** to get the proper effect.




▲ **INSTANT MOSAICING** The ***Photomerge*** action in *Photoshop* makes quick work of assembling panels into a seamless result. Simply open the tool, browse to the desired segments to stitch, select ***Reposition***, and click ***OK***.

# Testing a Tiny New Smartscope

*The Dwarf II won't win any imaging awards, but users will have a lot of fun taking pictures with it.*

## Dwarf II

U.S. Price: $459; Deluxe: $595
dwarflab.com

### What We Like

Extremely compact

Produces good images under bright skies

Equatorial mode to reduce field rotation

### What We Don't Like

Small, noisy sensor

Software bugs

Tiny tripod

**WE'VE SEEN SEVERAL** innovative "smartscopes" introduced in the past few years. Right out of the box, these sleek new devices contain everything necessary to take images of the night sky. Until recently, most have cost thousands of dollars. The $459 Dwarf II from the Chinese startup DwarfLab represents a price breakthrough. (Its Dwarf I was a daytime telephoto lens.)

As a smartscope, in mere minutes the Dwarf II can be set up, aligned, and beam star-filled images of deep-sky objects to your phone or tablet. Indeed, that's just what I did on my first night out with it. I was impressed.

### The Dwarf Design

The Dwarf II looks more like a security camera than a telescope. It's no bigger than a typical hardcover book and weighs just 1.2 kilograms (2.6 pounds). The "classic" package includes a rechargeable lithium-ion battery, a 64-gigabyte microSD memory card, a padded carry case, and a tiny tripod. A deluxe version is available that also includes a spare battery, a UHC light-pollution filter, and a pair of solar filters (one for each of the two apertures) as well as a special magnetic filter-mounting bracket. What it doesn't include is a wall adapter and charging cable. The company notes they aren't provided in order to reduce electrical waste. The Dwarf II accepts USB-C cables and chargers with at least 8-watt output.

The Dwarf II's main "Telephoto" lens is of 24-mm aperture with a 100-mm focal length producing a focal ratio of f/4.2. Unique among smartscopes, the Dwarf II also incorporates a second, "Wide-Angle" lens with a focal length of 48 mm paired to a 2-megapixel sensor that produces a simultaneous finder-like view. Its 50° field, which appears in a separate window in the control app, is essential for locating daytime targets and for finding the Sun and Moon.

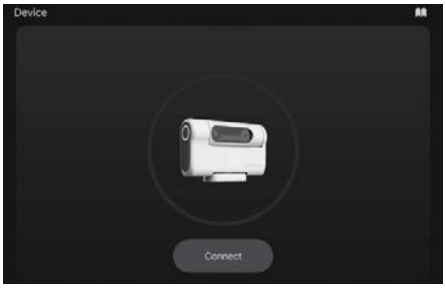
The telephoto lens is paired with an 8-megapixel Sony IMX415 Starvis color CMOS sensor. It has a GBRG Bayer-filter array over its 3,840-by-2,160 pixels in a 16:9 aspect ratio — a size called *4K* as per its video heritage. The sensor measures just 5.6 mm by 3.1 mm, with tiny 1.45-micron pixels, producing an image scale of 2.99 arcseconds-per-pixel.

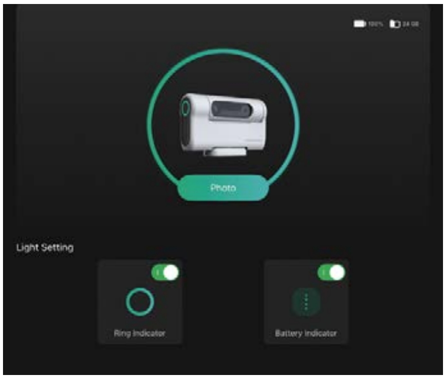
The resulting field of view is 3.3° by 1.8°, roughly equivalent to the field of a 620-mm lens paired with a full-frame camera. That's the widest native field of view of any smartscope, making it well-suited to large targets such as M31, the Andromeda Galaxy. Its sensor is oriented horizontally, so all images have the long dimension parallel to the

▲ The little Dwarf II smartscope is able to record enjoyable images of deep-sky objects even under bright, moonlit skies. *Inset:* This is the image of M13 the Dwarf II was capturing with the sky lit by a nearly full Moon.


▼ The Dwarf II deluxe package includes an extra battery and a filter kit, complete with a magnetic holder, two ND solar filters, and a UHC light-pollution filter. Only the tripod, case, one battery, and microSD card (with SD card adapter) are included with the basic package.

ALL IMAGES COURTESY OF THE AUTHOR





◀▲ Launching the *DWARFLAB* app presents you with the ***Connect*** page (top left). The Book icon at upper right of the screen goes to online help files, accessible only if your mobile device is not connected to the smartscope through its Wi-Fi. Once connected, the main page (left) allows shutting off the indicator lights. Tapping ***Photo*** takes you to the main shooting screen (above). There you have a choice of shooting modes and a virtual joystick. An inset screen shows the wide-angle finder view.

horizon. As with all smartscopes, users cannot rotate the camera to orient the field differently.

Controlling the Dwarf II requires the *DWARFLAB* app, free for Android and Apple iOS. (I did my testing using the Apple version.) The images it records are sent to the user's smartphone or tablet, and the stacked image as well as the individual subframes are saved to the onboard microSD memory card.

The Dwarf II has several different operational modes, including ***Photo Mode***, ***Video Mode***, ***Burst Mode***, ***Time-Lapse Mode***, ***Panorama Mode***, and ***Astro Mode***. In ***Astro Mode***, the Dwarf II records deep-sky targets at full resolution, producing 8-megapixel images, which is larger than most other smartscopes currently available provide. Users can also choose a binned 2K option, which electronically groups adjacent pixels into a 2×2 array, effectively doubling the pixel size to 2.9 microns. While this generates less noise and smaller file sizes, binning yields a coarse plate scale of 5.98 arcseconds per pixel and pictures having just 1,980 by 1,080 pixels.

While the Dwarf II tracks objects very well, like any alt-azimuth mount it suffers from field rotation as it follows celestial targets. This causes stars to trail in arcs around the field center over long exposures. To avoid this problem, the device records faint deep-sky objects by shooting dozens or hundreds of short-exposure subframes, limiting the maximum exposure to 15 seconds. Internal software automatically rotates, aligns, and stacks each subframe live on screen. It then saves its final, live-stacked image as a stretched, 16-bit FITS file to the microSD card.

