EXOPLANETS:
Discoveries Close to Home
PAGE 34

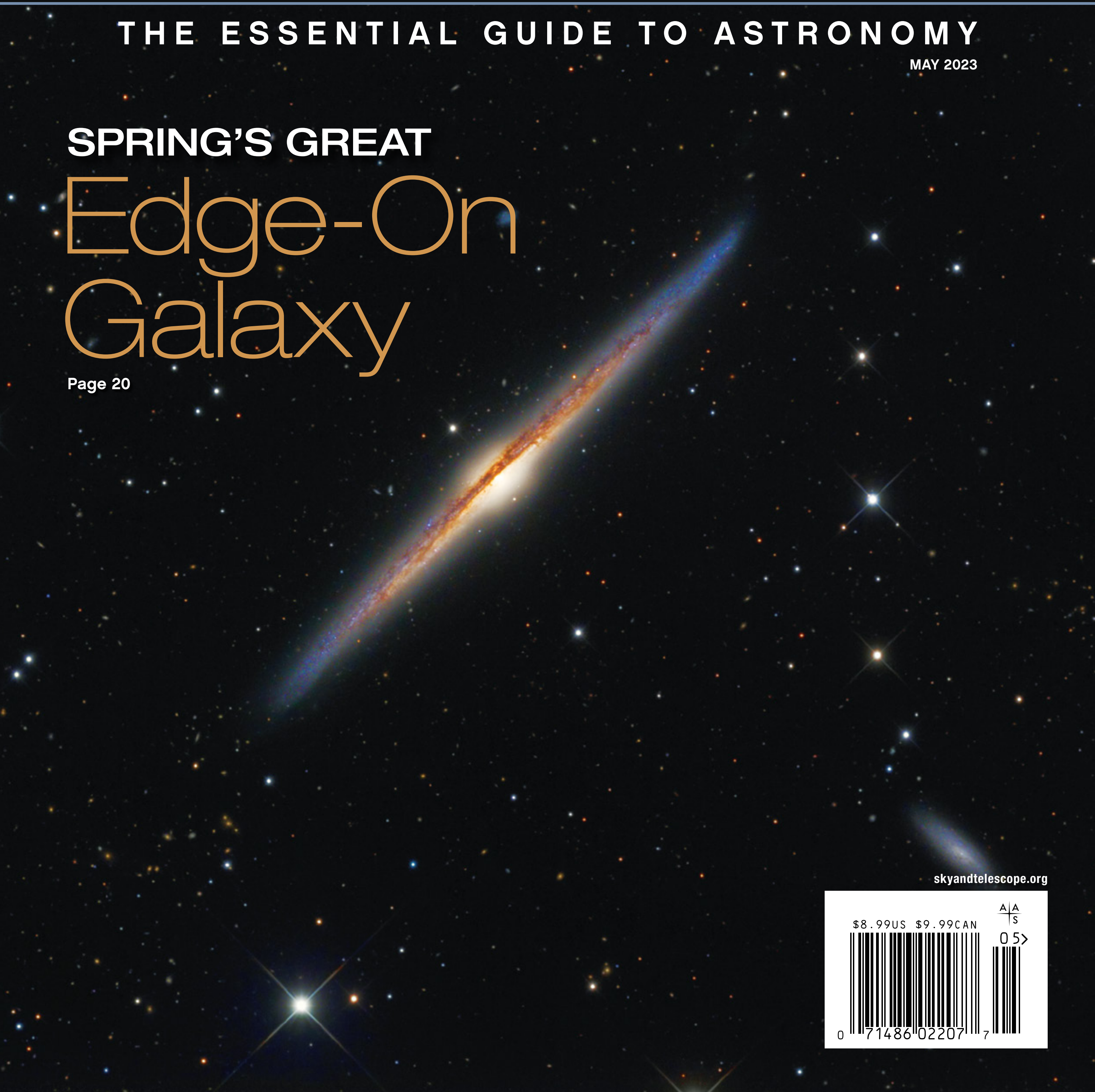
EASY IMAGING:
Live-Stacking the Night Sky
PAGE 58

OCCULTATION:
The Moon Covers Jupiter
PAGE 48

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2023



SPRING'S GREAT Edge-On Galaxy

Page 20

skyandtelescope.org

$8.99US $9.99CAN
05
0 71486 02207 7

CONTENTS

SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

NASA / MIT / TESS AND ETHAN KRUSE (UNIVERSITY OF MARYLAND, COLLEGE PARK)

FEATURES

S&T TEST REPORT

OBSERVING

COLUMNS / DEPARTMENTS

ON THE COVER

The spiral galaxy NGC 4565 beckons in Coma Berenices.
PHOTO: BOB FRANKE

ONLINE

INTERACTIVE SKY CHART
Find out what the sky looks like for your time and place. You can also print the chart as a handout.
skyandtelescope.org/interactive-sky-chart

