WORKBENCH: Mounting Encoders in Thin Air PAGE 72

SATURN: Two Observing Challenges PAGE 52

EXOPLANETS: Who Could Be Watching Us? PAGE 84

SKY & TELESCOPE

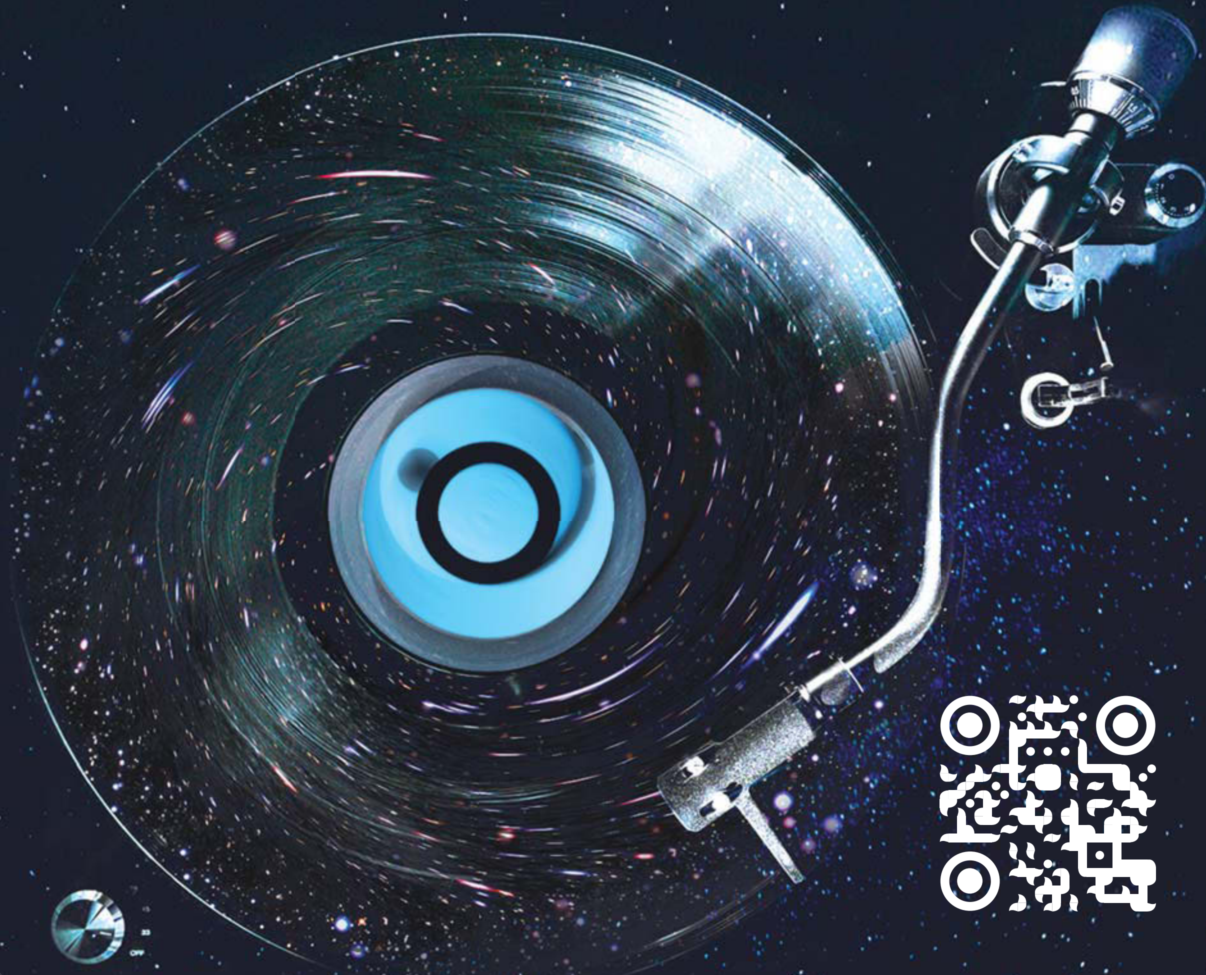
THE ESSENTIAL GUIDE TO ASTRONOMY

JULY 2021

SPECIAL ISSUE

Star Clusters

skyandtelescope.org



CONTENTS

SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

28

RON BRECHER

July 2021 VOL. 142, NO. 1

FEATURES

SPECIAL ISSUE: STAR CLUSTERS

OBSERVING

S&T TEST REPORT

COLUMNS / DEPARTMENTS

ON THE COVER

Globular cluster NGC 1466, in the Large Magellanic Cloud
PHOTO: ESA / HUBBLE & NASA

ONLINE

SAVE DARK SKIES
Find facts about what light pollution is and how you can help combat and reduce its effects.
skyandtelescope.org/light-pollution

OBSERVAR EL CIELO
The skies are everyone's, and astronomy is, too! Check out our Spanish guides for getting started in the hobby of astronomy.
skyandtelescope.org/observar

TIPS FOR BEGINNERS
New to astronomy? From learning the night sky to tips on buying your first telescope, here's everything you need to jump into the fun.
skyandtelescope.org/letsgo

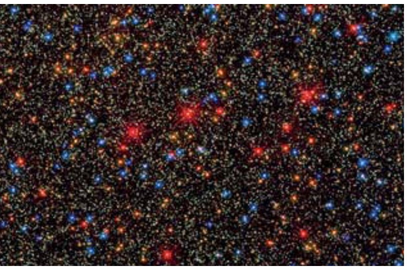
SKY & TELESCOPE (ISSN 0037-6604) is published monthly by AAS Sky Publishing, LLC, owned by the American Astronomical Society, 1667 K Street NW, Suite 800, Washington, DC 20006, USA. Phone: 800-253-0245 (customer service/subscriptions), 617-500-6793 (all other calls). Website: skyandtelescope.org. Store website: shopatsky.com. ©2021 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 420235, Palm Coast, FL 32142-0235. Printed in the USA. *Sky & Telescope* maintains a strict policy of editorial independence from the AAS and its research publications in reporting on astronomy.

A Tremendous Blaze

STAR CLUSTERS PLEASURABLY WORK YOUR BRAIN. As with crossword puzzles, give them time, and satisfying surprises often await.

Consider the open cluster Messier 7 in Scorpius (see image on page 38). Certain aspects jump out as soon as you have it in your eyepiece: shape, size, differing magnitudes, how well the cluster stands out from background stars. But dally a bit and you begin to discern subtleties: suns of varying colors, dark dust lanes seemingly weaving between the stars, asterisms you've heard of or invent yourself on the spot.

Sometimes the unexpected occurs. While on TravelQuest's annual observing trip to Costa Rica in 2017, I was enjoying M7 in my 10×42 binoculars when the cluster suddenly popped into 3D, like a Magic Eye image. It almost felt like I could project myself into its very midst. When I shifted my gaze to nearby M6, the Butterfly Cluster, the sensation vanished, but it returned the moment I swung back to M7.



▲ Panoramic Hubble Telescope view of 100,000 stars in the core of Omega Centauri

NASA / ESA / HUBBLE SM4 ERO TEAM

Globular clusters can tickle your mind, too. On that same trip, I lingered often on Omega Centauri, which many consider the finest globular of all. But each viewing featured the same tease. As I scribbled in my notebook while observing Omega Cen one night, "Want to resolve stars more clearly than can, like getting head around a new but elusive idea. *Just* out of reach, that clarification."

The cores of globular clusters appear so compressed that they can fool you into thinking stars there must collide all the time. The cores *are* crowded: As long-time *S&T* editor Walter Scott Houston once wrote of Omega Cen, "If we were located inside this cluster, we would see the night sky ablaze with many thousands of 1st-magnitude stars, and it would be twilight all night long." (So much for stargazing.) But in reality, space abounds in globular cores. The average distance between any two stars in the heart of Omega Cen, for example, is about one-third of a light-year, or roughly 3 trillion kilometers (2 trillion miles).

Throughout this special issue on star clusters, you'll find articles on a variety of subjects: how globulars formed billions of years ago (page 14); what exoplanets in open clusters can teach us about how planetary systems evolve (page 22); how to photograph star clusters (page 28); and which open clusters we recommend observing in the summer sky (page 34).

In all these pieces, you can savor photos of star clusters that Houston once called, while referring to the Double Cluster, "a tremendous blaze of scintillating suns." While you're at it, be prepared for a blaze of scintillating thoughts as well.

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

EDITORIAL
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, Robert Naeye, Roger W. Sinnott

Contributing Editors
Howard Banich, Jim Bell, Trudy Bell, Monica Bobra, John E. Bortle, Ronald Brecher, Greg Bryant, Thomas A. Dobbins, Alan Dyer, Tom Field, Tony Flanders, Ted Forte, Steve Gottlieb, David Grinspoon, Shannon Hall, Ken Hewitt-White, Johnny Horne, Bob King, Emily Lakdawalla, Rod Mollise, James Mullaney, Donald W. Olson, Jerry Oltion, Joe Rao, Dean Regas, Fred Schaaf, Govert Schilling, William Sheehan, Mathew Wedel, Alan Whitman, Charles A. Wood, Richard S. Wright, Jr.

Contributing Photographers
P. K. Chen, Akira Fujii, Robert Gendler, Babak Tafreshi

ART, DESIGN & DIGITAL
Art Director Terri Dubé
Illustration Director Gregg Dinderman
Illustrator Leah Tiscione
Webmaster Scilla Bennett

ADVERTISING
Advertising Sales Director Tim Allen

AMERICAN ASTRONOMICAL SOCIETY
Executive Officer / CEO, AAS Sky Publishing, LLC
Kevin B. Marvel
President Paula Szkody, University of Washington
Past President Megan Donahue, Michigan State University
Senior Vice-President Joan Schmelz, Universities Space Research Association
Second Vice-President Geoffrey C. Clayton, Louisiana State University
Third Vice-President Stephen C. Unwin, JPL, California Institute of Technology
Treasurer Doris Daou, NASA Planetary Science Division
Secretary Alice K. B. Monet, U.S. Naval Observatory (ret.)
At-Large Trustees Marcel Agüeros, Columbia University; Kelsey Johnson, University of Virginia; Tereasa Brainerd, Boston University; Hannah Jang-Condell, University of Wyoming; Edmund Bertschinger, MIT

Editorial Correspondence
(including permissions, partnerships, and content licensing): Sky & Telescope, One Alewife Center, Suite 300B, Cambridge, MA 02140, 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.

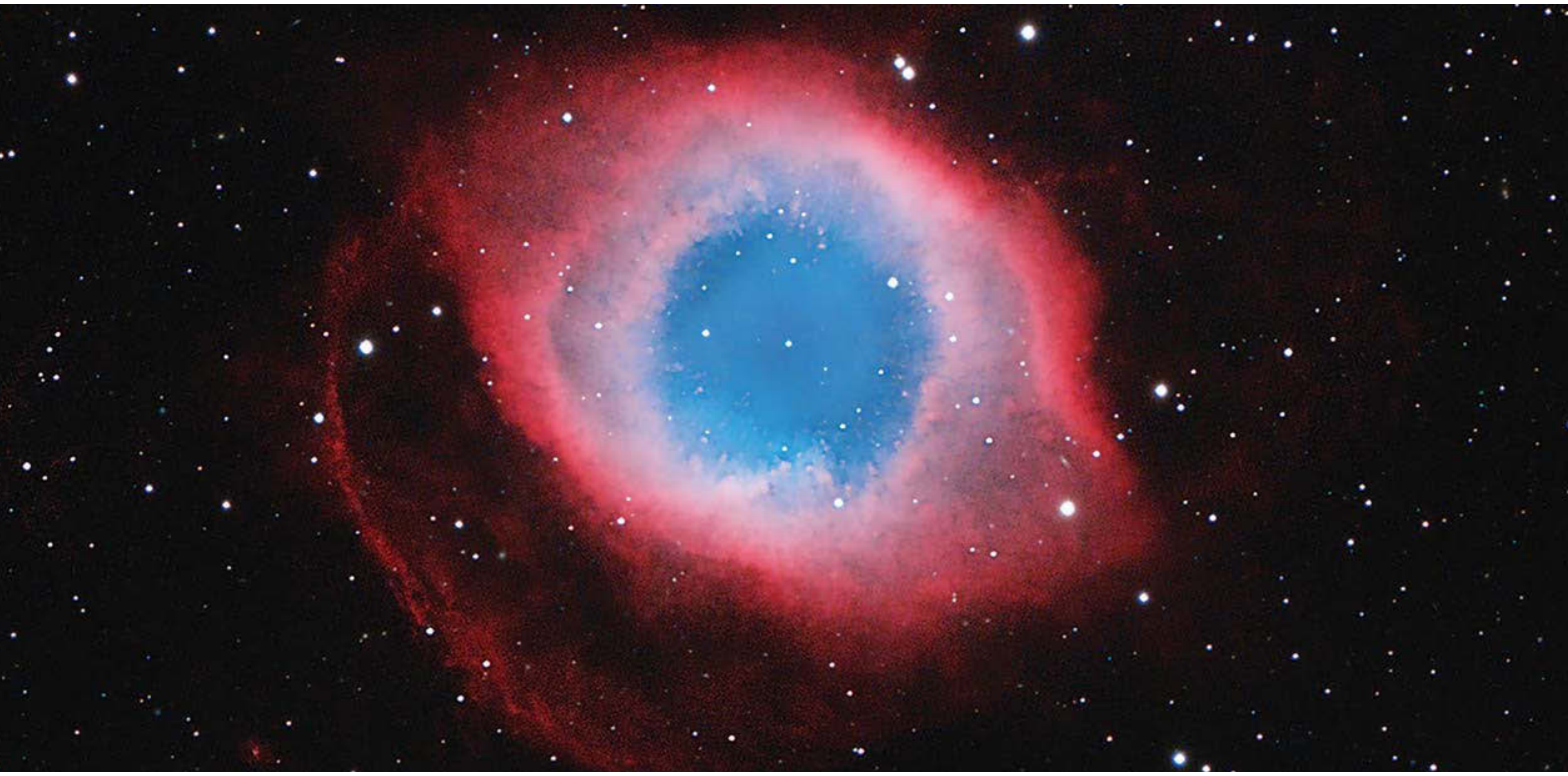
Advertising Information:
Tim Allen: 773-551-0397
E-mail: tallen@skyandtelescope.org
Web: skyandtelescope.org/advertising

Customer Service: Magazine customer service and change-of-address notices:
skyandtelescope@emailcustomerservice.com
Phone toll-free U.S. and Canada: 800-253-0245
Outside the U.S. and Canada: 386-597-4387

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

Subscription Rates:
U.S. and possessions: $54.95 per year (12 issues)
Canada: $69.95 (including GST)
All other countries: $84.95, by expedited delivery
All prices are in U.S. dollars.

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



Spend less time troubleshooting and more time imaging.

Presenting TheSky™ Imaging Edition for $595.

Have you ever blown an entire evening trying to get one or more of your imaging devices to work? If you have, you're not alone.

Our new imaging edition of TheSky™ can help you become more productive by letting you control *all* your imaging devices with a single amazing software application, and from one very reliable software developer.

TheSky Imaging Edition provides world class 64-bit device control, including cameras, mounts, focusers, filter wheels, autoguiders, and rotators, all right out of the box.

You'll enjoy lightning-fast renderings of the sky with amazing detail based on your preferences. Point to your object and start imaging.

With its integrated TPoint™ telescope modeling, you'll spend less time hunting and more time imaging. You can now polar align your telescope without needing any pole stars, which is great when relatively small patches of sky are visible.

TPoint also detects and compensates for any flexure in your telescope. And its extreme pointing accuracy is legendary — and unrivaled.

Available for Windows, macOS, and Linux, you can migrate operating systems without losing TheSky's familiar look and feel.[1]

If you already own TheSky software, you might be eligible for a discount with a current subscription.[2]

Spend more time imaging with TheSky Imaging Edition.

[1] Access all OS versions with our $149 Multi-OS and Six-License Module.
[2] Upgrade accommodations vary, please visit Bisque.com for details.

SB

SOFTWARE BISQUE

Superior imaging solutions for discriminating astronomers.

Another 6-Inch Brashear Restoration

I read Nicole Nazzaro's "Resurrecting a Classic Refractor" (*S&T:* Apr. 2021, p. 24) with great interest, because I have also had the honor of restoring a 6-inch (150-mm) Brashear refractor. We estimated that the year of manufacture was 1905.

Like the one belonging to the University of Washington telescope, Warner & Swasey also made the equatorial mounting and pedestal. We don't know much about the refractor's early history, but private owners donated it to the State University of New York at Oswego in 1956. It was installed in a new observatory a few years later.

▲ The John A. Brashear Company built this 6-inch refractor in the early 1900s. John Rusho later restored the telescope, and today it resides at the H. Lee White Maritime Museum.

JOHN F. RUSHO

Unfortunately, this instrument has a more checkered history and a less certain future.

Records show that the Wilmot Fleming Engineering Company refurbished the refractor in 1967. In the early 1980s, the objective lens was stolen, never recovered, and replaced with a new Jaegers f/15 lens. In the 1970s, a parking lot had been enlarged right up to the building, and a power substation was built next to it. The observatory served students, faculty, and the public until 2006, when both building and telescope were in barely usable condition.

While employed as an adjunct astronomy professor, I completely reconditioned the telescope using many of the steps described in the article. As someone with an engineering background, I was awed by the precision and craftsmanship I found in this instrument.

We maintained its character to the extent possible but could not return it to its original configuration. The original finder and brackets, weight-driven clock-drive parts, and eyepieces were missing. The original worm gear had been previously connected to a gearmotor. An old 60-mm (2.4-inch) refractor and a surplus Erfle eyepiece with crosshairs replaced the missing finder. A new focuser adapter permits the use of modern 2-inch (50-mm) eyepieces. And we had new internal glare stops fabricated.

The Brashear returned to use, but the college was planning a new, more secluded observatory. This was built in 2013 with a larger modern telescope and remote-access capabilities.

Without a champion like Ana Larson, the 6-inch refractor was declared surplus, and the university demolished the old building. To prevent the Brashear's disposal, they arranged a long-term loan to the nearby H. Lee White Maritime Museum. Potentially, the museum will place it in a roll-back shelter, so it can show the universe to the public again.

John F. Rusho
Chaumont, New York

I was so glad to learn about the historic telescope at the University of Washington in Seattle. Ralph Waldo Emerson wrote the article's opening quote, "What is so good in a college as an observatory? The sublime attaches to the door and to the first stair you ascend . . . this is the road to the stars," in his journal on November 14, 1865, after visiting our historic observatory built by Albert Hopkins and his students in 1836–38. Alvan Clark crafted the telescope in 1852. It was the first telescope he made commercially.

Jay M. Pasachoff
Director, Hopkins Observatory
Williamstown, Massachusetts

The Oddball Satellites of Mars

I thoroughly enjoyed Javier Barbuzano's article about the "oddball satellites" of Mars (*S&T:* Apr. 2021, p. 34).

It reminded me of Arthur C. Clarke's 1949 short story "Hide and Seek," in which a secret agent stranded on Phobos must elude his pursuers by keeping them diametrically opposite his position on that small rock. Clarke calculated, with the information available at that time, that a person could jump clear off Deimos unassisted due to its minute escape velocity but that it was not quite possible to do so on the larger Phobos.

Kenneth A. Heisler
Falmouth, Massachusetts

Spotting Saturn from the Mojave Desert

Martin Hajovsky's Focal Point, "Here, Dad, Take a Look" (*S&T:* Apr. 2021, p. 84) brought back wonderful memories.

In 1956, I was all of 11 years old. The previous Christmas, my dad had given me a 2-inch Unitron refractor. We couldn't see much living in Southern California. The night sky was light polluted even back then.

So off we went to the Mojave Desert to camp under the stars. I knew that at two o'clock in the morning, Saturn would be high in the sky. So I got up, pointed my scope, and there it was! What a sight! It had to be shared. "Hey, Dad, you've got to see this!" I exclaimed. "It's Saturn." My dad arose from his sleeping bag, looked through the scope, professed great interest and joy, and quickly returned to his sleeping bag. It was freezing. I didn't care about the cold. I had just seen Saturn for the first time and shared it with my dad.

Jim Bradburn
Rancho Bendito, Colorado

Remembering Gleanings for ATM's

Old-school amateur astronomers like me are used to pushing our telescopes around while looking through a finder; it's part of the fun. I still find it rewarding when I locate the harder-to-find deep-sky objects I see on star charts. Amateur astronomy is going through some big changes. The equipment available now could not have been imagined in my earlier years in this hobby.

I hold no animus toward those who let a computer guide them around the heavens, and I am in awe of the beautiful astrophotographs taken by this generation of amateur astronomers. Many of them, however, will never know the thrill of that first light from an optic that you made yourself. I made my first telescope mirror in 1985. As often happens, the thrill of observing with a home-built telescope spawned the hobby of amateur telescope making. The tail wagged the dog, and it was really fun. The height of amateur telescope making is mostly over now, and some of us old guys are in mourning.

I still enjoy reading Jerry Oltion's Astronomer's Workbench, and it is usually the first thing I look at in *S&T*. But I do miss the old days of Roger Sinnott's Gleanings for ATM's. Having said all of that, *Sky & Telescope* will always remain my portal to the world of astronomy and the incredible technology that accompanies it.

Art Gamble
Wichita Falls, Texas

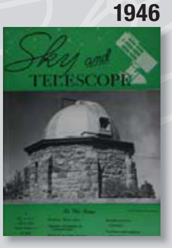
FOR THE RECORD

- The Rapid Approximate Spectral Calculations for All project is not an offshoot of the All Small Molecules project but rather an independent project created by Clara Sousa-Silva in 2016 (*S&T:* May 2021, p. 38).
- The "Marly" telescope's Campani lens referred to in "Giovanni Domenico Cassini and the Birth of Big Science" (*S&T:* May 2021, p. 58) had a focal length of 136 feet (41 meters).
- The portrait of Francesco de Vico in "The Strange Case of Comet Biela" (*S&T:* Nov. 2020, p. 58) depicts an Italian cleric of the same name who lived from 1660 to 1735. The image at right shows the correct Francesco de Vico (1805–48).

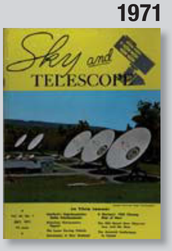
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

July 1946

New Meteor Shower "Through the bureau of astronomical telegrams at Copenhagen, we hear about an unexpected shower of meteors seen from the observatory at Skalnate Pleso, Czechoslovakia. For over four hours on the night of December 22, 1945, meteors fell from a radiant in Ursa Minor, for about 10 minutes at the rate of 169 per hour. In addition to a possible association with the comet of 1792 II, proposed by Director A. Becvar, a probable connection with Tuttle's comet is suggested by M. Rigollet, of the Paris Observatory. The secular decrease in perihelion distance of this comet might give rise to an important meteor shower observable in late December."

Nowadays, 10 or fewer Ursid meteors per hour is typical. But in some future year, around December 22nd, Earth could once again meet with an unusual bunching in this meteor stream.

July 1971

Nearby Supernova? "In 1961, during a sky survey with the 250-foot radio telescope at Jodrell Bank in England, M. I. Large and his coworkers discovered the enormous sky feature that is known as the Cetus radio arc. It is a broad band of enhanced radio emission that extends across the constellations of Cetus and Aquarius, forming an incomplete circle of about 45 degrees radius, centered near the star Beta Pegasi.

"The Cetus arc can be photographed in red light as a very faint wreath of filamentary nebulosity, as J. Meaburn demonstrated in 1966, using 6-inch f/1 and f/1.5 Schmidt cameras . . .

"While several alternative theories have been advanced, it is probable that the Cetus arc is the remnant of a supernova that occurred in the close vicinity of the sun. This old idea is given new support by the Soviet astronomers I. S. Shklovski and E. K. Sheffer in *Nature* for May 21, 1971."

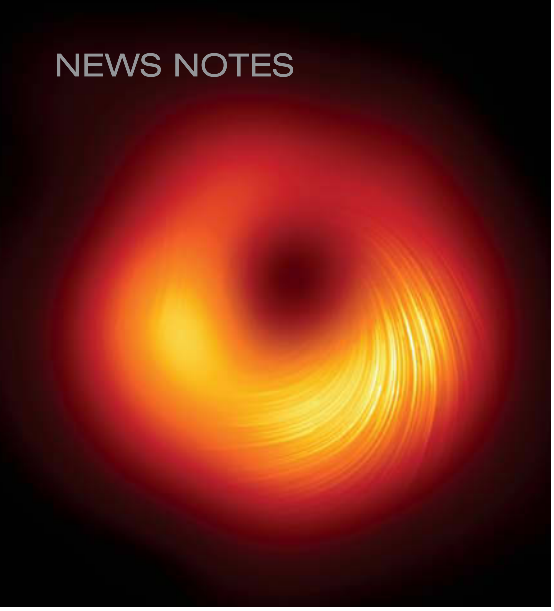
July 1996

Optical Magic "Interferometry has long been a technique reserved for radio astronomers. By combining the signals from separate antennas, a composite image can be assembled that has the resolution of a much larger aperture. . . .

"[Recently] John E. Baldwin (University of Cambridge) and his colleagues announced a milestone in this burgeoning field. The Cambridge Optical Aperture Synthesis Telescope (COAST) combines the light from three 40-centimeter (16-inch) apertures 6 meters apart to make an image with the resolution of a single 6-meter mirror. . . .

"COAST's mathematically enhanced resolution enabled Baldwin's group to split the 0.1-magnitude binary star Capella [with components] only 0.055 arcsecond apart, last September."

The News Note adds that mirrors of the Very Large Telescope in Chile might one day be teamed up this way. They have been, in various configurations, since 2005.



◀ This reconstructed image shows the polarized view of the gas-enshrouded supermassive black hole in M87. Superposed lines indicate the direction and amount of polarization.

BLACK HOLES

The Magnetic Fields Around M87's Black Hole

THE EVENT HORIZON TELESCOPE (EHT) collaboration has unveiled new images of the black hole shadow at the center of the elliptical galaxy M87, which sits at the center of the Virgo Cluster some 55 million light-years away. These images, unlike the iconic one released in 2019 (*S&T:* Sept. 2019, p. 18), include *polarized light* — photons that shimmy at only certain orientations as they travel through space. The new data contain long-awaited information about the behavior of magnetic fields near the black hole.

Magnetic fields are cosmic puppeteers whose marionette strings thread gas around a black hole and control its inflow. Turbulence in the fields robs gas of its angular momentum, enabling it to fall into the black hole. But if the fields are too strong, magnetic pressure chokes off the flow.

Until now, this picture has been largely theoretical. But using a planet-spanning network of radio telescopes, the EHT team observed the polarization of light emitted by gas right around M87's supermassive black hole. The *synchrotron emission* comes from electrons corkscrewing along magnetic field lines. The polarization of that emission is consistent with a fairly strong magnetic field. But it isn't simply wrapped around the black hole by the accretion disk; it's more complex, explains Jason Dexter (University of Colorado, Boulder).

The polarization is also weaker than the team expected. Synchrotron radiation ought to be highly polarized (roughly 70%), but the data show a maximum of only 30%. Tangles in the highly magnetized gas near the black hole likely scramble the signal.

After comparing data to simulations, the team concluded that the magnetic fields around M87 are strong enough to control the movement of the sparse gas.

Christopher Reynolds (University of Cambridge, UK), who wasn't involved with the study, agrees that the data point to strong magnetic fields, but he's hesitant to conclude that a magnetic-choking scenario is the only explanation for the observations. "What if the data are trying to tell us something that isn't in the lexicon of those models?" he asks. The EHT astronomers agree, acknowledging that their set of scenarios is incomplete.

Nevertheless, the new data might be direct evidence that magnetic fields can control the inflow of gas — a scenario that might explain the starvation diet of our own galaxy's central black hole. The results appear in the March 20th *Astrophysical Journal Letters*.

■ CAMILLE M. CARLISLE

COSMOLOGY

New Studies: The Universe Is Expanding Faster

TWO INDEPENDENT GROUPS have measured the *Hubble constant*, the universe's current rate of expansion, and their results have deepened the tension in an ongoing controversy (*S&T:* June 2019, p. 22).

Observations of the far-away (early) universe, particularly the cosmic microwave background emitted 380,000 years after the Big Bang, lead to a current expansion rate of 67 km/s per megaparsec. But near-universe observations point to a higher value of 73 km/s/Mpc.

Adam Riess (Space Telescope Science Institute) has been leading an effort to tie *Cepheid variables*, a "standard candle" typically found in nearby galaxies, to Type Ia supernovae, another standard candle that can be seen from farther away. Improving on previous work, Riess's team combined precise distances from the Gaia satellite with Hubble Space Telescope brightness measurements of 75 Cepheids in galaxies hosting Type Ia supernovae. In the February 10th *Astrophysical Journal Letters*, they report a more precise Hubble constant than any near-universe method: between 71.6 and 74.4 km/s/Mpc.

The second study, led by John Blakeslee (NSF's NOIRLab), examined 63 bright, mostly elliptical galaxies within 300 million light-years. The team was looking for brightness differences between pixels within each galaxy image. For nearby galaxies, relatively few stars are in each pixel, and the statistical fluctuations in the number of stars per pixel is higher. For more distant galaxies, more stars per pixel result in lower pixel-to-pixel variations. So when one galaxy appears smoother than another, it's typically farther away.

▶ NGC 1453, one of the giant elliptical galaxies used to calculate the expansion rate of the local universe

Surface brightness fluctuations yield a Hubble constant between 70.2 and 76.4 km/s/Mpc, a result that will appear in the *Astrophysical Journal*. While the range is larger than that from Riess's team, it still lands on the higher end of the spectrum. Both studies support the notion that the Hubble constant is greater when measured using objects in the near universe, indicating new physics at play.

■ ARWEN RIMMER

M87'S BLACK HOLE: EHT COLLABORATION; NGC 1453: CARNEGIE-IRVINE GALAXY SURVEY

SOLAR SYSTEM

Is an Ocean of Water Trapped in the Martian Crust?

MARS ONCE HAD ENOUGH water to fill a global ocean 100 to 1,500 meters (300 to 5,000 feet) deep. But scientists have had trouble explaining where all of it went. In the April 2nd *Science*, graduate student Eva Scheller and advisor Bethany Ehlmann (both at Caltech) used a model of the Martian water cycle to show that most of it was trapped in water-loving minerals in the Martian crust.

Water (H_2O) rarely contains a heavier form of hydrogen called *deuterium*, which has an extra neutron. Water on Mars has become heavier over the eons, and previous studies assumed this happened as water was lost to space. After ultraviolet light from the Sun broke apart water molecules, normal hydrogen atoms were more likely to escape the atmosphere than heavier deuterium.

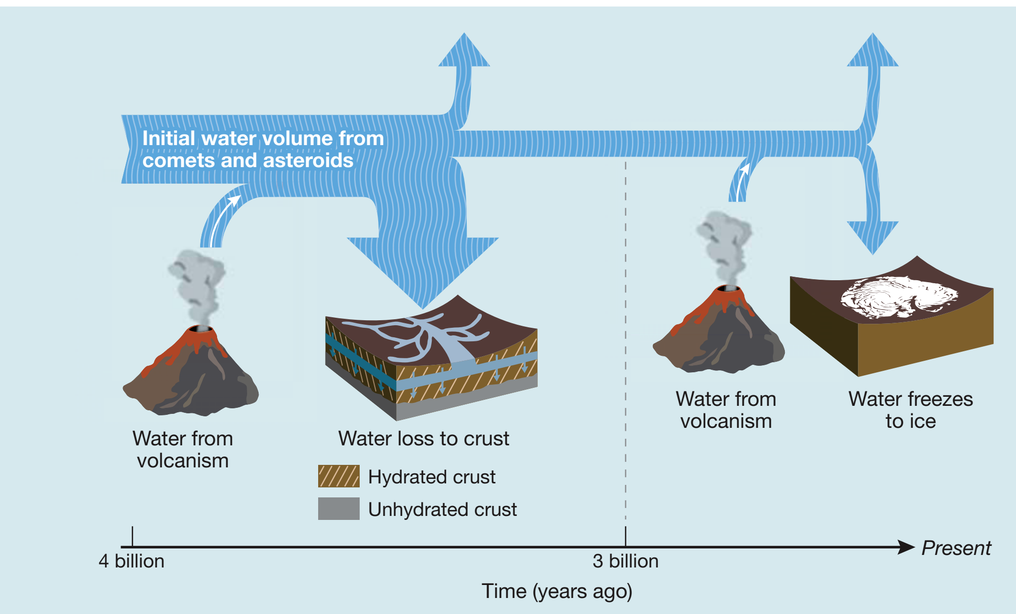
However, escape hasn't explained all of the water loss. So Scheller, Ehlmann, and their colleagues built a model that takes into account water-trapping chemistry on the surface, and they found it plays a significant role. "More than half of Mars's initial water was sequestered in the crust by 3 billion years ago," Scheller said at the 52nd Lunar and Planetary Science Conference in March.

Graduate student Liza Wernicke and Bruce Jakosky (both at University of Colorado, Boulder) independently used data from the Mars Odyssey and Mars Express orbiters to gauge the amount of water locked into hydrated minerals. Their estimates, published in the March *Journal of Geophysical Research: Planets*, are consistent with the results from Scheller's team. However, Jakosky cautions that there's still a lot we don't know about the planet's history. Those unknowns complicate the connection between the current presence of hydrated minerals and the long-term evolution of the water cycle.

NASA's Perseverance rover will be key to testing and building on the model of Mars's water cycle, Ehlmann says. The rocks in and around Jezero Crater are the oldest to be explored by a rover, and lab tests of eventual sample returns could distinguish between evolution scenarios.

■ MONICA YOUNG

WATER LOSS DIAGRAM: GREGG DINDERMAN / S&T; SOURCE: SCHELLER ET AL. / LPSC; LLSVP MASSES: SANNE.COTTAAR / WIKIMEDIA COMMONS / CC BY-SA 4.0



▲ This diagram shows water sources and sinks on Mars. Comets and asteroids initially delivered water to the planet, and volcanic outgassing continued to add more over time. Water was lost to the planet and to space, but in the end, crustal chemistry claimed more than space.

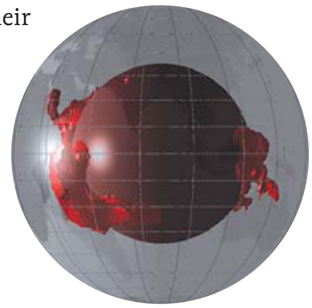
SOLAR SYSTEM

Bits of Theia Might Be in Earth's Mantle

EVIDENCE FOR the impact that created the Moon might lie far beneath our feet.

The leading theory for the Moon's formation is that a roughly Mars-size object, dubbed Theia, struck Earth around 4.5 billion years ago. At the virtual 52nd Lunar and Planetary Science Conference, Qian Yuan (Arizona State University) and his colleagues suggested that bits of Theia might remain as two dense masses deep in our planet's mantle. Their study will appear in *Geophysical Research Letters*.

The two continent-size masses are known as *large, low-shear-velocity provinces* (LLSVPs). Seismic waves traversing our planet's interior have revealed these to be roughly 1,000 kilometers tall and several thousand kilometers wide, stuck on either side of the Earth's core like misshapen earmuffs.



▲ This depiction of the large, low-shear-velocity provinces (LLSVPs) is based on a 2016 study using seismic tomography.

Inspired by recent results dating the LLSVPs to 4.45 billion years old, Yuan and his colleagues simulated the evolution of Theia's remains following the giant impact. The colliding objects' cores merged right away, but the researchers found that as long as Theia's mantle was dense enough, it would have stayed separate from Earth's mantle, sinking to the bottom instead of mixing into it.

However, Jennifer Jenkins (Durham University, UK), who was not involved in the study, says we still don't understand the LLSVPs' exact nature, as studies of them have used low-frequency seismic waves that paint a fuzzy picture.

Lunar sample returns from the South Pole–Aitken Basin, where a different ancient impact exposed the lunar mantle, would help settle the matter.

■ DAVID DICKINSON

MILKY WAY

Our "Local Arm" Is Longer Than Thought

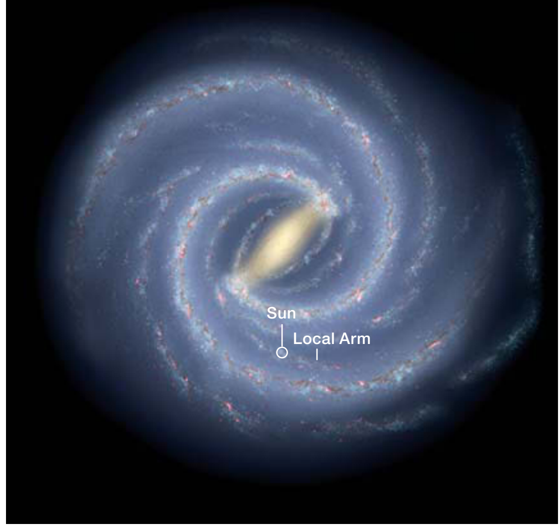
WHILE ASTRONOMERS generally agree that the Milky Way has four major spiral arms, what they look like is still an open question. This includes the Local Arm that we call home (which may or may not be an arm at all).

Now, two recent studies of the latest data release from the European Space Agency's Gaia mission, one led by Ye Xu (Purple Mountain Observatory, China) and the other by Eloisa Poggio (University of Côte d'Azur, France), have upgraded the Local Arm from a spur to a major spiral feature, if not quite to a full-size arm.

In the January *Astronomy & Astrophysics*, Xu and his colleagues picked out 9,750 stars of spectral type *O* to *B*2, massive and brilliant stars that are at most 20 million years old and thus not too far from their birthplaces in the spiral arms.

Meanwhile, Poggio and her colleagues mapped more than 750,000 of the most massive main-sequence stars, 353 newborn star clusters, and 1,923 young *Cepheid variables*, giant pulsating stars with well-known distances. This work, posted March 2nd on the arXiv preprint server, involves more objects and thus has better statistics. But these stars and stellar groups are up to 100 million years old; with more time to travel away from the spiral arm they were born in, they give a fuzzier view of the overall structure.

Despite their differences, both teams extend the Local Arm to roughly 26,000 light-years long, but its appearance remains in question. Further observations will help decide whether the arm bends in a spiral shape or continues in a straighter, spur-like line.



▲ Two new studies extend the Local Arm, which houses the Sun. (The arm in this classic artist's illustration is shorter than now thought.)

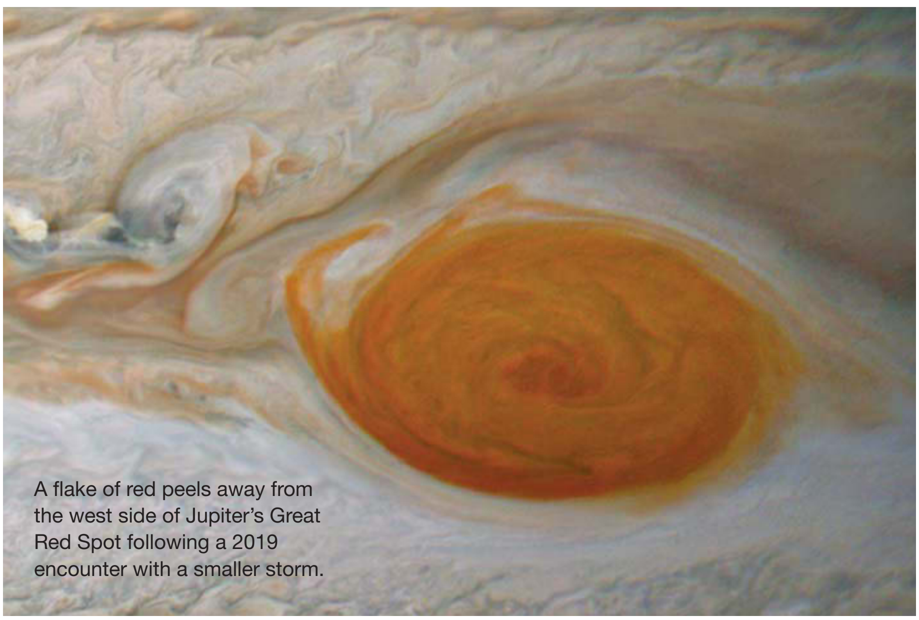
■ MONICA YOUNG

JUPITER

Great Red Spot Gets Smaller — But Stronger

JUPITER'S GREAT RED SPOT (GRS) has been shrinking ever since regular observations began in 1878, from about 48,000 kilometers (30,000 miles) across to its present width of about 15,000 km. But recent encounters with other storms shrank it further (*S&T:* Sept. 2019, p. 8), leading some to predict the iconic spot would come to an end. However, new data and analysis by a team of amateur and professional astronomers revealed that those encounters also pumped up the Great Red Spot's energy, likely extending its life.

Between 2018 and 2020, a series of smaller oval storms battered the GRS at a greater frequency than before, distorting the storm's shape and tearing "flakes" off its edge.



A flake of red peels away from the west side of Jupiter's Great Red Spot following a 2019 encounter with a smaller storm.

In early 2019, amateurs circulated an alert and began systematic observations to provide context to data from NASA's Juno mission. Professional astronomers also conducted observations using the Hubble Space Telescope and ground-based telescopes.

Agustín Sánchez-Lavega (University of the Basque Country, Spain) gathered a large team, including professional and amateur collaborators, to analyze the data. The findings will appear in the *Journal of Geophysical Research: Planets*.