The individual frames of a sequence can also be saved to the card, in the user's choice of TIFF or FITS format, as linear files (they look black). This allows advanced users to stack the subframes and process the result with their preferred image-processing software.

An individual FITS frame shot in 4K mode is 16.6 megabytes, while a final stacked file is about 50 Mb. A folder of 160 subframes (from 40 minutes of shooting in 4K mode), plus the stacked FITS file, amounts to about 2.7 gigabytes. So, the included 64-Gb memory

▲ *Left:* The Dwarf II has two lenses: a 50° wide-angle finder and 3° telephoto imaging lens. The compact form is made possible by a right-angle prism below the main lens that forms a periscope-like light path to the Sony sensor at the end of the altitude axis. *Middle:* The 5600mAh lithium battery is charged when installed in the device via a USB-C cable. The microSD memory card inserts into the slot covered by a rubber door. *Right:* The base has a standard ¼-20 threaded socket for mounting on any camera tripod.

card has plenty of space for several nights of shooting. The Dwarf II accepts microSD cards with up to 512 Gb of storage capacity.

## In the Field

I used the Dwarf II for an extended period throughout late 2023. The battery's life depended on the temperature. During winter at –20°C (–4°F), a full charge lasted for about two hours of shooting, but it lasted more than three hours on summer nights. If power runs low, you can plug the charger cable into an external USB power bank without interrupting a session.

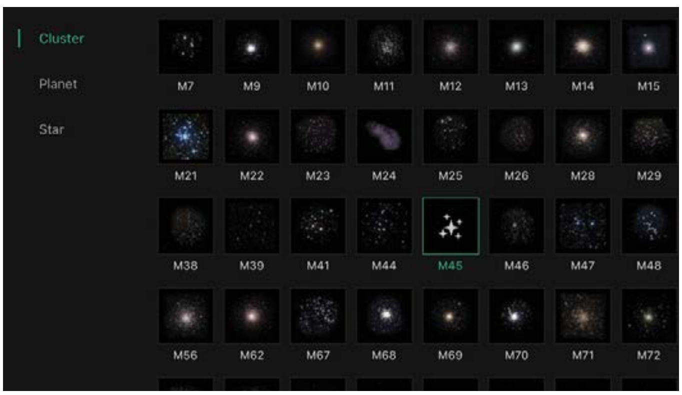
Dew formed on the telescope on a few summer nights, while frost was the issue in winter. However, the glass plate over the two lenses remained clear through all my test nights thanks to the device's internal heat, which helps ward off at least mild dew and frost. At the cost of shorter battery life, a ***CPU Mode*** option in the ***Advanced Settings*** of the app boosts the microprocessor's speed, which also generates additional internal heat.

As smart as it is, the Dwarf II cannot find the Sun or Moon on its own and has to be manually aimed at them using its wide-field finder view. Once they're in the field of the main lens, hitting ***Sun Track*** or ***Moon Track*** (available in any of the modes other than ***Astro***) keeps them nicely centered by tracking on their bright disks. And though it does a fine job on the Sun and Moon, it doesn't produce enough resolution to resolve the planets as anything more than featureless dots — this device is mainly suited to imaging deep-sky targets.

At night the Dwarf II finds planets or deep-sky targets automatically by the process of *plate solving* (taking a short exposure then analyzing the image to identify known star patterns). The device's small size and mass allow it to slew rapidly at 30° per second. Upon arriving at a target, it takes an image to determine where it's looking, then fine-tunes its position. All this takes only a few seconds and proved remarkably accurate, usually placing objects dead center on the sensor. Only targets directly overhead presented a problem to find and track, which is true of any alt-azimuth-mounted scope.

Before it can perform Go To slews, the Dwarf II must first be aligned to the sky, a process the app calls ***Calibration***. This is accomplished by first rotating the device by hand to line up two index marks located on the back. The front of the unit (the surface with the nameplate) must face the direction of the region of sky you want to explore. Then spin the cylindrical optics tube (again, it can be turned by hand) so the lenses are looking at an unobstructed area of sky. Not orienting the scope to the proper starting position can cause it to

▼ *Top left:* Objects can be selected from the ***Star Target*** screens. There is no indication which targets are above the horizon until you have tapped on one. *Top right:* In ***Astro Mode*** the ***Feature*** menu contains sub-menus, some partly hidden. Clicking ***Settings*** opens the camera control menu (upper left), where ***Shutter*** and ***Gain*** adjustments and the ***Infrared Cut*** options are found. *Bottom left:* Once the red shutter button is pressed, the Dwarf II begins recording and live stacking while displaying a running count of the number of frames shot and stacked. *Bottom right:* This is the final live-stacked image of the Pleiades, M45, consisting of 120, 15-second subframes with just the standard in-camera stretch applied.






hit its mechanical stops, resulting in a "Calibration Failure" message.

During calibration, the Dwarf II quickly takes three images from left to right spaced about 10° apart in azimuth. As long as it can see stars at each position, it will successfully calibrate and will be ready to slew to targets.

I tested calibration in twilight, moonlight, and on smoky summer nights, when I could see only the brightest stars. It worked just fine. The catch is that it can't calibrate unless it sees sharp stars. But to focus on a bright star, you have to first find one, yet without that initial calibration or with out-of-focus optics that's tough to do.

A helpful step is to initially focus the main optics during the day on a distant target or on the Sun (with the solar filters in place) using the ***Auto Focus*** button in the app. Once the optics are focused to infinity, they hold that position, even after the telescope is powered down, making calibration the next night quick and easy.

Once calibrated, I always slewed to a bright star to confirm exact focus before starting an imaging sequence. Checking the ***Auto Focus*** result with a Bahtinov mask, I found it accurate.

I tried Go To calibrations with the Dwarf II initially aimed south, but also east, west, and north, as users with restricted views of the sky might have to do. It worked fine, just as long

## The Promise and Perils of Smartscopes

Despite it being an entry-level telescope, the Dwarf II proved to be one of the most demanding products I've ever reviewed. It presents a multitude of options and modes of operation. And just when I had learned my way around the app, DwarfLab released a major update that changed everything!

Of course, one of the great benefits of integrated smartscopes is that their software *can* be updated easily, adding welcome new capabilities. But as I found with the Dwarf II, with new features can come new bugs.

To be fair, manufacturers have been good about fixing bugs. What they also do, for better or worse, is cater to advanced users who request yet more features, to give their entry-level scope the capabilities of a high-end astro-imaging rig. More choices sound wonderful, but they add more difficulty for beginners.