IMAGING FOUNDATIONS
Want to break into astrophotography? Learn the fundamentals in this blog series.
skyandtelescope.org/astrophotography

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

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by AAS Sky Publishing, LLC, owned by the American Astronomical Society, 1667 K Street NW, Suite 800, Washington, DC 20006, USA. Phone: 800-253-0245 (customer service/subscriptions), 617-500-6793 (all other calls). Website: skyandtelescope.org. Store website: shopatsky.com. ©2023 AAS Sky Publishing, LLC. All rights reserved. Periodicals postage paid at Washington, DC, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 219, Lincolnshire, IL, 60069-9806. Printed in the USA. *Sky & Telescope* maintains a strict policy of editorial independence from the AAS and its research publications in reporting on astronomy.

In a New Space

SKY & TELESCOPE WELCOMED 2023 on a new footing.

In December, we moved into our new offices at 1374 Massachusetts Avenue in Cambridge, Mass. This event was more significant than simply a relocation. Since March 2020, we *S&T* staffers have largely worked out of our homes. For two years, the pandemic was the cause, but then, in April 2022, we had to vacate our building because it had been sold as part of a major development project in West Cambridge. For the next eight months, our offices were in storage while we awaited our new space.

During this nearly three-year period, we coordinated with one another by email, phone, and video calls to ensure that we continued to produce the high-quality content our readers expect and deserve. As I write this, we're enjoying our first weeks of collaborating in person again as well as having ready access to things like back issues and incoming mail.

▲ A new day: Sunrise over Pacific as seen from the ISS

NASA

We also welcomed two new personnel at the start of this year. After 27 years at *S&T*, Illustration Director Gregg Dinderman retired at the end of 2022. We thank him for his dedication, hard work, and great guffaw of a laugh, and we wish him the best in his next pursuits. In January, we hired Gregg's successor — our new Technical Illustrator, Beatriz Inglessis. Venezuelan by birth, Beatriz has a doctorate in Japanese wood-block printmaking and is an extremely talented scientific illustrator.

Rod Nenner also began in January. The new Director of Strategic Partnerships and Chief Business Officer for the AAS, Rod will also handle advertising sales, sponsorship opportunities, and other initiatives for *S&T*. A man bursting with ideas and initiative, Rod spent 18 years with the NFL team now known as the Washington Commanders as VP of Corporate Partnerships. We look forward to working with Rod to enhance the *S&T* brand in myriad ways.

One such way is extending the brand overseas. In addition to our long-time content-licensing arrangements with *Australian Sky & Telescope* and the Chinese National Astronomy Magazine, we recently began sharing *S&T* content with the German astronomy publication *Sterne und Weltraum*. On the books front, the Beijing Science and Technology Publishing Co. has just brought out a Simplified Chinese edition of our popular book *Binocular Highlights*.

Lastly, late in the fall we received results from a reader survey we conducted last summer. We've only begun to mine the riches of this mother lode of data from readers — data that will inform our strategic plan for the next five years and beyond. Much obliged to all who participated.

Altogether, as 2023 progresses, we feel well-positioned and excited for the future. Thanks for your support.

Peter

Editor in Chief

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

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

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

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

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

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

The following are registered trademarks of AAS Sky Publishing, LLC: *Sky & Telescope* and logo, *Sky and Telescope*, The Essential Guide to Astronomy, Skyline, Sky Publications, skyandtelescope.org, skypub.org, *SkyWatch*, Scanning the Skies, *Night Sky*, *SkyWeek*, and ESSCO.

Preserving Astronomical History

I enjoyed reading Diana Hannikainen's encouraging article "Star Notes" (*S&T:* Mar. 2023, p. 57).

I have been an active volunteer for over nine years with the Harvard College Observatory's Digital Access to a Sky Century at Harvard (DASCH) and Preserving Harvard's Early Data and Research in Astronomy (Phaedra) projects. Tens of thousands of pages have already been transcribed/reviewed, and, currently, around 174,000 Star Notes pages have been reviewed.

Some unique historical items struck me, e.g., a handwritten note from 1862 indicating that Sirius' companion was discovered the night before; sketches of Halley's Comet in 1910; written notes by E. C. Pickering and E. E. Barnard; a note referring to the first image ever taken of a star (Vega) in 1860; and H. P. Tuttle's description of his comet discovery of 1858. There is even a side note by Henrietta Swan Leavitt about the armistice ending WWI on November 11, 1918!

I hope others will enjoy participating in these projects to help preserve astronomical history.

Al Lamperti • Royersford, Pennsylvania

▲ Volunteers are working hard to transcribe and preserve historic notes recorded in the notebooks of Harvard astronomers and "computers."