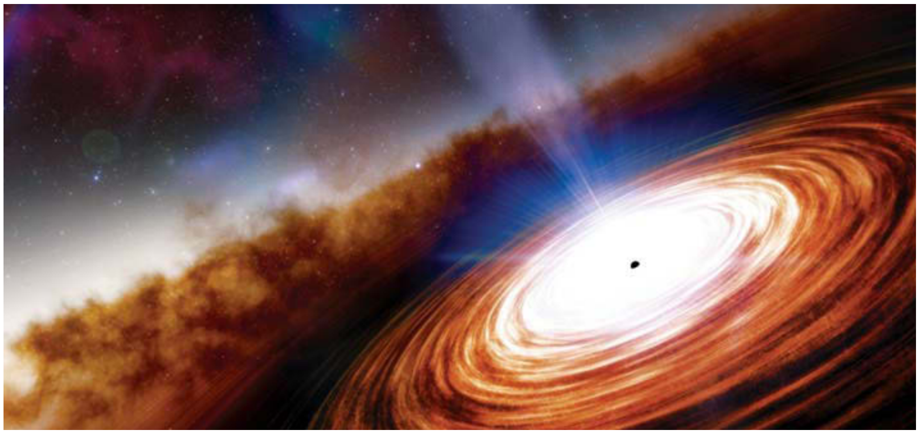
The observations, combined with computer modeling of the GRS's interior, suggest that the damage caused by the smaller storms was only skin deep. The Great Red Spot itself extends some 200 km below the cloudtops. Deeper in the planet, it was absorbing energy from the angular momentum of the smaller storms. That energy will keep the storm going, says Sánchez-Lavega: "The intense vorticity of the Great Red Spot, together with its larger size and depth compared to the interacting vortices, guarantees its long lifetime."

■ JEFF HECHT

MILKY WAY GALAXY: NASA / JPL-CALTECH / ESO / R. HURT; GREAT RED SPOT: AGU / *JOURNAL OF GEOPHYSICAL RESEARCH: PLANETS*

BLACK HOLES

A Supermassive Black Hole on the Move



▲ An artist's impression of a supermassive black hole within a galaxy

THE BLACK HOLE AT THE HEART of a nearby galaxy is drifting. The 3 million–solar mass behemoth is moving 100 kilometers per second (230,000 mph) relative to its host galaxy. It's also moving 50 km/s relative to the gas and stars about 100 light-years out. Even stranger, the gas and stars themselves seem to be out of whack with galactic material that's farther out.

The host galaxy J0437+2456 is a barred spiral 220 million light-years away, and it looks ordinary at first glance. But observations of its *megamaser*, a bright source of radio emission orbiting the central black hole, showed Dominic Pesce (Center for Astrophysics, Harvard & Smithsonian) and colleagues that the dark behemoth wasn't at rest with respect to its galactic host.

Pesce's team followed up using near-infrared spectroscopy to track the motions of stars and gas as close as 110 light-years to the black hole. The team also used the Arecibo Observatory (in early 2019, before its catastrophic collapse) to image neutral hydrogen gas farther out in the galaxy.

These observations, which appear in the March 10th *Astrophysical Journal*, show the black hole, the stars and gas around it, and the galaxy at large all moving at different speeds. The host probably merged recently with another, smaller galaxy, both of them bringing their own central black holes to the union. But what stage the merger's in is still up for debate. The black hole could just be falling into the galaxy, though Pesce says that seems less likely since it's already near the center. Or it could be orbiting another, not-yet-detected, supermassive black hole. Or perhaps the two black holes have already coalesced, and their merger resulted in recoil motion away from the center.

Current data can't distinguish between the options, but Pesce says high-resolution radio observations could reveal emissions from another supermassive black hole in the system — if it's there.

■ MONICA YOUNG

IN BRIEF

Asteroid Apophis Will Miss Earth in 2068

Radar measurements taken in early March rule out any chance of a collision with 99942 Apophis over the next 100 years. When scores of asteroid specialists convened virtually for a special three-day conference dedicated to Apophis last November, there was still a small chance of a 2068 impact. That was in part because its exact orbit was still uncertain, especially since Apophis's close approach to Earth on April 13, 2029, will alter the asteroid's path significantly. Fortunately, another opportunity for orbital refinement occurred on March 5th, when Apophis cruised by Earth at a distance of 17 million kilometers (10½ million miles). Using ground-based radar to determine the precise distance to Apophis and its line-of-sight velocity as it sped by, astronomers ruled out the already-remote chance of an impact in 2068. So now, no longer worried about 2068, astronomers are generating plans for how they'll observe Apophis when it brushes by in 2029. When closest, within 32,000 km (20,000 miles) of Earth's surface, the asteroid will appear as bright as a 4th-magnitude star.

■ J. KELLY BEATTY

Read the full story at https://is.gd/Apophis2068.

Pristine Interstellar Comet

Initial observations indicated that the interstellar comet 2I/Borisov, which zipped nearest the Sun in late 2019 (*S&T:* Jan. 2020, p. 10), was a dark-reddish object just like any of the long-period comets that loop in from the Oort Cloud. But new analysis appearing March 30th in *Nature Communications* reveals that Borisov was actually unique — the most pristine sample of a planet-forming system ever observed. Stefano Bagnulo (Armagh Observatory, UK) and colleagues measured visible and near-infrared light scattered by its *coma*, the diffuse "atmosphere" of gas and dust around the comet. Its high degree of polarization indicates that the dust grains in the coma are tiny, on the sub-micron scale, says team member Ludmilla Kolokolova (University of Maryland). Borisov's polarization pattern is unique among solar system comets except for Comet Hale-Bopp (C/1995 O1). The dust particles suffusing Hale-Bopp's coma were likewise small compared to those in other observed comets. Moreover, it was visible to the naked eye for a year and a half, a record that jived with scientists' assessment that Hale-Bopp had only approached the Sun once before. The similarities between the two suggest Borisov's encounter with our Sun was the first time it had come close to any star, including its own. If it originated far out from its host before being ejected into interplanetary space, our Sun would have been the first star to trigger its cometary activity.

■ MONICA YOUNG

Read more Borisov findings at https://is.gd/Borisovdust.

NOIRLAB / NSF / AURA / J. DA SILVA

Eavesdropping on Mars

The most compelling audio the Perseverance rover will record might well be the sounds it generates itself.

▲ The Perseverance rover took this selfie on March 7, 2021, during sol 16 of the mission.

NASA / JPL-CALTECH

I WAS STOKED WHEN I heard they were putting microphones on the Perseverance rover. Of all the instrument data we use to understand other planets, visual images are always the most compelling because they connect directly to our senses, with no interpretation needed to grasp a lot about each new place. Sound recordings ought to do this as well: provide something we can relate to directly and feel what it would be like to be there.

Shortly after the thrill of the rover's landing at Jezero Crater in February, we were treated to the first release of audio from Mars. What we heard, of course, was wind. We already knew that the Red Planet has wind, but when we finally heard it, we learned that wind on Mars sounds . . . like wind.

At first it was haunting to hear those distant zephyrs and realize they truly were recorded on another world. They were strangely gentle and quiet, because Mars's carbon-dioxide atmosphere is just 1% as dense as Earth's. Plus, there's scientific value in sounds the rover records. With the very first zap of the robot's SuperCam laser on rock, for instance, the mission team measured the speed of sound on Mars for the first time ever. As SuperCam Principal Investigator Roger Wiens told NPR, it's just a little over two-thirds as fast as it is on Earth.

I have to admit, though, that after listening several times to that Martian breeze, I found it anticlimactic and dissatisfying for a couple of reasons.

First, what we heard was not really sound, but the wind noise that is made when a breeze strikes the diaphragm of a microphone, converting the motion into an audio signal. That rumbling, popping sound is familiar to us from recordings made here on windy days, but it's not what you'd really hear if you were standing outside on Mars at the time (even if you could be listening without a helmet).

Since the Perseverance team released those first sounds of wind and laser zaps, we've heard the rover's metal wheels crunching over stony terrain and its various instruments in operation (hear these recordings at **https://is.gd/marssounds**). These sounds, too, have value — to engineers operating the rover and to scientists determining which rock samples to cache for later return to Earth (a major mission objective).

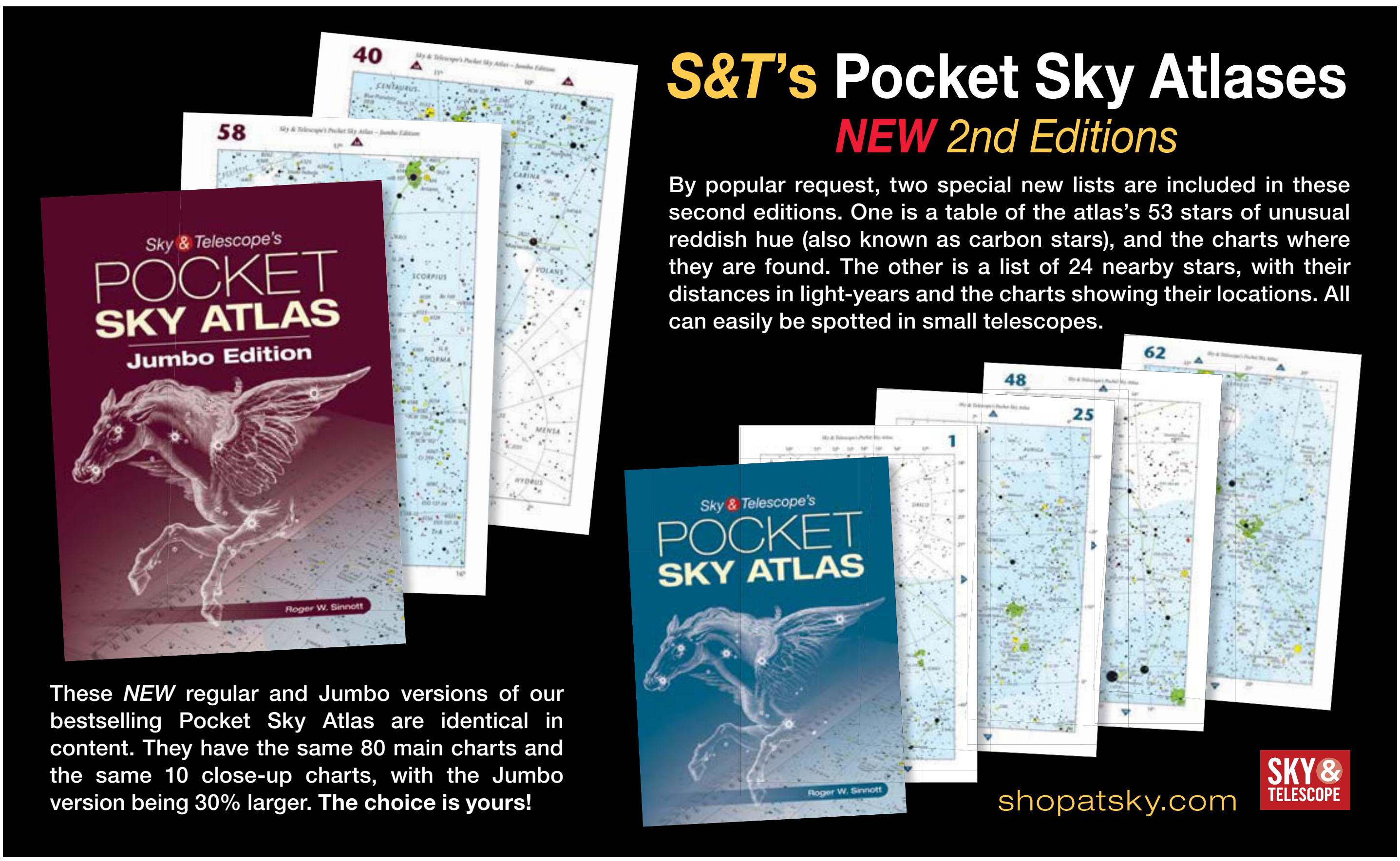
Beyond the audio of wind and rover, though, we don't expect to hear anything. Those two types of sounds represent Mars's greatest sonic hits.

Alas, compared to Earth, with its chirruping birds, rustling leaves, and cracking thunder, to say nothing of the music, traffic, and laughter that human beings generate, Mars is bound to be a pretty boring place, sonically. Perhaps we'll find places where breezes whistle as they reverberate through wind-sculpted canyons. There may be storms so ferocious that the wind will howl past Perseverance, and we may hear the hiss of wind-carried dust particles pelting the rover. But by and large I'm not hopeful, beyond that initial novelty, of being greatly surprised or delighted by fresh sounds from Mars.

In the end, Jezero Crater is profoundly interesting not for what we hear there today but for what happened there billions of years ago, when free-flowing streams were gurgling and — just maybe — something was swimming or even singing.

■ Astrobiologist **DAVID GRINSPOON** is Senior Scientist at the Planetary Science Institute in Tucson, Arizona.


NEW
CEM70G
First Center Balance Mount with a Built-in Guiding Camera
Two elements contribute to the CEM70G's competence as an imaging platform: the natural stability of iOptron Center Balance Mounts and the new integrated guide camera. Add in a 70-lb payload capacity, an iPolar electronic polar-alignment device, WiFi, USB 3.0, and the advanced cable management system, and the picture becomes clear that this capable mount offers extensive astrophotography capabilities.
CEM70G, M.A.P. $2,948.00
© 2021 iOptron® All rights reserved
iGuider
USB3. 0x3
iOptron®
www.iOptron.com


S&T's Pocket Sky Atlases
NEW 2nd Editions
By popular request, two special new lists are included in these second editions. One is a table of the atlas's 53 stars of unusual reddish hue (also known as carbon stars), and the charts where they are found. The other is a list of 24 nearby stars, with their distances in light-years and the charts showing their locations. All can easily be spotted in small telescopes.
Sky & Telescope's
POCKET
SKY ATLAS
Jumbo Edition
Sky & Telescope's
POCKET
SKY ATLAS
These NEW regular and Jumbo versions of our bestselling Pocket Sky Atlas are identical in content. They have the same 80 main charts and the same 10 close-up charts, with the Jumbo version being 30% larger. The choice is yours!
shopatsky.com
SKY & TELESCOPE

A combination of observations and simulations is upending our ideas about how globular clusters formed.

Ask astronomers what a globular cluster is, and they are likely to show you a picture of a glorious, dense ball of stars. These tight-knit stellar families hover like ancient swarms of bees around the Milky Way and galaxies like it, and they carry unique information about the conditions under which their host galaxy assembled in the early universe.

For centuries, astronomers have attempted to figure out how globular clusters formed. While doing this work, we have historically made a distinction between sparser *open clusters* like the Pleiades and globular clusters. Open clusters (see page 22) typically contain 100 to 100,000 stars, with a chemical composition similar to the Sun's; they are generally less than a billion years old, and we usually find them in the disk of the Milky Way. By contrast, globular clusters contain around 100,000 (but up to a few million) stars, with only a few percent of the heavy element content of the Sun. They are more than 10 billion years old — nearly as old as the universe itself — and they loop around the Milky Way in a halo-like configuration.

This might be a convenient division, but how would we categorize a globular cluster with an atypical age of only a billion years, or an open cluster residing outside of the Milky Way's disk? Such objects exist, too. Their existence tells us that the distinction between open and globular clusters might be an oversimplification. By the end of this article, you will know why.

Since William Herschel first introduced the term *globular cluster* in 1789, the puzzle of these objects' origin has inspired dozens of theories. Broadly speaking, there have been two families of ideas. In the first, globular clusters

▶ **MESSIER 92** This Hubble Space Telescope image shows the heart of M92 in Hercules. At magnitude 6.5, the cluster is one of the brightest globulars in the Milky Way. It contains more than 300,000 stars.

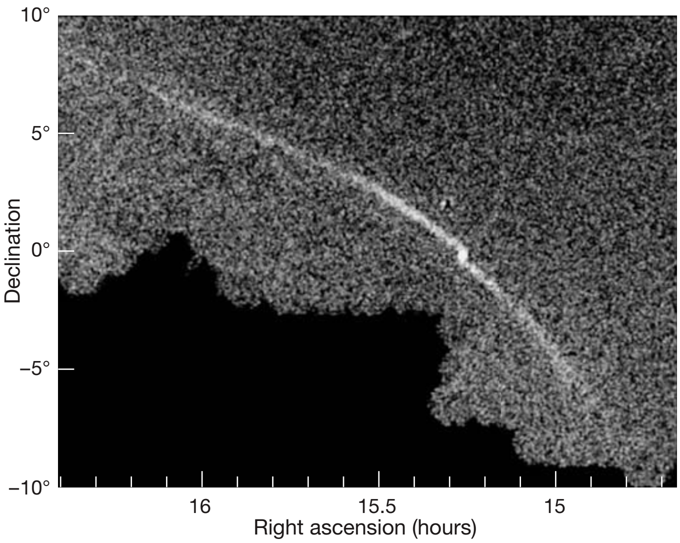
NASA / ESA / GILLES CHAPDELAINE

Relics of a Di

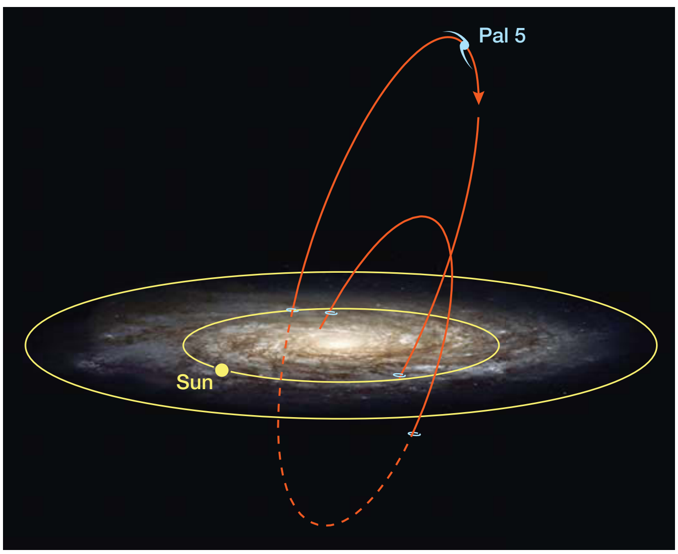
stant Past

are the outcome of unique conditions that only occurred in the early universe. These scenarios take various forms. Towards the second half of the 20th century, some of the first models described globular cluster formation in the hot gaseous halos surrounding massive galaxies shortly after the Big Bang. In the subsequent decades, others developed a variety of new models suggesting that globular clusters instead formed during major galaxy mergers (which were more common in the early universe); that each formed within its own dark matter halo; or that they represent the former nuclei of dwarf galaxies, shredded by a larger galaxy's gravitational forces.

In the years since, it has become clear that none of these ideas can explain the origin of most globular clusters: Not all galaxies are massive enough to have had hot gaseous halos or major mergers, there's no evidence the clusters host dark matter, and there are not enough dwarf galaxies in the universe to account for the star clusters' observed ubiquity. In short, the existence of globular clusters requires another explanation.



▲ **DISRUPTED CLUSTER** This composite image reveals the core and long tidal tails of the globular cluster Palomar 5, an 11.8-magnitude target in the constellation Serpens Caput.



▲ **PALOMAR 5** Based on the globular cluster's tidal tails, location, and motion, astronomers have reconstructed Palomar 5's orbit around the Milky Way.

Over the last decade or so, another idea has steadily gained traction, inspired by cluster formation we've observed in nearby galaxies. Even at the present day, there exist rare galaxies with global properties that were common in the early universe, such as extremely high gas pressures and rates of star formation — the latter up to 1,000 times higher than in the current Milky Way. In the few galaxies where these conditions can be found today, astronomers made an astonishing discovery: Young globular clusters are still forming. Not only does this disprove the idea that the conditions needed for their formation were unique to the early universe, it also provides an unprecedented opportunity to witness the conditions that might have governed their formation.

The discovery prompted a major rethink. Could globular clusters be the products of "normal" cluster formation in the early universe, which then survived until the present day?

This is a simple question, but it is extremely challenging to answer. We can only do so by constructing a complete model for star cluster formation and evolution, linked to the formation and evolution of the galaxy these clusters reside in. And such a model itself also needs to overcome a difficult problem: It must naturally explain why today's population of globular clusters differs considerably from the population of open clusters in so many ways, from ages and number of stars to location. Could open and globular clusters really be two extremes of the same types of object, formed through similar physical processes?

A series of pen-and-paper models soon demonstrated that the idea could work in principle. These models predicted that galaxies with higher gas pressures and star formation rates would form a larger fraction of their stars in compact clusters, and also allow the formation of more massive clusters. Observations of nearby gas-rich, cluster-forming galaxies confirmed these predictions. This was good news. At least it seemed possible for globular clusters to form under early-universe conditions, and quite commonly so. But what would happen to them over the billions of years of evolution since?

Destined for Destruction

Star clusters do not have everlasting life. Over time, clusters gradually dissolve due to three main processes, each of which we must account for if we are to understand how globular clusters formed and evolved into the objects that we see around galaxies today.

First, as stars in the cluster reach the end of their lives, they either explode as supernovae or, if they're less massive, gently shed their outer layers. In response to the loss of material, the cluster expands and the gravitational attraction between its stars weakens, enabling the most loosely bound stars to escape.

PALOMAR 5: ANA BONACA AND THE DESI LEGACY IMAGING SURVEYS (LEGACYSURVEYS.ORG); ORBIT DIAGRAM: SDSS AND STSCI / NASA

Second, the gravitational interactions between stars drive repeated dynamical slingshots that cause a cluster to expand. Stars pushed to the outskirts succumb to the galaxy's tidal pull and feed a consistent stream leaving the cluster. In the Milky Way, we observe such streams as long tidal tails emerging from globular clusters.

The third and final process turns out to be crucial, but historically it's received less attention. Whenever a cluster encounters another massive object, stars in the cluster are accelerated by the massive object's gravitational pull, often to velocities that allow them to escape the cluster. This is called a *tidal shock*, and it also happens when a cluster passes through a densely packed region, such as when it crosses the galaxy's disk or a spiral arm, or when it encounters a gas cloud within the galaxy. Tidal shocks are crucial in the history of globulars, because they occur frequently and are highly efficient at destroying clusters.

As if that huge diversity of mechanisms isn't enough, the story gets even messier. The processes driving cluster formation and destruction depend on the galactic environment. Newborn clusters differ depending on whether they're born in a dwarf galaxy or in a massive galaxy like the Milky Way. The rate of cluster destruction also differs between these cases. Destruction is especially common when a cluster resides within a galactic disk, where it frequently encounters gas clouds. The repeated tidal shocks rapidly destroy the cluster.

On the Cosmic High Seas

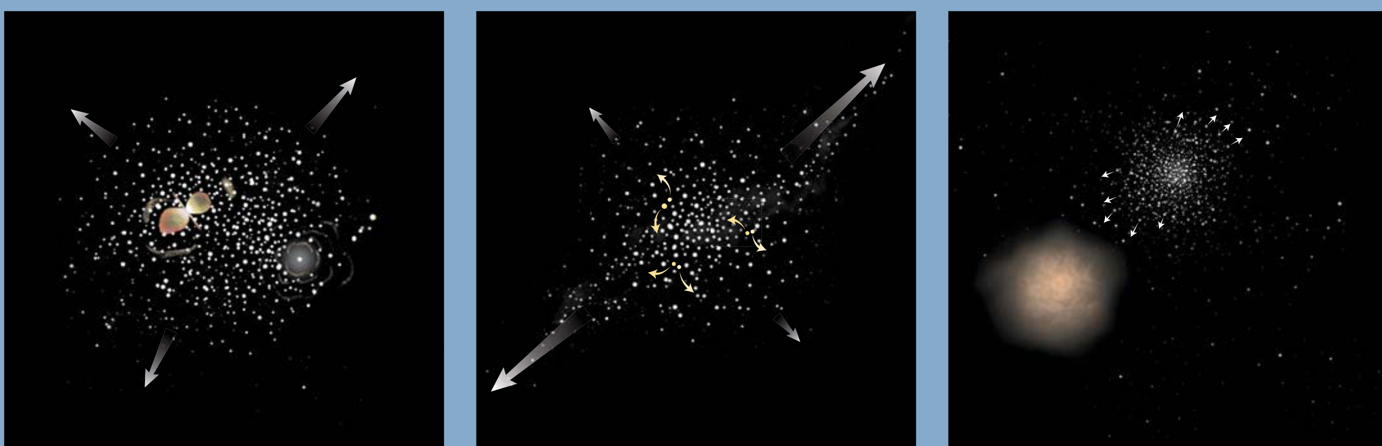
To understand the origin of globular clusters, we must combine the physics of cluster formation and destruction and

▲ **YOUNG GLOBULAR** This infrared Hubble image reveals the globular-like cluster R136 (right) in the Large Magellanic Cloud's star-forming region 30 Doradus. The cluster is only a few million years old.

STAR CLUSTER IN LMC: NASA / ESA / F. PARESCE (INAF-IASF, BOLOGNA, ITALY) / R. O'CONNELL (UNIV. OF VIRGINIA, CHARLOTTESVILLE) / WFC3 SCIENCE OVERSIGHT COMMITTEE; HOW STAR CLUSTERS ARE DESTROYED: GREGG DINDERMAN / *S&T*

HOW STAR CLUSTERS ARE DESTROYED

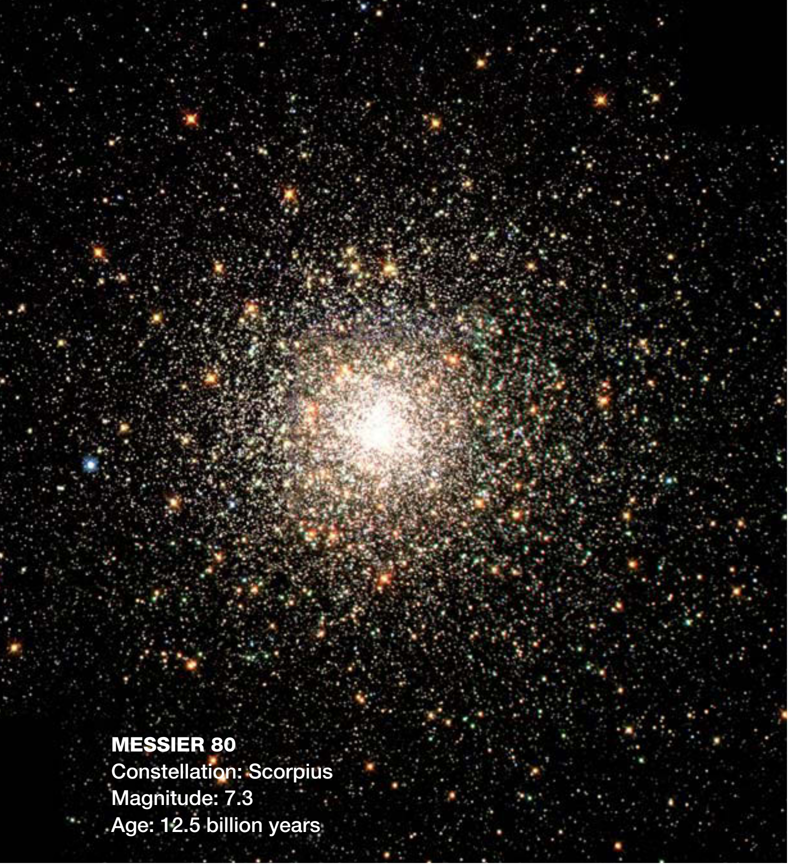
Three main processes dissolve a galaxy's star clusters.



Dying stars expel or redistribute material, weakening the stars' mutual gravitational attraction. The cluster expands.

Gravitational interactions sling stars around, making the cluster expand. Stars on the outskirts succumb to the galaxy's tidal pull and escape as streams of stars.

Encounters with gas clouds or dense regions in the galaxy's disk pull stars in the cluster toward the massive object, compressing and distorting the cluster. The *tidal shock* accelerates stars to velocities high enough for them to escape the cluster's self-gravity.



MESSIER 80
Constellation: Scorpius
Magnitude: 7.3
Age: 12.5 billion years

Stellar Souvenirs

Based on a combination of simulations and the ages and heavy-element content of the Milky Way's most massive globular clusters, roughly 40% of these stellar metropolises may come from galaxies that merged with ours.

place it in the context of the evolving conditions within galaxies, from the Big Bang till the present day. When undertaking the enormous challenge of combining all aspects of the problem into a single model, it is clear that this model cannot get everything right. But it is the only way of learning which elements are the most important.

In early 2014, I gave it a go. Armed with pen and paper and the simplest possible descriptions of all of the mechanisms discussed above, I tried to formulate a quantitative model for the origin of globular clusters. I started with the simple hypothesis that globular clusters resulted from the same, well-understood physics that governs open cluster formation and destruction in nearby, present-day galaxies, but applied to the extreme conditions observed in galaxies forming 12 billion years ago. The goal was to then predict the properties of the globular cluster population observed today.

Expressed in words, the model roughly works as follows. Galaxies in the early universe had high gas pressures and densities, which led to widespread star cluster formation. Most of these clusters had small numbers of stars (just like open clusters), but the high gas pressures sometimes compressed the gas sufficiently to enable the formation of very massive clusters, containing millions of stars. After their birth, these clusters thus had a wide variety of sizes. Because they resided within the gas-rich environment of their natal galaxy, they frequently encountered gas clouds. The resulting tidal shocks decimated the cluster population. The biggest clusters, with the largest numbers of stars, were able to survive the longest. But even they would need rescuing.

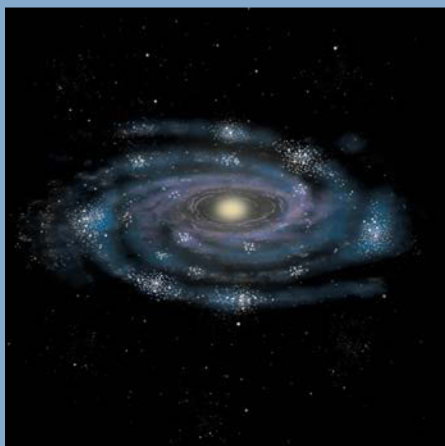
The earliest epochs of cosmic history were a celestial Wild West. Galaxies continuously collided and merged with one another, assembling into bigger galaxies in the process. These collisions completely transformed the galaxies, disrupting and later reforming their gas-rich disks, as well as throwing stars and stellar clusters into their gas-poor halos.

This was the lifeline the biggest clusters needed. By being thrown out of the stormy seas of their natal galaxy's disk and into the silent waters of its gas-poor halo, they escaped destruction by tidal shocks from encounters with gas clouds. Instead, they would only continue to dissolve by stellar deaths and internal gravitational interactions among stars. And these processes are slow — slow enough to allow globular clusters to survive for the age of the universe.

Despite its simplicity, this model naturally explains the differences between open and globular clusters as products of the same processes. Gas-rich galaxies in the early universe had the conditions necessary to form massive clusters and destroy the smaller ones through tidal shocks. Owing to the frequent collisions between galaxies, the surviving, massive stellar clusters were often ejected into the halo of the merger remnant, where we still see them today as globular clusters. By contrast, galaxies today are less gas-rich and form smaller clusters. These open clusters might initially survive a little longer, because tidal shocks are less frequent and severe, but eventually they are destroyed, because their rescue never comes: As the universe expanded, galaxy collisions became less common, such that modern galaxies like the Milky Way

M80: THE HUBBLE HERITAGE TEAM (AURA / STSCI / NASA); HOW GLOBULAR CLUSTERS SURVIVED: GREGG DINDERMAN / S&T

HOW GLOBULAR CLUSTERS SURVIVED



Star clusters form in galaxies full of dense gas. The most compressed gas can form massive clusters, with millions of stars.

rarely merge with similar-size (or bigger) galaxies. As a result, open clusters cannot escape into the safety of their natal galaxy's halo, like globular clusters once did.

Toward a Complete Picture

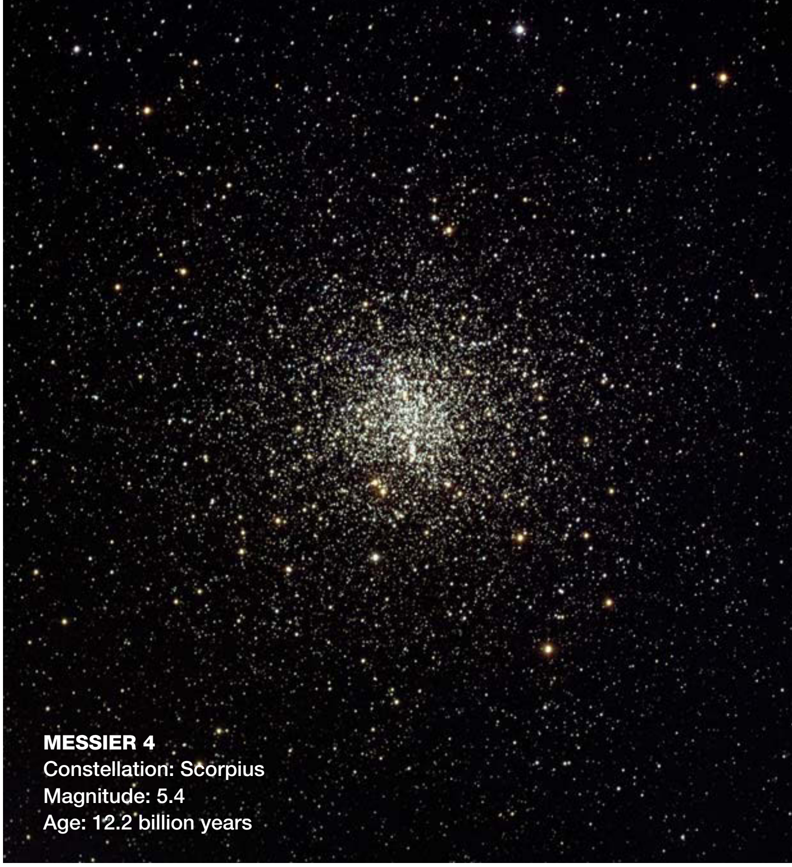
These are all interesting ideas, but the complexity of the problem means that we cannot conclusively solve it with pen and paper alone. The true test must come from running sophisticated computer simulations that combine the formation and evolution of star clusters with that of galaxies, and then comparing the results with observations.

In recent years, a variety of teams has started to develop such simulations, with world-leading groups in the U.S., UK, and Germany, among many others. This concerted effort of the astronomy community has brought about a revolution in globular cluster formation research. For the first time, we have state-of-the-art simulations that can link the conditions of star and cluster formation in the early universe to the globular clusters that we see today.

I set out with a team of collaborators in Liverpool and Heidelberg to develop the E-MOSAICS simulations for this purpose. To date, these simulations are the only ones that combine a description of all the cluster formation and destruction physics discussed above (MOSAICS) with a leading galaxy formation model (EAGLE). As such, they are the ultimate computational testbed for the idea that globular clusters are the natural outcome of regular cluster formation in the early universe.

Over the past few years, we have found that the E-MOSAICS simulations do surprisingly well in most areas. They closely reproduce the properties of young ("open") clusters forming today, most importantly their numbers of stars and their ages. Encouragingly, they also simultaneously reproduce most properties of globular clusters, such as their spatial distributions, their orbital motion around the host galaxy, their ages and chemical compositions, their large numbers of stars, and the number of globular clusters per galaxy. In itself, this is an enormous step, because no theory for globular cluster formation has ever reproduced the observed properties of the globular cluster population in such detail. This means that the premise of the simulations works: Globular clusters can indeed be seen as the products of regular cluster formation at early cosmic times.

Now that we have a reasonable model for the origin of



MESSIER 4
Constellation: Scorpius
Magnitude: 5.4
Age: 12.2 billion years

M4: NOAO / AURA / NSF

Encounters with gas clouds decimate the star clusters. The biggest clusters in the galaxy survive the longest.

Galaxy mergers throw star clusters out of their disrupted, gas-rich disks into the surrounding gas-poor halos.

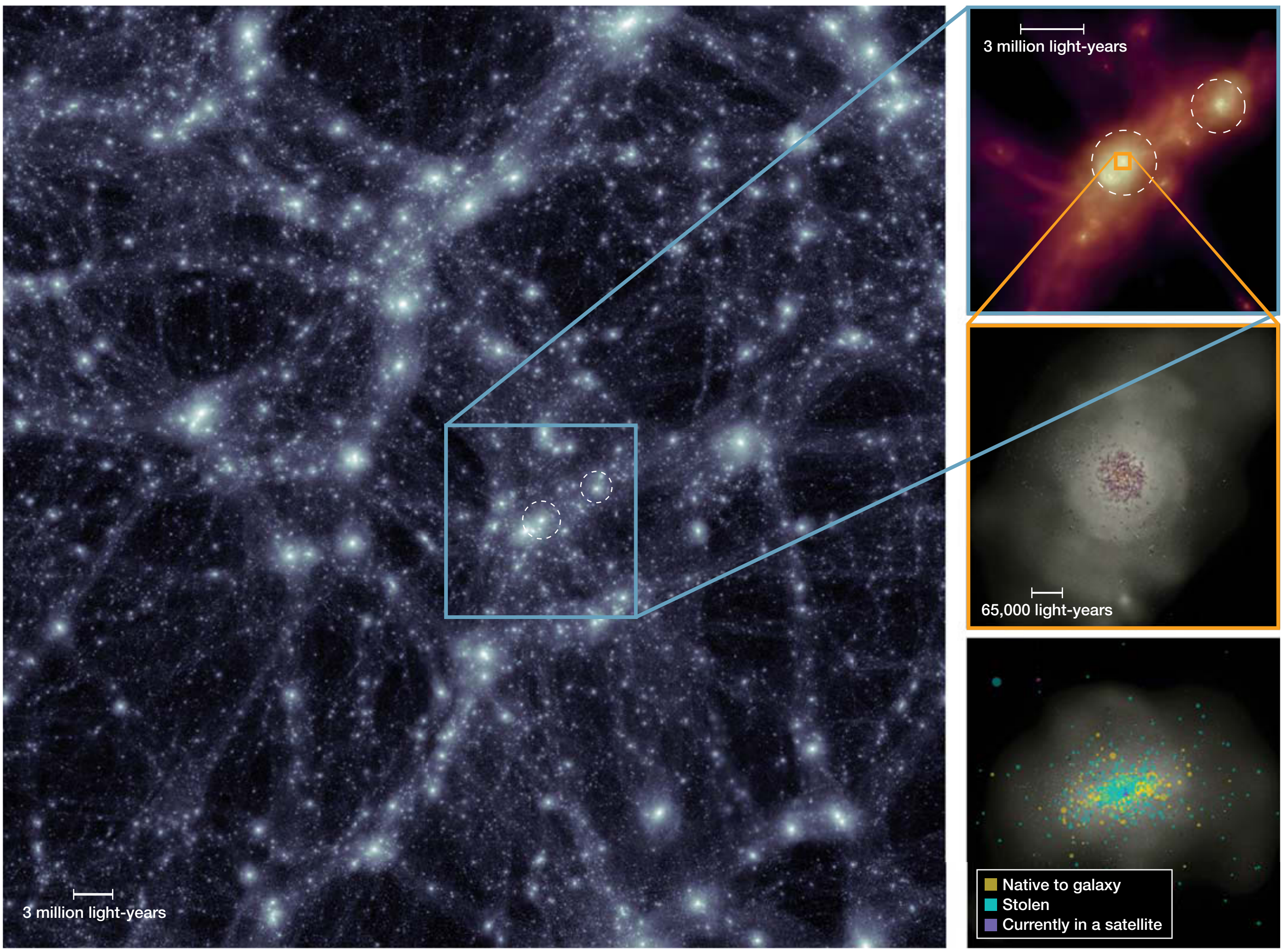
As the transformed galaxy settles down, the ejected clusters stay in the halo, largely safe from disruption. These are the globular clusters we see today.

globular clusters, we can also use the clusters to learn how galaxies like the Milky Way formed. From E-MOSAICS, we learned how the numbers, ages, chemical compositions, and orbital motion of (groups of) globular clusters around a galaxy can be linked to its assembly history. We found that galaxies with a higher number of globular clusters typically had experienced more collisions with other galaxies, and the globular clusters residing farther from the galactic center generally formed in smaller galaxies that were then eaten by the large one. By applying these insights to the properties of globular clusters in the Milky Way, we have been able to reconstruct our home galaxy's family tree, showing the sizes of galaxies it merged with and when this happened.

In itself, this is only a prediction. The true revolution comes from combining this theoretical family tree with the observations by spectacular new telescopes. Specifically, the European Space Agency's Gaia satellite has the unique ability to measure the motions of stars and globular clusters, allowing astronomers to search for the debris of galaxies that merged with the Milky Way many billions of years ago. Applying the input from E-MOSAICS to the Milky Way's globular clusters, we predicted the existence of about 15 galaxies that once merged with our home galaxy (*S&T:* Mar. 2021, p. 11). Of these, astronomers have already discovered the debris of five. Three of these were found with Gaia, and two of those three we predicted before discovery: They are now known as Gaia-Enceladus and Kraken. The remaining 10 or so galaxies await confirmation.

The Definitive Test

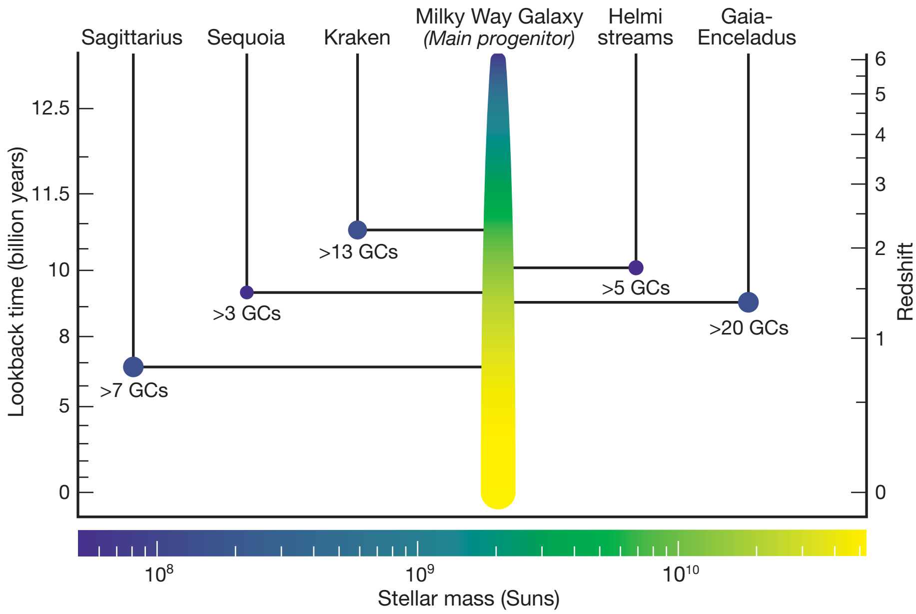
Despite these initial successes, there is much left to learn. The most successful models for globular cluster formation take the detailed observations of (open) star cluster formation in nearby galaxies, including their dependence on the galactic environment, and then apply these to the global conditions observed in early-universe galaxies. Even if these models are



▲ **E-MOSAICS** The author and his collaborators zoomed in on galaxies in a cosmological simulation and re-simulated how they and their star clusters changed with time. The large panel at left includes only dark matter; the top right panel shows gas density (white is hotter). Zooming in to just one of the galaxies reveals a complex mix of star clusters — some are native to the galaxy, while others formed in other galaxies that later merged with this one or still reside in satellite galaxies that will eventually be accreted.