When mastered, smartscopes can work so well that, as avid fans proclaim, "They are the way all astronomy will be done in the future!"

I certainly hope not. We should always have the option to stand outside under the stars to just enjoy the view with our unaided eyes, through binoculars, or through a telescope eyepiece. By contrast, smartscopes allow us to distance ourselves from the sky even more, to spend yet more of our lives looking at screens and struggling with technology.

Those are some of the perils I see. Their promise is rewarding images captured with unprecedented ease and under increasingly light-polluted skies. Longtime amateur astronomers who want to try their hand at astrophotography, or who just want to simplify their imaging, will find smartscopes fun to use.

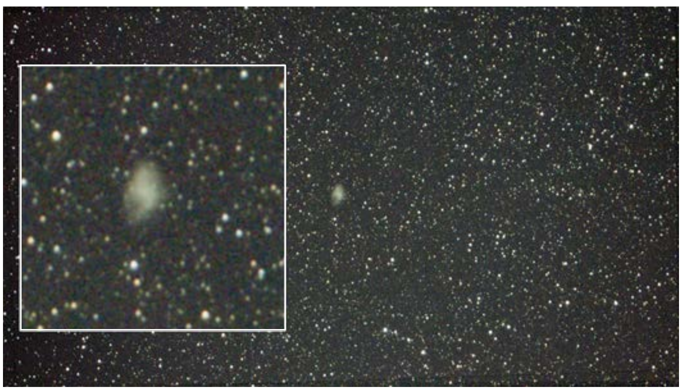
But it is newcomers who will benefit the most from a smartscope. Here at last are devices (in the case of the Dwarf II and its main competitor, ZWO's Seestar S50 reviewed in our March issue, p. 66) that can produce presentable images of the brighter deep-sky objects beginners want to capture, at a price many are willing to pay, and without the complexity of conventional gear.

Adults with children or grandchildren keen on stargazing might well consider a smartscope as a great gift. I can't imagine a starstruck child being anything but thrilled by their first images of the Moon or Andromeda Galaxy!

Astronomy clubs can make good use of these devices during outreach events. The phone or tablet's view of the app and incoming images can be cast to a smart TV. A group can watch as a presenter explains what they're looking at. Members of the audience can help choose targets.

Lastly, anyone with mobility challenges will be able to explore the sky with greater ease. Smartscopes can open up the hobby to many more people, a goal DwarfLab's designers told me they aspired to achieve with the Dwarf II. I know that's true of other smartscope manufacturers. I heartily applaud their success!

▼ These pictures compare images of the Crab Nebula, M1, shot at 2K resolution or 1,920 × 1,080 pixels (left) with a stack taken at 4K resolution, or 3,840 × 2,160 pixels (right). As seen in the insets, the 4K mode produces noticeably sharper images with smaller stars.



as it can see stars at each of its three calibration stops.

## App Control

As noted earlier, the Dwarf II is controlled by the *DWARFLAB* app. Upon launching the app, hitting ***Connect*** first links to the Dwarf II via Bluetooth, then asks to connect to its 5 GHz Wi-Fi hot spot. Once established, I found the Wi-Fi connection was usually reliable, working from up to 6 to 9 meters away (20 to 30 feet) and through one wall or glass doors.

The current version 2.1.0 of the app contains a database of 550 targets, including 68 stars, 52 nebulae, 98 galaxies, and 323 star clusters. While the latter category seems overly represented, it mistakenly contains quite a few objects that are actually nebulae.

Although the *DWARFLAB* app database contains no comets or asteroids, nor any means of adding them, users can enter the RA and declination coordinates of any targets. However, as of this writing, the app does not include an internal star atlas for visualizing where targets are located and that would allow users to "tap and go." (The company plans to add such an atlas in a future update.)

The lack of any "Tonight's Best" target list (as of early 2024) requires users to know the sky well enough to decide what to shoot among the hundreds of targets on offer. Having the app provide more information about objects would also make using the Dwarf II more educational and enhance its appeal for new astronomers.

The app offers options for adjusting the exposure time, sensor gain (the default setting of 80 proved good), how many subframes to shoot (up to the maximum of 999), and whether the internal infrared-blocking filter is engaged (***Cut***) or not (***Pass***). I found the latter setting best for most deep-sky objects. While these are all helpful settings for experienced imagers, the choices can be a source of confusion to new users.

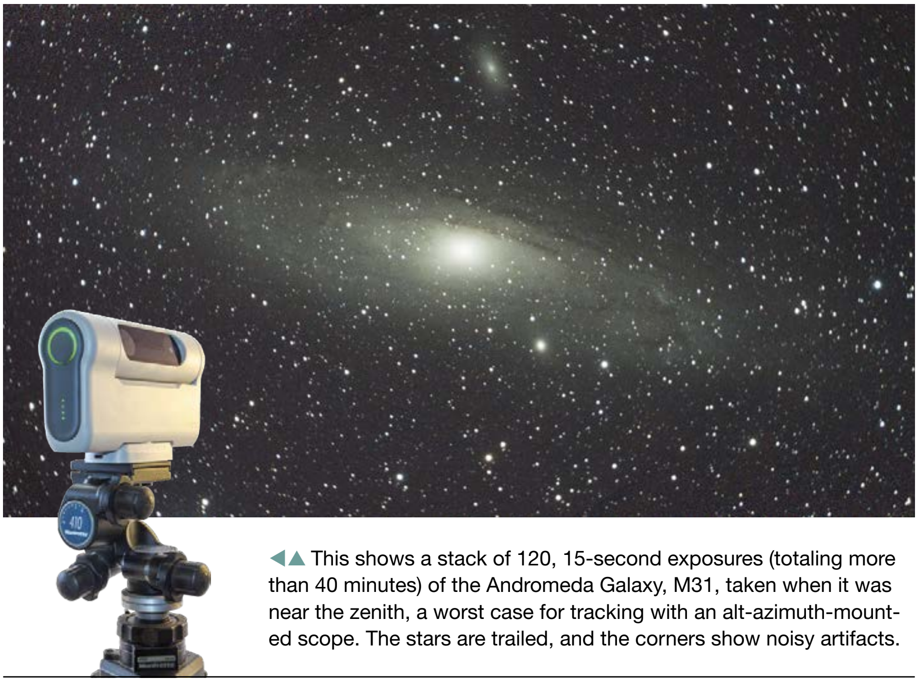
Most annoyingly, after completing a target the exposure time reverts to a default of one second (the shutter speed the device uses for plate solving when finding the next target). Other user settings, thankfully, remain in effect from target to target.