What Speed Is Your Car?

The first line of Ted Forte's "Winter Outreach" (*S&T:* Feb. 2023, p. 18) is, "What's the power of your telescope?" I've heard that so many times. My usual response is, "That's like asking: What speed is your car? With a car, it depends on a bunch of factors, including what gear you are using. With a telescope, it also depends on several factors, including what eyepiece you are using." I then explain what magnification they are using and that I like to use a low-power eyepiece because it shows the most area of sky with the sharpest view and is easiest for most people to focus. That's simplistic, but it's enough for most folks. On rare occasions I find someone interested enough that I can begin to discuss apertures, focal ratios, eyepiece focal lengths, and the concept of "useful magnification." I try to stop myself before their eyes glaze over.

Ray Harris
Macungie, Pennsylvania

Respecting Schmidt-Cassegrains

Just after I purchased a new Schmidt-Cassegrain Telescope (Celestron C8 Powerstar III), I was barraged with articles attesting to the poor planetary performance of these telescopes. A fellow SCT owner, who supervised a small college planetarium, asked me one evening, "Aren't you sick of people bad-mouthing these scopes?" I certainly was. That is just one of the reasons why I found Tom Dobbins' "What Makes a Good Planetary Telescope?" (*S&T:* Jan. 2023, p. 58) so enjoyable. Recently, I have read many more positive evaluations of these scopes. It was valuable to see some of the factors contributing to this explained in Dobbins' article. Some of the best planetary images are now produced by amateurs who own these instruments.

I have a question concerning the effect of the central obstruction of SCTs as it relates to the atmospheric distortion of our scintillating skies. As explained and illustrated in the article, the amount of atmospheric distortion is dependent on aperture. With an 8-inch aperture and a 2-inch central obstruction, would that result in the scope's image receiving a 6-inch dose of distortion or the full amount of distortion?

Gene Santagada
Newburgh, New York

Thomas Dobbins replies: *SCTs have been unjustly maligned as planetary telescopes for many years. Undoubtedly, much of the criticism arose from variability in optical quality, which has been much reduced in recent years due to improved optical fabrication and testing techniques combined with more stringent quality control. The central obstruction has often been cited as a cause of inferior performance, but central obstructions of SCTs are similar to those of Maksutov-Cassegrains, like the Questar, instruments that have always enjoyed a sterling reputation. The old proverb that the proof of the pudding is in the eating has never been more apropos — the planetary images obtained by SCT owners speak for themselves.*

Like resolution, the sensitivity of a telescope to atmospheric turbulence is a function of its aperture. An 8-inch telescope with a 2-inch central obstruction would suffer the same amount of distortion as an 8-inch scope without a central obstruction.

Comet Conundrum

I'm interested in a theme of Javier Barbuzano's "Earth's Wellspring" (*S&T:* Mar. 2023, p. 34) — that most of the water on Earth probably wasn't delivered by comets. To quote from page 37, ". . . many comets have much higher D/H [deuterium-to-hydrogen] ratios than Earth's oceans . . ." This set me to wondering: How does one measure the D/H ratio in a comet? And in how many comets has this ratio been measured?

Jeremy Tatum
Victoria, British Columbia

Camille Carlisle replies: *We have D/H ratio measurements for about a dozen comets; I think the plot on page 38 of the article includes them all. You can find a version with the comet names at* ***https://is.gd/Rosetta_DHratio****, but we reorganized the data points to list them by orbital period, left to right, so that the whole plot is approximately ordered by distance from the Sun.*

For Halley's Comet and 67P/Comet Churyumov-Gerasimenko, spacecraft measured the D/H ratios in each comet's coma with mass spectrometers, which measure the masses of the various molecules present to determine the isotopes and their ratios. For the others, astronomers determined the D/H ratios using spectroscopic observations: For example, the spectral lines of H_2O*, HDO, and* D_2O *are different. (Page 12 of* ***https://is.gd/DeuteriumFractionation*** *has a technical discussion of various comet D/H measurements if you'd like to read about the details.)*

Lunar Live Feed

It would be great if video cameras could be placed on the Moon that sent us continuous high-resolution, color images of Earth and the surrounding lunar terrain! During total lunar eclipses, we could all see Earth become a dark circle ringed with red light formed by its simultaneous sunsets and sunrises. At the same time, we could watch the moonscape turn red. These cameras would not only be useful during eclipses but also allow fascinating observations of Earth's phases and dramatic changes in appearance of the moonscape under varying sunlight and earthlight. They could be installed as one task of an Artemis mission. This might boost the public's interest and support for funding.