J. M. D. KRUIJSSEN ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY* 2019 successful in reproducing both the properties of clusters forming today and the final properties of globular clusters, the true test would be to also reproduce the properties of globular clusters *at the time of their formation*.

Due to the speed at which light travels, we can look back in time by observing galaxies that are more distant. The peak of globular cluster formation occurred more than 10 billion years ago. The distances our observations need to bridge in order to see this far into the past are so large that galaxies reduce to faint blobs that barely stick above the noise levels of our telescopes' detectors. As a result, nobody has ever been able to directly observe the formation of an individual globular cluster in these early galaxies.

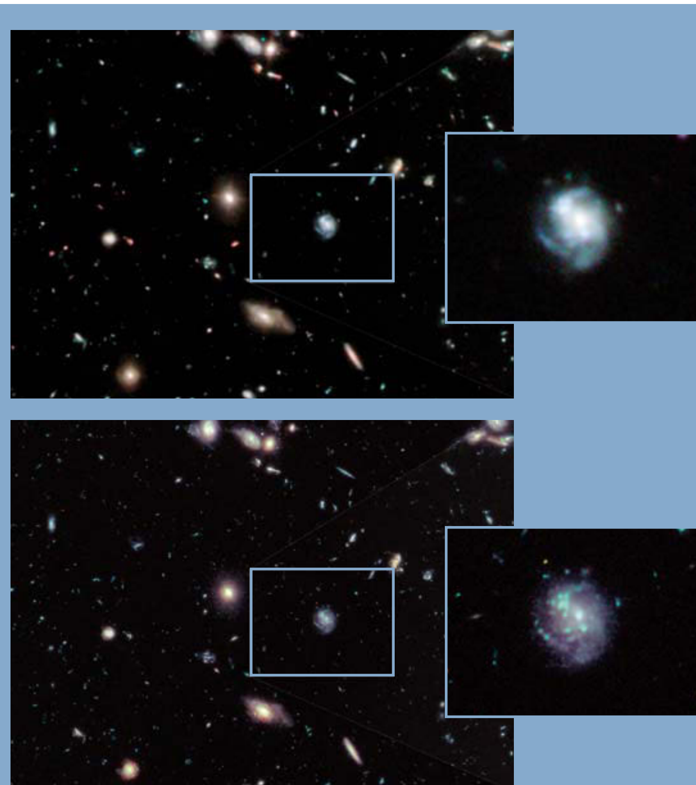


▲ **THE MILKY WAY'S MERGER TREE** Based on simulations, the author's team predicted our galaxy has likely collided with 15 galaxies over cosmic time. Astronomers have found evidence of five, shown here with the minimum number of globular clusters they brought with them. Most of the other mergers likely happened earlier, during the galaxy's first two billion years. Collision times are approximate.

But that will hopefully soon change. With the planned launch of the James Webb Space Telescope later this year and construction of ground-based telescopes with mirrors around 30 meters across (*S&T:* Nov. 2018, p. 14), it will be possible for the first time to detect young star clusters in early-universe galaxies. Our new framework makes a clear prediction: The formation of the globular clusters that survived to the present day should be accompanied by the formation of many more, smaller clusters that got destroyed shortly after they were born — unlike what we expect based on previous theories, which predict that globular clusters are unique creations, not part of a larger flurry of star-cluster formation. By testing these and other predictions against these revolutionary observations, the mystery of globular cluster formation might finally be solved.

This ultimate test could not come at a better moment. With Gaia observations continuing and increasingly sensitive telescopes like the upcoming Vera C. Rubin Observatory enabling the detection in other galaxies of debris from dissolved star clusters and their hosts, a comprehensive framework for globular cluster formation would provide a unique perspective on galaxy formation and assembly. In the Milky Way, the use of globular clusters has enabled the reconstruction of its family tree. If you think that's exciting, wait until we can do the same for dozens of galaxies across the universe. Globular clusters have always been enigmatic, but as we get closer to uncovering their origins, they inevitably lead us on to confront even bigger mysteries.

■ **J. M. DIEDERIK KRUIJSSEN** is an astrophysicist at Heidelberg University in Germany and originally comes from a tiny country that used to sail the seas. He became a cosmic explorer when he realized that we no longer need a boat to discover new worlds — a telescope does the trick, too.



▲ **HST VS. JWST** The top two images are infrared composites that show distant galaxies in the Hubble Ultra Deep Field. The bottom images are simulations of what the same deep field may look like with the James Webb Space Telescope's near-infrared camera. Note the bright star-forming regions in the JWST close-up.

MILKY WAY MERGER TREE: LEAH TISCIONE / *S&T*, SOURCE: J. M. D. KRUIJSSEN ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY* 2020; HST VS JWST: ANN FEILD / STSCI

Open Cluster E

Worlds found in open clusters are giving astronomers a unique perspective on how planetary systems come to look the way they do.

Open clusters, often glittering against a black velvet background, beckon astronomers both amateur and professional. But beauty aside, these young troupes of stars are also important for studies in stellar evolution. Stars often form clumped together — in part inheriting the complex shapes of the giant molecular clouds that collapse and make them. Over time, loosely held families simply disperse, but open clusters last longer because their stars are actually gravitationally bound to one another. Eventually, the galactic tide gently tears these clusters apart. The stars disperse, becoming the solitary field stars scattered across tonight's sky. Because of this disruption, the open clusters we see today are generally young, less than a few billion years old.

That same youthfulness has in recent decades led astronomers to use open clusters as important testbeds for theories about both the time frames and early processes of planetary formation, which led to the systems we see around older stars today. We think that planets form in the first few tens of millions of years after a molecular cloud collapses to form a star and its surrounding protoplanetary disk. This early stage determines much of the world's chemical makeup (*S&T:* Dec. 2020, p. 20). But it is the subsequent few hundred million years of a planet's life that are arguably its most formative: Its orbit may shift dramatically during this period, and radiation from its parent star may bloat or tear its atmosphere away.

In the Eye of the Bull

In 2014, the International Astronomical Union (IAU) launched a global competition for the public to suggest popular names for 305 exoplanets. Epsilon Tauri b was one of the 30-odd worlds given names and is now officially known as Amateru — a Japanese name for Shinto shrines of the goddess Amaterasu, who was born from the left eye of the god Izanagi. However, professional astronomers don't regularly use the popular names, since they're not as informative as the constellation-based designations.

To test these theories, though, astronomers need to find young exoplanets. Open clusters offer excellent opportunities. Unlike with field stars, astronomers can determine the age of open clusters quite well (*S&T:* Nov. 2020, p. 28). And by exploring exoplanets in today's open clusters, we can better understand the origin of some of the strange planetary systems we've observed elsewhere.

Exoplanet Doubts

In 1996, Kenneth Janes (Boston University) proposed that by targeting several well-known open clusters, astronomers could determine in just a few years how common planetary systems are in these environments.

Independently that same year, a team of astronomers led by William Cochran (University of Texas, Austin) began a survey of 98 dwarf stars in the Hyades open cluster using the 10-meter Keck I telescope on Mauna Kea. While the observers identified several promising candidates during the first five years of the survey, confirmation was not forthcoming. By 2006, several teams had surveyed numerous open clusters and all had been unsuccessful in finding exoplanets.

There were certainly challenges involved in the search. For radial-velocity surveys, young stars tend to be more active, and the "noise" of their spots and flares interferes with the results. For transit surveys, probabilities were not overwhelmingly high that a planet would cross in front of its star in the observing time available with ground-based telescopes, limited as it is by competing observing schedules and nighttime's end — in contrast to space-based missions such as Kepler, which stared at a single field continuously for years. Nevertheless, by the mid-2000s astronomers began to wonder if there was something about the environment of open clusters that prevented the formation of planets.

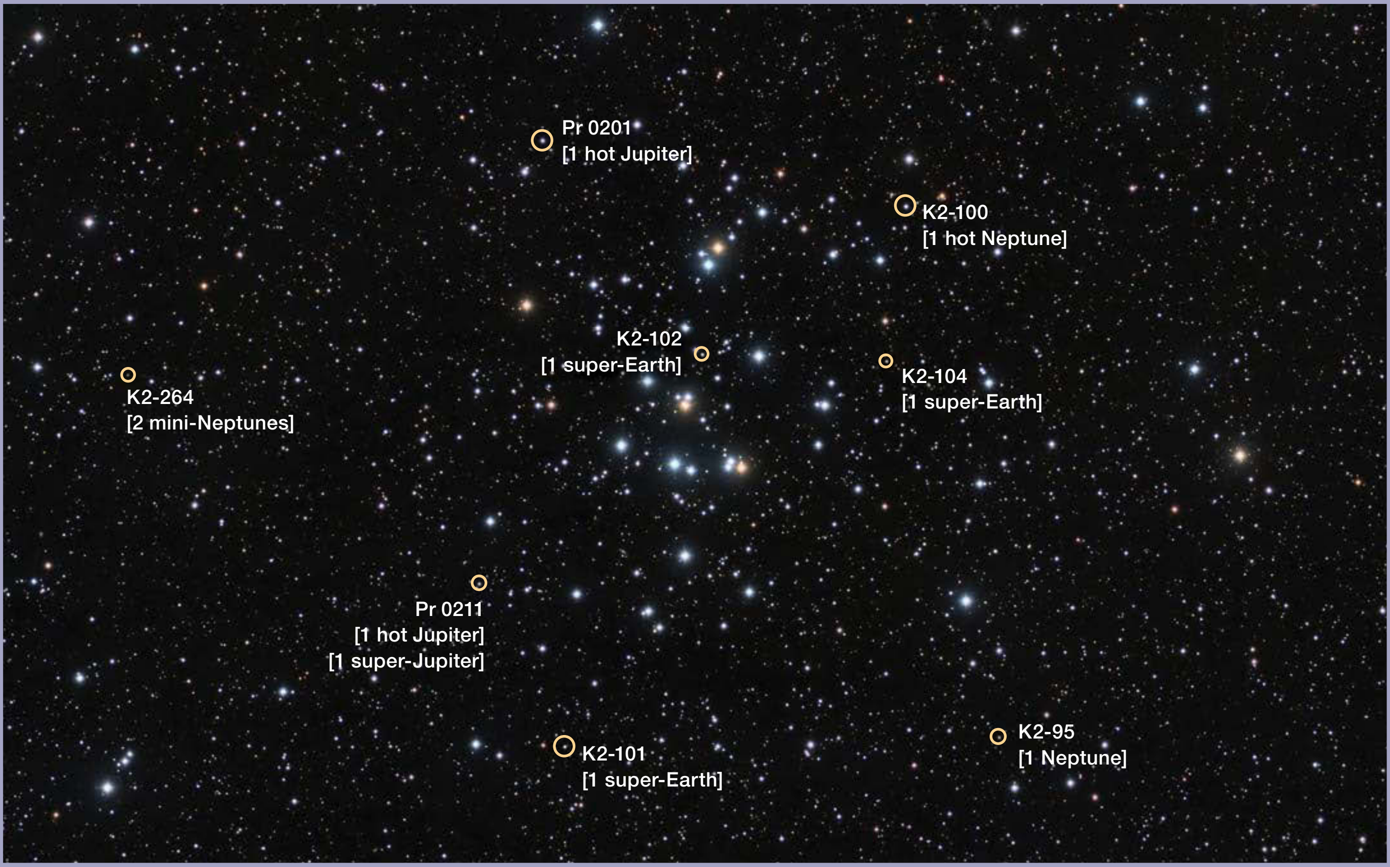
Bull's Eye

The breakthrough finally came in 2007. Bunei Sato (now at the Tokyo Institute of Technology) and colleagues from several institutions in Japan announced the discovery of the first exoplanet in an open cluster, orbiting Epsilon Tauri in the Hyades. Also known as Ain ("eye") and representing the northern eye of Taurus, the Bull, Epsilon Tauri is a 3.5-magnitude orange giant about 2.7 times the mass of our Sun. It's the second-brightest star in the Hyades.

AKIRA FUJII

xoplanets

HYADES AND PLEIADES Astronomers have found several exoplanets around stars in the Hyades open cluster, but so far they've found none in the younger Pleiades (upper right).



▲ **M44** Astronomers have found about 10 exoplanet systems in the Beehive Cluster, many of which are marked here (some are out of the field of view). The open cluster lies in Cancer, the Crab.

RON BRECHER

Between December 2003 and July 2006, Sato and his team took radial-velocity measurements of Epsilon Tauri using the 1.88-m telescope at Okayama Astrophysical Observatory in Japan, as part of an exoplanet search around *G* and *K* giants. From the data they were able to tease out the unmistakable sign of a 7.6-Jupiter-mass planet orbiting Epsilon Tauri every 595 days, at an average distance of 1.93 astronomical units from the star — a trek slightly larger than the one Mars takes around the Sun. The age of the Hyades is around 625 million years, at the time providing the most secure upper limit for how quickly giant planets form.

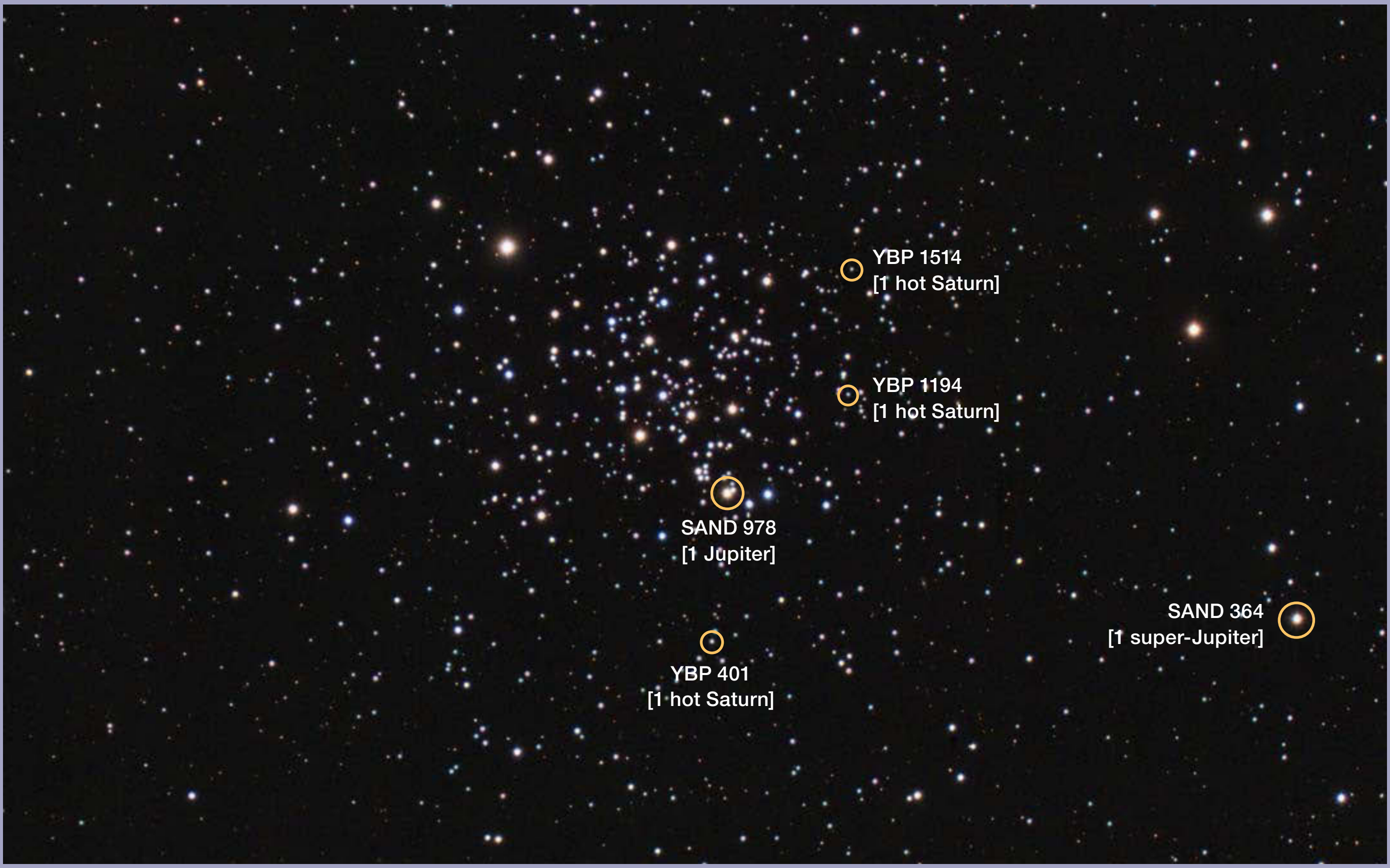
Besides a world around a star in NGC 2423 that might or might not be a brown dwarf, it would be five years before astronomers found more open cluster exoplanets: two gas giants orbiting stars in M44, the Beehive Cluster. Further discoveries trickled in afterwards, but it wasn't until three Jupiter-mass planets were reported around three stars in M67 in 2014 that astronomers felt confident that the frequency of giant planets in open clusters agreed with that for field stars. Today, we know of around 30 exoplanets in open clusters.

Planetary Migration

Back in 1995, when the first exoplanet around a main-sequence star was announced, the most surprising aspect of its nature was that it was a Jupiter-mass planet orbiting close to its parent star. The exoplanet makes one revolution around the field star 51 Pegasi every 4.2 days, at a distance just over 10% that of Mercury from the Sun. Planetary-formation theories at the time didn't consider the possibility of such *hot Jupiters*; we were expecting Jupiter-like planets in Jupiter-like orbits, because we didn't think gas giants could form close to stars. Attention quickly turned to the idea of *planetary migration*, planets moving to different orbits over time.

Two of the leading ideas for planetary migration involve either interactions with the young circumstellar disk or gravitational interactions with other planetary or stellar companions. The time scales for these mechanisms are very different. Circumstellar disks are only expected to survive for around 10 million years, and modeling suggests that the orbits of any planets interacting with the disks would remain circular while the drag brings them in closer to the star.

Gravitational interactions with other bodies can occur over much longer timescales, and unlike disk drag, these lead to the exoplanet's orbit becoming slightly elongated. Over time, tidal interactions with the parent star will circularize the exoplanet's orbit again. There is thus a window in a planet's evolution when the shape of its orbit may tell astronomers how it wound up where it is around its star.



▲ **M67** The discovery of three hot gas giants (labeled here as "Saturns" and with masses roughly 100 to 150 times that of Earth) in this cluster in Cancer helped convince astronomers that planets can indeed form in open clusters.

RON BRECHER

Studying hot Jupiters in young open clusters can help determine which of the above two processes is most important for these worlds' migration. If hot Jupiters are consistently found in circular orbits, and not enough time has elapsed for their orbits to have recircularized, then that would be evidence for disk migration. On the other hand, hot Jupiters in elongated orbits around young stars would support recent encounters with other exoplanets.

Thus far, astronomers have found five hot Jupiters in open clusters. The two in the Beehive, orbiting the stars Pr 0201 and Pr 0211, are in circular orbits. HD 285507b in the Hyades, on the other hand, is in a slightly elongated orbit, similar in shape to Mars's. Discovered in 2014 by Samuel Quinn (now at Center for Astrophysics, Harvard & Smithsonian) and colleagues, the planet's orbit suggests that it could have migrated as a result of gravitational interactions with another body, though as yet no evidence has been found for other planets orbiting HD 285507. However, a follow-up study published last year by Ilaria Carleo (Wesleyan University) and colleagues points to a more circular orbit.

Hopefully, more discoveries of hot Jupiters in open clusters will clarify the picture. As Quinn and colleagues succinctly note in their 2014 study, "a good way to enhance this sample is to continue finding young planets."

Stellar Flybys

Just as the discovery of 51 Pegasi b was a surprise, the many long-period exoplanets found to be on elongated orbits puzzled astronomers. Theories of planet formation had planets forming in orderly fashion in disks around young stars, leaving planets in almost circular orbits, as we see in our own solar system. But planets such as 16 Cygni Bb and 14 Hercules b — discovered in 1996 and 1998, respectively — didn't match that expectation.

Theoretical studies have shown that a Jupiter-like planet in a normal circular orbit can have its orbit altered quite considerably by an encounter between its host star and another star (or binary star). The flyby triggers gravitational interactions between the planets in the system, which change their orbits. Michael Shara (American Museum of Natural History) and colleagues also demonstrated in 2016 that several exoplanets around field stars (HAT-P-32b, HAT-P-2b, HD 80606b, and GJ 876d) have orbits that most likely could have only originated as a result of an early flyby influencing the planets' interactions, back when the host stars were originally in their birth open cluster. Based on their simulations, the astronomers predicted that these planets, rather than being alone, are likely to have distant companions in very elongated orbits.

An opportunity to test this scenario came with the star

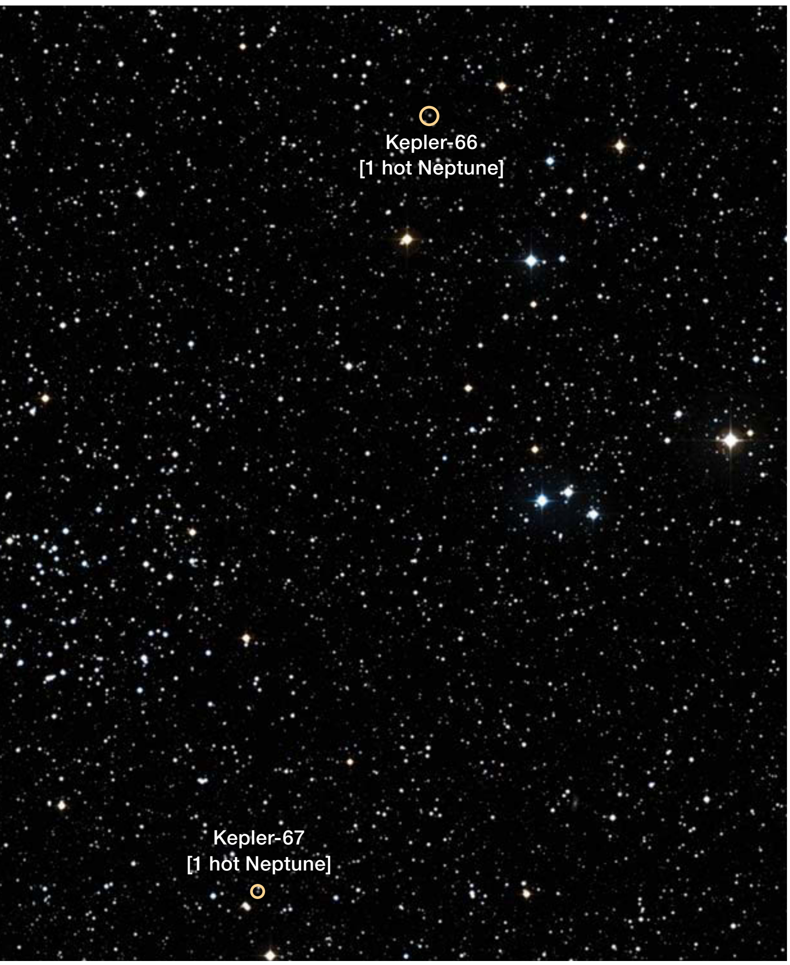
Pr 0211, one of the two in M44 known to have a hot Jupiter (Pr 0211b). Four years after its discovery, Luca Malavolta (University of Padova, Italy) and colleagues reported that continued observations had not only improved the orbital characteristics of Pr 0211b but had also revealed a second planet, Pr 0211c. This marked the discovery of the first multi-planet system in an open cluster. Moreover, the newly found planet was much more massive (at least 7.8 times that of Jupiter), orbiting at an average of 5.5 a.u. from the star every 10 years or so, and with an *orbital eccentricity* of at least 0.6. That translates to the ellipse of the orbit being squashed from a perfect circle by 20%. No planet in the solar system comes close to having such an oblong orbit.

A study published in 2018 by Susanne Pfalzner (Max Planck Institute for Radio Astronomy, Germany) and others explored whether a close flyby of a neighboring star in the Beehive could have led to Pr 0211c's elongated orbit. They modeled the dynamics of stars in an M44-like environment and found that given the frequency of flybys that would lead to a planetary system with orbit shapes and sizes similar to those around Pr 0211, it is quite realistic to consider Pr 0211's planetary architecture as the result of a previous stellar flyby.

Flyby Sculpting

Simulations of M44-like conditions suggest that stellar flybys inside the cluster would force about 14% of planetary systems to be smaller than 10 astronomical units, the size of Saturn's orbit around the Sun. Flybys' influence would be stronger in more massive compact clusters.

▼ **NGC 6811** Astronomers used Kepler to discover two exoplanets around far-flung stellar members of this open cluster in Cygnus, the Swan (the heart of the cluster is the group of stars to the left of center). Although the stars look like they're not part of the cluster, careful observations of their motions and properties confirmed Kepler-66 and Kepler-67 are indeed NGC 6811 members.



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Planetary Atmospheres

Studying young planets is also teaching us how their host stars affect them. Main-sequence stars emit high levels of X-ray and ultraviolet radiation during their first 100 million years or so, with the intensity then steeply declining. Low-mass stars are particularly active. Astronomers expected this radiation would evaporate away the thick gaseous envelopes of planets roughly Neptune's mass or smaller, if they were close enough — say, within a tenth of an a.u.

In 2013, James Owen (now Imperial College London) and Yanqin Wu (University of Toronto) looked at exoplanet candidates and found that indeed, closer-in planets tend to be smaller and denser. They argued that early on, the stars' intense radiation had stripped the planets of their hydrogen and helium gas atmospheres. But these exoplanets were done being downsized; none was caught in the act.

Three years later, Andrew Mann (now University of North Carolina, Chapel Hill) and colleagues announced the discovery of a Neptune-size planet orbiting a star in the Hyades. Using data taken the previous year from the repurposed Kepler spacecraft (the "K2" mission), they found the planet to be transiting a 16th-magnitude red *M* dwarf (cataloged as K2-25) every 3.48 days. Comparing the planet, K2-25b, to older transiting planets with similar orbital periods and host stars, the team found that K2-25b had a significantly larger diameter than its older counterparts. Here was an example, the team argued, of a planet still going through the phase of atmosphere stripping.

That same year, Christian Obermeier (Max Planck Institute for Astronomy, Germany) and colleagues found a Neptune-size planet called K2-95b transiting an *M* dwarf every 10 days in the Beehive Cluster. Again, it exhibited a much larger diameter than older planets in similar orbits around similar stars.

There is at least one possible exception to this trend. In 2019, John Livingston (University of Tokyo, Japan) and colleagues announced they'd found two transiting planets orbiting the *M* dwarf K2-264 in the Beehive. This time, though, neither planet appeared larger compared to similar older planets. However, K2-264 is slightly more massive than K2-25 and K2-95, so it might do less damage to its planets. Livingston warns that there are still too few examples to know for sure what's going on.

Missing in the Pleiades

While exoplanets were being found around several well-known open clusters, one cluster stood out by exception: None had been found in the Pleiades. It was particularly striking comparing the planets detected in the 600- to 800-million-year-old Beehive and Hyades clusters (at least 15) versus the 125-million-year-old Pleiades (nil). This was despite the samples being similar in size (roughly 1,000 stars surveyed in the Beehive and the Hyades combined, and about 1,000 stars in the Pleiades), as well as the stars having similar spectral characteristics.

While it's likely that the level of stellar activity of the young Pleiads interferes with detecting signals from exoplanets, Andrew Mann and colleagues in 2017 suggested that the negative results thus far could instead be an early indication of the time scale of planetary migration. The closer a planet is to its host star, the greater the likelihood it will be detected through its gravitational tug on the star or its crossing the star's face from our point of view. Because the Pleiades are only 125 million years old, it's possible that giant planetary migration hasn't had time to occur yet, whereas it has in the Beehive and Hyades clusters.

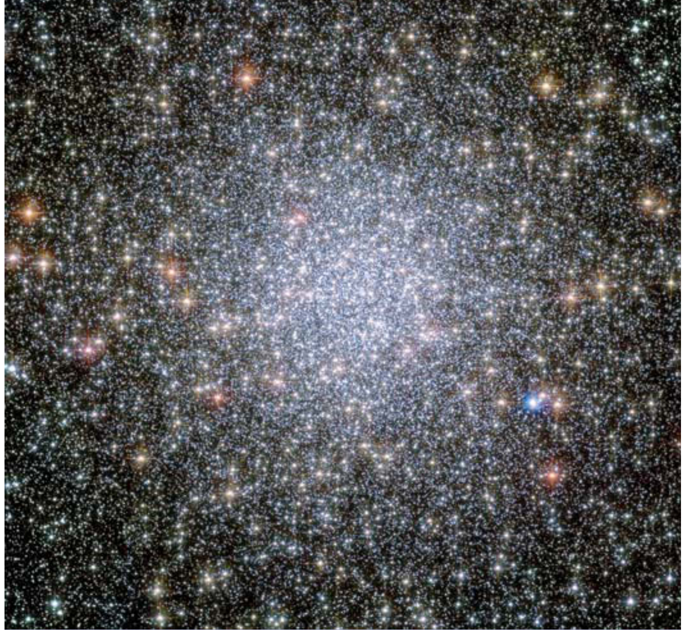
There is circumstantial evidence that the Pleiades *have* produced planets. Work by Lorenzo Spina (now at Astronomical Observatory of Padua, Italy) and colleagues in 2018 identified the chemical fingerprints of rocky material in several Pleiads' atmospheres, which could be explained by small planets having been engulfed by the stars. These small rocky planets would have formed near their parent stars and had short lifetimes, shorter than the time it would take for the outer Jupiter-class planets to migrate inward or be shifted into elongated orbits.

Future Prospects

Long-term monitoring of open clusters is valuable. Astronomers haven't found any long-period, non-eccentric planets in clusters yet. The discovery of such planets would help us better understand the orbital architecture of planet-hosting stars. Cold Jupiters within this population could act as a reservoir for future evolution into hot Jupiters.

For now, the number of very bright nearby clusters that are accessible to ground-based exoplanet searches is limited. But the development of extremely large telescopes in the near future will expand the number of clusters available for study, as fainter stars in more-distant clusters become accessible to radial-velocity and transit studies. The retired Kepler spacecraft helped discover most of the transiting exoplanets now known in open clusters. Immediate prospects for space-based discovery of transiting exoplanets lie with the current TESS spacecraft and the forthcoming European PLATO mission.

Just as the study of stars in open clusters has been one of the foundations of our understanding of stars in general, so too the continued surveying of open clusters for exoplanets and the subsequent follow-up will lead to a much clearer picture of planetary formation and evolution — and provide context for the thousands of exoplanets we know of today.



Planets in Globular Clusters

If open clusters are good areas to search for exoplanets, then surely the vast, ancient stellar populations of a globular cluster would significantly improve the chances of exoplanet transit detections, right? With that in mind, several teams of astronomers searched for transiting planets in the globular clusters 47 Tucanae, NGC 6397, and Omega Centauri. All searches yielded no planets, despite bountiful expectations. Astronomers had predicted 47 Tuc in particular to be one of the better targets due to its higher level of heavy elements relative to other globular clusters.

Observers have so far found only one planet in a globular, and it's a strange case. In 2003, they spotted a planet 2.5 times the mass of Jupiter in M4, orbiting a binary system consisting of a white dwarf and a pulsar. It's possible that the planet is a second-generation planet, formed from material thrown off as the stars aged (*S&T:* Mar. 2015, p. 33).

Astronomers have proposed two factors to account for the lack of planets in globulars. Firstly, the proximity and dynamics of stars in globulars would ensure that close encounters between the stars are relatively frequent, stripping planets from their hosts and creating a large population of free-floating planets. Secondly, hot Jupiters — which the teams were specifically looking for — are more prevalent around younger stars than older stars.

▲ **47 TUCANAE** This globular cluster in the southern constellation Tucana, the Toucan, contains hundreds of thousands of stars but — as far as astronomers can tell — no exoplanets.

NASA / ESA / THE HUBBLE HERITAGE (STSCI / AURA)-ESA / HUBBLE COLLABORATION, ACKNOWLEDGMENT J. MACK (STSCI) AND G. PIOTTO (UNIV. OF PADOVA, ITALY)

Contributing Editor **GREG BRYANT** wonders what planetary surprises await in his other favorite open clusters as seen from his home city of Sydney, Australia.

Sparkles in the Dark

Target these glittering star clusters year-round — they look great even through moonlight.

My mother-in-law, Joy Batt, was a poet, who often jotted down lines on whatever was available wherever she went. One of my favorites was penned on a grocery list:

To you my love I send a thousand stars
To light your soul when all is dark and grey

She and I spent many nights together observing her favorite star cluster, M13, in Hercules. Such stellar groupings have since become regular imaging targets of mine. While they may lack the detail of extended deep-sky objects like galaxies and nebulae, they're colorful and relatively easy to capture, even with modest equipment or under less-than-ideal conditions.

Star clusters come in two main varieties — *globular clusters* and *open clusters*. Globulars are spherical groups of stars containing hundreds of thousands or even millions of stellar members that are gravitationally bound together. They reside, more or less, in the galactic halo outside the main disk of our galaxy, the nearest being tens of thousands of light-years or more away from us (see page 14).

Open clusters are loose, younger groups of stars with dozens to thousands of stars that were born from the same molecular cloud. These are sometimes referred to as "galactic clusters," because they litter the arms of spiral galaxies like our Milky Way.

▲ **DOUBLE TREAT** NGC 884 and 869 in Perseus (left and right, respectively) are a delight to observe or photograph through any optic. The many star colors that the Double Cluster presents are enhanced when shot with Newtonian reflectors, which add diffraction spikes to the brighter stars.

Star clusters are plentiful, presenting a virtually endless choice of fine targets year-round. Perhaps best of all, cluster stars are points of light that shine through even strong light pollution, so you can get a great photographic result whether you image them under a dark, moonless sky or even from urban locations. Here's a selection of many of my favorites visible from the Northern Hemisphere.

Mid-year Targets

Let's begin our tour in Cancer, with **M44** (see page 24). You can record this large cluster in a single, short imaging session. However, accumulating hours of exposure with 6-inch or larger scopes brings out dozens of distant galaxies that appear as little smudges and streaks throughout the field of view. Also known as the Beehive Cluster, M44 contains sev-

ALL PHOTOS COURTESY OF AUTHOR

eral striking gold and blue stars that reward imagers with a colorful result. This is likely why it gets more attention than the other cluster in the constellation, **M67** (see page 25). Unlike those in M44, the stars in M67 are mostly of similar brightness, which results in a more homogenous look.

The appearance of a globular cluster depends mainly on four factors: its size, distance, mix of star colors, and spatial distribution of the member stars. **M53** and **NGC 5053** in Coma Berenices illustrate these differences well. The two globulars appear less than 1° apart, allowing imagers to frame both in a single composition. Both globulars lie at similar distances from us (about 57,000 and 60,000 light-years, respectively). However, M53 is a typical dense globular with a tight concentration of stars in its core, while NGC 5053 is a relatively low-mass globular and is significantly fainter than its neighbor. Images that include both clusters emphasize the diffuse nature of NGC 5053 in comparison to M53.

Moving on to Hercules lands us on one of the best globular clusters visible from mid-northern latitudes: **M13**. We could have a knock-down, drag-out debate about the best photographic globular cluster visible from northern skies. My short list includes **M3**, **M5**, M13, and **M22**. For my money, M22 in Sagittarius would edge out the competition if it were only slightly higher in the sky. It's large and bright with a distinctive oval shape and set against a rich Milky Way background. M13 is large and bright, too, and has a distinctive, dark propeller-like feature in its southwest that sets it apart from other globulars. Another bonus for M13 is a couple of galaxies situated less than ½° north-northeast of it, IC 4617 and NGC 6207, that reveal some detail in images. M3 in Canes Venatici and M5 in Serpens are both big, bright, and colorful globular clusters. To help you decide which of this bunch is best, shoot them all and compare them yourself!

Ophiuchus is home to dozens of globular clusters, most of which are fine imaging targets for most any sized telescope. Three of the brightest are **M10**, **M12**, and **M14**. They're all quite close to one another and are an interesting trio to compare since you can frame M10 and M12 in the same composi-

▲ **WHICH IS BEST?** Several globular clusters vie for the title of best visible from northern latitudes. *Clockwise from top left:* M3, M5, M13, and M22 each have individual characteristics, but the author favors M22.

tion if you can capture a field of view of about 4° or more. In my images, M10 is clearly the largest and most concentrated and contains many blue-hued stars. M14 is smaller, while M12 appears looser, showing stars all the way to the core.

Skipping over to Scutum, **M11**, the Wild Duck Cluster, is a premier imaging target favored by newbies and experienced astrophotgraphers alike. As a young open cluster, M11's bluish stars stand out easily despite being located within the dense star field of the Milky Way. The area surrounding M11 is peppered with dark nebulae, and the entire area makes for a great target with most any sized instrument (see page 36).

Farther to the north on the eastern border of Lyra is **NGC 6791**, a fainter, redder open cluster whose color belies its great age of approximately 8 billion years. Its appearance

◀ **GLOBULAR CASCADE** More than two dozen globular clusters bespeckle Ophiuchus, including the three brightest (left to right: M12, M10, and M14), which form a 13°-long east-west arc.

▲ **DENSE AND DENSER** M53 (top right) in Coma Berenices is a dense globular cluster presenting an interesting contrast to its fainter and less compact neighbor NGC 5053 (lower left).

in images provides a fascinating contrast to young M11; NGC 6791's reddish stars are dispersed relatively evenly throughout the cluster, which has looser central density than M11. The old cluster shares Lyra with globular cluster **M56**, roughly 7° to the south of NGC 6791. This small, bright globular resides in a rich Milky Way star field and is loaded with many reddish stars and a few blue ones.

Moving north into Cepheus, you have an opportunity to capture two very different objects in the same 1.5° field of view. **NGC 6939** is a fairly loose open cluster that happens to reside about ⅔° northwest of the face-on spiral galaxy NGC 6946. Long exposures will also reveal the faint interstellar dust that permeates the area.

Fall and Winter

Later in the year, several excellent clusters await in Cassiopeia. My first stop of the season often includes **M52**, which contains lots of bright, blue stars, and a golden-hued one that stands out markedly. A big bonus when targeting this cluster is that it lies just about 40 arcminutes northwest of NGC 7635, the Bubble Nebula, making for a very rich and colorful composition.

Two nice pairs of clusters are found in the area, so let's jump over to the best first. Perhaps the most striking pair of open clusters visible from northern latitudes is the Double Cluster, **NGC 884** and **NGC 869** in Perseus. While both clusters are great targets for imagers of any level, I've always found it challenging to capture the subtle differences in the stellar hues between both clusters, particularly the several striking orange stars scattered across NGC 869.

About 8° to the west of the Double Cluster is the broader pair of open clusters **NGC 436** and **NGC 457**, separated by just ¾°. The latter cluster is often referred to as the Owl Cluster due to the two brightest blue stars in the cluster's southeast, which serve as the owl's "eyes." Capturing both clusters together requires a camera and scope combination that yields a field of 1½° or greater.

Moving farther south, we come to one of the nearest and brightest collections of hot, young stars: **M45**, the Pleiades. I find myself photographing M45 almost every winter. Despite its large and bright appearance, M45 makes for a surprisingly challenging imaging target. Displaying its full dynamic range is an exercise in compromises among the brightness of its main stars and the faint reflection and dust nebulosity that surrounds them. M45 and its nebulae require a field of more than a full degree to frame comfortably. Imagers with larger, wide-field astrographs will also resolve dozens of distant galaxies that show through the cluster.

▲ **NEAR AND FAR** Open cluster NGC 6939 (top right) displays a mix of both blue and yellow stars. Its claim to fame is its proximity to face-on spiral NGC 6946, the Fireworks Galaxy, which has hosted 10 supernovae in the past 100 years.

◀ **ANCIENT STARS** *Top:* NGC 6791 in Lyra is an old cluster thought to have formed nearly 8 billion years ago. All its hundreds of stars have left the main sequence and appear yellowish in photographs.

◀ **BUSY FIELD** *Bottom:* M52 in Cassiopeia (upper left) is a rich open cluster with several hundred stars. Long exposures through a wide-field instrument will reward imagers with several reddish emission nebulae in its immediate vicinity, including NGC 7635, the Bubble Nebula, seen at lower right.

▲ **EXTRATERRESTRIAL CLUSTER** NGC 4326 (top right) and NGC 457 (lower left) make a nice pair in wide-field instruments. Though often referred to as the Owl Cluster, NGC 457 is sometimes called the E.T. Cluster. It particularly resembles the fictional movie character complete with an outstretched, overly long left arm if you rotate the image so that the bottom left corner is at top.

▶ **DISTANT GLOBULAR** *Top:* NGC 2419 is one of the most distant globular clusters associated with the Milky Way, residing roughly 300,000 light-years from Earth and from the galactic center.

▶ **STAR FACTORY** *Right:* The Orion Nebula, M42, is the nearest star-forming region and contains one of the youngest star clusters nearest to Earth: the Trapezium, also known as θ Orionis. Two other bright clusters are seen in near proximity, including NGC 1980 (bottom) and NGC 1981 (top).