## Image Quality

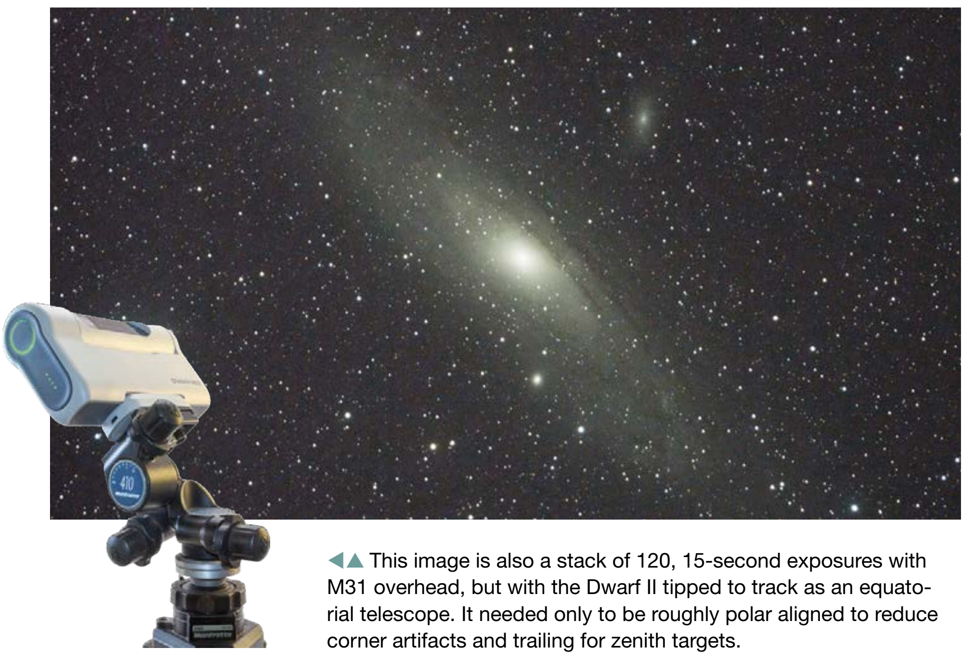
I tested the Dwarf II under rural skies, but often on nights with bright moonlight or with reduced transparency due to wildfire smoke. I was always pleasantly surprised by how much it could show even under poor conditions. City-bound users should be able to image bright deep-sky objects that would be hard to see visually.

However, even under clear, dark-sky conditions, I found the results to be noisy and star images soft due to lens aberrations. You can't expect great resolution from a one-inch lens, and an uncooled sensor with tiny pixels is bound to be noise-prone.

To mitigate the worst of the noise,



◀▲ This shows a stack of 120, 15-second exposures (totaling more than 40 minutes) of the Andromeda Galaxy, M31, taken when it was near the zenith, a worst case for tracking with an alt-azimuth-mounted scope. The stars are trailed, and the corners show noisy artifacts.



◀▲ This image is also a stack of 120, 15-second exposures with M31 overhead, but with the Dwarf II tipped to track as an equatorial telescope. It needed only to be roughly polar aligned to reduce corner artifacts and trailing for zenith targets.

the app rightly encourages users to take dark frames, to record the thermal noise that builds up during each exposure. A ***Darks*** routine does that automatically over 20 minutes, with the instructions advising the user to place the Dwarf II in its black bag and in a dark location. This needs to be performed only once, not each night.

The resulting dark-frame library (totaling 800 megabytes on the microSD card) contains a series of 15-second exposures over a range of sensor-gain levels at both 2K and 4K sizes. The appropriate darks (three are taken at each sensor setting) are then automatically subtracted from each incoming image with the matching gain setting. It's a basic level of image calibration, but without it you'll get a blizzard of colorful hot pixels in your image.

For electronically assisted astronomy (EAA), the Dwarf II provides presentable images after only a minute. But to acquire the best images to keep on file, the more exposures you stack the better. However, shooting more images introduces more field rotation. While the live-stacking routine aligns the images well, an increasing amount of the frame becomes unusable with longer exposures due to twisting artifacts at the corners, requiring ever more cropping of the already small image the system produces.

DwarfLab recently endorsed one solution to the field-rotation problem. While it was initially designed to be used in alt-azimuth mode, the little Dwarf II (unlike most other smartscopes, at least officially) can be tilted and polar aligned for use as an equatorially mounted telescope. While the app has no "equatorial mode" per se, the three-field calibration and Go To pointing work perfectly well with the Dwarf II polar aligned. Doing so allows longer stacks with minimal edge artifacts, even for targets crossing the zenith.

However, tipping the Dwarf II over equatorially requires bolting it to a solid tripod, ideally with a geared three-axis head. The included tabletop tripod and small ball head are adequate only for use in alt-azimuth orientation, and only then if set on a solid table or on the ground when there's no wind.

You can download the stacked, final image from the *DWARFLAB* app to your mobile device's photo gallery as a JPG, for basic processing and sharing on social media. For most users that will be sufficiently satisfying.

However, the individual FITS files allow you to pursue more advanced processing. A favorite program among ambitious Dwarf II owners is *Siril* (**siril.org**), which is free for MacOS and Windows but comes with a steep learning curve.

◀ The result of M42 seen at left was stacked in-camera and looks presentable. At lower left, the author stacked and processed the separate FITS files with *Siril*, then finished by adjusting the image with *Adobe Photoshop*.

From the images I shot, and the best examples posted by other users, I think it's fair to say that even with advanced processing, images will always suffer from either noise or a loss of detail due to aggressive noise reduction. But it's worth remembering that getting award-winning images is not the goal of a small smartscope like this.

## Bottom Line

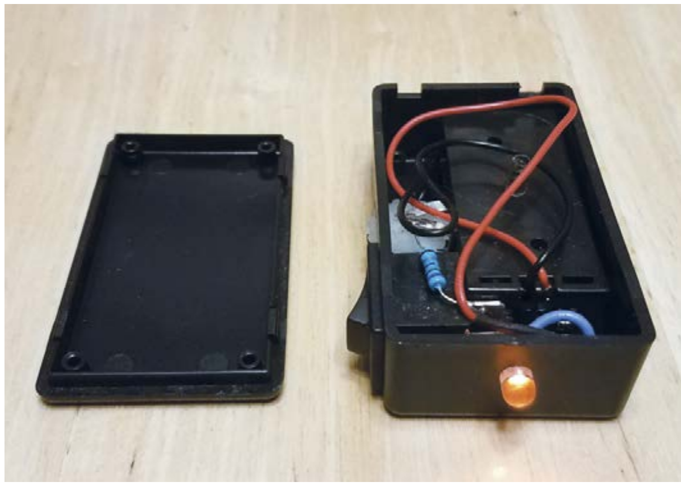
If the Dwarf II cost the same as a conventional astrophoto rig or high-end smartscope, I'd be much more critical. But for its price it provides great value for anyone, young or old, getting into deep-sky imaging or into the hobby, period. I had a lot of fun with it. I think others will, too.