Another clutch of hot, young stars lies at the heart of M42, the Orion Nebula. Short exposures in very steady seeing resolve the six primary stars of the Trapezium (**θ Orionis**) still ensconced in their nebulous womb, M42. Short exposures reveal both θ Orionis and the inner clouds of gas and dust nearest to the young cluster. To reveal the faint extensions in the surrounding molecular cloud, it's best to combine short and long exposures — ranging between 30 seconds and 10 minutes — using High Dynamic Range (HDR) image-processing techniques. Several other open clusters are found within 2° of the Orion Nebula. Just 1° north is **NGC 1981**, a widely spaced open cluster with hot, blue stars arrayed in a distinct W shape. In the opposite direction (½° south of M42), **NGC 1980** is even brighter and includes several naked-eye stars.

Skipping up to Auriga, we find M36, M37, and M38, a trio of great open clusters. Of the three, I find **M37** the most

▶ **BONUS NEBULOSITY** M45 is the brightest of the Messier clusters and among the five closest clusters to Earth. Long exposures reveal bluish reflection nebulosity as well as the brownish dust clouds that permeate the entire region.

appealing as an imaging target. It shows a distinctive triangle of bright stars standing out from the rest of the cluster.

Our final stop is **NGC 2419** in Lynx. This tight globular is one of the loneliest-looking deep-sky objects I've imaged. The field in which NGC 2419 resides contains relatively few stars, and the cluster has a small, distant appearance. Being so much further away from us than its northern cousins like M13, NGC 2419's star colors are mainly reddish hues, and the core is well resolved.

Imaging Strategies

When it comes to imaging star clusters, it's quite literally all about the stars. Perfect focus is essential to make the stars as sharp and contrasty as possible — poor focus makes them appear puffy and bloated. I refocus the telescope frequently as the temperature drops during my imaging session to ensure I retain the smallest stars. It's also easy to overexpose very dense clusters (particularly globulars), so I try to find the exposure that best reveals the fainter cluster members without turning the brighter core region into an over-exposed blob.

For clusters with a wide range of brightness, or clusters embedded within bright nebulosity (such as θ Orionis in M42), consider using HDR techniques for acquisition and processing. This involves capturing and later blending short and long exposures to reveal detail in both the brightest and faintest regions in a single image. Keep in mind that too much brightness suppresses the perception of color, robbing the brightest stars of their beautiful hues, so you may need to increase the saturation settings while also decreasing the brightness of the highlights in your picture.

Open clusters are also great tools for evaluating an imaging system's performance. I often use them to confirm optical performance in my imaging systems — star images quickly reveal problems with camera tilt and collimation, and they help me confirm the proper spacing between a field flattener and my camera's sensor. Stars emit light across the visible spectrum, rather than at a few specific wavelengths, so clusters aren't ideal targets for narrowband filters, including the multiple-bandpass filters often used with one-shot color cameras.

Go for Galactic Glitter

Star clusters come in a wide variety of shapes, sizes, and brightnesses. Some are surrounded by a variety of beautiful celestial scenery, which creates a wide range of compositional choices. Next time you think the Moon is too bright for deep-sky imaging, remember that many of these sparkles in the dark can show through even strong light pollution. So, give them a shot — you won't be disappointed!

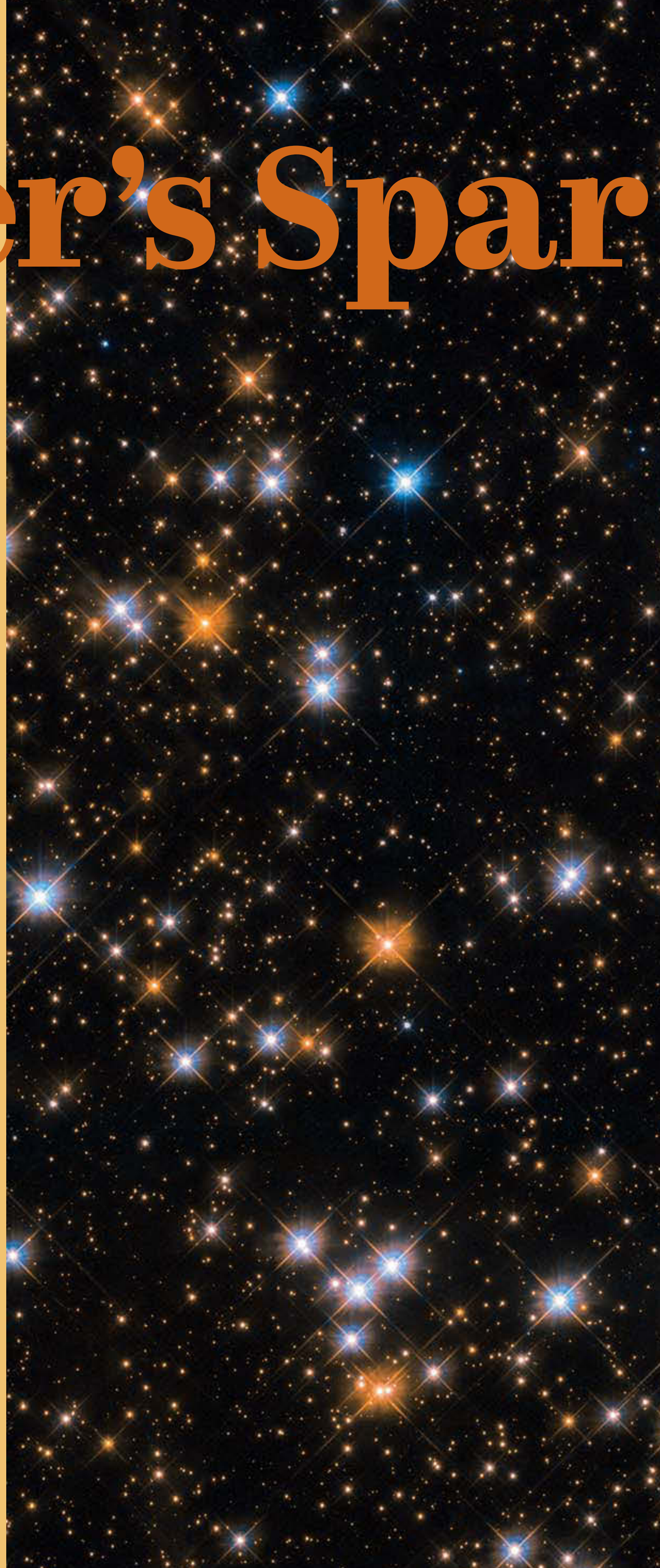
■ **RON BRECHER** photographs the night sky from his backyard observatory in Guelph, Ontario.

Select Star Clusters for Mid-Northern Latitudes

Object	Constellation	Size	RA	Dec.
M44	Cancer	1.7°	08^h 40^m	+19° 59′
M67	Cancer	30′	08^h 51^m	+11° 49′
M53	Coma Berenices	12′	13^h 13^m	+18° 10′
NGC 5053	Coma Berenices	8′	13^h 17^m	+17° 42′
M13	Hercules	20′	16^h 42^m	+36° 28′
M3	Canes Venatici	16′	13^h 42^m	+28° 23′
M5	Serpens Caput	21′	15^h 19^m	+02° 05′
M22	Sagittarius	33′	18^h 36^m	–23° 54′
M10	Ophiuchus	19′	16^h 57^m	–04° 06′
M12	Ophiuchus	14′	16^h 47^m	–01° 57′
M14	Ophiuchus	10′	17^h 38^m	–03° 15′
M11	Scutum	14′	18^h 51^m	–06° 16′
NGC 6791	Lyra	10′	19^h 21^m	+37° 46′
M56	Lyra	7′	19^h 17^m	+30° 11′
NGC 6939	Cepheus	7′	20^h 31^m	+60° 38′
M52	Cassiopeia	12′	23^h 24^m	+61° 35′
NGC 884	Perseus	30′	02^h 22^m	+57° 07′
NGC 869	Perseus	30′	02^h 19^m	+57° 09′
NGC 436	Cassiopeia	5′	01^h 16^m	+58° 49′
NGC 457	Cassiopeia	12′	01^h 19^m	+58° 20′
M45	Taurus	1.8°	03^h 47^m	+24° 07′
θ Orionis	Orion	30″	05^h 35^m	–05° 23′
NGC 1981	Orion	25′	05^h 35^m	– 04° 26′
NGC 1980	Orion	14′	05^h 35^m	– 05° 55′
M37	Auriga	15′	05^h 52^m	+32° 33′
NGC 2419	Lynx	4.7′	07^h 38^m	+38° 53

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

Summer's Spar



Spend some time sifting through this collection of favorites during July's warmer evenings.

What makes an open cluster outstanding? Size and brightness are important, but observers also consider other factors. These include how rich and concentrated the cluster is; the range in brightness of its stars; how clearly the cluster stands out from the background sky; the presence of star tendrils or other distinctive patterns; whether a few rubies or golden stars are scattered among the diamonds; and whether other deep-sky objects ornament the field of view.

In my recent article (*S&T:* Oct. 2020, p. 28), I described the best globular clusters in the entire sky. But the heavens offer a vastly larger number of open clusters than globulars, so my more modest goal here is just to present my favorites. Also, while working through my logbooks, I was surprised at how many different types of clusters I have called "magnificent." Rich, concentrated clusters usually make the strongest impression on me, but several large, straggling binocular clusters also earn that descriptor.

Here's my collection of top-notch open clusters best visible in summer skies. I'm listing them in order of preference, but of course, you might have your own take on these stellar gems!

Fabulous Five

Messier 11 is one of three open clusters I consider in the running for the title of the most splendid. The other two candidates are the Pleiades and NGC 3532 in Carina — but since neither is well-placed during Northern Hemisphere summer, M11 reigns undisputed over this season. It's a rare summer night when I don't reward myself with a quick look at M11 after hours of hunting faint fuzzies.

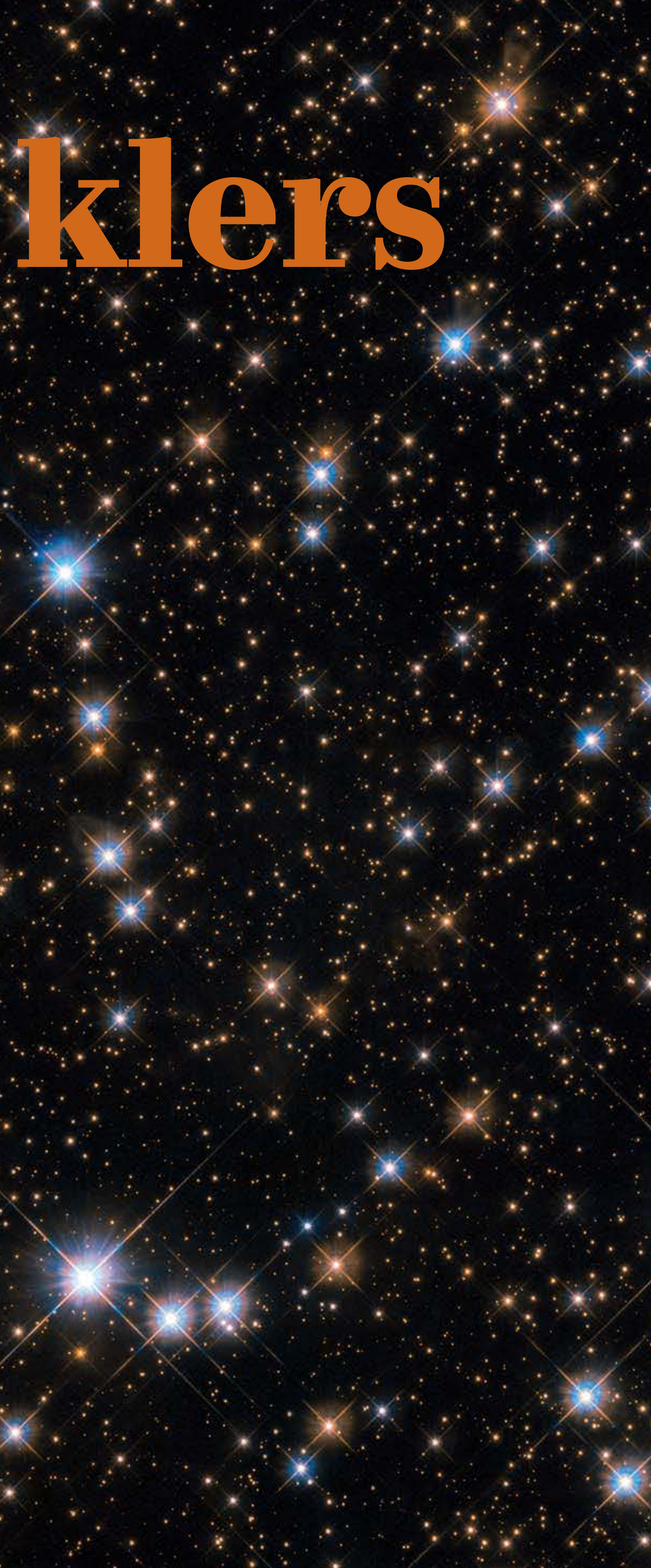
German astronomer Gottfried Kirch discovered this cluster in 1681, but his small telescope couldn't resolve it. It's a naked-eye object lying on the northern edge of the shield-shaped Scutum Star Cloud, yet it's stellar in appearance. Even in 7×50 binoculars it's still tiny.

On an excellent night, M11 is glorious through my 8-inch Dobsonian at 244×. As the rich, uniform-brightness cluster drifts into the field of view, it almost looks like a globular-rise. The main concentration of stars consists of many discrete clumps, as in bubble wrap. The lucida is light orange.

ESA / HUBBLE / NASA / P. DOBBIE

▶ **STELLAR SPARKLES** Summer skies are replete with pretty open clusters, such as M11 shown in this Hubble Space Telescope image.

klers



Transparent nights reveal numerous dust lanes winding through the Scutum Star Cloud in M11's vicinity, including one that's very opaque and narrow consisting of — north to south — B115, B114, B116, and B117. I've enjoyed viewing these Barnard dark nebulae with everything from binoculars to a 17.5-inch scope.

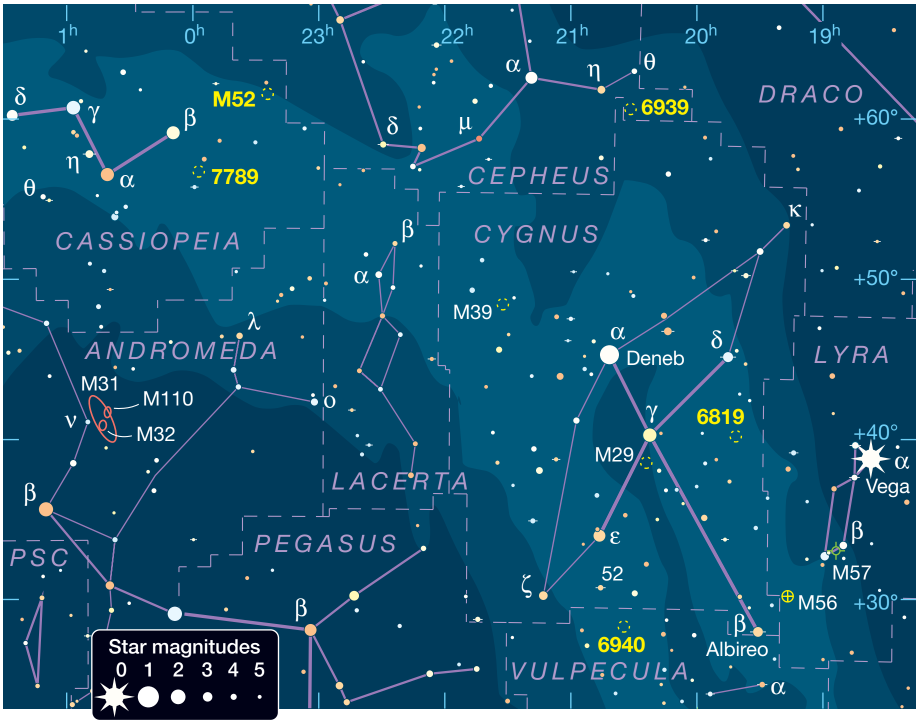
Almost everyone who writes about this showpiece object refers to it by its popular name, the Wild Duck Cluster (see page 54). Inevitably the author then notes that they've never seen ducks flying in a V formation. Neither have I, nor I suspect, have very many of you.

Way back in the Victorian age, English amateur astronomer Admiral William Smyth wrote that Messier 11 ". . . somewhat resembles a flight of wild ducks in shape. . . ." The admiral had presumably spent years at sea — in fact, my ornithologist brother, Rick, advises: "Some ducks, like Scoters, and perhaps other species that are more oceanic, do often arrange themselves in some sort of crescent or fan or vee." But since few of us are mariners, I suggest that we mercifully bury the name Wild Duck Cluster or else call it the Wild Geese Cluster, since most of us do regularly see *geese* flying in this formation. The V shape stands out better with small apertures than in larger scopes because the stars in the V are slightly brighter than the other cluster members.

Messier 6, known from antiquity, is an obvious fuzzy spot with the unaided eye — hard to miss by its proximity to bright M7. Its location in the dark Great Rift makes M6 even easier to see. On the night in July 1962 that I first viewed it with my 60-mm refractor, M6 struck me as looking like a butterfly *even before* I saw the same description the next morning in *Norton's Star Atlas*. My 80-mm apochromatic refractor at 25× adds an orange spark on the cluster's following edge; my 8-inch at 76× reveals the butterfly's antennae. Is there any cluster that's more distinctive than the Butterfly Cluster?

Messier 7 is so large and bright that my first observation of it was an independent naked-eye "discovery." I noticed the fuzzy patch low over Grand Lake, New Brunswick, on my first-ever night under a pristine sky, during a family camping trip at age 15. It's also known as Ptolemy's Cluster, in deference to the great Alexandrian astronomer who wrote about it in the 2nd century AD. But in my opinion, nobody should be honored with the discovery of the third-brightest cloud visible in the Milky Way from mid-northern latitudes. Before light pollution invaded our skies, surely *almost every* astronomer with good eyesight would have noticed this magnitude-3.3 cluster near the Scorpion's stinger.

This target is very low from my latitude of 49° north, but in my 8-inch at 76× it still manages to appear large and loose, with bright suns. There are three yellow-orange embers, one in the center and two on the northern edge. M7 features three almost-straight lines of stars, and a small Y-shaped group that has a double marking the junction of the Y. Christian Luginbuhl and Brian Skiff's *Observing Handbook and Catalogue of Deep-Sky Objects* describes a K-shaped asterism in the cluster's center. Do you see it?



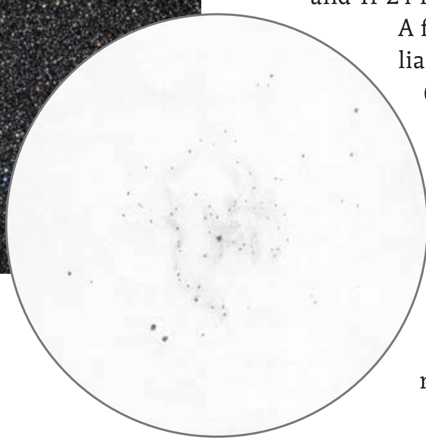
Shining at the northwestern edge of M7 is the small globular cluster NGC 6453 (an 1837 John Herschel discovery). At the 1999 Starfest in Ontario, Steve Barnes's 12-inch Schmidt-Cassegrain telescope showed what I recorded as "slight resolution" of the globular at 222×, but Luginbuhl and Skiff suggest that what I saw might just be foreground stars.

The very bright open cluster **NGC 6231** (discovered by Giovanni Hodierna c. 1650) and the False Comet are special to me. On June 8, 1983, along the Rio Grande en route to the Texas Star Party, I "noticed a comet-like structure in Scorpius consisting in the 7×50 binoculars of Zeta^1 (ζ) and Zeta^2 Scorpii and the open clusters NGC 6231, Collinder 316, and Trumpler 24." I showed the naked-eye "comet-like structure" to many observers at the TSP and was quite surprised to learn that none of them had ever noticed the striking Milky Way feature before.

Sky Publishing's *Sourcebook Total Solar Eclipse 1998*, targeted to *Sky & Telescope*'s five trips to witness that year's February 26th eclipse, included my detailed description of this "striking comet-like structure" in the Scorpius OB1 association. During the following year several authors picked up on the nickname, and the False Comet started to appear in other books and articles. (Typically, such monikers of deep-sky objects usually begin as a visual description, which eventually morphs into the popular name.)

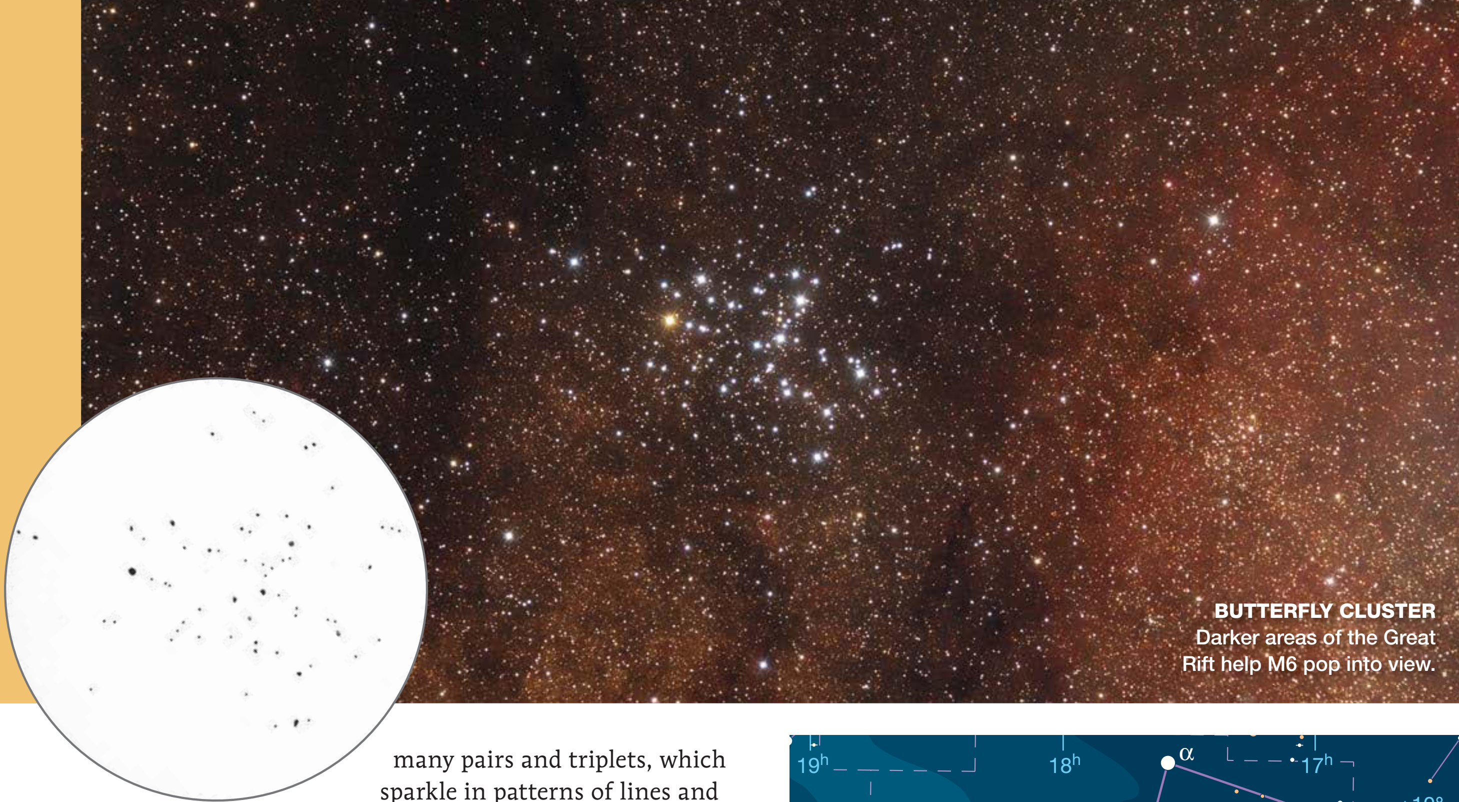
In the days at sea before the 1998 eclipse, I was busy providing weather consultation for *Sky & Telescope*'s three cruise ships in the Caribbean. But after the eclipse I was free to spend memorable nights on the dark Sky Deck with my 4.2-inch Astroscan reflector and Kent Blackwell's 20×120 Japanese battleship binoculars, enjoying views of many of the southern sky's showpieces. My Astroscan showed a central circle of diamonds in NGC 6231 at 56×. Elongated Cr 316 and Tr 24 run northward through several fields.

A few years later, in March 2001 in Australia, I viewed NGC 6231 in Tony Buckley's (cofounder of OzSky Star Safaris) 8-inch Dobsonian at 188×. The sight was a treat — eight brilliant stars in a rich mass of moderately bright ones. The cluster has O-type supergiants and Wolf-Rayet stars. The handy guidebook *Hartung's Astronomical Objects for Southern Telescopes* gives this description of NGC 6231 through a 12-inch reflector: "There are many bright white and yellow stars, and



▲ **A STUDY IN CONTRASTS** Brightly sprinkled M11 lies near dark nebulae — two mentioned in the text appear in this image. Guy Mackie, the author's friend, provided the sketches.

M11: RON BRECHER



BUTTERFLY CLUSTER Darker areas of the Great Rift help M6 pop into view.

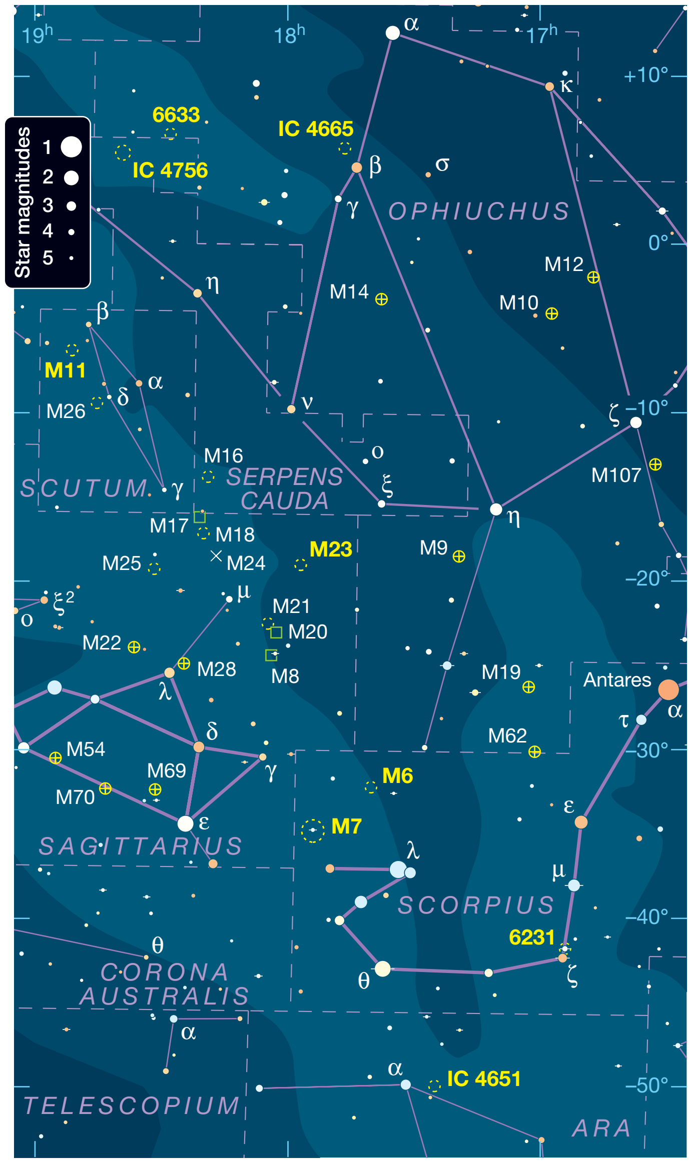
many pairs and triplets, which sparkle in patterns of lines and small groups." No wonder Ernst Johannes Hartung called it a "glorious cluster."

Charles Messier discovered **M23** in 1764. It's not too difficult naked-eye — it's the fuzzy found about 4° west of M24, the Small Sagittarius Star Cloud. My home observatory's 16-inch Newtonian showcases a bright, magnificent, rich cluster, arranged in three concentric arcs. The stars, mostly of the same magnitude, are uncountable.

Best Things Come in Threes

The clusters **IC 4665** and **NGC 6633** in Ophiuchus and **IC 4756** in Serpens Cauda are all large, bright, and very suitable for binoculars. I also find they're not too difficult with the unaided eye from my dark backyard (located in a lakeside subdivision without streetlights). Swiss astronomer Philippe Loys de Chéseaux discovered NGC 6633 in 1745. He's also credited with finding IC 4665 around the same time, but, given my independent, naked-eye discovery as an inexperienced teenage observer, I have to believe that many ancient astronomers must have noted this 4.2-magnitude fuzzy patch. IC 4665 was the second naked-eye object that I spotted while admiring the summer Milky Way for the first time at a dark site (on the same evening that I first noticed M7). But IC 4665 wasn't plotted on my 1959 edition of *Norton's Star Atlas*, so it was many years before I learned what I had found.

IC 4665, sometimes called the Summer Beehive, is large and prominent in my 7×50s. It's a loose cloud of at least 10 resolved sparklers — more if outliers are members. In my 8-inch at 61× it *does* resemble the Beehive Cluster. There are two touching circles of jewels at the center, a reddish gem, and lines of stars marking the cluster boundary. A half degree east of the main throng of glittering jewels winds a loop of 9th-magnitude stars (including three pairs) that appear to form a border to IC 4665. (But they may not even be associated with the cluster.)



M6: WOLFGANG PAECH / FRANZ HOFFMANN / CHAMÄLEON OBSERVATORY; SKETCH: GUY MACKIE

NGC 6633 is ideal for 7×50 binoculars and should be better known. It looks somewhat like a T with a bent upright, except that the lower (southwestern) end of the upright broadens into a rich wedge of stars. My 70-mm finder works well on the elongated cluster, revealing about 40 nearly equal-magnitude sparks at 17×. NGC 6633 is better separated from the field with the 70-mm finder than with my 16-inch.

The cluster nicely fills the 51′ field of view of my 16-inch at 76×, which shows it as very elongated southwest to northeast, bright, and straggling. However, *Star Clusters* (by Brent Archinal and Steven Hynes) gives the diameter as only 20′, which would mean that the northeastern end is likely not part of NGC 6633. Three doubles and a nice arc adorn the northeastern end of the true cluster. At this low power I see about 50 fairly bright stars and as many faint ones. A Cassiopeia-shaped asterism highlights the western side.

Similarly, IC 4756 is also perfect for 7×50 binoculars. It's a rich, similar-magnitude group straggling 1° east-northeast to west-southwest, and is many times the area of NGC 6633. In my 4.2-inch Astroscan at 16×, the cluster is a formless mass of eighty 10th-magnitude stellar pinpoints, overlain with a few brighter ones. It's an enjoyable object but doesn't lend itself to a compelling description as there are no prominent arcs or star chains. Even so, I still called it a "beauty" in my logbook. IC 4756 is well separated in my 70-mm finder at 17×, while it's far too big for the 16-inch at 76× — but I nevertheless enjoyed using the big scope to sweep through this loose, equal-magnitude cluster. Two orange stars decorate the southern side, and a bright yellow one lies on the eastern side.

Some guidebooks label IC 4756 Graff's Cluster, honoring Polish-German astronomer Kasimir Romuald Graff's independent discovery of it in 1922. But both Steve Gottlieb and Wolfgang Steinicke point out that in *Celestial Objects for Common Telescopes* (published in 1859), British astronomer and reverend Thomas William Webb wrote: "Between it [NGC 6633] and Theta [(θ) Serpentis], nearer the former, is a beautiful large cloud of stars, chiefly 8 and 9 m^{g}., a nearer part, apparently, of the Galaxy; visible to naked-eye, and requiring a large field." Therefore, it might be more appropriate to refer to the object as *Webb's* Cluster.

▲ **NGC 6231** Twinkling above Zeta^1 (bottom, at right) and Zeta^2 Scorpii, the cluster forms the "head" of the False Comet (see also page 41).

M7: WOLFGANG PAECH / FRANZ HOFFMANN / CHAMÄLEON OBSERVATORY; M7 SKETCH: GUY MACKIE; NGC 6231: JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY

Last But Not Least

NGC 7789 is known as Caroline's Rose, a succinct name that both describes the cluster and hails Caroline Herschel as its

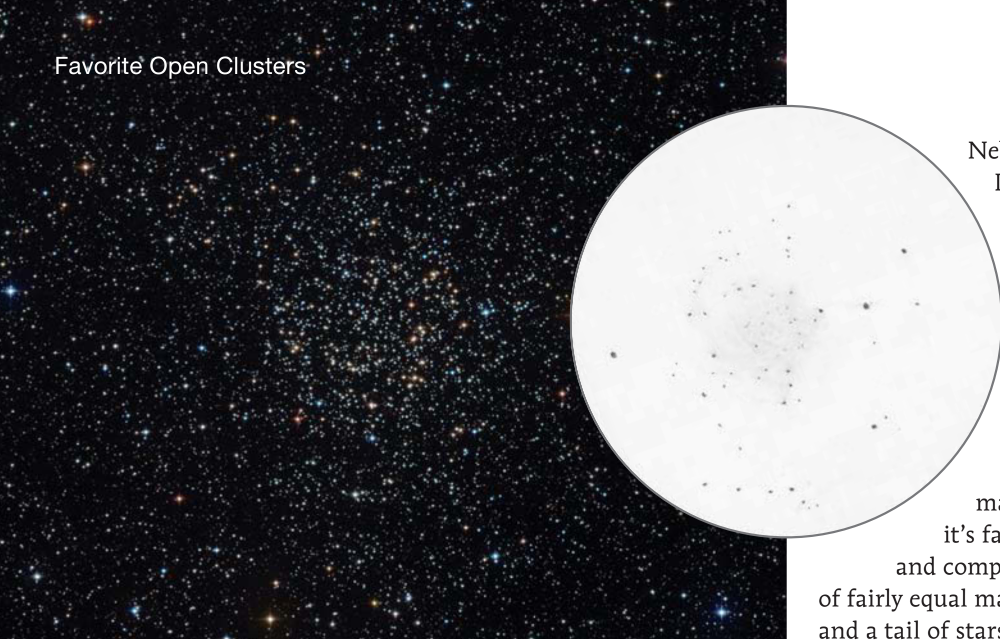
NEAR THE STINGER M7, the most southerly of the Messier objects, is so large and bright that it's an easy naked-eye target. It's sublime in binoculars.

discoverer. She found it in 1783 using her 4.2-inch comet-seeker. Caroline's Rose lies midway between Rho (ρ) and Sigma (σ) Cassiopeiae. It was very prominent in my 7×50s on a night of excellent transparency. At 60× in poor conditions my 8-inch showed a large group of faint diamond-dust stars in concentric arcs — presumably why some say that it resembles a rose. With the 16-inch on a very clear night with only fair seeing, NGC 7789 was very rich, and I rated it "probably a top 20 in the entire sky." About 70 stars appeared at 76×; they were uncountable at 152×. This well-separated cluster gives the general impression of comprising mostly equal-magnitude stars (despite the fainter ones revealed at 152×). The slightly brighter sparklers are around the periphery of the roundish cluster. I see the stars in clumps as well as in a few short arcs and a very few triangles. I also note a number of dark vacancies.

Diving south to Ara we find **IC 4651**. Scottish astronomer James Dunlop discovered this largely unknown splendor from New South Wales, Australia, in 1826. I chanced upon this fine open cluster with Tony Buckley's 14.5-inch Dobsonian while star-hopping from Alpha (α) Arae to the globular cluster

▼ **VERITABLE JEWELS** The number of stars in open clusters ranges from some tens in the sparsest examples to a few thousand in the most extreme cases. No matter how many there are, these stellar collections present some of the prettiest sights in the entire sky.

M23: WOLFGANG PAECH / FRANZ HOFFMANN / CHAMÄLEON OBSERVATORY; IC 4665: STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; NGC 6633: STEFAN BINNEWIES / RAINER SPARENBERG / JOSEF PÖPSEL / CAPELLA OBSERVATORY; IC 4756: ANTHONY AYIOMAMITIS



▲ **CAROLINE'S ROSE** Can you see the arcs and swirls of stars and dark lanes that give NGC 7789 its nickname?

NGC 6352. The open cluster is 1° west of Alpha. It's very attractive, featuring loops and chains of 70 equal-magnitude jewels enclosing voids. The lucida is orange, as is often the case with galactic clusters. While my views were from Australia, I've included IC 4651 on this list because it can be observed from the southern half of the U.S.; and open clusters suffer less from low altitude than any other class of deep-sky object.

Finishing in Vulpecula we come to **NGC 6940**, which William Herschel discovered in 1784. It's 3.4° southwest of 52 Cygni, the star that pins the western section of the Veil Nebula. My first view of NGC 6940 was when I chanced upon it while sweeping the Milky Way with 7×50 binoculars. It was unresolved in the binoculars, but after observing it with my 8-inch at 50× on a superb night I wrote: "What a beauty — definitely a splendor! A large rich cluster of 60 stars in a very rich Milky Way field, its stars are arranged in a bulbous Y-shape. That is, each arm of the Y is composed of clouds of stars, rather than a single line. A reddish star marks the center." Through my 16-inch at 141× it's fairly well separated from the Milky Way field and comprises — by my estimation — about 200 stars of fairly equal magnitude. There's an oval of stars preceding and a tail of stars following.

I hope you enjoyed this ramble through the skies visiting my favorite open clusters. Maybe one day some of these will become your favorite targets, too.

■ Contributing Editor **ALAN WHITMAN** developed a greater fondness for viewing *inside* his observatory when bent over an eyepiece, neck exposed, after a cougar neatly butchered a deer on his front lawn.

INVALUABLE RESOURCE

Alan thanks Steve Gottlieb for creating and maintaining his excellent website on the history of NGC and IC objects and invites you to visit it at **https://is.gd/AstronomyMall**.

Favorite Summer Open Clusters

Object	Constellation	Mag(v)	Size	RA	Dec.
M11	Scutum	5.8	11′	18^h 51.1^m	–06° 16′
M6	Scorpius	4.2	33′	17^h 40.3^m	–32° 16′
M7	Scorpius	3.3	75′	17^h 53.8^m	–34° 47′
NGC 6231	Scorpius	2.6	14′	16^h 54.2^m	–41° 50′
M23	Sagittarius	5.5	25′	17^h 56.9^m	–19° 01′
IC 4665	Ophiuchus	4.2	70′	17^h 46.2^m	+05° 43′
NGC 6633	Ophiuchus	4.6	20′	18^h 27.2^m	+06° 30′
IC 4756	Serpens Cauda	4.6	40′	18^h 38.9^m	+05° 26′
NGC 7789	Cassiopeia	6.7	25′	23^h 57.5^m	+56° 43′
IC 4651	Ara	6.9	10′	17^h 24.7^m	–49° 55′
NGC 6940	Vulpecula	6.3	25′	20^h 34.5^m	+28° 17′
NGC 6819	Cygnus	7.3	5′	19^h 41.3^m	+40° 11′
NGC 6939	Cepheus	7.8	10′	20^h 31.5^m	+60° 40′
M52	Cassiopeia	6.9	16′	23^h 24.8^m	+61° 36′

Angular sizes 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.

Honorable Mention . . .

. . . goes to three rich clusters in the northern Milky Way: **NGC 6819**, some 7.8° west of Gamma (γ) Cygni, one of Caroline Herschel's discoveries with her comet-seeker; **NGC 6939** in Cepheus, lying 2° southwest of Eta (η) Cephei and sharing a field of view with the fine, multi-armed, face-on spiral galaxy NGC 6946; and western Cassiopeia's **Messier 52** (in the same field of view as the famous but faint Bubble Nebula). Extend the line from Alpha to Beta Cassiopeiae by slightly more than one length and you will land directly on M52.

NGC 7789: VOLKER WENDEL / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; SKETCH: GUY MACKIE

OBSERVING
July 2021

The False Comet is an impressive collection of star clusters and nebulae in Scorpius. Turn to page 36 for more details, including how it got its name. GARY SERONIK

2 DUSK: Look very low toward the west-northwestern horizon after sunset to see Venus in Cancer near the Beehive Cluster (M44); binoculars will improve your view. Mars gleams some 5° to 6° upper left of the pair. Turn to page 46 for more observing tips on this and some of the other more challenging events listed here.

5 EARTH is at aphelion, farthest from the Sun for the year (some 3.4% farther than it was at perihelion in January).

6 DAWN: The waning crescent Moon rises in Taurus, about halfway between Aldebaran and the Pleiades.

7 DAWN: Find the Moon between the Bull's horns, now forming a wide triangle with Aldebaran and Mercury. You'll have to time it right so as to catch Mercury, very low on the east-northeastern horizon, before the rising Sun washes the scene away.

8 DAWN: The Moon, one day shy of new, has rolled farther down the ecliptic and is positioned some 4½° left of Mercury.

11 DUSK: The two-day old Moon has slipped into the evening sky and forms a line about 6° long with Venus and Mars low on the west-northwestern horizon.

12 DUSK: Now Venus and Mars are within ½° of each other, while the Moon hovers upper left.

16 EVENING: Find the waxing crescent Moon in Virgo, roughly 6° from Spica. Watch as the pair sinks toward the western horizon.

19 EVENING: The waxing gibbous Moon is placed around 1° from Beta (β) Scorpii, in the Scorpion's claws. Antares smolders lower left of the pair.

21 DUSK: Venus shines brightly in deepening twilight as it sets in Leo; around 1° separates it from Regulus.

24 DAWN: The Moon, one day past full, and Saturn form a graceful vertical pair low in the southwest before sunrise. Jupiter guards from upper left.

25 DAWN: Positioned between the two gas giants, the waning gibbous Moon forms a shallow arc with Jupiter and Saturn.

26 DAWN: Above the southwestern horizon, the Moon and Jupiter hang together with some 5° between them.

28–29 ALL NIGHT: The Southern Delta Aquariid meteor shower is expected to peak, though the waning gibbous Moon will interfere with viewing.

29 DUSK: With binoculars, you might just catch a glimpse of Mars and Regulus very low on the western horizon. Venus shepherds the pair from upper left as they sink out of view.
— DIANA HANNIKAINEN

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

NASA / LRO

MOON PHASES

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

LAST QUARTER
July 1
21:11 UT

NEW MOON
July 10
01:17 UT

FIRST QUARTER
July 17
10:11 UT

FULL MOON
July 24
02:37 UT

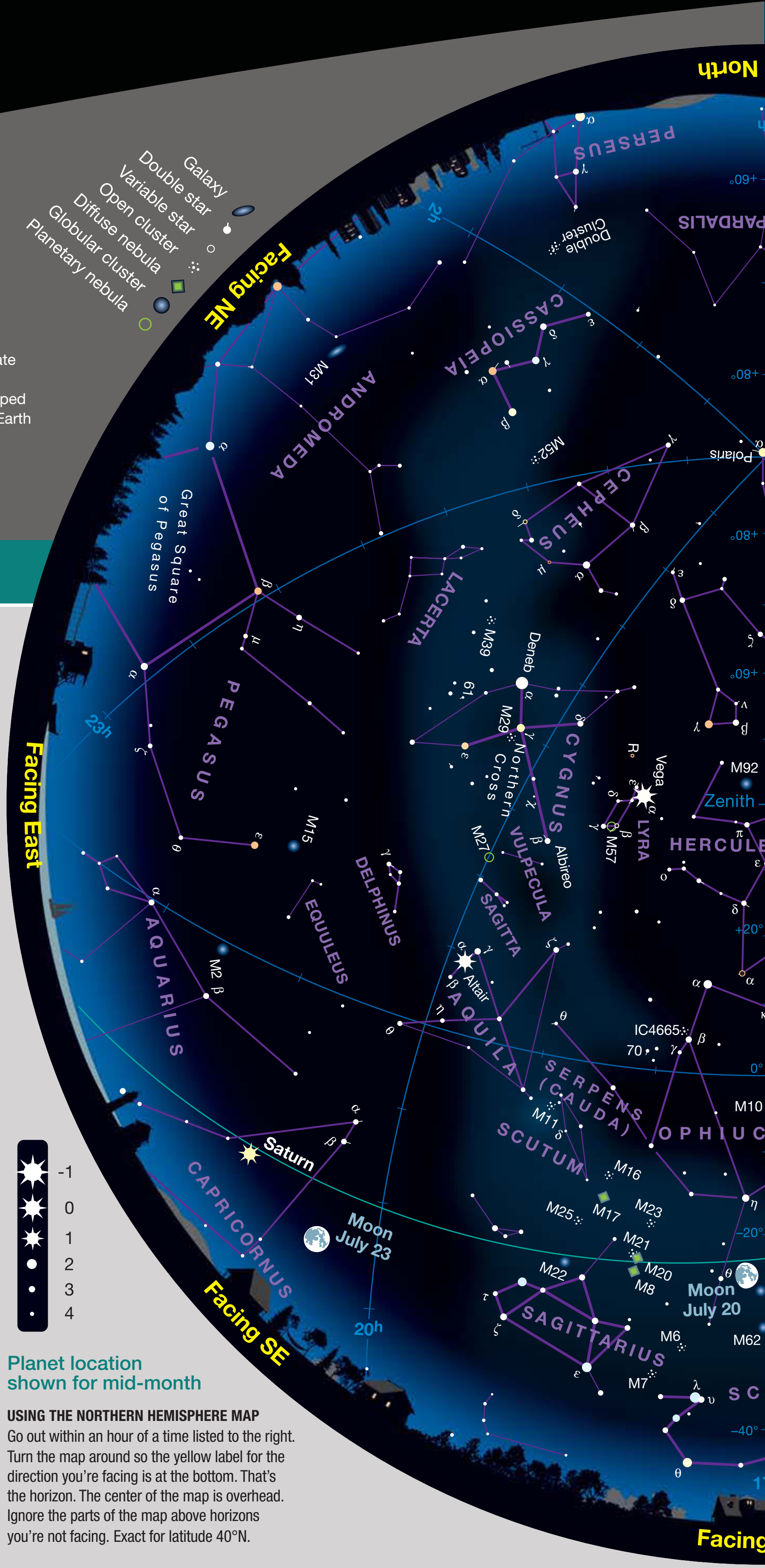
LAST QUARTER
July 31
13:16 UT

DISTANCES

Apogee 405,341 km	July 5, 15h UT Diameter 29′ 29″
Perigee 364,523 km	July 21, 10h UT Diameter 32′ 47″

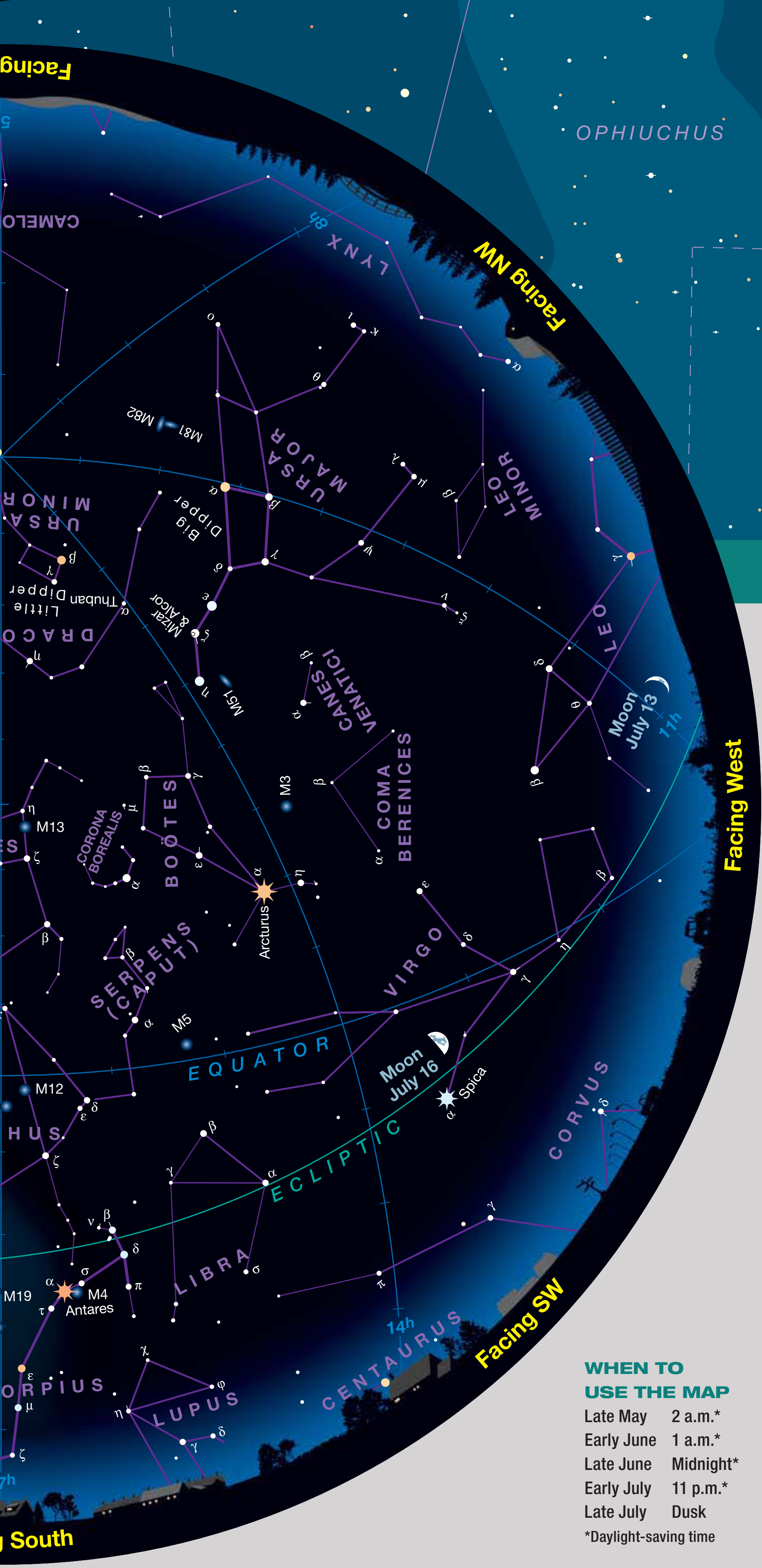
FAVORABLE LIBRATIONS

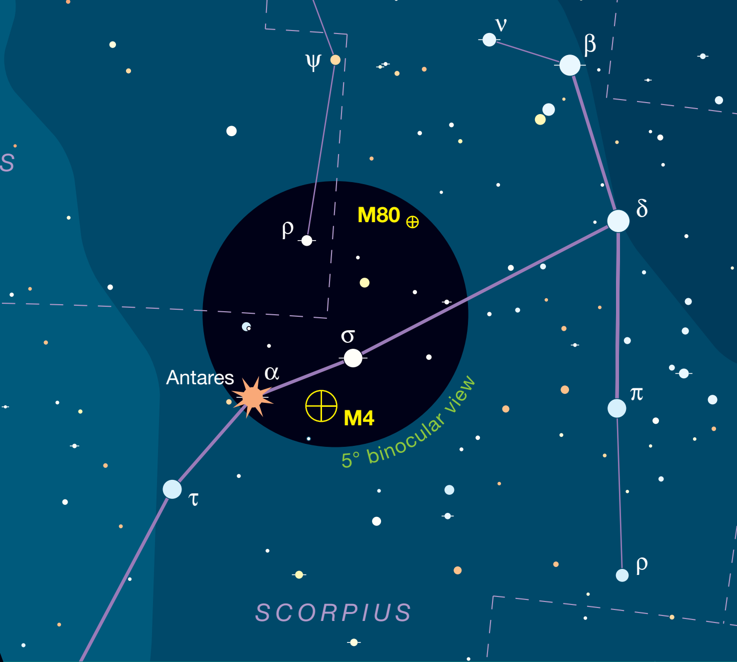
• Lagrange Crater	July 8
• Belkovich Crater	July 22
• Mare Humboldtianum	July 23
• Compton Crater	July 24



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.





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

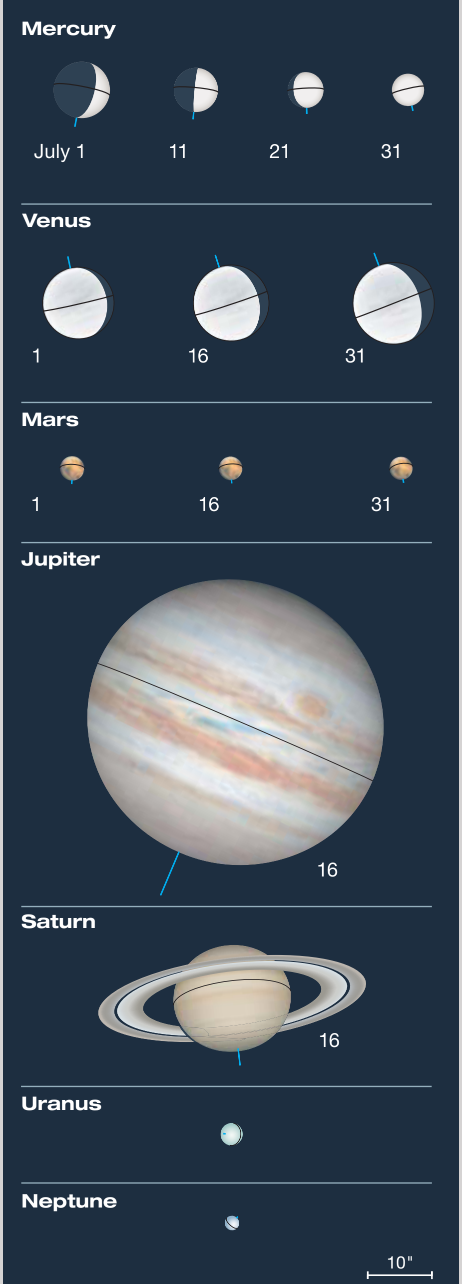
Scorpion Tales

Summer is here, and although the Milky Way is spangled with even more nebulae, open clusters, and asterisms than in winter, it also has something particular to this time of year: globular clusters in abundance.

Two outstanding summer globs are **M4** and **M80** in the head of Scorpius, the celestial scorpion. M4 sits just 1.3° west of Antares, the "rival of Mars," whose fiery glare is unchallenged in this part of the sky. It looks like a dim and hooded eye next to Antares, but at magnitude 5.4 it's a naked-eye target under any decently dark skies. About 4° to the north-northwest of M4 you'll find another summer globular, 7.3-magnitude M80. Rather like M92 in Hercules, M80 might attract more attention if it weren't overshadowed by its brighter neighbor. As it is, both M92 and M80 are relegated to sidekick status.

I always figured M4 must be some kind of monster glob, a northern rival for Southern Hemisphere titans like 47 Tucanae. (Of course, Omega Centauri is in another class altogether.) But it turns out that M4 isn't particularly large — with a diameter of 75 light-years it's actually quite a bit smaller than M80, which spans 96 light-years. M4 appears large because it's close, in fact one of the closest globular clusters to the solar system at a distance of only 7,200 light-years. In contrast, M80 is more than four times farther out, at 33,000 light-years. Try to catch them both in the same field of view and consider this thought: M4 is only about as distant as the next spiral arm inward, whereas M80 is just a bit farther from us than the galactic core. What a wonderful leap of the eye and the mind!

■ **MATT WEDEL** is on a quest to shatter the bowl of the sky — to really perceive the depths of space — and binoculars are his favorite wrecking ball.



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

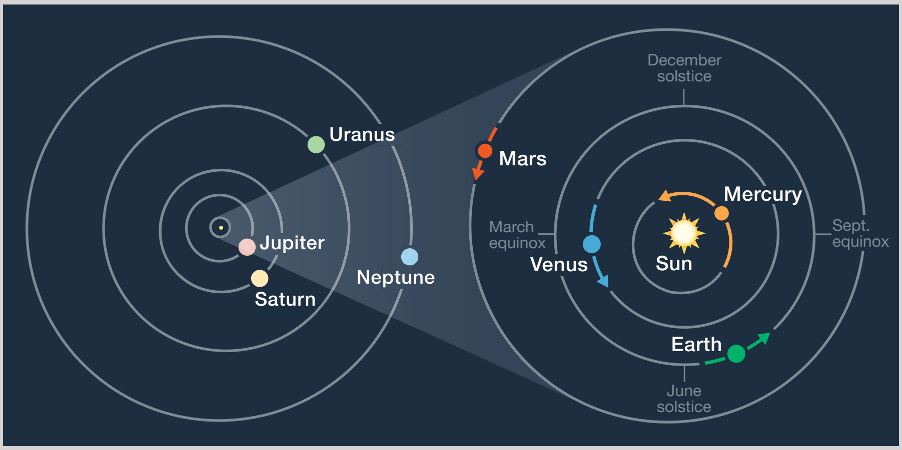
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during July. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is visible at dawn until the 23rd • **Venus** shines brightly at dusk all month • **Mars** is visible at dusk and sets in the late evening • **Jupiter** and **Saturn** rise in the evening and are visible through dawn.

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$6^h\ 39.6^m$	+23° 07′	—	–26.8	31′ 28″	—	1.017
	31	$8^h\ 40.6^m$	+18° 20′	—	–26.8	31′ 31″	—	1.015
Mercury	1	$5^h\ 11.0^m$	+19° 13′	21° Mo	+0.8	8.8″	27%	0.765
	11	$5^h\ 53.6^m$	+21° 38′	20° Mo	–0.3	6.9″	54%	0.980
	21	$7^h\ 06.4^m$	+22° 53′	13° Mo	–1.2	5.6″	84%	1.202
	31	$8^h\ 34.9^m$	+20° 21′	2° Mo	–2.1	5.0″	100%	1.334
Venus	1	$8^h\ 28.3^m$	+20° 45′	25° Ev	–3.8	11.2″	90%	1.492
	11	$9^h\ 17.6^m$	+17° 30′	28° Ev	–3.9	11.6″	88%	1.440
	21	$10^h\ 04.8^m$	+13° 29′	30° Ev	–3.9	12.1″	85%	1.383
	31	$10^h\ 49.9^m$	+8° 54′	33° Ev	–3.9	12.6″	82%	1.323
Mars	1	$8^h\ 58.2^m$	+18° 28′	33° Ev	+1.8	3.9″	97%	2.429
	16	$9^h\ 35.3^m$	+15° 36′	28° Ev	+1.8	3.7″	98%	2.498
	31	$10^h\ 11.6^m$	+12° 21′	23° Ev	+1.8	3.7″	99%	2.554
Jupiter	1	$22^h\ 16.4^m$	–11° 48′	127° Mo	–2.6	45.3″	99%	4.356
	31	$22^h\ 07.8^m$	–12° 44′	158° Mo	–2.8	48.4″	100%	4.073
Saturn	1	$20^h\ 59.0^m$	–17° 52′	147° Mo	+0.4	18.3″	100%	9.088
	31	$20^h\ 50.9^m$	–18° 28′	178° Mo	+0.2	18.6″	100%	8.936
Uranus	16	$2^h\ 46.7^m$	+15° 39′	69° Mo	+5.8	3.5″	100%	20.081
Neptune	16	$23^h\ 35.3^m$	–3° 55′	121° Mo	+7.9	2.3″	100%	29.393

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.



The Path from Arcturus to Vega

Let two of the season's brightest stars guide you to evening delights.

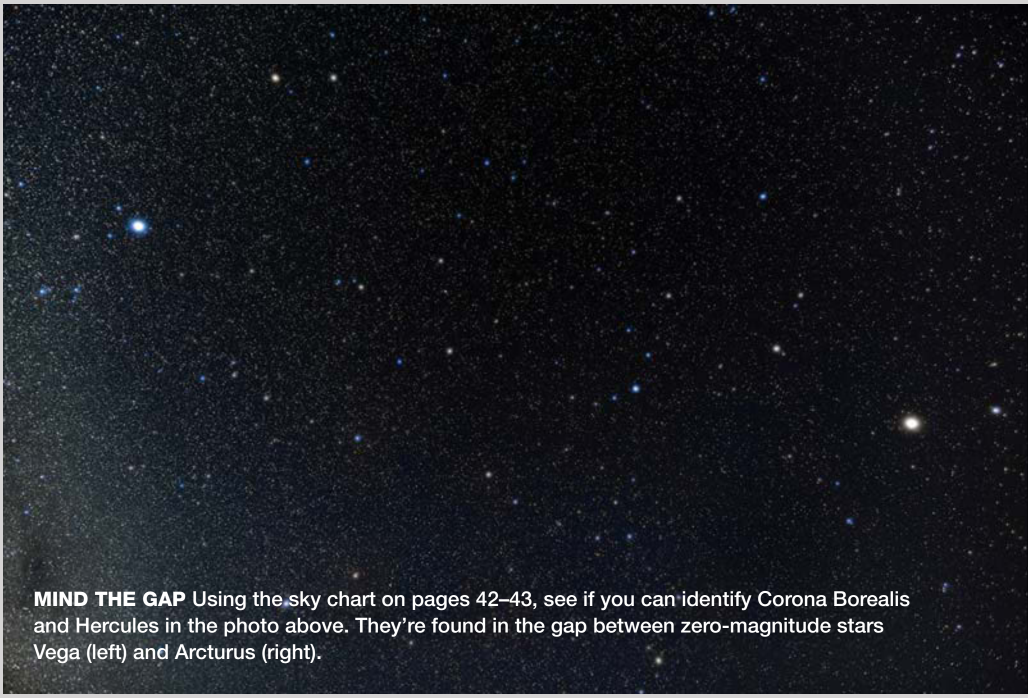
A pair of zero-magnitude stellar jewels shine high in the sky on July evenings. One of them, Arcturus, occupies a rather lofty position in the southwest but is starting to descend. The other, Vega, is approaching the meridian.

Both are the Alpha stars of their respective constellations. Vega dominates little Lyra, the Lyre, while Arcturus anchors the kite-shaped formation of Boötes, the Herdsman. (See the June issue for my write-up of Arcturus.) These two stars offer an interesting comparison since they're the second- and third-brightest visible from mid-northern latitudes.

But it's difficult to judge which is brighter just by looking. The precise magnitude of Arcturus is –0.05, while Vega is magnitude +0.03 — a difference of only 0.08. Even a very experienced variable-star observer isn't able to reliably distinguish between stars less than 0.1 magnitude apart. What's more, the lower a star is in the sky, the more atmosphere there is to absorb and scatter the starlight, thus making the star appear dimmer. That means on July evenings Arcturus might appear a touch fainter than Vega.

What is certain, however, is that drawing a line from Arcturus to Vega will help you locate two of summer's most interesting constellations. The first of these is the arc of stars that forms the main pattern of Corona Borealis, the Northern Crown. It's located about one-third of the way along the path from Arcturus to Vega. Farther along, about two-thirds of the way from Arcturus to Vega, is Hercules with its distinctive Keystone asterism.

The compact semicircle of Corona Borealis can be made out even in fairly light-polluted skies. The constellation's outstanding gem is the 2.2-magnitude star known as Alphecca or Gemma.



MIND THE GAP Using the sky chart on pages 42–43, see if you can identify Corona Borealis and Hercules in the photo above. They're found in the gap between zero-magnitude stars Vega (left) and Arcturus (right).

ALAN DYER

Gemma is Latin for "gem," but perhaps more intriguingly, Alphecca is from the Arabic *al-fakkah*, which means "the broken." That fits when you consider that the constellation's semicircle can also be perceived as a broken ring of stars.

There is, however, one star in Corona Borealis that has been known to outshine Alphecca — the famed recurrent nova, T Coronae Borealis. It's also known as the Blaze Star, for good reason. In 1866, it very briefly flamed from its normally dim telescopic brightness (around magnitude 10) to reach 2nd magnitude, slightly surpassing Alphecca. The performance was repeated in 1946, though on that occasion it topped out at magnitude 3.0. In the remote possibility that such outbursts happen at regular intervals, the next event would occur in late 2025 or in 2026. But the star is unpredictable. So, whenever you observe Corona Borealis, check to see if there's a bright interloper just southeast of Epsilon Coronae Borealis, the southeasternmost star in the semicircle.

The next stop on our journey from Arcturus to Vega, is Hercules — or, rather, the famous asterism known as the Keystone. Any deep-sky observer will tell you that one of the absolutely classic objects to view on summer nights is M13, the Great Globular Cluster in Hercules. It shines right at the limit of naked-eye visibility, so if you find yourself under a dark country sky on a moonless summer night, try detecting the cluster with your unaided eyes. As shown on our center star map, M13 is conveniently located about one-third of the way from Eta (η) to Zeta (ζ) Herculis, which form the west side of the Keystone. The globular should appear as a faint, hazy spot of glow.

■ Contributing Editor **FRED SCHAAF** always thinks of M13 as a beneficent monster as seen in his 8-inch scope.

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

Inner Planets Rule

Mercury and Venus have a busy month with several eye-catching conjunctions.

FRIDAY, JULY 2

Grab your binoculars and aim them at **Venus**, gleaming at magnitude –3.9, low in the west-northwest at dusk. Obviously, you don't need optical aid to spot one of the brightest objects in the night sky, but if you look carefully this evening, you might see a little star fuzz nearby. That's the Beehive Cluster, M44, in Cancer. And on this occasion, Venus is positioned just right (north) of the main clump of cluster stars. However, this won't be an easy observation to make. The two objects are only 10° up half an hour after sundown. You'll need an unobstructed horizon to have any hope of catching this challenging sight.

SUNDAY, JULY 4

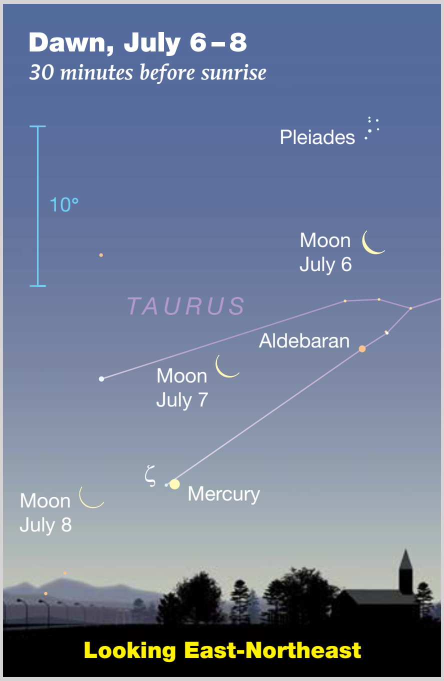
Little **Mercury** has its greatest elongation (22° west of the Sun) this morning. The planet shines at a relatively subdued magnitude +0.4, but don't worry — the best is yet to come. Thanks to the steep angle the ecliptic makes to the dawn horizon during summer, the planet actually achieves its greatest elevation several days later, on the 9th and 10th. By then, it will have brightened by nearly a full magnitude, to –0.3. Mercury continues to gain brightness as it begins its sunward plunge and loses altitude throughout the rest of July.

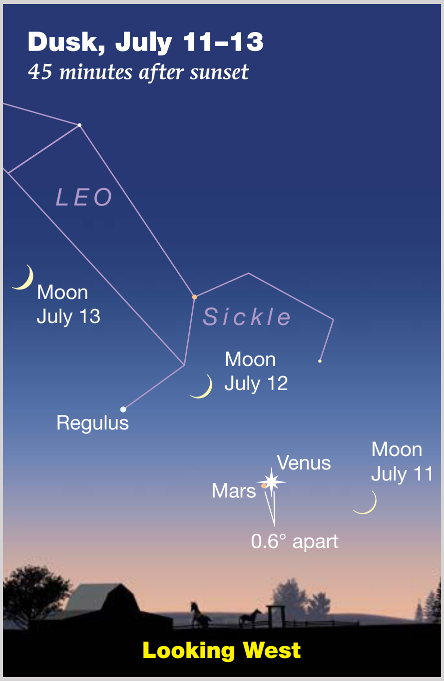
THURSDAY, JULY 8

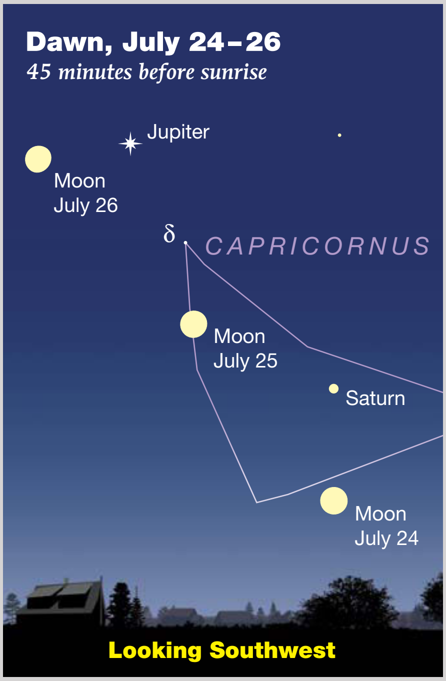
The July **Mercury** show continues this morning when it's joined by a very thin (2.4% illuminated) waning crescent **Moon**. About 4½° separate the two objects, which means they'll fit together in the field of view of standard binoculars. You don't actually *need* binoculars to take in this luminous pairing, but optics will help make a couple of bonus sights more apparent. First of these is earthshine bathing the portion of the lunar disk not illuminated directly by sunlight. Second is the 3rd-magnitude star **Zeta (ζ) Tauri**, which marks the tip of the Bull's lower (eastern) horn. The star is just ½° (roughly one Moon diameter) from Mercury. On this morning, the planet shines at magnitude –0.1, some 17 times brighter than its stellar partner.

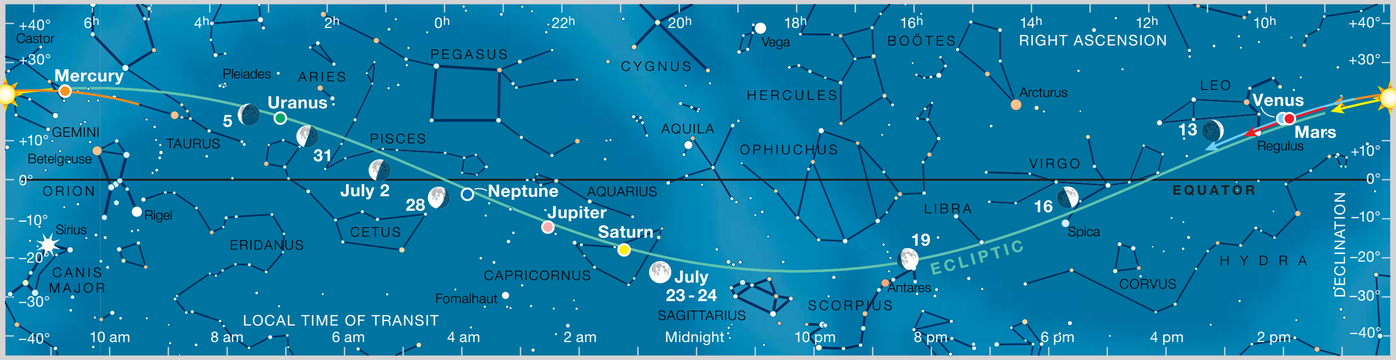
SUNDAY, JULY 11

Mars has had quite an eventful showing since emerging from the Sun's glare all the way back in October 2019. The highlight, of course, was its close opposition in the late summer and autumn of 2020. Now, as the current appari-









▲ 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.

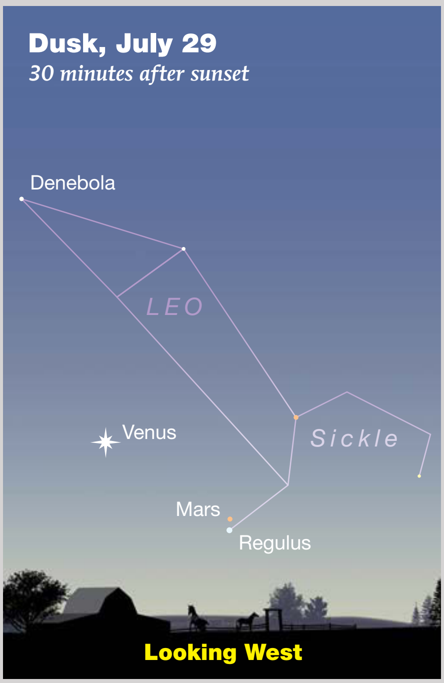
tion winds down, Mars glows relatively feebly at magnitude 1.8 and needs help to get any attention. And this evening, that help arrives in the form of an especially luminous supporting cast. Indeed, the Red Planet is seriously upstaged by **Venus** and the **Moon**. Venus gleams a brilliant magnitude –3.9 just 1° right of Mars, while the lunar crescent sits roughly 5° right of Venus. The threesome are a lovely sight, low in the west-southwest as twilight dims. On the following two nights (the 12th and 13th), the Moon exits the scene and Venus closes in on Mars. The separation between the two worlds narrows to just a little more than ½° on the 12th before they begin to move apart, with Venus climbing higher as Mars continues to descend.

THURSDAY, JULY 15

One week after its encounter with Zeta Tauri, **Mercury** sidles up to another star. This morning it's **Mu (μ) Geminorum**. Illustrating just how quickly the innermost planet moves across the sky, in this single week Mercury has traversed more than 10° to cover that distance. Although Mu Geminorum is just a tiny bit brighter than Zeta Tauri (magnitude 2.9 versus 3.0), this conjunction will be a little harder to see. One reason is that the planet and star will be just 7° up at the start of civil twilight. Another reason is the gap between the planet and star will be a tight 5′ — time to get those binoculars out again! This encounter will be a bit of a challenge to take in, but if you have clear skies and an unobstructed east-northeastern horizon, give it a go.

SATURDAY, JULY 24

Late this evening, the nearly full **Moon** is flanked by **Jupiter** and **Saturn** as the trio rise in the southeast. If your neighbors are like mine, expect to hear the question, "What are those bright stars near the Moon?" But as eye-catching as the gathering is, it improves throughout the night and into the morning of the 25th as the Moon's relentless eastward motion places it nearly equidistant between Jupiter and Saturn. (But only observers on the West Coast will see the Moon truly equidistant from the planets, at around 5 a.m. PDT.) When the waning gibbous Moon rises later that evening, it'll be crowned by Jupiter, positioned some 4½° above and slightly to its left. Expect more questions from the neighbors.

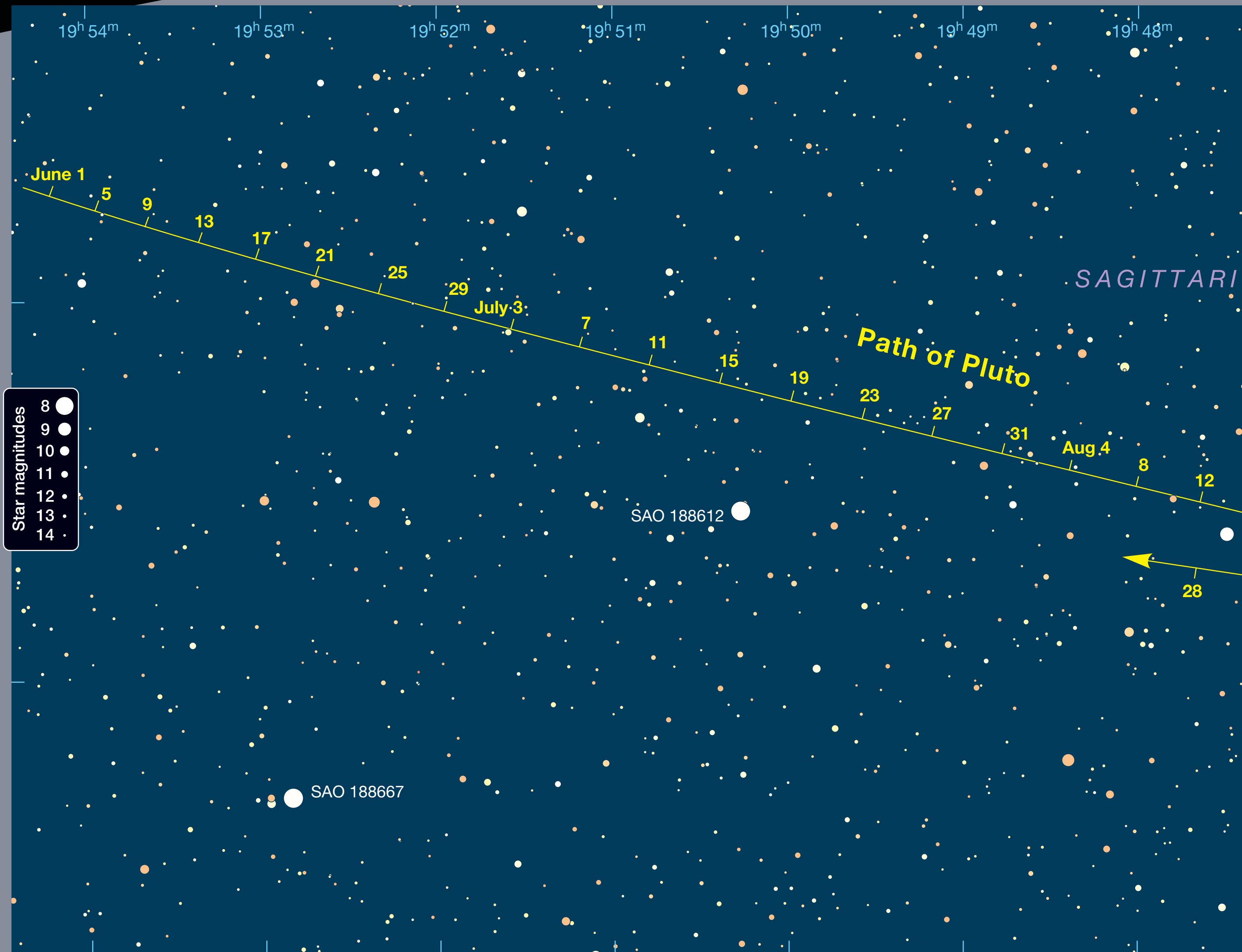


◀ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your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

THURSDAY, JULY 29

The month wraps up with one final evening conjunction for **Mars**. At dusk today, the planet has a close encounter with **Regulus**, the brightest star in Leo. Indeed, the 1.4-magnitude star is nearly half a magnitude brighter than Mars, which is nearly 58 times fainter than at its eye-catching peak last October. Once again, you'll need your binoculars to get a good look. Just 37′ separate the star and planet as they hang low in the west-northwest during twilight. Although its current apparition doesn't officially end until October 8th, chances are that after tonight you won't look in on Mars again until it emerges at dawn in late November. So, as the show tune goes, it's time to "Say cheerio, not goodbye!"

■ Consulting Editor **GARY SERONIK** has kept his astro binoculars handy for nearly five decades.



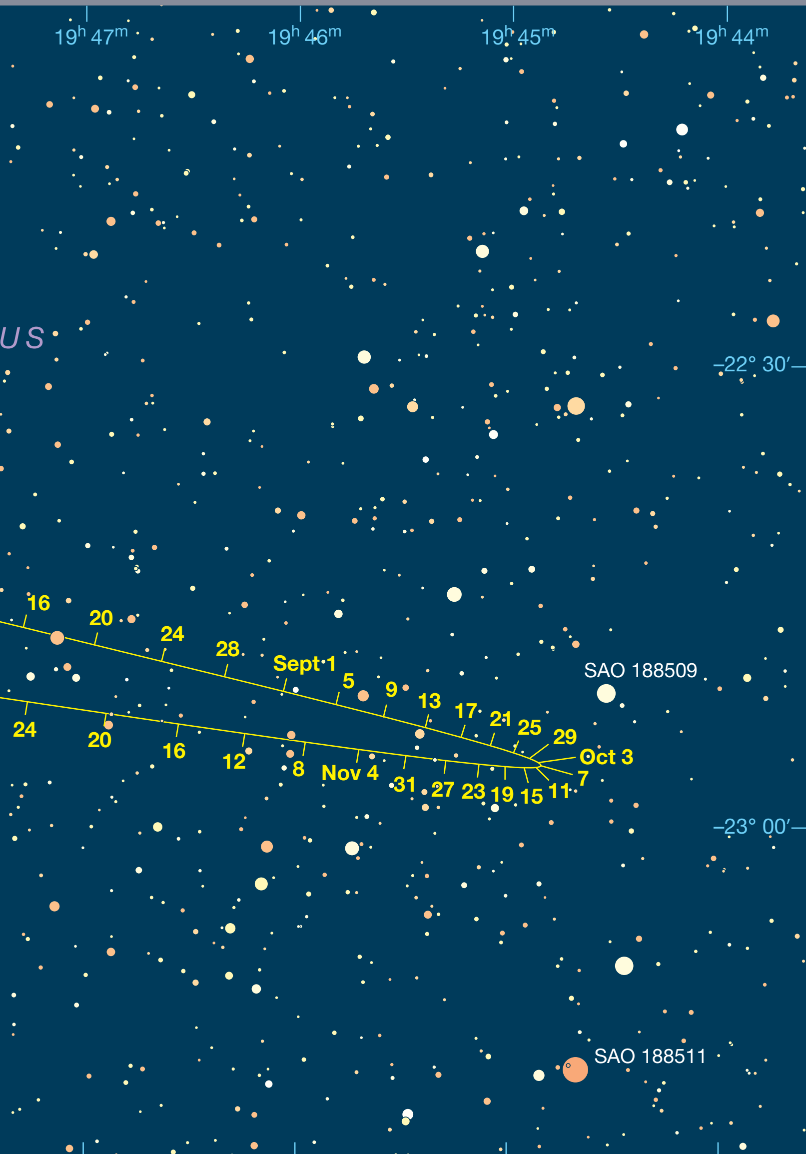
Visiting Pluto

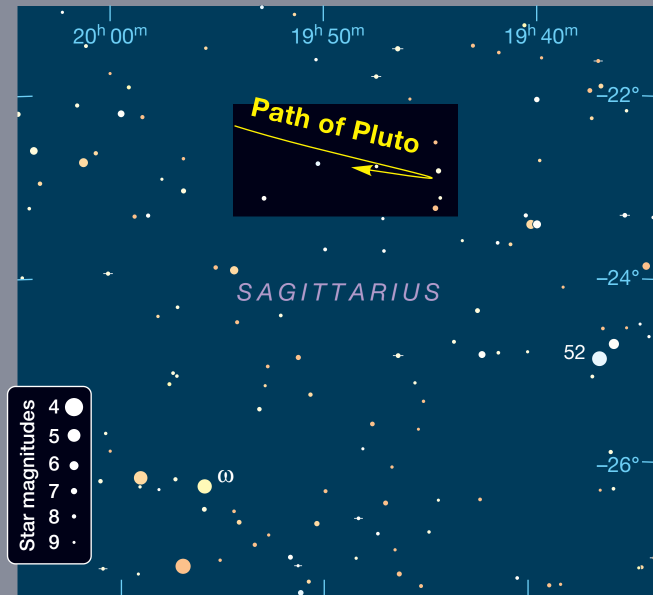
Trek into eastern Sagittarius to locate this remote dwarf planet.

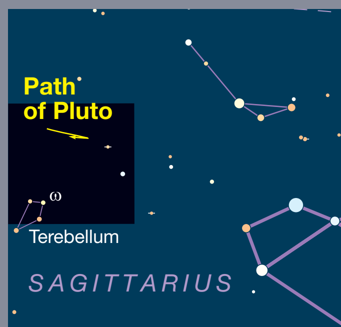
Last year Jupiter proved an able guide to finding Pluto, but the gas giant has since moved on, leaving the dwarf planet by itself in the wilds of eastern Sagittarius. However, a distinctive asterism and several bright telescopic stars point the way this season. As long as your scope can dig down to Pluto's magnitude of 14.3, with a careful approach you should be able to find this Holy Grail of astronomical challenges.