■ Contributing Editor **ALAN DYER** is co-author of *The Backyard Astronomer's Guide*. He can be reached through his website at **amazingsky.com**.

▼▶ The filtered Sun is seen at right with both the main and smaller finder lenses, using the solar filters in place over both lenses as seen below. In either ***Photo*** or ***Video*** modes, hitting ***Sun Track*** initiates tracking good enough to keep the Sun centered for an hour or more.

# Give Amber a Try

*Preserve your night vision with a better flashlight.*



▲ *Left:* Here are all the components for the flashlight: the project box, the battery holder, a 1K pot, a 75-ohm fixed resistor, a rocker switch, and a bright amber LED. Note the holes cut in the box to accommodate the switch and the potentiometer. *Right:* The components made a tight fit. The battery holder worked best upside down, so I crafted a little handle to lift it out when the batteries need replacing, which won't be often. I figure it'll take about 250 hours of use at half brightness.

**MOST AMATEUR ASTRONOMERS** use red flashlights to preserve their night vision. One of my very first columns (*S&T:* July 2016, p. 72) was about making your own variable-intensity red flashlight, but that project was already obsolete by the time my column came out, because in the preceding issue was an excellent article by Robert Dick explaining why amber was a better choice than red (*S&T:* June 2016, p. 22). The cone cells in our eyes are much more sensitive to amber than to red light, so we don't need as much of it to illuminate charts, eyepiece barrels, etc. The result is less overall intensity to wash out the rod cells responsible for night vision.

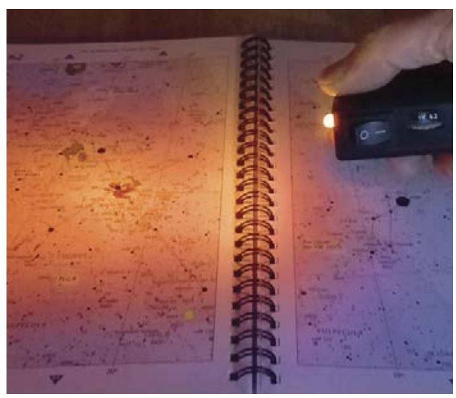
You can buy amber flashlights, but they all tend to be too bright. What we need is a variable-intensity amber light that dims down enough to be useful to fully dark-adapted eyes. So I set out to make one.

The biggest problem I encounter when making a flashlight is figuring out what to put the electronics in. My first red one used the handle of an old battery-operated fan, and my second one was just a potentiometer stuck to the outside of a cheap LED flashlight, but this time I wanted something a little more elegant. I needed a box that would let me arrange the components in an orderly fashion yet would look at least reasonably decent when finished.

Fortunately, "project boxes" are made for exactly this sort of thing, and there are a bewildering variety of them available at electronics stores, hobby shops, and online. They're made of ABS plastic, so they're easy to drill, file, glue, and screw into.

I measured the components I intended to use and came up with a layout that would require roughly 2.75″ by 1.5″ by 1″ (70 mm by 38 mm by 25 mm) of interior space. So I ordered a box that was advertised as 2.83″ by 1.65″ by 0.91″ outside dimensions. That was almost too small! I made it work, but it was tight. If you try this, you might want to give yourself a little more wiggle room. (But bear in mind that you don't want it too big or you can't hold it in your teeth, a must for a truly useful astro-flashlight!)

The components are simple: a battery holder for two AAA batteries, a 1- or 2-kilohm variable resistor (called a potentiometer or just a "pot"), a 75-ohm fixed resistor, a switch, and a



▶ The switch and brightness control are positioned in convenient spots to reach with a thumb. The light doesn't look like much by day, but it's plenty bright at night . . . and can be dimmed down to whatever level you want.

ALL IMAGES COURTESY OF THE AUTHOR

bright amber LED. I've collected a ton of random electrical parts over the years, so I just went with stuff I had on hand: a 1K ohm Linear Piher thumb-wheel pot, a simple on/off rocker switch, a half-watt resistor (overkill), and a 9,000 millicandela amber LED (probably overkill as well).

The pot is the dimmer, and the 75-ohm resistor limits the current. If the pot's resistance goes to zero on one end of its range, the AAA batteries can deliver more than the LED's safe current of 20 milliamps, so you need to add some resistance in series with the LED. A little experimentation showed me that 75 ohms kept the current to about 12 milliamps, which made the LED plenty bright but was well within safe range.

Everything gets wired in series. You can arrange the components in any order so long as they make an electrical loop. Make sure you test the circuit first to confirm you've got the polarity right going to the LED (the long leg is positive) and have the pot's action increase brightness in the direction you find natural. (For me, I roll the thumbwheel forward to make it brighter.)

Figure out how everything is going to fit, then start cutting holes in the project box. To make the rectangular slots, I drilled small holes inside the lines, then cut between the holes with a box knife and filed the edges smooth. For the pot, I angled the edges of the hole to accommodate its curved barrel and cut notches for the thumbwheel. I scuffed up the inside of the box and glued the pot into place with Shoe Goo (making sure not to glue the thumb-wheel!). The switch snaps into place. The LED just wedges into a hole drilled a smidgen tight. My LED had bright and dim spots, so I frosted its dome with 400-grit sandpaper. Now its light is as even as you could ask for. And I do indeed think it works better than red for preserving my night vision.

That's pretty much the flashlight. Snap the cover on and go out observing!

■ Contributing Editor **JERRY OLTION** thinks no project is too small to be fun.

# How Powerful Is Your Telescope?

**OPTICAL MIGHT** A telescope possesses the seemingly magical power to bring faint and distant celestial sights into view. It accomplishes this by harnessing three powers: magnification, light-gathering, and resolution.