Under a dark sky, an 8-inch telescope should be up to the task. An excellent place to start is the small asterism called the Terebellum — four stars brighter than 5th magnitude in the shape of a kite with Omega (ω) Sagittarii at its peak. Use the charts above and a wide-field eyepiece to locate Pluto on the specific date you're looking. Once you're in the vicinity, boost the magnification to identify your prize.

When dealing with this faint star-like speck, I use nearby field stars to complete a triangle or box that includes Pluto. This helps me know exactly where





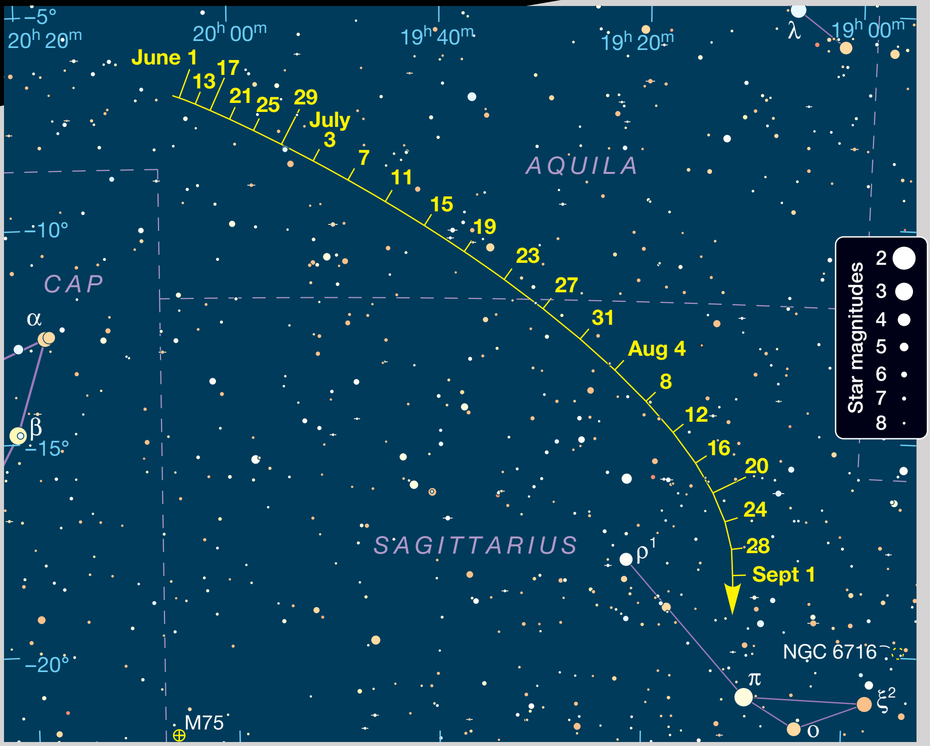


to look because the speck is now part of a pattern. In my 15-inch reflector, Pluto stands out well at around 200×. Returning to the field the next clear night to see if your suspect has shifted position is a good strategy to confirm your initial sighting. Catching Pluto on the move is also the method used by Clyde Tombaugh in 1930 when he discovered Pluto by methodically examining photographic plates captured on different nights. Pluto's motion over a 24-hour span will probably suffice for a positive identification, especially if the erstwhile planet happens to pass near a field star.

On July 17th when it's at opposition, Pluto will be nearly 5 billion kilometers (3 billion miles) from Earth and crawling west in retrograde motion at the rate of about 1.4′ per day. That's a distance 2½ times greater than the separation between the component stars of the famed double Albireo in Cygnus.

Pluto seekers embark on a journey to an exotic land. With a bit of planning and steady seeing, your adventure will take you to remote country visited by few. Your destination is the Kuiper Belt — a cold and distant place where you'll see a globe enrobed in icy nitrogen, methane, and carbon monoxide.

Your impression of Pluto, like other difficult targets, is largely about what *you* bring to the telescope eyepiece. That includes knowledge of the subject and its history. Equally important is the effort you expend in finding it — all of which adds to the pleasure of accomplishing the journey.



Homing in on Hebe

IN THE MARCH CELESTIAL CALENDAR, I described how Vesta is the parent body of a group of meteorites known as the HED clan. But astronomers may have uncovered yet another origin story — this one involving 6 Hebe, which reaches opposition in southern Aquila on July 19th.

Hebe is a stony, main-belt asteroid that measures 205 km across. It's also the suspected source of two classes of meteorites: The H-chondrites (the most common type found on Earth) and the related, but rarer, IIE irons. Not all scientists agree that Hebe is the primary source of H-chondrites, arguing that its craters are too small to have produced the volume of material found on Earth. But recent research indicates some of Hebe's fragmental remains may have created a small family of neighboring asteroids that also generate H-chondrites.

Make your connection with this fascinating asteroid this summer when it inches southwest from southern Aquila into northern Sagittarius. Hebe starts July at magnitude 8.7 and brightens to 8.3 by the 20th. A pair of 10×50 binoculars should suffice to snag it under dark skies, otherwise any small telescope will do the trick.

Selected Jupiter Mutual Satellite Events

Date	Time (UT)	Event	Mag change
June 1	11:06 – 11:13	Io eclipses Ganymede	0.3
June 10	7:58 – 8:05	Callisto eclipses Europa	0.9
June 18	5:26 – 5:55	Europa eclipses Callisto	0.6
June 21	6:13 – 6:17	Io eclipses Europa	0.8
June 28	8:33 – 8:36	Io eclipses Europa	0.9
July 5	10:54 – 10:57	Io eclipses Europa	1.0

Action at Jupiter

THE JUPITER OBSERVING SEASON is entering its prime. By mid-July, the planet rises late in the evening and reaches the meridian just before the start of astronomical twilight. On the 15th, the planet displays a disk 47″ across and shines brightly at magnitude −2.7 from western Aquarius.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable July interactions between Jupiter, its satellites, and their shadows are tabulated on the facing page. Find events timed for dawn in your time zone, when Jupiter is at its highest.

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

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

23: 8:16, 18:12; **24**: 4:07, 14:03, 23:58; **25**: 9:54, 19:49; **26**: 5:45, 15:41; **27**: 1:36, 11:32, 21:27; **28**: 7:23, 17:19; **29**: 3:14, 13:10, 23:05; **30**: 9:01, 18:57; **31**: 4:52, 14:48

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

Phenomena of Jupiter's Moons, July 2021

July 1	12:29	I.Sh.I
	13:33	I.Tr.I
	14:46	I.Sh.E
	15:50	I.Tr.E
July 2	4:52	II.Ec.D
	9:47	I.Ec.D
	9:56	II.Oc.R
	13:08	I.Oc.R
July 3	6:57	I.Sh.I
	8:00	I.Tr.I
	9:15	I.Sh.E
	10:17	I.Tr.E
	14:38	III.Sh.I
	18:16	III.Sh.E
	18:54	III.Tr.I
	22:28	III.Tr.E
	23:51	II.Sh.I
July 4	1:54	II.Tr.I
	2:42	II.Sh.E
	4:15	I.Ec.D
	4:42	II.Tr.E
	7:34	I.Oc.R
	13:56	IV.Ec.D
	18:42	IV.Ec.R
	23:44	IV.Oc.D
July 5	1:26	I.Sh.I
	2:27	I.Tr.I
	3:44	I.Sh.E
	4:07	IV.Oc.R
	4:44	I.Tr.E
	18:11	II.Ec.D
	22:43	I.Ec.D
	23:08	II.Oc.R
July 6	2:01	I.Oc.R
	19:54	I.Sh.I
	20:54	I.Tr.I
	22:12	I.Sh.E
	23:11	I.Tr.E
July 7	4:41	III.Ec.D
	8:20	III.Ec.R
	8:42	III.Oc.D
	12:17	III.Oc.R
	13:08	II.Sh.I
	15:05	II.Tr.I
	15:59	II.Sh.E
	17:12	I.Ec.D
	17:53	II.Tr.E
	20:28	I.Oc.R
July 8	14:23	I.Sh.I
	15:21	I.Tr.I
	16:41	I.Sh.E
	17:38	I.Tr.E
July 9	7:29	II.Ec.D
	11:40	I.Ec.D
	12:19	II.Oc.R
	14:54	I.Oc.R
July 10	8:52	I.Sh.I
	9:48	I.Tr.I
	11:09	I.Sh.E
	12:05	I.Tr.E
	18:38	III.Sh.I
	22:16	III.Sh.E
	22:25	III.Tr.I
July 11	1:59	III.Tr.E
	2:25	II.Sh.I
	4:15	II.Tr.I
	5:16	II.Sh.E
	6:09	I.Ec.D
	7:03	II.Tr.E
	9:21	I.Oc.R
July 12	3:20	I.Sh.I
	4:14	I.Tr.I
	5:38	I.Sh.E
	6:31	I.Tr.E
	20:48	II.Ec.D
	21:46	IV.Sh.I
July 13	0:37	I.Ec.D
	1:30	II.Oc.R
	2:30	IV.Sh.E
	3:47	I.Oc.R
	6:23	IV.Tr.I
	10:44	IV.Tr.E
	21:49	I.Sh.I
	22:41	I.Tr.I
July 14	0:06	I.Sh.E
	0:58	I.Tr.E
	8:41	III.Ec.D
	15:42	II.Sh.I
	15:46	III.Oc.R
	17:24	II.Tr.I
	18:33	II.Sh.E
	19:06	I.Ec.D
	20:12	II.Tr.E
	22:14	I.Oc.R
July 15	16:17	I.Sh.I
	17:07	I.Tr.I
	18:35	I.Sh.E
	19:25	I.Tr.E
July 16	10:06	II.Ec.D
	13:34	I.Ec.D
	14:39	II.Oc.R
	16:40	I.Oc.R
July 17	10:46	I.Sh.I
	11:34	I.Tr.I
	13:04	I.Sh.E
	13:51	I.Tr.E
	22:38	III.Sh.I
July 18	1:52	III.Tr.I
	2:17	III.Sh.E
	4:59	II.Sh.I
	5:26	III.Tr.E
	6:33	II.Tr.I
	7:50	II.Sh.E
	8:03	I.Ec.D
	9:21	II.Tr.E
	11:07	I.Oc.R
July 19	5:14	I.Sh.I
	6:00	I.Tr.I
	7:32	I.Sh.E
	8:18	I.Tr.E
	23:25	II.Ec.D
July 20	2:31	I.Ec.D
	3:50	II.Oc.R
	5:33	I.Oc.R
	23:43	I.Sh.I
July 21	0:27	I.Tr.I
	2:01	I.Sh.E
	2:44	I.Tr.E
	8:06	IV.Ec.D
	12:41	III.Ec.D
	12:49	IV.Ec.R
	14:58	IV.Oc.D
	18:16	II.Sh.I
	19:10	III.Oc.R
	19:19	IV.Oc.R
	19:41	II.Tr.I
	20:59	I.Ec.D
	21:07	II.Sh.E
	22:29	II.Tr.E
	23:59	I.Oc.R
July 22	18:11	I.Sh.I
	18:53	I.Tr.I
	20:30	I.Sh.E
	21:11	I.Tr.E
July 23	12:43	II.Ec.D
	15:28	I.Ec.D
	16:58	II.Oc.R
	18:25	**I.Oc.R**
July 24	12:40	I.Sh.I
	13:19	I.Tr.I
	14:58	I.Sh.E
	15:37	I.Tr.E
July 25	2:39	III.Sh.I
	5:16	III.Tr.I
	6:18	III.Sh.E
	7:34	II.Sh.I
	8:49	II.Tr.I
	8:50	III.Tr.E
	9:56	I.Ec.D
	10:24	II.Sh.E
	11:37	II.Tr.E
	12:51	I.Oc.R
July 26	7:09	I.Sh.I
	7:45	I.Tr.I
	9:27	I.Sh.E
	10:03	I.Tr.E
July 27	2:02	II.Ec.D
	4:25	I.Ec.D
	6:08	II.Oc.R
	7:18	I.Oc.R
July 28	1:37	I.Sh.I
	2:12	I.Tr.I
	3:55	I.Sh.E
	4:29	I.Tr.E
	16:41	III.Ec.D
	20:51	II.Sh.I
	21:57	II.Tr.I
	22:31	III.Oc.R
	22:53	I.Ec.D
	23:41	II.Sh.E
July 29	0:45	II.Tr.E
	1:44	I.Oc.R
	15:57	IV.Sh.I
	20:06	I.Sh.I
	20:38	I.Tr.I
	20:40	IV.Sh.E
	21:11	IV.Tr.I
	22:24	I.Sh.E
	22:56	I.Tr.E
July 30	1:32	IV.Tr.E
	15:20	II.Ec.D
	17:22	I.Ec.D
	19:16	II.Oc.R
	20:10	I.Oc.R
July 31	14:35	I.Sh.I
	15:04	I.Tr.I
	16:53	I.Sh.E
	17:22	I.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 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons

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

Saturnian Challenges

Try to spot these elusive features in Saturn's rings.

I recently perused a copy of the fifth edition of *Le Ciel* by French science writer and journalist Amédée Guillemin. Published in 1877, this profusely illustrated tome contains a beautiful lithograph depicting Saturn based on observations by Otto Wilhelm von Struve (1819-1905) in the autumn of 1851 at the Pulkovo Observatory on the outskirts of St. Petersburg.

The most striking detail of the print is a well-defined division in the faint, tenuous C ring. Struve detected this feature three-quarters of the distance from the ring's inner edge to its outer border using the observatory's 15-inch Merz refractor at magnifications of 400× and 700×. This feat demonstrates the high optical quality of the best 19th-century refracting telescopes. He announced his discovery in the *Memoirs of the St. Petersburg Academy of Sciences* in 1852.

Known for a time during the 19th century as the Struve Division, this delicate feature remained unconfirmed by independent observers, and Struve himself was unable to detect it the following year. Although the human eye has a remarkable ability to discern dark lines against a bright background (*S&T:* Nov. 2000, p. 117), the low surface brightness and contrast of the C ring make it a challenge to observe in comparison to divisions in the bright A and B rings.

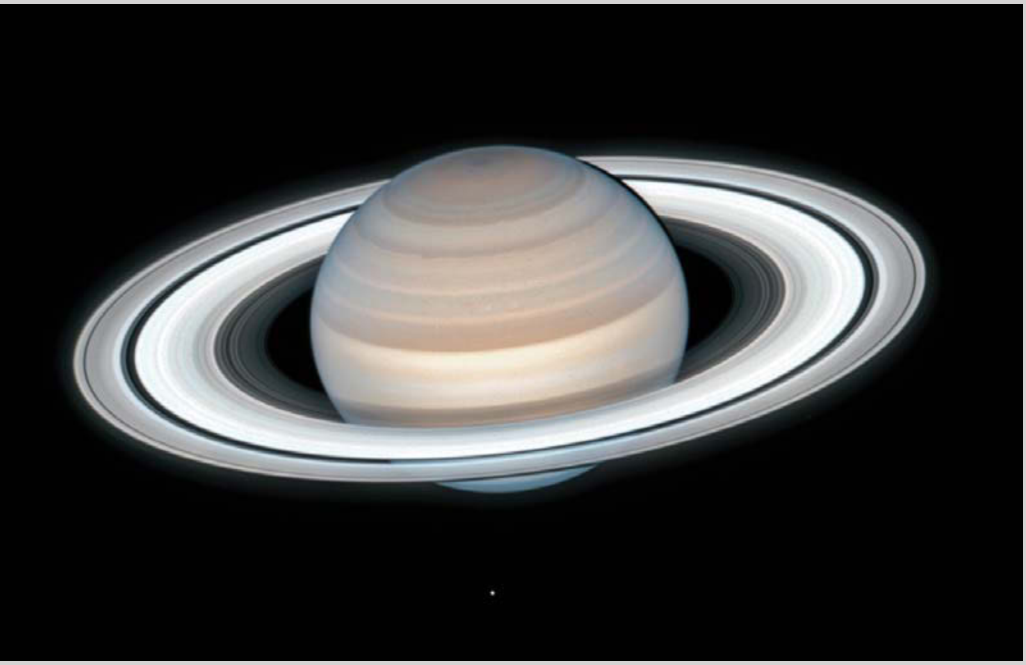
In 1980, NASA's Voyager 1 spacecraft returned images of a 270-kilometer-wide division located precisely where Struve had reported it. Members of the Voyager imaging team opined that earthbound telescopes could not have detected the feature. The International Astronomical Union named it the Maxwell Gap to honor the Scottish scientist James Clerk Maxwell (1831-1879), who demonstrated that Saturn's rings must be composed of a myriad of small bodies, each independently orbiting the planet. Poor Struve!

Today, surprisingly few planetary imagers process their videos of Saturn in a fashion that optimally displays features in the C ring, though several observers using instruments with apertures as small as 12 inches have recorded the Maxwell Gap. It's the ultimate challenge for visual observers, requiring superb seeing and a telescope with enough light-gathering power to make the pale C ring stand out boldly at high magnifications.

The Maxwell Gap is undoubtedly the most difficult feature in Saturn's ring system detectable by a visual observer. Amazingly, a far more prominent feature eluded generations of planetary observers even though it can be seen through a 4-inch telescope.

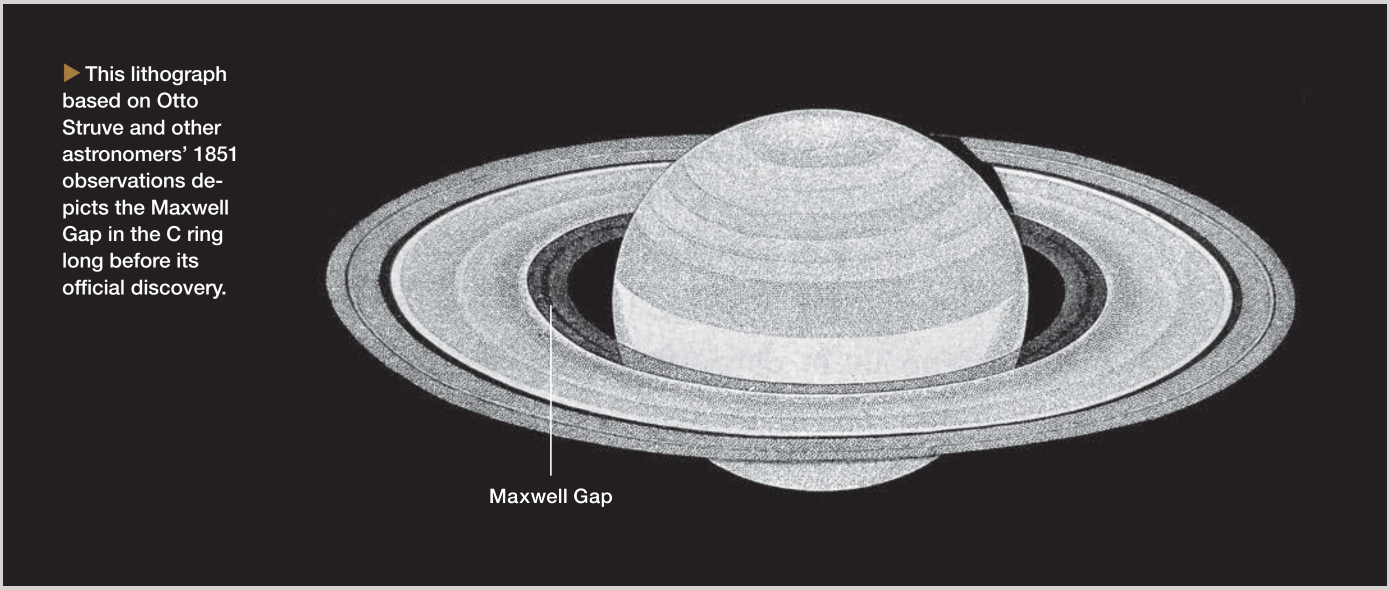
In 1958, French astronomer Henri Carmichel noticed a peculiar brightness modulation along the circumference of Saturn's A ring when he examined low-resolution photographs of the planet. If we begin where Ring A passes in front of the planet and follow its course westward, we encounter a brightness minimum (-) about 25° from the western ansa, followed by a brightness maximum (+) at a distance of 90° on the opposite side of the ring, 65° beyond the ansa. A second brightness minimum occurs near the eastern ansa, followed by a second brightness maximum after another interval of 90°.

Known as the "quadrupole azimuthal brightness asymmetry" today, this persistent pattern has been extensively studied in images obtained by the Hubble Space Telescope as well as the Voyager and Cassini spacecrafts. It's produced by gravitational interactions between ring particles. As a large particle glides through the ring, its gravitational attraction perturbs the orbits of smaller particles in its vicinity, forming long, linear wakes. Particles in



◀ A host of divisions in Saturn's ring system are visible in this image captured by the Hubble Space Telescope on July 4, 2020.

NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER), M. H. WONG (U.C. BERKELEY), AND THE OPAL TEAM



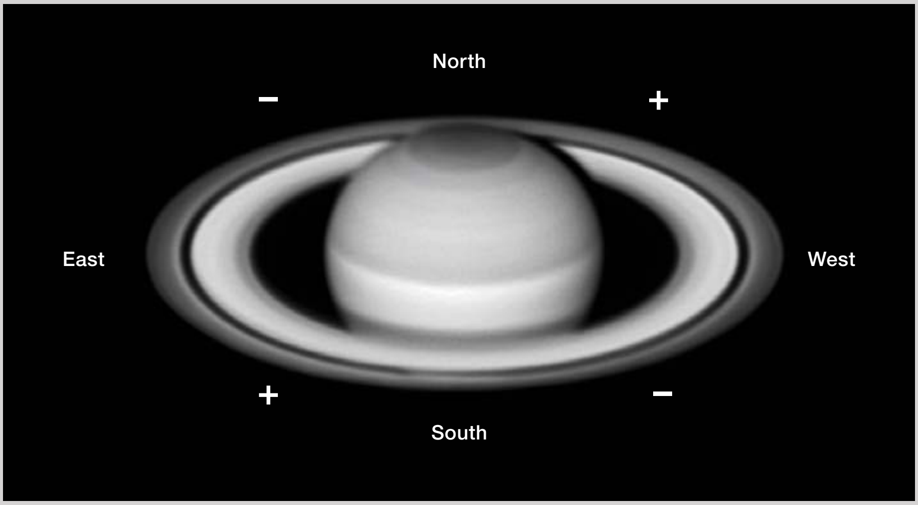
▶ This lithograph based on Otto Struve and other astronomers' 1851 observations depicts the Maxwell Gap in the C ring long before its official discovery.

the inner parts of these transient shoals orbit Saturn faster than the particles in the outer parts. This differential rotation inclines the wakes 20° to 25° with respect to their orbital motion, much like the trailing arms of a spiral galaxy.

The apparent brightness of these wakes depends on viewing geometry. When wakes are viewed along their long axes, the rarefied regions between the wakes are obscured, increasing the overall apparent brightness of the area. Conversely, from an end-on viewing angle the intervening rarefied regions are more exposed, causing the area to appear less bright.

The typical amplitude of the brightness modulation in the A ring is about 10% — well within the human eye's threshold of perception. A much weaker brightness modulation was also detected in the B ring. The effect is more pronounced in the A ring because it has a sparser particle density and lacks the B ring's plentiful sub-micron "dust" that mutes brightness differences.

In retrospect, it's surprising that the brightness modulation in the A ring eluded generations of visual observers. It stands out boldly in many amateur images, particularly after increasing the picture's contrast. During the 1990s, I observed the effect on many occasions using a monochrome analog video camera. When I gradually lowered the camera's gain to make the image slowly fade from view, the brighter regions of the A ring were the last portions of the ring to disappear on the monitor display. Visual observers can mimic this technique by using a variable polarizing filter.



▲ The so-called quadrupole azimuthal brightness asymmetry in Saturn's A ring lurks in most any image of the planet recorded when the rings are wide open. It becomes apparent after boosting the image contrast as in the diagram above.

During the late 1970s, renowned observer Stephen James O'Meara was the first to visually confirm Carmichel's photographic discovery. His eyepiece impressions through the 9-inch Clark refractor at Harvard College Observatory compared favorably to photoelectric photometer data obtained with a 16-inch reflector at the nearby Oak Ridge observing station. (It was during this months-long observing campaign that he also discovered the ephemeral dusky "spokes" in the B ring.) Interestingly, O'Meara found the brightness differences in Ring A easier to distinguish during twilight than under fully darkened skies.

The relatively open presentation of Saturn's rings throughout this year's apparition provides an excellent opportunity to glimpse these undeservedly obscure features.

■ Contributing Editor **TOM DOBBINS** uses historical observations to inform his modern ones.

LITHOGRAPH: OTTO STRUVE / *LE CIEL*; DIAGRAM: SEAN WALKER / S&T

▲ **STARLIT DUCKS** The magnificent open cluster M11 is also known as the Wild Duck Cluster. Its stellar ducks are flying in a rich swath of Milky Way in the diminutive constellation Scutum.

ALL IMAGES COURTESY OF ALAN DYER

Behind the Shield

One part of Scutum succumbs to light pollution; another holds up just fine.

Good things come in small packages. Tiny Scutum, the Shield, hosts the Scutum Star Cloud, a glittering condensation in the summer Milky Way. Unfortunately, the Shield can't block light pollution. Viewed from my suburban yard on the Canadian side of the 49th parallel, Scutum never climbs very high above the southern horizon. To make matters worse, I live at the north end of a light-blighted burgh. My south sky is awful.

Gazing at Scutum on a humid night last summer, I beheld precisely two Shield stars and no hint of the famous Star Cloud. I attacked anyway. For weapons, I chose my 4.7-inch (120-mm) f/7.5 apochromatic refractor on a Go To equatorial mount, and my 10-inch (25-cm) f/6 Dobsonian. The Go To mount works perfectly well, but I don't mind aiming the Dob manually. Its 6×30 finderscope was all I needed for a successful Scutum star-hop.

Wild Ducks

Occupying the northeast corner of the Scutum Star Cloud is a deep-sky showpiece even my local LED streetlights can't wreck: the 5.8-magnitude open cluster **M11**. Two centuries ago, retired British admiral (and astronomer) William Smyth wrote that it "somewhat resembles a flight of wild ducks." Hence the evocative nickname, Wild Duck Cluster.

The admiral's flock of flyers is roughly 700-strong and crowded into a space 11′ across. Their leader, a 8.6-magnitude lucida, gleams near the apex of the formation. Except for that stellar standout (likely a foreground object), the cluster contains no stars brighter than 11th magnitude, giving "M11" extra meaning. It's only because those myriad pinpoints are jam-packed that the Wild Duck Cluster is so alluring — in a dark rural sky. Having never observed M11 from town before, I first turned to my auto-apo and punched in M11 on the hand-controller.

The Go To completed its duck hunting in mere seconds. Working at 30×, the refractor presented M11 as a teeny, mottled mass guarded by a pair of 9th-magnitude stars. By slightly averting my vision, I sensed a comet, its "tail" fanning northwestward from the lucida "nucleus." Increasing to 38× was enough to resolve the faux comet into a dense salting of suns. Doubling to 76× produced a vague patchiness. At 100×, the cluster seemed very mottled — and it became squarish.

Next, I grabbed the aim-by-hand Dobsonian. I began my star-hop in neighboring Aquila, the Eagle. To me, the Eagle's tail is a curl of feathers dominated by 3.4-magnitude Lambda (λ) Aquilae. Dimmer 12, 14, and 15 Aquilae, plus Beta (β) and Eta (η) Scuti (on loan to Aquila for this occasion), round out the Aquila Curl. Spanning 5°, the Curl makes an eye-catching gateway to Scutum. After centering Lambda in the Dob's finder, I nudged southwestward to 4th-magnitude 12 Aquilae, veered west to 5th-magnitude Eta Scuti, then slipped beneath the Curl into Shield territory.

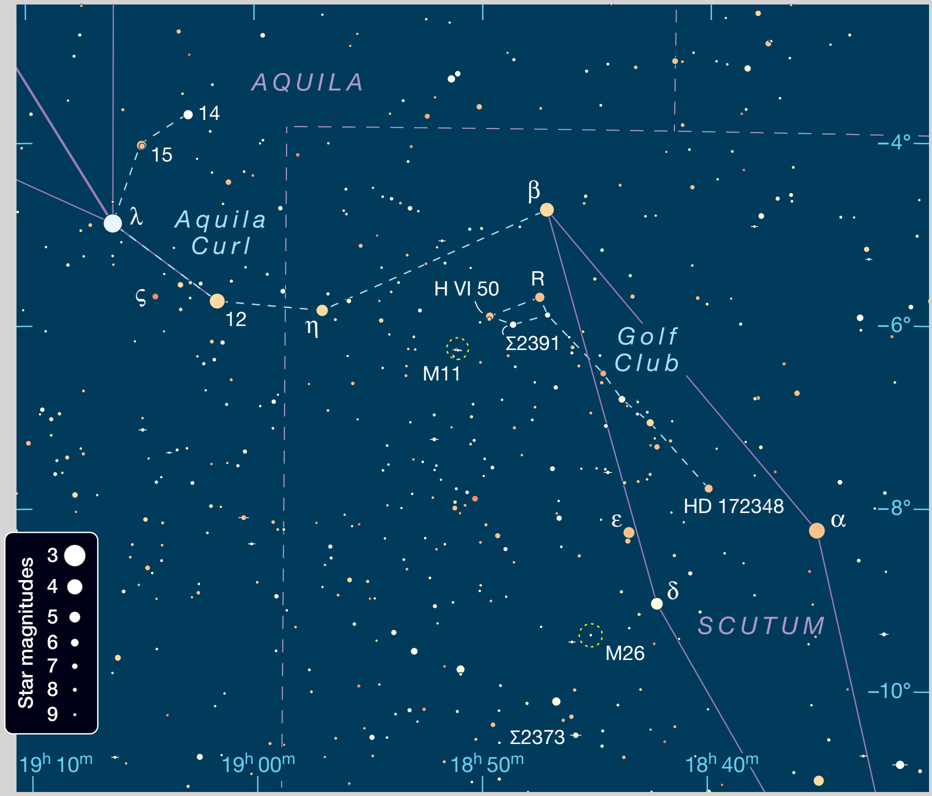
The little finderscope swept up M11 right away. In the 10-inch at 48×, I got the star-rich fan effect. But higher magnification greatly enhanced M11's odd squareness, the four-sided cluster comprising several rows of stars. To my eye, the boxy pattern of bright rows and dark lanes resembled a farmyard corn maze viewed from above. (Hey, a corn maze is no worse than a flock of wild ducks!) Here are my taped impressions made at the telescope, edited for clarity and a PG rating:

"At 48×: Well-resolved, fan-shaped. The lucida isn't quite on the southeast apex. There's a narrow clump of faint stars between the cluster and a close 9th-mag tandem. At 64× now. Darn good resolution, and it looks squarish. I see short rows of stars; some parallel, others at right angles. At 128×, the geometrical structure is captivating. Let's try 169×. Yuck — too much turbulence. Still, right-angled rows define this thing. Really a-*maze*-ing!"

Plenty to Like

A half-degree hop northwest of the Wild Duck Corn Maze Cluster is more Scutum scenery. I confess it isn't postcard pretty, but I've learned to grab whatever my suburban skies offer. To misquote film legend Humphrey Bogart as detective Sam Spade: "When you're slapped with light pollution, you'll take it and you'll like it."

What I "like" is a ½°-long quadrilateral of stars whose northwest corner is adorned with the yellow variable star **R Scuti**. Erratic R fluctuates mainly between 5th and 6th magnitude over a time scale of months. Occasionally, though, it dips slightly below 8th



▲ **SCOPING THE SHIELD** The easiest way to locate the treasures found in Scutum is to star-hop from neighboring Aquila by following the arc of stars the author has dubbed the Aquila Curl, which terminates at Beta (β) Scuti.

▲ **SUBURBAN DREAM** The magnificent Scutum Star Cloud (right of center) is a sight that city-bound observers can only dream of. However, some of its highlights (such as M11, M26, and several double stars) are accessible even under adverse conditions. This photo has been cropped and scaled to match the chart.

magnitude, which noticeably alters my perception of the quad. I always keep an eye on R. The corners closest to M11 are distinguished by doubles. **Herschel (H) VI 50**, a 6.2-magnitude orange sun with a wide 8.2-magnitude companion to the south-southeast, is super-obvious. **Struve (Σ) 2391** attractively packages 6.5- and 9.6-magnitude elements 38″ apart. The entire scene — R to M — fits in almost any telescope's low-power field.

The abovementioned quadrilateral is part of an asterism I call the Golf Club. The quad outlines the golf club's 9-iron head. From the head, trending southwestward along the west side of the Scutum Cloud, is a 2°-long shaft of 6th- and 7th-magnitude dots ending at the golf club's grip, established by orangey, 5.8-magnitude HD 172348. In an improbable stroke of luck, my night-sky 9-iron is ready to hit a grainy golf ball branded M11.

The Golf Club's grip-star, together with Epsilon (ε), Delta (δ), and Alpha (α) Scuti, trace out a quadrilateral similar to the 9-iron head, except mirror-reversed, upside-down, and three times larger. In my Dob's finderscope, this group provided two routes to my next quarry, 8.0-magnitude open cluster **M26**. Going from Alpha through Delta gets me straight there. Alternatively, I enjoy zig-zagging in one-degree steps from HD 172348 across to Epsilon, down to Delta, then over to M26. It's a picturesque course — the grip-star glinting orange, Epsilon and Delta each sporting wide companions.

Kite Cluster

Wimpy M26 is no match for Smyth's wild ducks. M26 rivals M11 in terms of size, but its 120 stars are loosely arranged. What would the scopes reveal? Since M26 never climbs higher than 32° above my light-blighted southern horizon, I expected more woe than wonder.

▲ **SMATTERING OF STARS** Although overshadowed by nearby M11, open cluster M26 is a fine sight even in modest-aperture, suburban scopes.

Predictably, the refractor at 30× yielded only a gray, granular blob. However, upgrading to 38× teased out four pinpricks in the form of a slender, 140″-long kite. The wee kite slants northeast; it's weighted at its southwest end by the cluster's 9.2-magnitude lucida. Doubling to 76× clarified the kite, and patient averted vision added numerous surrounding pinpricks of light concentrated toward the northeast. The extra stuff was unmistakable at 100×.

The 10-inch punched through the ugly pollution to grab lots of very faint stars. I detected perhaps two dozen stars at 169×. As noted above, they trend northeast of the likewise-leaning kite, making M26 seem elongated. Not bad for a lower-tier cluster submerged in a creamy sky.

My Scutum exploration concluded at a finder-friendly, diamond-shaped asterism 1° south of M26. The ½°-long grouping features a 6th-magnitude yellowy star on top, dimmer orange suns tinting its sides, and a binary called **Struve (Σ) 2373** at bottom. Offering 7.4- and 8.4-magnitude components just 4″ apart, this little duo is exquisite. Struve 2373 divided oh-so-delicately in the refractor at 75×. Nice!

From ducks to diamonds, this is a fun ramble. Needless to say, these glories of the Scutum Milky Way are best enjoyed far from city lights. But if you're stuck in town, as I often am, attack the Shield anyway — you'll like it.

■ Longtime *S&T* contributor **KEN HEWITT-WHITE** is waiting for a citywide power failure to observe the rest of the Scutum Milky Way.

Suburban Scutum Finds

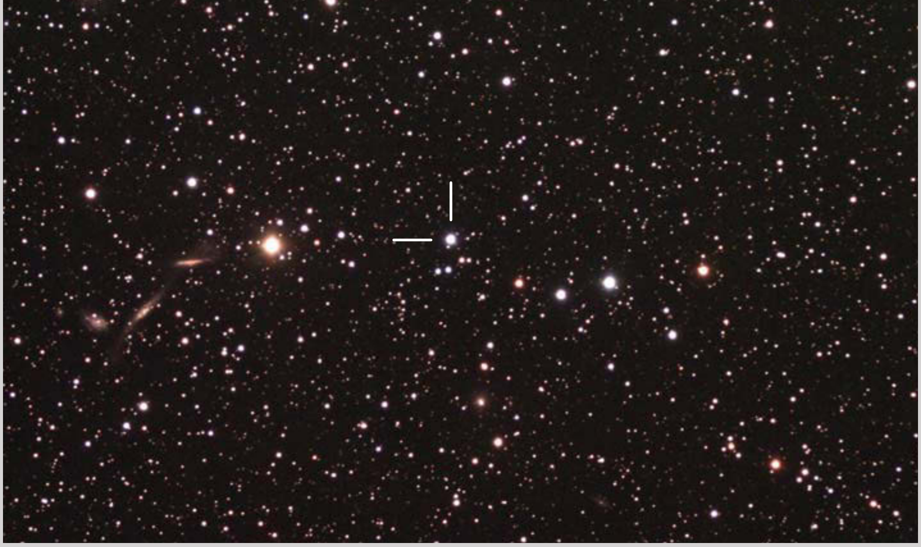
Object	Type	Mag(v)	Size/Sep	RA	Dec.
M11	Open cluster	5.8	11′	$18^h 51.1^m$	−06° 16′
R Scuti	Variable star	4.2 – 8.6	—	$18^h 47.5^m$	−05° 42′
H VI 50	Double star	6.2, 8.2	112″	$18^h 49.7^m$	−05° 54′
Σ2391	Double star	6.5, 9.6	37.7″	$18^h 48.6^m$	−06° 00′
M26	Open cluster	8.0	8′	$18^h 45.3^m$	−09° 23′
Σ2373	Double star	7.4, 8.4	4.3″	$18^h 45.9^m$	−10° 30′

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.

by Diana Hannikainen

Go After Dwarf Novae

Follow in the footsteps of two amateurs to see how you can contribute to variable star research.



▲ Frank Colosimo captured this image of the dwarf nova SS Cygni on November 14, 2020, when the source was around magnitude 10.7. The final product combines two-minute exposures of 11 luminance, 9 red, 8 green, and 10 blue frames. You can see how finder charts could be helpful for your observations.

In the late 1700s, when William and Caroline Herschel were busy discovering galaxies and comets, known variable stars — objects that exhibit brightness changes over time — numbered fewer than a dozen. By the early 1900s, nearly 1,500 had been discovered. It's no coincidence that the American Association of Variable Star Observers, or AAVSO, was founded in 1911 (see, e.g., *S&T:* Jan. 2021, p. 57) — professional astronomers couldn't keep up with the wealth of data pouring in and enlisted the help of amateurs. Nowadays we know of more than 150,000 variable stars, with many thousands awaiting confirmation.

Al Lamperti and Frank Colosimo are among the amateurs who are contributing to the scientific understanding of variable stars. Let's meet them.

Al, Frank, and a passion. Fellow observers Al and Frank met through the Delaware Valley Amateur Astronomers. Al's interest in astronomy blossomed when his son bought a small telescope from Kiddie City. But Al really became hooked after catching his first glimpses through larger scopes at a local star party. Frank's lifelong passion began early, when he purchased a 50-mm refractor with money saved up from chores. Eventually, he graduated to an 11-inch Schmidt-Cassegrain telescope and discovered the joys of imaging. Frank was so invested in the hobby that he actually moved to a darker location and established an observing field (that he shares with his club members), complete with two observatories to house his gear. The pair have collaborated on many projects, including several published in these pages (see, e.g., *S&T:* Mar. 2018, p. 57; Nov. 2019, p. 60; Apr. 2021, p. 58). Now they've embarked on observing a particular class of variable star.

Dwarf novae are binary systems in which a *K*- or *M*-type subgiant fills its *Roche lobe* and transfers material toward a white dwarf companion. This stellar matter doesn't splat directly onto the surface of the white dwarf but instead swirls around it into a hot *accretion disk*. Variations in the mass transfer rate trigger outbursts from these objects. Al and Frank observe these phenomena as a sudden brightening of typically two to six magnitudes in the space of a day or so, followed by a much slower and more gradual fading. This pattern repeats every few weeks or months.

While reviewing his observing notes, Al realized that he had tracked significant magnitude changes over time. His logbook on SS Cygni on the AAVSO website shows that he recorded a brightest magnitude of 8.5 on May 14, 2020, and a dimmest magnitude of 11.6 less than half a year later! To see these data, go to the AAVSO website (**aavso.org**): Under "Resources," input "SS Cyg" in the box below "Pick a Star," then click "Plot a light curve." The returned graph contains data points from all observers. If you deselect "All" and search for Al's name, you'll pluck his data out of the lot. At the top of the table, you'll also find links for generating finder charts.

Equipment and advice. To observe dwarf novae, Al likes to use his 22-inch reflector (it fits nicely in his car so he can lug it to Frank's field). But you don't need such large aperture if you're interested in observing these objects — even a 6-inch scope works. Al recommends printing and studying the AAVSO finder charts ahead of time in order to identify reference stars for estimating your target's magnitude. He concludes, "Photons are zipping by, waiting to be captured, and the less time it takes finding the star field, the more efficient it becomes — and the less frustrating!"

Frank's telescope of choice is a 12.5-inch reflector, and for imaging he uses several CCDs with an Apogee U8300 camera as the workhorse. "With the light-gathering capability of modern CCD cameras, even small telescopes can be used for imaging, and smaller telescopes may have advantages in times of poor atmospheric seeing," Frank says. Just make sure you have a stable tracking mount for imaging.

Whether you discovered astronomy as a kid (like Frank) or later on (like Al), you can try your hand at observing dwarf novae — or any of the other myriad classes of variable star. Just don't forget to upload your data to the AAVSO website, where you, too, will contribute to the ever-growing database of knowledge.

■ Observing Editor DIANA HANNIKAINEN used to observe X-ray binaries, which also go into outburst.

HALLEY DOWN UNDER This portrait of the famous comet is one of the very best from the 1985–86 apparition. It was captured on February 22, 1986, with the 1.2-meter U.K. Schmidt telescope near Coonabarabran, Australia. The 2-minute exposure records roughly 3° of tail length.

HALLEY'S COM

Last summer's surprise Comet NEOWISE echoed the return of the most famous "dirty snowball" of all.