**IT'S A QUESTION THAT** I'll bet most readers have heard many times — and perhaps have even asked. It seems that whenever a telescope appears in a public setting, someone will want to know, "How powerful is it?" And if you've been on the receiving end of that query, you may have struggled to answer what at first blush seems like a very simple question. I know I have. The root of the difficulty lies in defining exactly what "powerful" means.

One thing that everyone knows about telescopes is that they have an almost magical power to reveal the wonders of the night sky by making distant objects appear bigger and brighter than they do with the naked eye. Let's look at the most popular meaning of the word "power" — a telescope's *magnification*. This is what most people are trying to get at when they ask the question. Ironically, however, it's actually the least important telescope specification.

Magnification power is calculated by simply dividing the focal length of a telescope's *objective* (a refractor's front lens, or the primary mirror in a reflector) by the focal length of the eyepiece inserted into the instrument's focuser. What is your objective's focal length? Chances are it's printed somewhere on the scope itself (as in, F = 2,000, or similar) or specified in the instruction manual. The eyepiece's focal length is always engraved on its barrel. So, a 2,000-mm telescope used with a 10-mm eyepiece will magnify 200×. A 25-mm eyepiece on the same instrument yields 80×.

◀ **CHECK THE NUMBERS** Telescope eyepieces come in a wide range of shapes, sizes, and optical designs. However, they all serve one important function: to magnify the image produced by a telescope's objective. The amount of magnification depends on the eyepiece's focal length, which is printed on its barrel.

Although so-called department-store trash scopes always hype magnification as if it's of crucial importance, the reality is that any telescope can be made to magnify almost any amount with the right eyepiece, often in combination with a multiplying *Barlow lens* to double or triple the power. But more magnification isn't always a good thing. Experienced observers know that anything greater than 50× per inch of aperture is usually "empty magnification" that

ALL IMAGES COURTESY OF THE AUTHOR

fails to show additional detail beyond what less magnification can. So, if you have a 3-inch (76-mm) scope, it'll top out at around 150×. Indeed, you'll often use half that amount even when looking at the Moon or planets. On most nights, all you'll accomplish by upping the magnification is to turn a small, sharp image into a big, fuzzy one. And since the size of the field of view and magnification are related, quite often you'll opt for low power just so you can fit the entire Moon or a splashy cluster into your eyepiece.

A second but much more important specification is a telescope's *light-gathering power*. Here again basic math tells us everything we need to know to compare one scope with another. Light-gathering is almost entirely a function of the instrument's *aperture*, be it the objective lens (in a refractor) or primary mirror (in a reflector). Bigger is better — it's as simple as that. But there's a subtlety to the calculation. You might expect a 6-inch telescope to collect twice as much light as a 3-inch, but it actually collects *four* times as much. That's because it's the total surface area of the objective that matters, not the diameter. Doubling the aperture *quadruples* the surface area.

Light-gathering power is important because the more photons your telescope delivers to your eye, the fainter the celestial objects you'll be able to see, and the more obvious a given object will appear. So, while a 3-inch scope can show you stars as faint as magnitude 12.6 under a dark sky, a 6-inch lets you reach down to around magnitude 13.7. That might not sound like much of an improvement, but it means being able to pull in three times as many stars! And the more light your telescope gathers, the better it can handle higher magnification. In other words, when you have a brighter image to begin with, you can

▲ **LITTLE DETAILS** The Moon is a wonderland of fascinating features. The quality of a telescope's optics, the size of its aperture, and the magnification used all play a role in determining how much detail you'll be able to see.

magnify it more before it starts to break down and look dim and fuzzy.

You'll note that earlier I said that light-gathering power is *almost* entirely down to the size of the aperture. That "almost" qualifier is simply to acknowledge the fact that no telescope — no matter how well made — delivers 100% of the light it gathers to the eyepiece. Some percentage is lost to dust on the optics and/or inefficiencies in optical coatings. But generally, we're talking about an amount that would be difficult for even an experienced observer to perceive. For all practical purposes, it's a telescope's aperture alone that governs its light-gathering potential.

Our final telescope power is *resolution* — an instrument's ability to reveal fine detail. Resolving power is determined by the scope's aperture *and* magnification. In a nutshell, the bigger the telescope's objective and the higher the magnification, the finer the detail you'll be able to perceive. Whether we're trying to make out tiny lunar craters, surface markings on Mars, splitting close double stars, or observing individual stars in a tightly-packed globular star cluster — a telescope's resolving power is key. But because (as stated earlier) any telescope can be made to magnify any amount, aperture is effectively the only variable we need to consider.

As a crude measure of resolving power, we can employ something called the Dawes limit. A simplified version of the formula is $R = 4.56/D$, where $D$ is the telescope's aperture (in inches) and the result ($R$) is expressed in arcseconds — the smaller the number, the better. So, our 3-inch scope can resolve a pair of stars separated by 1.5 arcseconds, but our 6-inch can get down to 0.8 arcseconds. Once again aperture wins the day, but the true resolution of your scope depends on a number of variables, most crucially the quality of its optics. Better lenses and mirrors produce sharper images, which allow us to see greater detail. The specific optical design of the telescope also plays a role, though not as great as aperture and quality.

But the most significant limitation in your ability to see fine planetary features or resolve close double stars is usually the steadiness of our planet's churning atmosphere — a property astronomers refer to as *seeing*. The air above us can smear details and make a good telescope seem bad. But when seeing conditions are steady, your scope will present its very best views of whatever celestial sight has caught your fancy. And that truly has the power to take your breath away. ■



▶ **READ THE LABEL** A telescope's focal length is usually printed somewhere on the instrument itself. In the case of this vintage, 3-inch reflector *(right)*, the label tells us the instrument's focal length is 700 mm. The retaining ring of this refractor's 66-mm objective lens *(far right)* tells us its focal length is 388 mm.