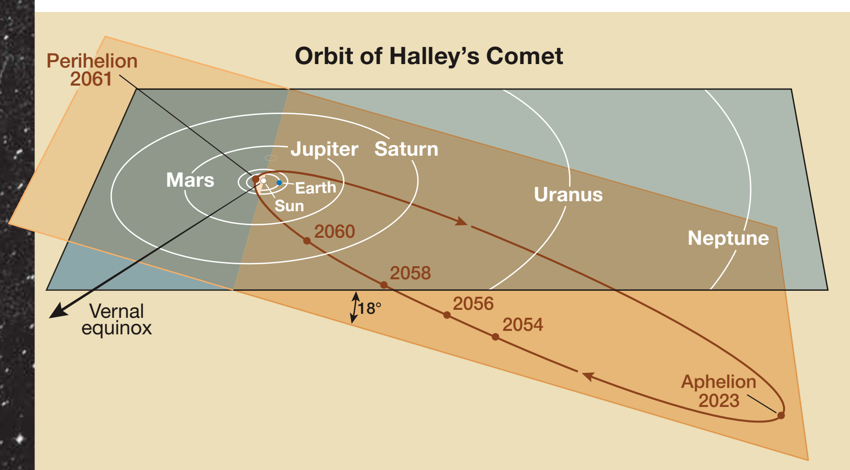
It was one year ago that skywatchers worldwide enjoyed warm summer nights viewing Comet NEOWISE, a relatively bright and conveniently placed visitor that attracted widespread attention. And 40 years from now, in July 2061, the most famous comet of all will be tracing a similar path across the night sky.

▲ **A COMET BY ANY OTHER NAME** Although he didn't discover the comet that bears his name, it was Edmond Halley who figured out that the comets that appeared in 1531, 1607, and 1682 were one and the same. Halley then went on to calculate that it would return in 1758 — something he didn't live long enough to see.

Celebrated Halley's Comet (a.k.a. 1P/Halley) will arrive at *aphelion*, its farthest point from the Sun (5.25 billion km, 3.26 billion miles) in December 2023. From there, it will begin its long journey back toward the inner solar system for its 31st recorded appearance since 240 BC.

But for many who saw it (or tried to see it) in 1986, Halley is best remembered as a disappointment. Heavily promoted as the most anticipated celestial event of the second half of the 20th century, the comet turned out to be an underwhelming sight that belied promises of a never-to-be-seen-again spectacle. But why did it do so poorly in 1986? And more importantly, how will it perform on its 2061 return?

HALLEY'S COMET: *S&T* ARCHIVES; PORTRAIT OF HALLEY: IANDAGNALL COMPUTING / ALAMY STOCK PHOTO; HALLEY ORBIT DIAGRAMS: GREGG DINDERMAN / *S&T* (2)



ET: A LOOK BACK AND AHEAD

Orbital Matters

The strength of a Halley's Comet apparition depends on Earth's position when the comet reaches *perihelion* — the point in its orbit when it passes nearest to the Sun. Have a look at the diagrams below. When the comet makes its closest approach to Earth *after* perihelion, it descends through Earth's orbital plane and takes a southward path across the stars, favoring observers at southern latitudes. Such post-perihelion apparitions have typically occurred in the spring, with the comet sweeping to within an average of roughly 0.15 to 0.25 a.u. of Earth around five weeks after perihelion (although there have been times when it has approached much closer than this).

Halley typically reaches its greatest brightness two weeks or so following perihelion. During post-perihelion apparitions it passes Earth after it's more or less fully developed and can appear quite dazzling — usually brighter than zero magnitude. The comet can be so striking and impressive that even a casual observer will stop and say, "Oh my, look at that!" Halley is estimated to have appeared as bright as Venus during the post-perihelion apparition of AD 837. And when it's close to Earth, the comet's dust tail can appear stupendously long. In 1910, some observers saw its tail extend across the sky for more than 120°!

Then there are the performances in which Halley makes its closest approach to Earth *before* perihelion, when it climbs northward through our planet's orbital plane. That's when viewing circumstances generally favor those in the Northern Hemisphere, with the comet taking a track high across the northern sky. For example, during the 1531 apparition, Halley skirted the southern boundary of Ursa Major when it passed nearest to Earth.

Most pre-perihelion visits have occurred during late summer or early fall and on average have brought the comet to within 0.20 to 0.30 a.u. of Earth, roughly four weeks before perihelion. During these apparitions Halley shines around first magnitude and sports a long (15° to 30°) bluish ion tail, like the one that accompanied Comet Hyakutake in 1996. But before perihelion, Halley has yet to rev up to its peak brightness and consequently is less showy.

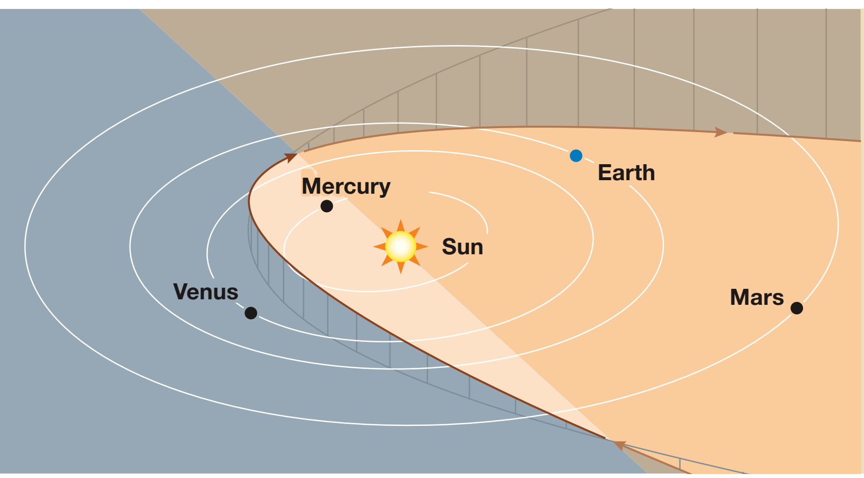
Nonetheless, any time Halley returns to the inner solar system a very fine display is possible. Little wonder that most people expected great things from it in 1986.

Halley in 1986

It's worth remembering that Halley's subpar performance in 1986 was not entirely unexpected. Already in the June 1975 issue of *Sky & Telescope*, Robert Roosen (NASA) and Brian Marsden (Harvard-Smithsonian Center for Astrophysics) warned that the comet would likely disappoint much of the general public. Despite that, the comet's impending arrival was accompanied by a frenzy of T-shirts, commemorative comet medals, bumper stickers, and specially marketed telescopes. Halley logos could be found on warm-up jack-

▲ **BIG, DIRTY SNOWBALL** A comet's tail can extend many millions of kilometers into space, but the solid nucleus that's its source is deceptively compact. In the case of Halley's Comet, the nucleus is an elongated lump spanning 15 km (9 miles) on its major axis. This close-up view was captured in March 1986 by the European Space Agency's Giotto spacecraft when it was approximately 2,000 km from the comet.

ESA / MPS



◀ **LONG ELLIPSE** The orbit of Halley's Comet is an elongated ellipse. The comet's motion is retrograde, that is, it travels in a direction opposite to the motion of the planets around the Sun. The comet's orbital plane (orange rectangle) is inclined 18° from the plane of Earth's orbit (blue rectangle). Halley lies north (above) Earth's orbital plane for only about four months as it swings around the Sun. The famous comet last reached perihelion, about 0.587 a.u. from our star, on February 9, 1986.

ets, cocktail glasses, cereal boxes, and just about everything in sight. Caught up in the grip of Halley-mania, the mainstream media emphasized that the comet would be a "once-in-a-lifetime spectacle!"

Unfortunately, as Halley approached perihelion during the fall and winter of 1985–86, its orbit kept it well away from Earth. To make matters worse, Halley didn't start to brighten notably until late January, when it was lost in evening twilight. Shortly after perihelion (on February 9th) when the comet was near its brightest, it was positioned on the far side of the Sun as seen from Earth. During March, Halley only appeared as bright as 3rd magnitude and displayed a tail measuring about a dozen degrees long — or a mere tenth of its 1910 splendor — for much of the month. At the same time, it had moved below the ecliptic plane, making it difficult to view from the United States and locations farther north. Add to that a combination of twilight, moonlight, and light pollution, and for many people the comet was essentially a no-show.

The 1986 apparition was, in fact, decried as the comet's worst in 2,000 years. And, as one would expect, the public wasn't impressed. Having read he'd need binoculars and a star map just to find the comet, taxi driver David A. Gittelman penned a *New York Times* opinion piece entitled "Who Cares About Halley's Comet Anyway?" In it he wrote, "I was devastated. How could such an injustice be allowed to prevail? All my life I'd been waiting — all my life. What had happened to the cosmic leviathan of my childhood dreams?"

What happened was that at its closest approach to Earth, on April 10th, Halley was nearly three times farther away than at its minimum distance in 1910. And it had arrived at this point a full two *months* after perihelion (instead of two weeks, as in 1910) — long after its brightest phase had passed. Even those living in or traveling to the Southern Hemisphere (where the comet was well placed) didn't witness a true showstopper. To make matters worse, Halley's tail suddenly ebbed at the beginning of April, leaving behind a small, condensed, nebulous mass with a stubby, fan-shaped appendage. The leviathan turned out to be a mere tadpole!

Looking Ahead

So, what can eager comet watchers expect from Halley's next appearance in 2061?

A lot will depend on how the ongoing problem of light pollution worsens in the intervening 40 years. As everyone who witnessed Comet NEOWISE can attest, even a good comet is no match for city lights. Even if Halley performs well, the biggest challenge may simply be finding a location where you can still see a decent number of stars.

But there are reasons to be optimistic. Reviewing the table on the facing page, we see that the 2061 apparition is smack in the middle of the listing, which means Halley's closest approach to Earth will happen very near perihelion. In fact, there were five other appearances (240 BC, 87 BC, AD 451, AD 912, and AD 1456) when it passed closest to Earth within 10 days of perihelion. That's good news.

Indeed, the 2061 appearance is in many respects the mirror image of 1986. This time, the comet will be in full view on the same side of the Sun as we are and should appear at least 10 times brighter! In the morning sky, the comet will climb to its most northern position, achieving a declination of nearly +49° on July 24th. Then it will rapidly head south as it enters the evening sky and will gradually favor more

▲ **A TAIL OF DISAPPOINTMENT** *Sky & Telescope* Senior Contributing Editor Dennis di Cicco captured this view of Halley on April 14, 1986 — two nights after it shed its dust tail. Halley's tadpole-like appearance both surprised and disappointed many observers.

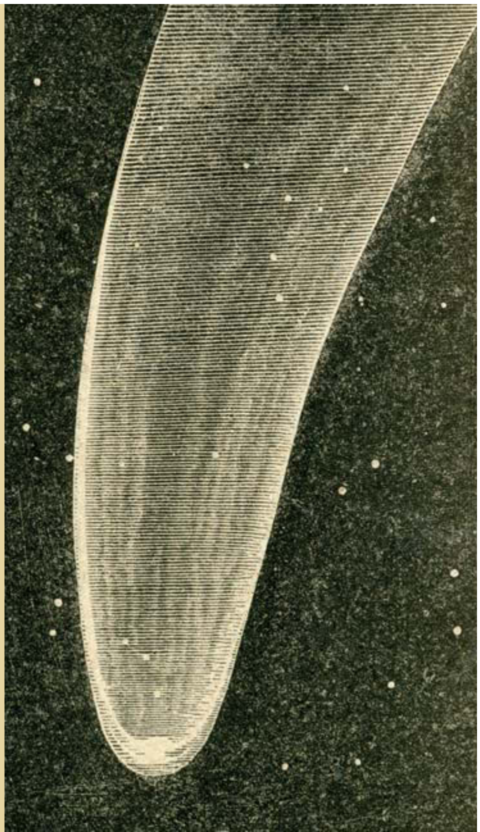
▲ **HALLEY FROM MASSACHUSETTS** The photo was captured from a beach south of Boston on the morning of March 21, 1986, and depicts the comet's naked-eye appearance with reasonable accuracy. At the time, Halley was making its way through southern Sagittarius (four stars of the Teapot asterism are visible right of the comet).

HALLEY AT DAWN: DENNIS DI CICCO

Halley Through the Years

Date of Perigee	Distance from Sun (a.u.)	Days from Perihelion	Historical Notes
164 BC September 3	0.11	–44	Recorded on Babylonian tablets
1378 October 13	0.12	–38	Swept <10° from Polaris (Korea)
1835 October 12	0.19	–35	1st mag. 20° to 30° tail
1301 September 23	0.18	–32	Giotto's "Christmas Star"
12 BC September 9	0.16	–31	Death of Roman General Agrippa
1607 September 24	0.24	–28	Observed by Johannes Kepler
684 September 6	0.26	–26	Depicted in Nuremberg Chronicles
530 September 2	0.28	–25	"Lamp-like" (Byzantium)
1222 September 5	0.31	–23	"Red with a great tail" (Europe)
989 August 20	0.39	–16	"Broom Star" (China/Japan/Korea)
1682 August 31	0.42	–15	Observed by Edmond Halley
1531 August 14	0.44	–12	Observed by Petrus Apianus
87 BC July 27	0.44	–10	"Bushy star" (China)
912 July 15	0.49	–3	"Broom star" (Japan)
2061 July 29	0.48	+1	Next predicted return
451 June 30	0.49	+2	Attila's loss; Battle of Châlons
240 BC June 3	0.45	+9	"Broom Star" (China)
1456 June 18	0.45	+9	"Long tail like a dragon" (Turkey)
295 May 11	0.32	+11	"Broom star in west" (China)
218 May 30	0.42	+13	Caused panic in Rome
760 June 2	0.41	+13	White tail (China)
1145 May 12	0.27	+24	Pictured in Eadwine's Psalter
141 April 21	0.17	+30	Shone pale blue (China)
1910 May 20	0.15	+30	Tail >120° (USA); mag. –1.2
1066 April 23	0.10	+34	Rendered on the Bayeux Tapestry
607 April 19	0.09	+35	Anomalously bright (mag. –2.4)
837 April 10	0.03	+41	Very bright; >90° tail (China)
2134 May 7	0.09	+41	Closest approach since 837
374 April 1	0.09	+44	"Sparkling star" (China)
1759 April 26	0.12	+44	First predicted return
66 March 20	0.25	+54	"Sword" hanging over Jerusalem
1986 April 10	0.42	+60	Worst apparition in 2,000 years!

In the table above are details for all 30 previous apparitions dating back to 240 BC and the future apparitions of 2061 and 2134. Apparitions are listed in order of ascending number of days from perihelion. Column 1 provides the date of perigee — when Halley is closest to Earth. Column 2 gives the distance in astronomical units. Column 3 indicates the number of days either before (–) or after (+) perihelion that the comet is from the date of perigee. Finally, column 4 cites a historical reference associated with that particular apparition.



▲ **HALLEY IN 1835** This engraving of the comet's 19th-century return appeared in the French publication *Le Magasin Pittoresque* (*The Picturesque Store*). During its 1835 appearance, Halley shone at 1st magnitude and sported an impressive tail 20° to 30° long.

▲ **THE TAIL OF 1531** Halley is depicted moving through the constellation Leo in this fanciful artwork by Petrus Apianus. He observed the comet in 1531 and the following year published his discovery that a comet's tail always points away from the Sun.

HALLEY ENGRAVING: LE MAGASIN PITTORESQUE / WIKIMEDIA COMMONS / PUBLIC DOMAIN; HALLEY'S COMET IN 1531: SCIENCE HISTORY IMAGES / ALAMY STOCK PHOTO

BETTER THAN HALLEY Last July's Comet NEOWISE (C/2020 F3) delighted observers by putting on a show that (for observers in the Northern Hemisphere, at least) greatly outperformed Comet Halley. This remarkably detailed image of NEOWISE was captured on the morning of July 12th by Nicolas Lefaudeux from the northern coast of Finistère, France.

southerly locations. But for viewers at mid-northern latitudes the comet should still become an eye-catching evening sight in early August low in the west-northwest sky.

A Splendid Summer Pageant

Imagine a mild August evening 40 years in the future. You step into the backyard as twilight deepens and glance to the west-northwest. There it is! Hanging above the horizon like a luminous, delicate feather is Halley's Comet.

Interestingly, you won't have to apply much imagination to visualize this future scene, because Halley will be visible during the same hours and occupy the same stretch of sky that Comet NEOWISE did last summer. The difference is Halley is expected to be much brighter.

Halley's magnitude increases linearly as it approaches the Sun during the pre-perihelion phase of its visit. The magnitude estimates mentioned in the following paragraphs are necessarily approximate — comets have a well-earned reputation for defying expectations.

The main Halley show will begin in mid-June in the morn-

▶ **TOUGH COMPETITION** As Halley's Comet swung south for the grand finale of its 1985–86 apparition, it passed by the rich swath of Milky Way in Sagittarius, making the comet even less impressive by comparison.

HALLEY DOWN UNDER

Our group had traveled halfway around the world to the Australian Outback for a good look at Edmond Halley's comet in April 1986. Many of us had been waiting decades for this once-in-a-lifetime chance to see astronomy's most fabled comet. Others, however, were new inductees to the hobby of astronomical observing, having been inspired to join our tour by months of widespread publicity leading up to the comet's apparition.

This astronomical tour was also the first in what has become a regular activity for *Sky & Telescope*. Prior to Halley, Editor in Chief Leif Robinson and I had served as guides on astronomical trips arranged by other organizations. But with so much reader interest in the comet, we decided the time was right to organize a tour sponsored by the magazine itself. After several months of planning, the two of us headed to Australia in mid-1985 to scout out potential observing sites. We ended up choosing what is now called the Ayers Rock Resort several hours drive southwest of Alice Springs. Along with the creature comforts afforded by the resort, the location offered incredibly dark and transparent skies — perfect for nighttime observing.

No one in our group was young enough to have another shot at seeing Halley, so everyone was thrilled by the opportunity to view the comet under such ideal conditions. We also had the pleasure of having a Halley two-timer among us. Clarence P. Custer, Jr., a retired doctor from Stockton, California, was introduced to astronomy in 1910 as a 4-year-old living in Denver, Colorado, when his father showed him Halley in the evening sky. In later years Custer became a well-known telescope maker, astrophotographer, and contributor to *Sky & Telescope*, appearing on the cover of the May 1958 issue with his unusual 12½-inch f/8 Newtonian reflector.

Halley had top billing on our tour marquee, and during April it was an impressive naked-eye sight as it moved from under the tail of Scorpius toward Centaurus. But in this part of the sky the comet was competing with a brilliant Milky Way backdrop, and it was often the southern sky that stole the show as the Milky Way rose higher during the evening and appeared nearly overhead in the wee hours of the morning. For many in our group it was a chance to peruse the heavens under the darkest sky they had ever experienced.

Our tour was such a big success that in future years the magazine organized additional visits to the same location to view and photograph the night sky.

Halley is now only a memory, and while there have been bigger and brighter comets in the years since Halley headed back into the depths of the solar system, it remains the comet apparition that many of us remember most vividly.

DENNIS DI CICCO

◀ Dennis di Cicco and Comet Halley two-timer Clarence P. Custer, Jr., were part of the *Sky & Telescope* tour to the Australian Outback to view the comet in April 1986.

HALLEY AND THE MILKY WAY: ESO; AUTHOR AND CUSTER: JOHNNY HORNE ing sky. On the 18th, Halley will be in Taurus, 1.2° northwest of the Pleiades. Thanks to the comet's distance (1.8 a.u.), it will be rather dim at around magnitude 5.6, and it's unlikely that even observers in good locations will see the comet's bluish ion tail exceeding 1°.

But the comet will be approaching both the Sun and Earth with increasing speed and should brighten noticeably as it climbs higher into darker skies each passing morning. By July 10th, Halley will be 1 a.u. from Earth and may double in brightness, to magnitude 3.5. A week later, it'll races east-northeast across the pentagon of Auriga and likely hover around magnitude 2.5, with a tail reaching about 5° long. On the 23rd, the comet's head could be as bright as 1st magnitude, with a long tail pointing almost straight up from the horizon.

Like NEOWISE last summer, Halley will gradually transition from being a morning sight to an evening one as it tracks some 21° north of the Sun at perihelion. From July 25th to 28th, it might be possible to see Halley as a zero-magnitude object against the late twilight sky in both the morning and evening. It's at this point that the bright, white dust tail that greatly impressed our forebears will begin to unfurl.

As August begins, the comet will become exclusively an evening sight. Initially, the presence of a full Moon will hamper its visibility on the 1st, but by the evening of the 4th, the comet will finally be able to shine in all its glory in a moonless sky. Indeed, the period of August 4th through 8th might well be the pinnacle of the 2061 apparition. The comet's head could be as bright as 1st magnitude and accompanied by a straight, narrow tail streaming outward 10° to 15°.

In the evenings that follow, Halley will recede from both the Sun and Earth and its luster will start to wane. At the same time, the comet will track southeast through the stars of Virgo, dropping lower to the horizon. A bonus awaits skywatchers on the evening of the 18th, when the 2.8-magnitude comet forms an isosceles triangle with Venus and a nearly four-day-old crescent Moon. On the 24th, having faded to magnitude 3.3, Halley will pass within a degree of Venus.

Halley will cross its descending node on August 26th but must compete with a bright, waxing, gibbous Moon. Shortly thereafter the comet will be reabsorbed in the bright twilight sky, marking the end of the apparition for most casual observers.

Once in a Lifetime?

In 1986, NASA planetary scientist Donald Yeomans (now retired) commented, "Its periodic returns every 76 years act like a clock counting time in units of human lifetimes. Thus, the ever-returning comet marks transitions from one era to the next. Once every 76 years, nearly everyone in recorded history has had an opportunity to view the comet." Given that average life expectancy for Americans is currently close to 79 years, if you were born after 1982, you have a better than 50-50 chance to witness Halley's 2061 return.

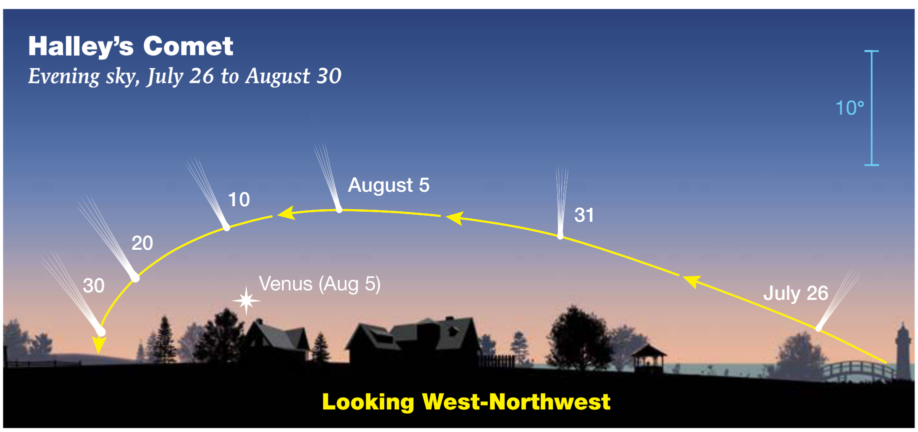
It's my fervent hope that over the next 40 years, we somehow find solutions to significantly stem the growing tide of light pollution. If not, there's a very real danger that our children and grandchildren will end up being denied their rightful opportunity to greet Halley for themselves.

While we can provide a pretty good assessment of what Halley's Comet will do on its next visit, it's anybody's guess what the state of our night skies will be in 40 years.

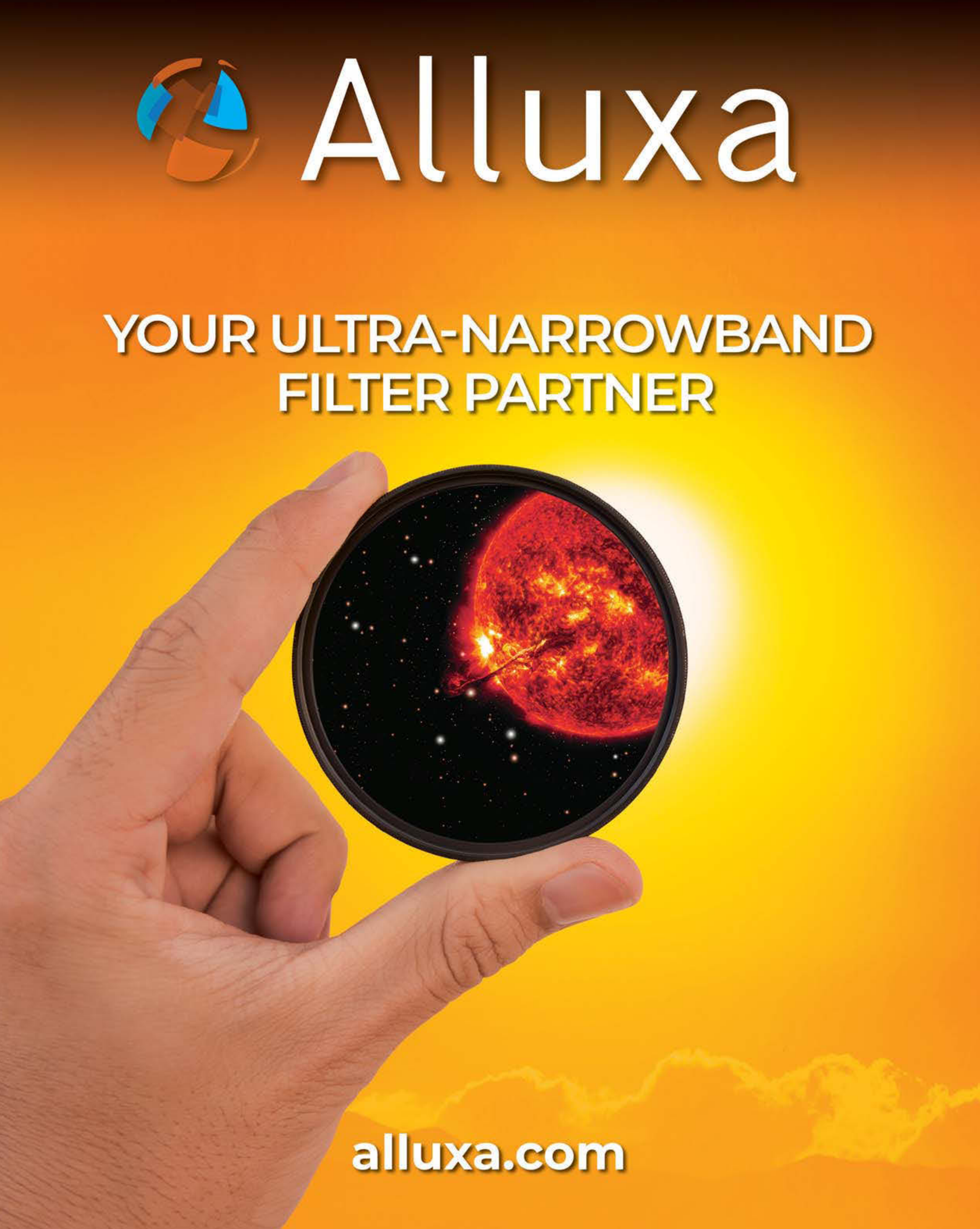
■ Contributing Editor **JOE RAO** observed Halley's Comet extensively from Easter Island and the Chilean Andes in April 1986. When the comet arrives at perihelion in 2061, he will be several days shy of his 105th birthday.

▶ **RETRACING A PATH** Comet NEOWISE was photographed above Crater Lake, Oregon by Gary Kronk during the dawn hours of July 11, 2020. Capella is the bright star upper right of the comet. Interestingly, on July 23, 2061, Halley's Comet will be positioned almost exactly where NEOWISE is pictured here, though it's expected to shine a full magnitude brighter.

▼ **LOOKING FORWARD** The high point of Halley's 2061 apparition will occur when it skirts the west-northwestern horizon in August. This diagram depicts the scene for observers at latitude 40° north. For each date, the Sun is positioned 12° below the horizon.



HALLEY'S PATH: GREGG DINDERMAN / *S&T*


Alluxa
YOUR ULTRA-NARROWBAND
FILTER PARTNER
alluxa.com

iOptron's Self-guiding CEM70G Mount

iOptron ups its game by adding integrated autoguiding to this center-balanced mount.

iOptron's CEM70G is a feature-packed, center-balanced equatorial mount built with the imager in mind. The mount has a 70-pound payload capacity.

CEM70G Equatorial Mount

U.S. Price: $2,998 (equatorial head), $598 (Tri-Pier)

What We Like

Excellent Go-To and tracking accuracy

Onboard guiding system

Solid Pier

What We Don't Like

Captive mounting screws hard to engage and tighten

Inconsistent power connectors

MOST DEEP-SKY ASTROIMAGERS have a list of preliminary tasks to nail down before beginning a sequence of guided exposures, particularly if the imaging session involves travel to a remote site. Gear needs assembling, cables connecting, and the mount accurate polar aligning. Next, the guidescope (or off-axis guider) needs to be focused and guide stars identified — all before the complex process of calibrating the guider to the mount can occur. This can take up a lot of valuable time.

The new CEM70G mount from iOptron makes some of those time-consuming chores much easier. The mount features both the iPolar digital polar alignment system and the new iGuider onboard guidescope and camera.

The latest addition to iOptron's signature Center-Balanced equatorial mount series, the CEM70G is designed to place the telescope's center of gravity directly over the supporting tripod head, resulting in greater stability and increased payload capacity, while reducing the mount's overall weight in comparison to conventional German Equatorial mounts. I tested the mount with the company's optional Tri-Pier tripod and a variety of telescopes.

Out of the Box

The mount's equatorial head is finished in textured black paint and features a gleaming stainless-steel counterweight shaft. The drive housings contain 151-millimeter, 248-tooth gears driven by hefty 21.2-mm worm wheels. The mount is rated for up to a 70-pound (32-kilogram) load, not including counterweights. The equatorial head weighs just 30 pounds without counterweights, resulting in a mount weight-to-payload ratio of 2.33. Specifications state a periodic error of 3.5 arcseconds, which can be improved by using the mount's programmable periodic error correction.

The CEM70G comes with a lockable 16-by-20-by-9-inch hard case with custom-cut, high-density foam inside to accommodate the equatorial head, hand control, counterweight shaft, and additional small accessories.

Like the original CEM70, this new model includes a three-port USB 3.0 hub on the rear of the saddle plate, allowing owners with the latest deep-sky and planetary cameras to connect to multiple accessories while requiring just a single USB connection to the control computer. Most cameras, elec-

ALL PHOTOS PROVIDED BY AUTHOR

tric focusers, and filter wheels will only be several inches from a USB port or power outlet when mounted aboard the CEM70G, reducing the chance of cable snags during the night.

Your OTA connects to the 8-inch-long universal saddle plate, which accepts both Vixen- and Losmandy-style dovetail plates and is secured with two large knobs that are easy to tighten even while wearing gloves. A panel on the base of the equatorial head contains the 12-volt DC power jack, on/off switch, ST-4-style autoguider input port, the USB 3.0 hub input, the Go2Nova hand controller input, and a short antenna for the mount's Wi-Fi.

The CEM70G also includes gear disengagement knobs for both axes. Turning the knobs separates the worm from the drive gears, protecting them from damage during transport and aiding with balancing the load.

Setting up the CEM70G

Securing the equatorial head to the top plate of the iOptron Tri-Pier was difficult and didn't improve with practice. The two spring-loaded cap screws that secure the head to the Tri-Pier are deeply recessed into the CEM70G base plate. Using the supplied 6-mm hex wrench to turn the screws first involves lining up the screws with their mating holes, but the springs push the screws outward, preventing them from easily engaging with the holes.

Due to the tight clearance between the mount's polar-axis support and altitude locks, you can only achieve about ⅓ of a turn before you need to remove and reinsert the wrench — a process that had to be repeated many times to fully tighten each screw. Users may want to purchase a very long, 6-mm T-handle hex wrench to make the task easier.

Once the head is attached, the Tri-Pier is hard to beat for rock-solid stability and vibration dampening. It breaks down to a compact, 26-pound package only about 25½ inches long that fits in a duffle bag. It can extend from 31 to 43 inches, and its hollow central column also serves as storage space for the three removable steel legs. Index holes in the column engage spring-loaded steel balls at the top of each leg to allow selecting between its six indexed height positions. The three legs spread out to a 46-inch-diameter footprint.

Assembly of the Tri-Pier is a little time consuming because it includes the process of inserting and clamping the three leg extensions in place and selecting the desired height for the center column. But the stability of the Tri-Pier is well worth the trouble.

I often extended the column to one of the uppermost positions when using my 11-inch SCT or 102-mm (4-inch) refractor, while the lowest position put the eyepiece of my 8-inch f/5 Newtonian at a convenient height. The Tri-Pier is solid in all height configurations, with a rap on the mounted telescope dampening out in a second or less thanks to the permanently installed vibration-reduction pads on each foot.

Users with long refractors should consider adding iOptron's Mini Pier Tripod Extension to raise the eyepiece level to a convenient position when aiming near the zenith.

From a completely stowed position, the Tri-Pier, mount, and scope took

▲ The mount comes in a hard case with a custom foam lining that accommodates the head, AC power supply, counterweight shaft, and Go2Nova 8407+ hand controller.

◀ *Far left:* The iOptron Tri-Pier's center column varies in height by sliding its center column up and down using indexed holes and spring-loaded bearings. Permanently installed anti-vibration pads on each foot ensure vibrations cease in a second or less.

◀ *Left:* The Tri-Pier's removable steel legs conveniently store inside the central column. The three cast-aluminum legs collapse against the tripod's outside.

about 30 minutes to assemble and get polar aligned using the iPolar device.

The CEM70G's included 20-pound counterweight is more than adequate for balancing a wide range of telescopes. Placing the weight all the way to the end of the counterweight shaft balanced my 11-inch SCT, while the weight of my 8-inch Celestron Rowe-Ackerman Schmidt Astrograph (RASA) was accommodated by sliding the weight about halfway up the shaft. For smaller scopes, users should consider purchasing a smaller counterweight, because the included weight collides with the corners of the declination drive housing when it's at the top of the shaft.

The mount includes a hefty 5-amp AC power supply whose 2.5-mm × 5.5-mm connector plugs into the power input socket of the mount. Thankfully, three of the four outlets on the saddle for powering accessories (such as cameras, electronic focusers, and filter wheels) are of the much more common 2.1-mm × 5.5-mm sockets. There's also a single 2.5-mm × 5.5-mm socket on the front of the saddle.

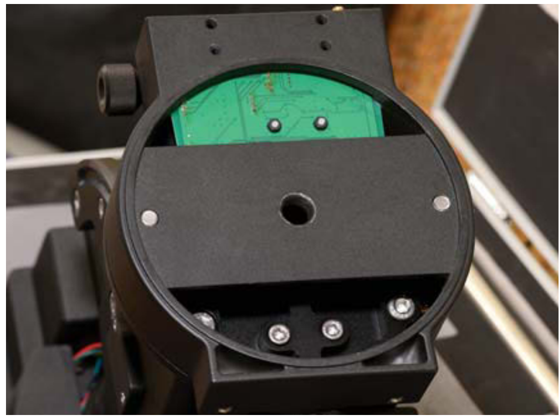
The socket sizes are listed in the manual, but I first noticed them when I attempted to power the mount with a 12-volt battery fitted with a 2.1-mm × 5.5-mm connector. The connector, of course, didn't work with the main power input on the base of the CEM70G. Users powering the mount with a DC power supply other than the included AC adapter in the field must make sure the connector is the correct size and is center positive. Given the uncommon connector sizes, an included adapter would be welcome, though I picked up one for less than $2.

The mount's Go To accuracy is outstanding, and the Go2Nova 8407+ hand controller with its eight-line display makes navigating the menus easy and intuitive. Additionally, the built-in Wi-Fi feature allows the mount to be controlled remotely using your favorite planetarium software or smart-device app.

i-Devices

Before even mounting a telescope or camera on the CEM70G, the mount already has two lenses with cameras looking skyward. The iPolar and iGuider optical systems are built into the CEM70G. Both are operated by connecting to a host computer.

The iPolar is the same device included on many current iOptron mounts, including the GEM45 I reviewed in the November 2020 issue, page 66. This iPolar device worked just as well and within minutes provided excellent polar alignment each time I set up the mount. Any remaining star drift was due to the slight periodic error in the right ascension drive.



▲ This view of the bottom surface of the CEM70G mount shows the two spring-loaded retracting screws on the left and right that secure the mount to the Tri-Pier. Extending them to engage the threads on the Tri-Pier involves using the supplied hex wrench to press and turn the screws.

The big news on the CEM70G is the iGuider — the gadget that puts the "G" in the model name. This device is a small guidescope and camera conveniently built into the mount's saddle. It consists of a 30-mm guidescope with a 120-mm f/4 focal length that focuses its image on a tiny 1,280 × 960-pixel CMOS sensor.

A screw-on aluminum objective cover protects the iGuider's lens when not in use. Focus is achieved by inserting a 2-mm hex wrench into a hole on the underside of the saddle plate. Once set, turning a small thumbwheel on the

▼ *Left:* On the rear panel of the CEM70G you'll find the power input port, the on/off switch, an ST-4 guider port, hand control input, as well as the small Wi-Fi antenna. The USB 3.0 port connects to a 3-port USB 3.0 hub on the saddle. The azimuth adjustment knobs include a handy positional scale as seen at top. *Right:* While the mount comes with a 5-amp AC power supply with a 2.5-by-5.5-mm barrel connector, users expecting to power the mount with a cigarette lighter with a common 2.1-mm × 5.5-mm connector will need to purchase an inexpensive adapter.

▲ *Left:* The CEM70G's 9½-kg counterweight can collide with the right ascension drive housing when balancing light loads; an optional smaller weight is recommended for such payloads. *Right:* The built-in iGuider is permanently installed within the saddle. Its objective is recessed about 50 mm inside the housing to prevent dew formation on the lens. A threaded aluminum cap covers the objective when not in use. Two slightly differing 12-volt DC power ports are seen to the left of the objective. The iPORT socket at left is used to connect other proprietary iOptron accessories.

side of the saddle plate locks the focus position. The objective lens is recessed 2 inches within the saddle, protecting it from most dewing.

The iGuider is controlled using *PHD2* guiding software. Both *PHD2* and the *iPolar* software for PC and Mac computers are available at iOptron's website. No additional guide cable is necessary when using the iGuider system, though iOptron includes an ST-4-style guiding port when imaging at very long focal lengths with external guide cameras.

Downloading and installing both software packages and drivers to my Windows 10 computer went without a hitch. Users acquire, focus, and calibrate the iGuider device the same way that is so familiar with veteran *PHD2* users. A tutorial of its use appears in the December 2017 issue on page 64.

In use, you'll only need to adjust the focus of the iGuider once and lock it down. That's a good thing, as it proved a bit of a challenge to insert and turn the hex wrench into the hole on the underside of the saddle. Furthermore, the fast f/4 optics of the guidescope makes adjustment very sensitive, and focus shift would occur when locking down focus. Success came when I had one hand on the hex wrench and the other on the focus knob as I zeroed in on sharpest focus. Fortunately, the system held the focus securely, even after multiple setups and breakdowns of the mount.

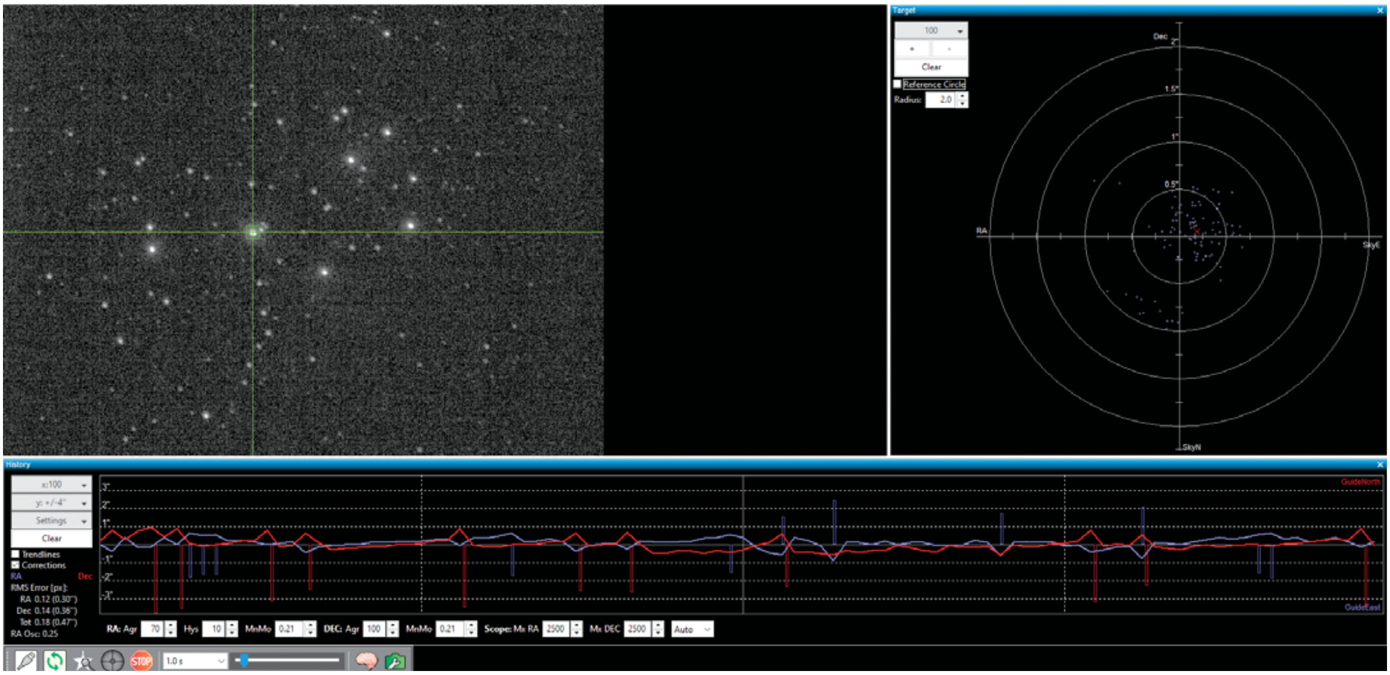
The relatively small aperture of the iGuider worked best on bright guide stars, and *PHD2* lets you increase the camera gain to make fainter stars visible, though at the expense of increased image noise. Creating a good library of dark frames in *PHD2* is key to going deeper with guide stars and keeping noise levels low.

I found the iGuider to be extremely accurate for guiding telescopes with short focal lengths. Not surprisingly, iGuider produced round stars on all the images I took with my 8-inch Celestron RASA with its 400-mm focal length. Even without guiding this scope produced very few poorly tracked exposures on the CEM70G. On other nights, I obtained a solid set of well-tracked exposures using a 102-mm refractor operating at f/7. Of the 30, 120-second exposures I took of M42 with the refractor at its native focal ratio of f/6.9, 21 of them showed no appreciable star elongation.

Based on my tests, I could get round stars in unguided, 2-minute exposures captured with telescopes with less than about 500 mm focal length, and perfectly tracked images of 10 minutes or more with iGuider operating. Moving up to my 8-inch f/5 Newtonian also guided generally well with iGuider in control, though the weight and length of the scope together with the slightest breeze introduced some errors.

Stepping up to an 8-inch f/8 Ritchey-Chrétien began to show the limits of the iGuider system. The combination produced slightly elongated stars in about

◀ A 3-port USB 3.0 hub is located on the rear of the saddle plate, along with two 12-volt DC power jacks providing a total of 3 amps of current.



▲ Autoguiding with the iGuider and *PHD2* locked on to the star Alcyone in the Pleiades star cluster

half the images in a 25-frame sequence, though guiding with the CEM70G was very accurate when I switched to an off-axis guider and camera instead.

Summing It All Up

The CEM70G is a mid-sized equatorial mount best suited to fast astrographs and catadioptrics of up to about 11-inch aperture. This accurate, versatile, and rugged mount will perform impressively whether it's set up in the field before each use or is permanently mounted in an observatory. Its onboard guiding capability with the guidescope's 120-mm focal length is accurate enough for imaging with instruments having focal lengths up to about 1,000 mm. And its built-in, 3-port USB 3.0 hub significantly reduces the number of cables running to your control computer. With the CEM70G, iOptron continues its history of innovative solutions to the challenges of astrophotography.

■ After decades of using non-Go To mounts, Contributing Editor **JOHNNY HORNE** is finally attempting to modernize his 43-year-old observatory.

▲ *Left:* This image of the Horsehead Nebula region in Orion was guided using iGuider and *PHD2*. A total of 50, 2-minute exposures made with a ZWO ASI294C camera and 8-inch Celestron Rowe-Ackermann Schmidt Astrograph were stacked together to produce this colorful, perfectly guided result. *Right:* Long-focal-length instruments require an external guider and guidescope or off-axis guider when imaging on the CEM70G. With its focal length of 1,625 mm, the author's 8-inch Ritchey-Chrétien proved too much for the iGuider, though the mount easily tracked this image of M78 with the aid of an off-axis guider and additional autoguider.

Make Your Own Push-To Scope

Install digital setting circles in thin air.

LAUREN WINGERT IS A GADGET GIRL. She has modified every telescope she's owned — flocking the inside of the tubes, making extended dew shields and shrouds, installing cooling fans, and adding manual setting circles. She even converted her 10-inch Orion IntelliScope to send its position signals to a tablet running *SkySafari* to make a push-to scope with visual feedback. Lauren liked the latter setup so well that when she purchased Mel Bartels's famous 13-inch Zip Dob (*S&T:* Jan. 2012, p. 62), she wasted no time adding digital setting circles to that, too.

There was just one little problem: The Zip Dob lacks any physical horizontal or vertical pivot points to attach the encoders to. The scope sits on a flex rocker and ground ring, so there's nothing but space where the azimuth pivot bolt would be on a traditional Dobsonian scope, and it uses its own open framework for the altitude bearing, so there's no central point there, either.

Lauren reasoned that there was still a center of rotation in both the altitude and azimuth axes — they were just virtual. That meant all she needed to do in order to install encoders at those pivot points was to make them real, solid points instead.

It was a fairly straightforward progression from there. Lauren taped a piece of paper across the Zip Dob's side and tilted the scope up and down a few times to find the point that didn't move. The azimuth axis was even easier: Set the ground ring on a thick plywood base and spin the flex rocker around to find the center of rotation.

Once she'd found the points where the encoders needed to go, she had to build something to hold the encoders in place. The azimuth axis was already half done with the plywood base, but it needed an arm reaching inward to

◀ Lauren Wingert put digital setting circles on her scope despite the lack of solid pivot points to mount them on.

▲ The encoders are mounted at the ends of arms that reach from the telescope's framework to the center of rotation on the altitude and azimuth axes.

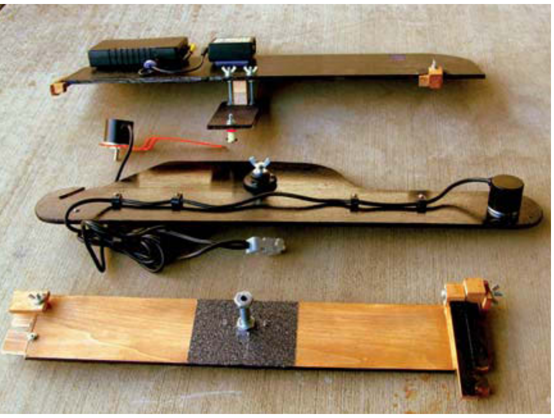
the center from the telescope, too. And the altitude axis needed both an arm and a cross-member spanning from side to side of the scope.

Lauren faced an additional complication: She didn't want to drill holes in Mel's classic telescope. So she designed everything to attach with clamps instead. She came up with three structures: a board that spans the altitude axis, a shelf that clamps to the back of the telescope, and an arm that reaches inward from the shelf to the center of the altitude axis. The shelf holds the battery and the encoder's Bluetooth transmitter, and it supports the arm that reaches out to the azimuth axis's center of rotation.

After assembling it for the first time, Lauren found there were minor imperfections in how the scope rotated on its ground ring. That required a fix that would prevent encoder stress or damage. The solution: Put a slip joint in the arm holding the encoder so it could shift slightly as the telescope moved. The altitude arm required similar flexibility, which a simple notch that held it to the shelf provided. The encoder shaft supported the arm's weight, so that notch didn't need to be tight.

Lauren used DobsonDream4 encoders from the Ukrainian company Astro-Gadget (**astro-gadget.net**). She bought the version that has 4,000 pulses per revolution. The controller that interprets the encoder pulses communicates via

LAUREN WINGERT (2)



▲ Everything fits into three subassemblies that clamp to the telescope, requiring no additional holes and leaving no scars.

Bluetooth to an Android tablet running *SkySafari*. There's also a wireless version that talks to iOS devices. To use the system, you put *SkySafari* in telescope-control mode, align on two stars, and from that point on *SkySafari* follows and displays every move the telescope makes.

Lauren quickly learned that the encoders have to be almost perfectly perpendicular to the rotation axis or the software gets a skewed picture of the telescope's aim. When they weren't aligned properly, she could aim the scope at the horizon and spin it in a circle and watch *SkySafari*'s aiming indicator weave up and down. Using *SkySafari* as a real-time diagnostic proved to be a good method for adjusting the correct position for the encoders, though, and now that they're mounted orthogonally, the scope can hit targets anywhere in the sky with ½° precision. Even a less-than-perfect alignment puts objects in the eyepiece nearly every time.

Setup takes an additional 10 minutes or so beyond the telescope's normal assembly time. And after that, with *SkySafari* showing you exactly where you're aimed, observing goes as fast as you want to push it.

For more information contact Lauren at **lauren@sneakpeekglass.com**.

LAUREN WINGERT

■ Contributing Editor **JERRY OLTION** is still a star hopper, but after a night viewing through Lauren's push-to scope, his resistance is weakening.

▷ CARINA CLUSTER

Kfir Simon

Dense, reddish dust lanes weave around the bright, young stars of the open cluster NGC 3293 in Carina, the Keel. The gas and dust behind those stars reflect their light, creating the brilliant blue color at the center of this image.

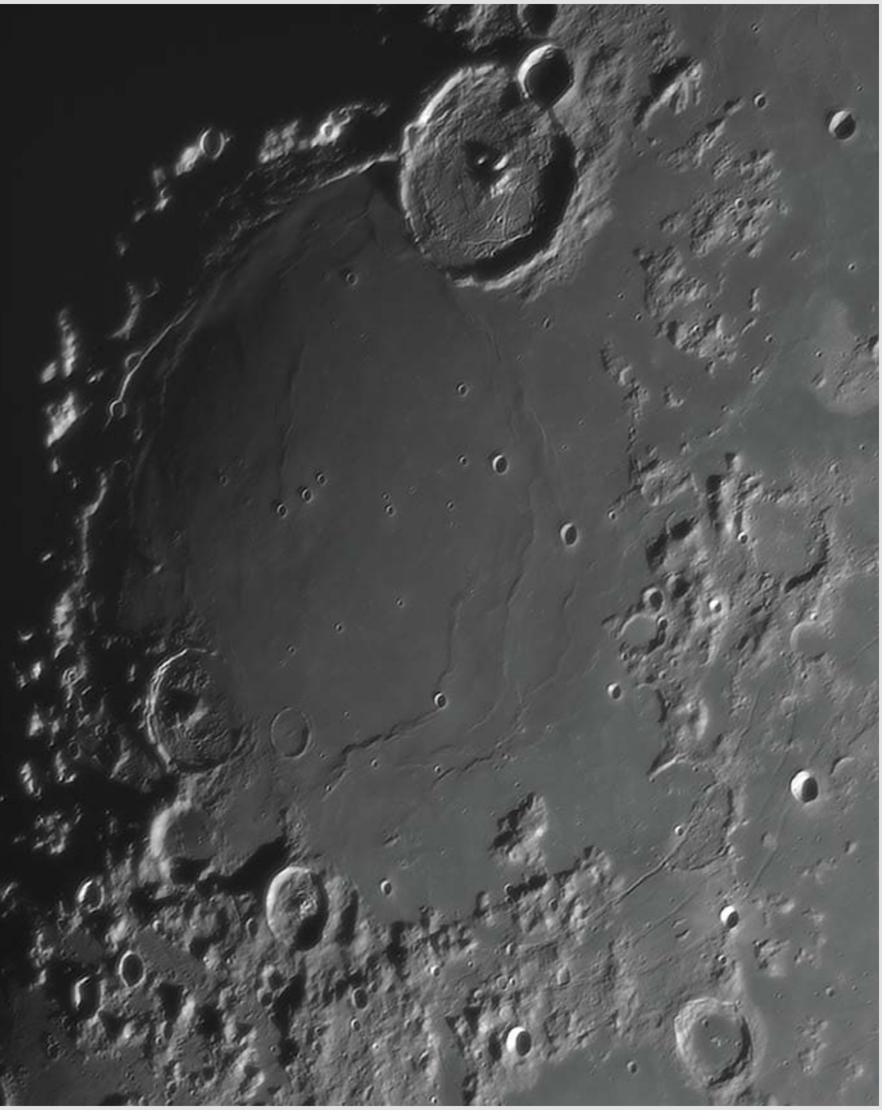
DETAILS: *16-inch f/3.75 Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure: 5½ hours through Hα and LRGB filters.*

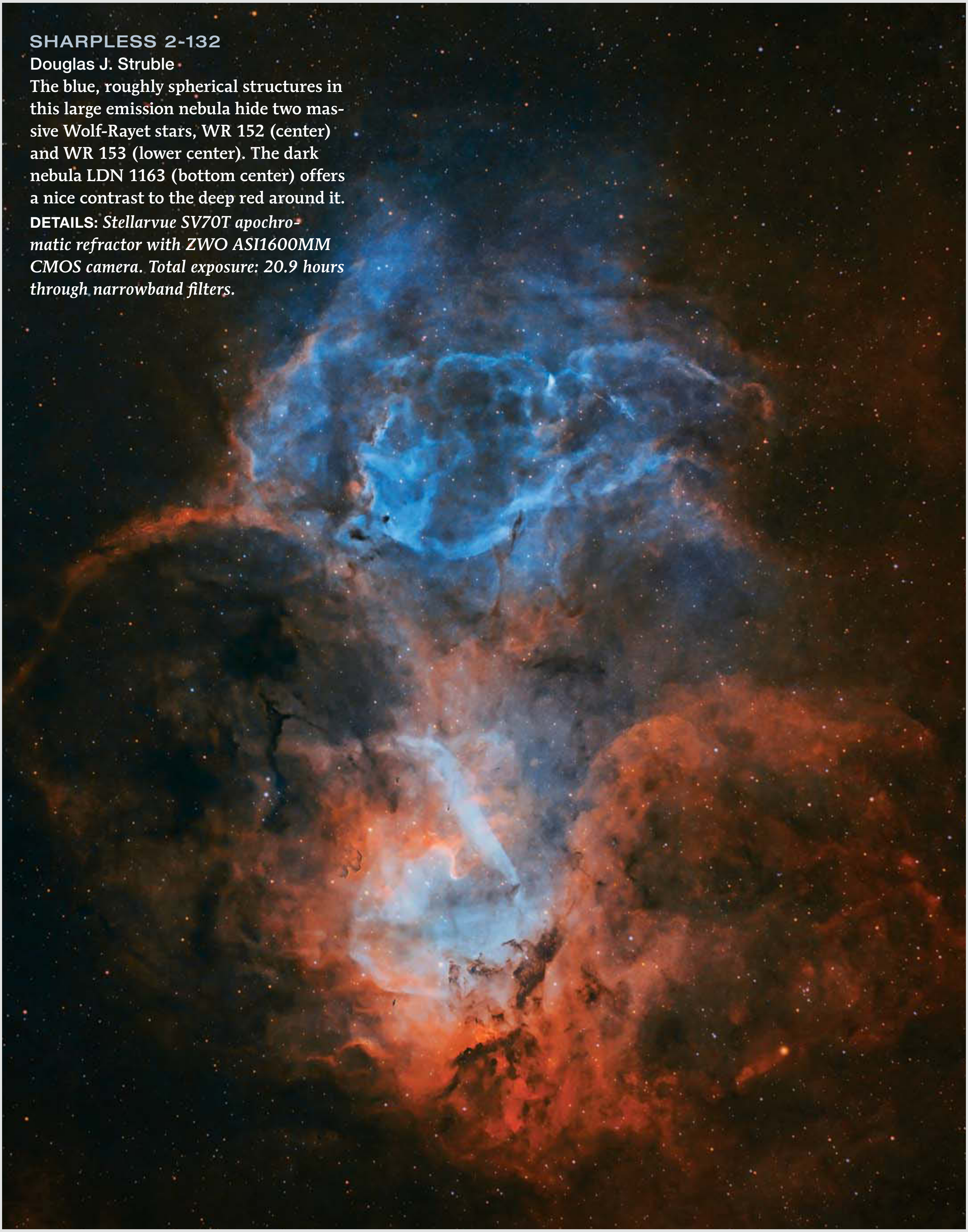
▽ SUNRISE ON THE SEA OF MOISTURE

Steve Thornton

Despite its name and the ridges that appear to ripple across its surface (center right), Mare Humorum is not wet. A thick layer of dark basalt fills this ancient crater. Later impacts created Gassendi Crater and its partner Gassendi A, which sit on the mare's northern edge.

DETAILS: *Celestron C9.25 Schmidt-Cassegrain telescope with ZWO ASI290MM video camera. Stack of about 1,200 frames.*





SHARPLESS 2-132
Douglas J. Struble
The blue, roughly spherical structures in this large emission nebula hide two massive Wolf-Rayet stars, WR 152 (center) and WR 153 (lower center). The dark nebula LDN 1163 (bottom center) offers a nice contrast to the deep red around it.
DETAILS: *Stellarvue SV70T apochromatic refractor with ZWO ASI1600MM CMOS camera. Total exposure: 20.9 hours through narrowband filters.*

◁ A HERCULEAN GLOBULAR

Patrick Winkler

The Great Globular Cluster in Hercules, M13, brims with bright, densely packed stars. Under extremely dark skies, sharp-eyed observers may spot it as a hazy blur without optical aid, but a mid-size telescope can resolve individual stars.

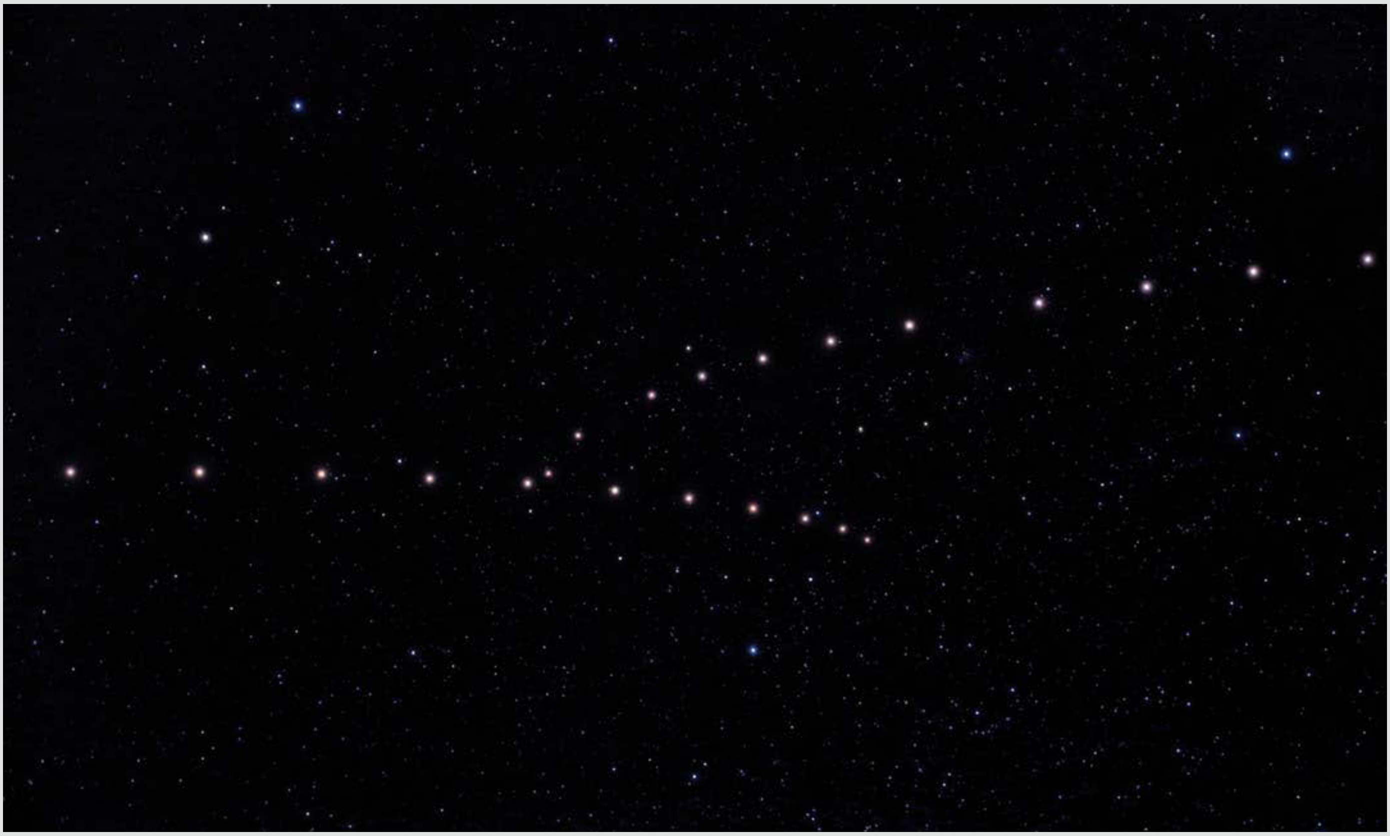
DETAILS: *AstroSysteme Austria ASA RC400 Ritchey-Chrétien telescope with ZWO ASI6200MM MC Pro CMOS camera. Total exposure: 3½ hours through LRGB filters.*

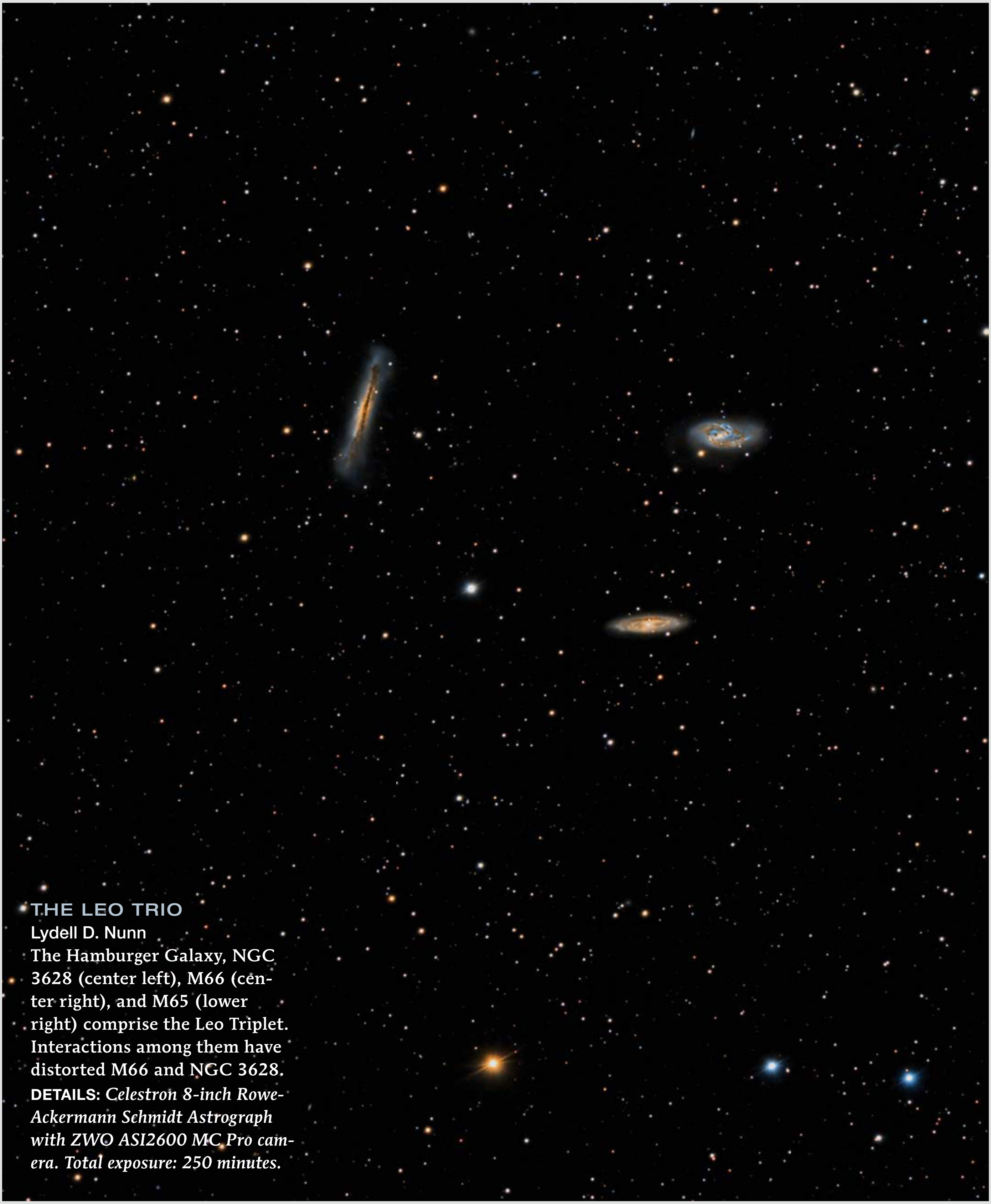
▽ LOOPING AROUND GEMINI

Tunç Tezel

This image follows Mercury as it draws a retrograde loop around the legs of the Gemini twins during the summer of 2020. The Solar and Heliospheric Observatory captured the tiny images of Mercury on the far side of the loop before and after it reached inferior conjunction on July 1st.

DETAILS: *Canon EOS 6D DSLR with 50-mm lens. Composite of 28 exposures captured at ISO 200, 400, and 800.*





THE LEO TRIO
Lydell D. Nunn
The Hamburger Galaxy, NGC 3628 (center left), M66 (center right), and M65 (lower right) comprise the Leo Triplet. Interactions among them have distorted M66 and NGC 3628.
DETAILS: *Celestron 8-inch Rowe-Ackermann Schmidt Astrograph with ZWO ASI2600 MC Pro camera. Total exposure: 250 minutes.*

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

Your Custom Adapter is just a few clicks away

HOT PRODUCT 2011 SKY

www.preciseparts.com
305 253-5707
info@preciseparts.com
PRECISEPARTS®
CUSTOM PARTS FOR ASTRONOMY

Robo-Focus™
Digital Focusing

- Precision focus control via PC
- Autofocus capability
- Full manual operation as needed
- Temperature compensated
- Automatic backlash correction
- Remote power outlet box (option)
- Fits most scopes & focusers

$495

See www.homedome.com for details

TECHNICAL INNOVATIONS
407-601-1975 domepage@erols.com
"RoboFocus is a gem!"

ACCESSORIES

Bob's Knobs™
COLLIMATION THUMBSCREWS
www.bobsknobs.com

BOOKS

Cosmonauts do it in Heaven
Keith Gottschalk

Poems on astronomy and spaceflight

Order from African Books Collective (ABC) or Amazon

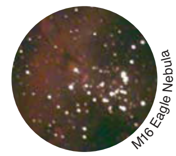
CAMERAS

The best $299 eyepiece you'll ever buy.

Just insert this camera into where your eyepiece normally goes, and you'll soon be "seeing" objects that are impossible to see the same way in your eyepiece! Works in cities too.

No computer required. Battery-powered 7-inch color monitor included.

Visit our website to see lots of cool new accessories that let you do even more!



HOT PRODUCT 2017 SKY

DEALERS
Agena AstroProducts
High Point Scientific
Oceanside Photo & Telescope
Skies Unlimited
Woodland Hills Telescopes

REVOLUTION IMAGER
RevolutionImager.com

SOFTWARE

Deep-Sky Planner 8

Exceptional Planning & Logging software for Visual Observers and Imagers

Introducing our new version!

Learn more at www.knightware.biz

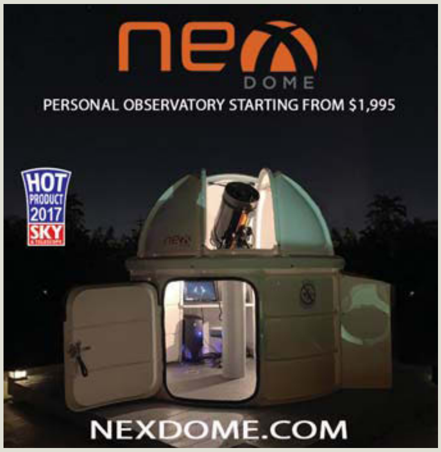
skyandtelescope.org

MISCELLANEOUS

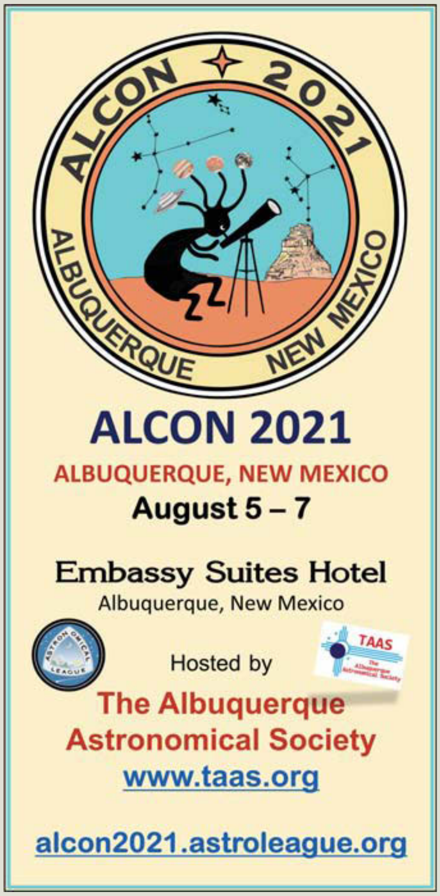
MOUNTS

OBSERVATORIES/DOMES

OBSERVATORIES/DOMES



ORGANIZATIONS



TELESCOPES

TRAVEL

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.

MIRADOR ASTRONOMY VILLAGE: https://miradorastrovillage.org. Contact David Oesper @ davedarksky@mac.com 608-930-2120.

SOUTHWEST NEW MEXICO: Casitas de Gila Guesthouses. Dark skies, great accommodations; power, wifi, and pads available. casitasdegila.com/astronomy.html. 575-535-4455.

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, Suite 300B, One Alewife Center, Cambridge, MA 02140.

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

Alluxa, Inc.
» page 65
filters
alluxa.com

Astro-Physics, Inc.
» page 81
telescopes / mounts
astro-physics.com

Celestron
» page 3
binoculars / eyepieces / mounts / telescopes
celestron.com

Diffraction Limited
» page 1
cameras
diffractionlimited.com

iOptron
» page 13
mounts / telescopes
ioptron.com

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

Software Bisque
» page 5 + back cover
mounts
bisque.com

Stellarvue
» inside back cover
eyepieces / telescopes
stellarvue.com

Ad Index

To advertise in our Product Locator, please contact Tim Allen at 773-551-0397, or email him at Ads@skyandtelescope.org

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 5–12
GRAND CANYON STAR PARTY
To be held virtually at:
https://is.gd/gcsp2021

June 9–12
BRYCE CANYON ASTRONOMY FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 10–13
BOOTLEG SPRING STAR PARTY
Harmon, IL
bootlegastronomy.com

~~*June 10–13*~~ CANCELED
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 10–13
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

June 25–27
RASC GENERAL ASSEMBLY
To be held virtually at:
https://is.gd/RASCGeneralAssembly

~~*July 7–11*~~ CANCELED
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

August 1–6
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

August 3–7
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

August 3–8
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 4–9
SASKATCHEWAN SUMMER STAR PARTY
Maple Creek, SK
sssp.saskatoon.rasc.ca

~~*August 5–7*~~ CANCELED
ALCON 2021
Albuquerque, NM
alcon2021.info

~~*August 5–8*~~ CANCELED
STARFEST
Ayton, ON
nyaa.ca/starfest.html

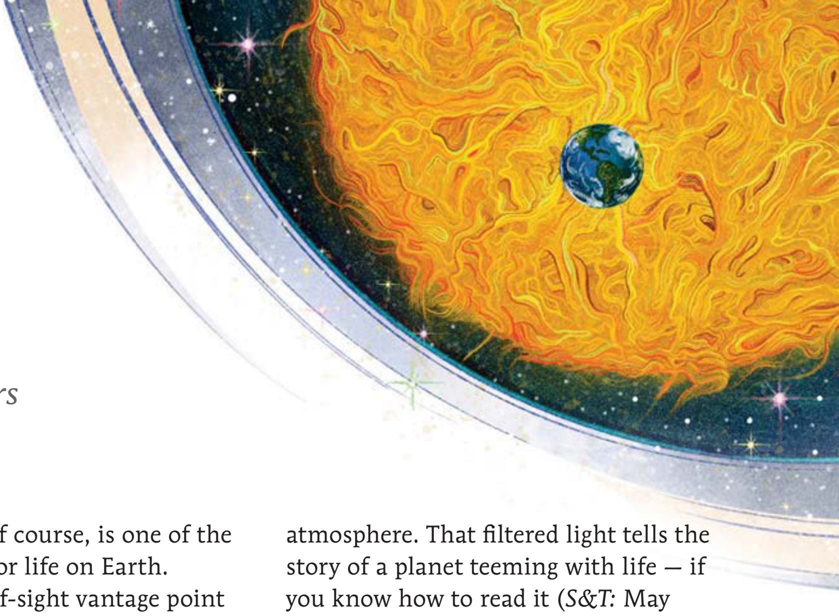
August 5–8
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 6–8
NORTHWOODS STARFEST
Fall Creek, WI
cvastro.org/northwoods-starfest

August 6–8
NOVA EAST
Smileys Provincial Park, NS
novaeast.rasc.ca

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

WILLIAM PEDRO / NPS



Who Could Be Watching Us?

If they exist, intelligent aliens around nearby stars could observe Earth cross the face of the Sun.

WE LIVE IN AN AMAZING TIME. For the first time ever, we have developed the means to potentially spot life in our galaxy, if it is out there. The upcoming James Webb Space Telescope and ground-based 30-meter-class telescopes will open our eyes to thousands of new worlds in our celestial neighborhood, burnishing our hope of finding other Pale Blue Dots.

In our search, *transiting exoplanets* feature prominently. Such worlds block a tiny part of their host star from our view when they pass between us and the star. That's when we notice them. We can't see most of the exoplanets directly, but we know they're there, because we can detect that slight dimming with a precision like clockwork.

Some of these worlds are at just the right distance from their star to possibly make them warm Pale Blue Dots. They orbit not too close and not too far away and thus may have surface conditions that allow liquid water to flow aboveground. Water, of course, is one of the key ingredients for life on Earth.

But our line-of-sight vantage point is not unique. When we change the perspective from Earth to other stars, we discover about 1,000 suns less than 350 light-years away that could detect *our* planet the same way. Anything or anybody that could observe from near those stars could see Earth block a minute portion of our Sun's light.

All 1,004 of these main-sequence stars inhabit a small strip on the sky, a geometry that puts Earth between those stars and the Sun once a year. Thirty-eight of these stars are no more than 100 light-years away from us. That means radio waves from our world have already reached them. You can even figure out when each one of those stars "sees" Earth transit and wave back at the right time!

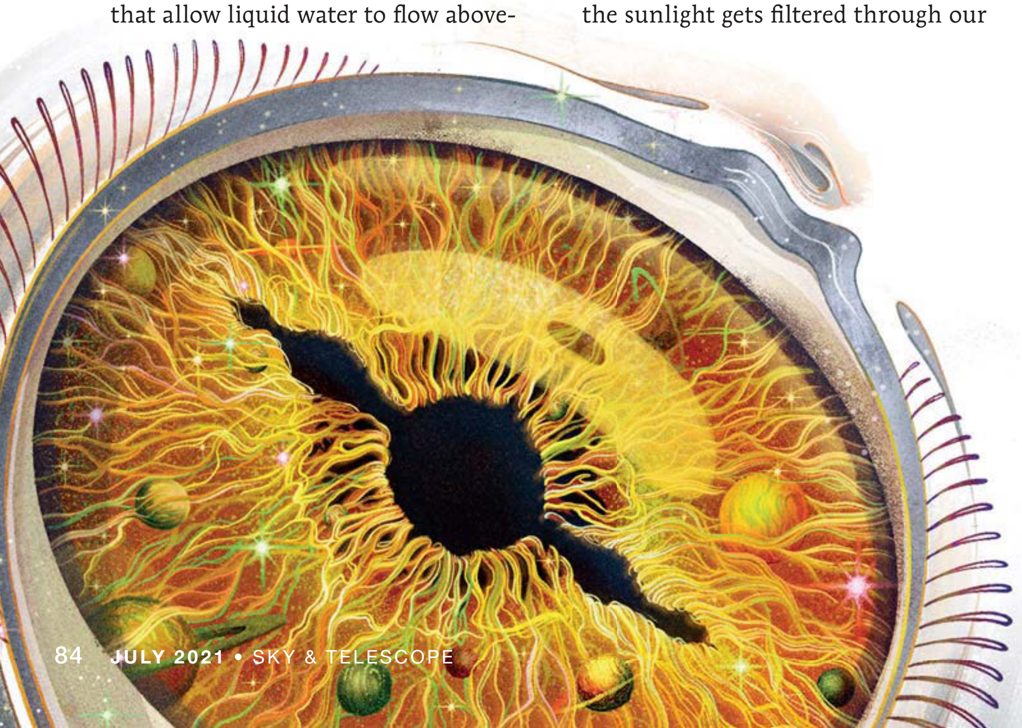
When our planet passes through a star's line of sight to the Sun, part of the sunlight gets filtered through our atmosphere. That filtered light tells the story of a planet teeming with life — if you know how to read it (*S&T:* May 2021, p. 34).

Because light carries energy that's proportional to its wavelength, it interacts with molecules it encounters on its path, making them swing and rotate. And because every molecule has a unique structure, it will only move if it gets hit with just the right energy.

All that information is encoded in the light astronomers collect in their telescopes. The missing light tells the story of which chemicals the photons encountered on their way to us, just as passport stamps indicate which countries you visited before you arrived. It allows us to read the chemical makeup of the air on transiting planets over vast cosmic distances.

Earth's vibrant biosphere has changed the chemical makeup of our own air for billions of years. In that time, it left telltale signs for anyone looking. We don't know yet if any of those 1,000-plus stars host small planets — NASA's Transiting Exoplanet Survey Satellite, or TESS, mission is searching for them now (*S&T:* Apr. 2020, p. 11).

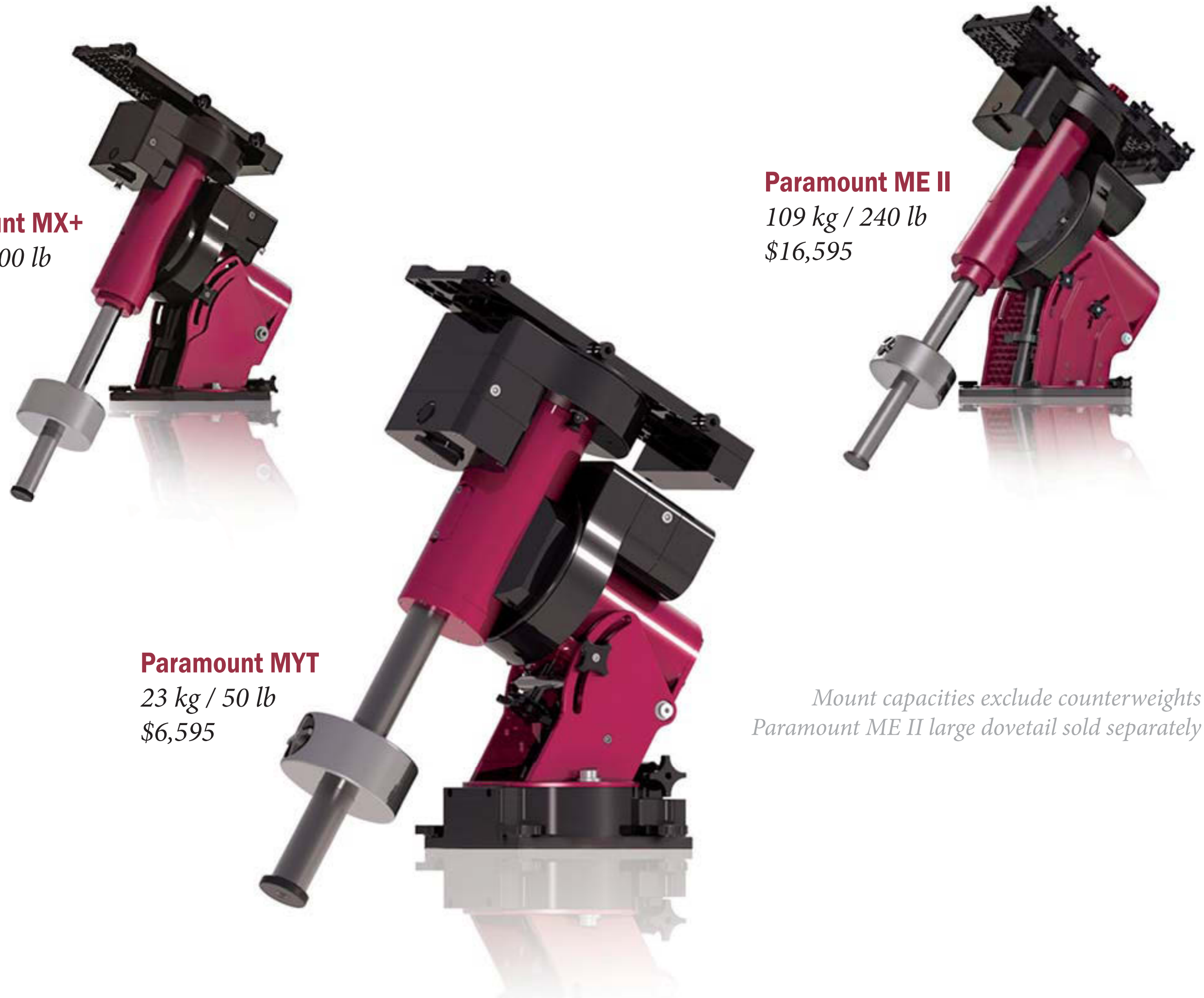
But imagine a planet near one of those stars that bears astronomers with our level of technology or better. They might well have spotted Earth already. What would they think of our world?



■ **LISA KALTENEGGER** is Director of the Carl Sagan Institute and an associate professor of astronomy at Cornell University. See her full paper on this topic, coauthored with Joshua Pepper (Lehigh University), at **arxiv.org/abs/2010.09766**.

DAVID CURTIS

Omne Trium Perfectum



Mount capacities exclude counterweights
Paramount ME II large dovetail sold separately

You deserve the best, right now. And, if not now, when?

Paramount™ robotic telescope systems combine precision mechanics, advanced control-system electronics, and TheSky™ Imaging Edition to achieve unmatched performance, reliability, and productivity.

Its unrivaled TPoint™ telescope modeling software helps optimize your efficiency and productivity while its ProTrack™ assisted tracking ensures pinpoint stars with long exposures.

Whether you choose the portable MYT, the transportable MX+, or the legendary observatory-class ME II, make a Paramount the foundation of your digital imaging pursuits.

And thanks to our state-of-the-art manufacturing facility, we can typically deliver the model you want without the long wait.

Make a Paramount yours today.

SOFTWARE BISQUE

Superior imaging solutions for discriminating astronomers.