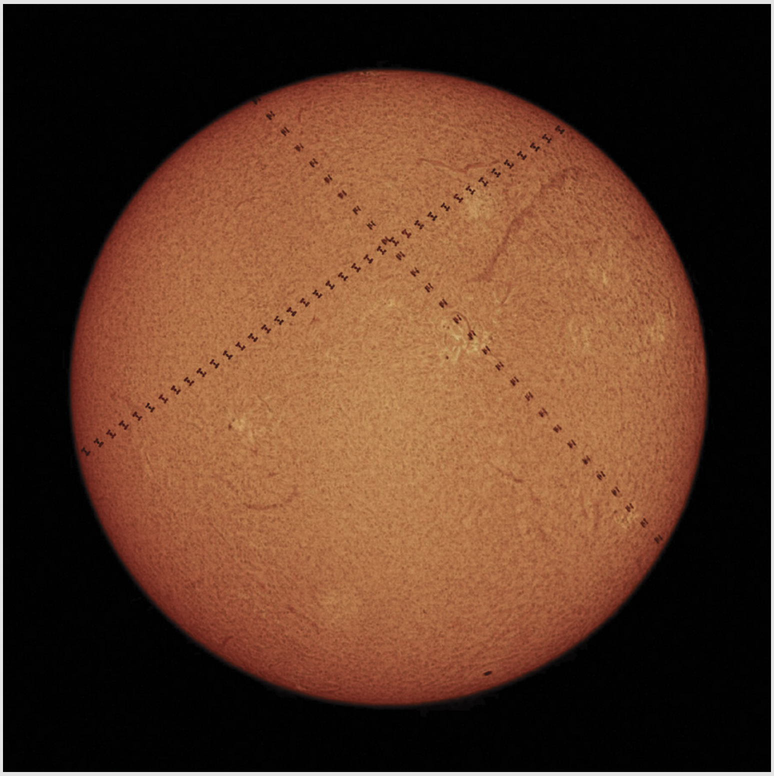
NEBULOUS WAVES

Emil Andronic

The California Nebula (NGC 1499) is a large emission nebula spanning some 2½° in Perseus. Strong ultraviolet radiation from Menkib, or Xi (ξ) Persei, the 4th-magnitude star seen at top left, causes the nebulosity to fluoresce.

**DETAILS:** *Teleskop-Service 65Q refractor with QHY294M Pro camera. Total exposure: 20 hours, 55 minutes through RGB and narrowband filters.*

**DUSTY IRIS**
Harshwardhan Pathak and Telescope Live Team
The western region of Cepheus teems with faint dust. The brighter region at upper right is Caldwell 4, a reflection nebula illuminated by the central star HD 200775. It also contains the open cluster NGC 7023.
**DETAILS:** *Takahashi FSQ-106ED refractor with QHY600M Pro camera. Total exposure: 5 hours through LRGB filters.*



◁ DOUBLE TIME

Jorge Restrepo

Recording a transit of the International Space Station across the Sun is a challenge, but successfully capturing *two* in a month is particularly rare. This composite image shows the path of the ISS on both December 12th and December 31st of 2023, as seen from Mexico City, Mexico. The solar surface shows the chromosphere as it appeared on the 31st.

**DETAILS:** *Lunt LS60THa solar telescope and ZWO ASI174MM camera. Composite of 70 images.*

▽ THE PRINCESS AND THE COMET

José J. Chambó

Comet 12P/Pons-Brooks displayed a long, bluish ion tail as it passed M31, the Andromeda Galaxy, on March 12th.

**DETAILS:** *Canon EOS 6D camera and Samyang 135-mm lens. Total exposure: 40 minutes at ISO 800.*

Gallery showcases the finest astronomical images that our readers submit to us. Send your best shots to gallery@skyandtelescope.org. See **skyandtelescope.org/aboutsky/guidelines**. Visit **skyandtelescope.org/gallery** for more of our readers' astrophotos.

SKY&TELESCOPE

# Market Place

Your essential source for astronomical products

## ACCESSORIES











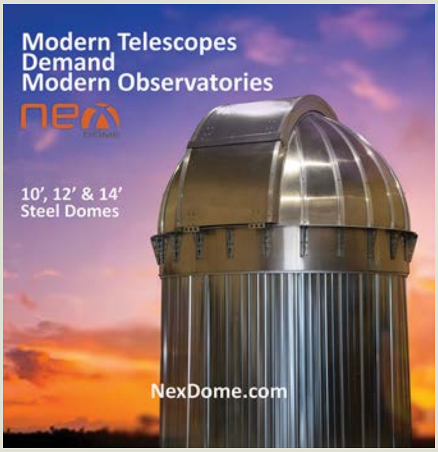


## CLASSIFIEDS

- **FOR RENT:** 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500
- **SOUTHWEST NEW MEXICO:** Casitas de Gila Guesthouses. Dark skies, great accommodations; power, wifi, and pads available. casitasdegila.com/astronomy.html. 575-535-4455.
- **BADLY NEEDED BACK ISSUES** of *S&T* to complete my collection — assembling over 50 yrs. I'm partially disabled and completing my collection is important to me. I need all of 1941, 1942, 1943, 1948. Missing 18 issues between 1944 & March 1953. My income is SSDI, so I hope offers for help are not too expensive. This ad is my last hope. Will donate to my university when I pass. Email poisonokie@aol.com

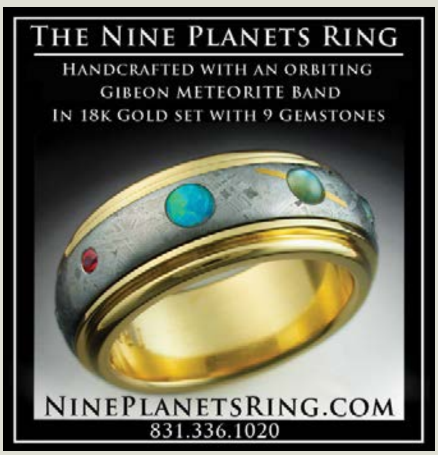
Classified ads are for the sale of noncommercial merchandise or for job offerings. The rate is $1.75 per word; minimum charge of $28.00; payment must accompany order. Closing date is 10th of third month before publication date. Send ads to: Ad Dept., Sky & Telescope, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138.

## OBSERVATORIES/DOMES






## MISCELLANEOUS




## MISCELLANEOUS (cont.)


## BOOKS




## TELESCOPES


## SOFTWARE


**shopatsky.com**

# Advertisers in This Issue

Astronomy equipment manufacturers and dealers are a valuable resource for amateur and professional astronomers alike. Patronize our advertisers in this issue and enjoy all the benefits of their expertise.

## Product Locator

### Archaeological Paths
»back cover
guided archaeological tours
**archaeologicalpaths.com**

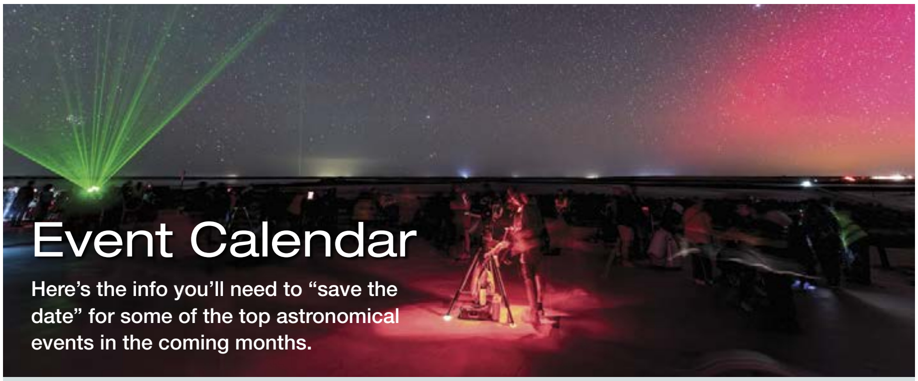
### Astro-Physics
»page 81
mounts / telescopes
**astro-physics.com**

### QHYCCD
»page 1
cameras
**qhyccd.com**

### Sky-Watcher
»inside front cover
binoculars / mounts / telescopes
**skywatcherusa.com**

### Stellarvue
»inside back cover
eyepieces / telescopes
**stellarvue.com**

## Ad Index



# Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

*June 1–8*
**GRAND CANYON STAR PARTY**
Grand Canyon, AZ
**https://is.gd/GCStarParty**

*June 5–8*
**BRYCE CANYON ASTRO FESTIVAL**
Bryce Canyon National Park, UT
**https://is.gd/brca_astrofest**

*June 5–9*
**ROCKY MOUNTAIN STAR STARE**
Gardner, CO
**rmss.org**

*June 5–9*
**YORK COUNTY STAR PARTY**
Susquehannock State Park, PA
**yorkcountystarparty.org**

*June 6–9*
**BOOTLEG SPRING STAR PARTY**
Harmon, IL
**bootlegastronomy.com**

*June 6–9*
**CHERRY SPRINGS STAR PARTY**
Coudersport, PA
**cherrysprings.org**

*June 6–9*
**WISCONSIN OBSERVERS WEEKEND**
Hartman Creek State Park, WI
**https://is.gd/WIObserversWeekend**

*July 3–7*
**GOLDEN STATE STAR PARTY**
Adin, CA
**goldenstatestarparty.org**

*July 17–20*
**ALCON 2024**
Kansas City, KS
**https://is.gd/ALCON2024**

*July 28–August 2*
**NEBRASKA STAR PARTY**
Valentine, NE
**nebraskastarparty.org**

*July 30–August 3*
**OREGON STAR PARTY**
Ochoco National Forest, OR
**oregonstarparty.org**

*July 30–August 3*
**TABLE MOUNTAIN STAR PARTY**
Oroville, WA
**tmspa.com**

*August 1–4*
**STELLAFANE CONVENTION**
Springfield, VT
**stellafane.org/convention**

*August 1–5*
**GATEWAY TO THE UNIVERSE**
Corbeil, ON
**https://is.gd/GWTTU**

*August 2–4*
**NORTHWOODS STARFEST**
Fall Creek, WI
**cvastro.org/northwoods-starfest**

*August 3–11*
**MT. KOBAU STAR PARTY**
Osoyoos, BC
**http://www.mksp.ca**

• For a more complete listing, visit https://is.gd/star_parties.

# Our Fundamental Ignorance

***Many think life beyond Earth is all but assured given the number of possibly habitable worlds out there. But we simply have no idea.***

▲ Does Saturn's moon Enceladus harbor life in its subsurface ocean? For now, we can only speculate.

NASA / JPL / SPACE SCIENCE INSTITUTE

**ARE WE ALONE** in the universe? The short answer is, nobody knows. As meetings organizer for a small astronomy club near Cambridge, England, I've had the privilege of hearing some great speakers. But often I've sensed that many of them consider extraterrestrial life to be a foregone conclusion. That stance makes me uneasy.

I can appreciate the scientific argument that the huge number of potentially habitable exoplanets increases the odds of finding life elsewhere. But an inner voice keeps saying, *How can you be so sure?* For me at least, it's a big ask to expect a set of chemical molecules to assemble into even the most primitive organism. How likely is this to happen?

With time on my hands courtesy of the pandemic, and drawing on my background in biochemistry, I wrote a review article, "Rational Ignorance in the Search for Extraterrestrial Life," which appeared last year in *New Astronomy Reviews*. (Abstract, intro, and more are available for free at **https://is.gd/ZandersET**).

In our search for extraterrestrial life, turning ignorance into understanding requires the two-pronged attack of informed speculation and evidence gathering. If we study even the most primitive organisms on Earth, we are, in a sense, locking the stable door after the horse has bolted. That's because these entities are modern descendants of basic molecular assemblies that disappeared long ago.

This caveat doesn't stop us, however, from using molecular biology, chemistry, and geology, among other scientific disciplines, to speculate backwards towards a world in which prebiotic molecules devoid of life were transformed into the biotic molecules that drive living processes. We focus on features we consider essential for life of any sort: information storage, processing, and transmission; encapsulation of the relevant molecules; and energy production.

The molecules underlying these processes depend on the properties of chemical elements, as listed in the Periodic Table. Some elements have distinctive properties that will be more suitable for life processes than others. A prime example is the enormous variety of biologically active compounds made possible with carbon. Also, inorganic minerals, in conjunction with water, can act as catalysts to turn atmospheric gases — such as carbon dioxide, methane, and ammonia — into larger, carbon-containing molecules.

Scientists have created components of DNA, proteins, and energy metabolism in the lab from the simple starting points noted above. That's an impressive achievement, but it doesn't provide firm evidence for how such genesis came about in the deep past, nor whether similar arrangements, likely using different molecules, occur beyond Earth. For this, we need direct evidence from solar system exploration and exoplanet imaging.

Luckily, data from spacecraft, rovers, and observatories support potentially habitable regions in our solar system and beyond. Further, analysis of meteorites and samples returned from asteroids reveal carbon-based compounds with the potential to generate life (see page 20). Maybe one day our robotic proxies will discover living organisms, or their fossilized remains, on or within bodies like Mars or the moons of the outer planets. That would be an enormous discovery. Of course, finding extraterrestrial *intelligence* would, both scientifically and philosophically, be a complete game-changer.

But for now, we remain fundamentally ignorant of whether or not we're alone. I don't know if I'll be around long enough to learn the answer to this vital question, but I hope so!

■ ED ZANDERS has a PhD in biochemistry and worked for several decades in the life sciences. He enjoys stargazing from his home in Cambridge, England, using his new smart telescope.