Gary Deatsman
Walla Walla, Washington

Printing to Please

Your monthly magazine is wonderful! I've been impressed for a couple of years now, and I am hard to impress. 😜

Dale Lichtblau
Reston, Virginia

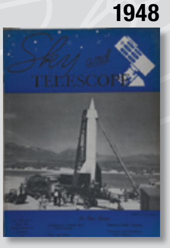
FOR THE RECORD

- "Earth's Wellspring" (*S&T:* Mar. 2023, p. 34) misstated hydrogen's makeup: A hydrogen atom has one proton and one electron.

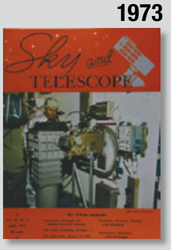
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1948



1973



1998

◖ May 1948

Noisy Sun "The temperature of the sun's corona is of the order of a million degrees. How is this high temperature maintained? This is the problem Dr. Martin Schwarzschild, of Princeton University Observatory, sets out to answer. [He] reports that acoustical waves of energy are produced by the turbulence of the solar granules, [which] may be likened to gas bubbles hundreds of miles in diameter, each lasting only a few minutes. . . .

"The granule-produced compression waves . . . pass upward, [and] some 500 miles above the photosphere the mechanical energy of the 'noise' is converted into heat [that keeps] the corona hot."

◖ May 1973

Comet Mania "The newly discovered Comet Kohoutek (1973f) should become a conspicuous naked-eye object, 1st magnitude or brighter, around the end of this year. It was found at Hamburg Observatory in West Germany by Lubos Kohoutek on the evening of March 7th . . . On two plates it appeared as a 16th-magnitude diffuse spot . . . still five astronomical units distant from the sun.

"According to preliminary orbital elements calculated by Brian G. Marsden, Smithsonian Astrophysical Observatory, it will pass through perihelion on December 29, 1973, at about 0.14 astronomical unit from the sun. This great decrease in heliocentric distance promises a spectacular increase in brightness."

So unusual was this find that Marsden hand-carried his printout to the S&T *offices. Comet Kohoutek inspired a sensational book and a comet-watching cruise but, alas, never lived up to expectations.*

◖ May 1998

Sagittarius Dwarf "'We were in the middle of the survey when I noticed a few of the stars, which happened to be very red, had rather peculiar velocities . . . ,' says [Rodrigo Ibata, then a graduate student at Cambridge University]. 'They appeared to be moving together. . . .'

"Ibata wondered how these fast stars were distributed in the sky. To find the answer he walked down the road to the Royal Greenwich Observatory, where Michael Irwin had a stack of photographic plates taken with a wide-field Schmidt telescope. Together Ibata and Irwin scanned the plates . . . and plotted the positions of red stars that have brightnesses similar to those with the unusual velocities. 'All of a sudden, you could see the contours of what looked like a new galaxy,' says Ibata. And that's exactly what it [was] — a nearby dwarf spheroidal galaxy that had eluded astronomers because it lies roughly 100,000 light-years away on the other side of our galaxy's center . . ."

As Ray Jayawardhana went on to report, the Sagittarius dwarf galaxy is being "eaten" by our Milky Way and is adding its own globular clusters to those already populating our galaxy's halo.

ASTRONOMY & SOCIETY

Light Pollution Increasing Faster Than Thought

HOW MANY STARS can you see at night? According to results from a study appearing in the January 20th *Science*, that number is likely less than it was just a few years ago.

To arrive at that conclusion, Christopher Kyba (GFZ German Research Centre for Geosciences) and his collaborators looked to the Globe at Night citizen-science project. Using data reported from users on the ground, the researchers found that the average brightness of the night sky around the globe increased by 9.6% every year between 2011 and 2022.

Until now, our best global view of light pollution came from satellite measurements, which had indicated that scattered light was growing on average 2.2% per year between 2012 and 2016. The new result from citizen scientists suggests that satellites have vastly underestimated the increase.

The new estimate differs from earlier results in part because the instruments aboard the current generation of satellites are effectively blind to blue light. LEDs emit much more in the blue part of the spectrum than earlier light sources did, and that light scatters more efficiently in the atmosphere than other colors do. Also, because LEDs use much less energy than earlier light sources did, regions tend to install more

▲ The greater the light pollution, and therefore skyglow, the fewer the stars that are visible.

(and brighter) fixtures. But satellites missed the magnitude of these changes. Satellite measurements also don't fully account for light emitted toward the horizon, such as from windows and illuminated signs.

Visual observations like those collected by Globe at Night can account for at least some of the "missing" light. By counting the number of visible stars in the night sky, citizen scientists include the influences of both increasing light emissions and the shift toward generally bluer light sources.

Participants contributed more than 50,000 individual observations during the study period. Yet even that mountain of data could sample night-sky conditions only on large scales.

"We were only able to look at continental trends, because we don't have sufficient data to look at smaller regions," Kyba explains. Increasing the number of Globe at Night observations by a factor of 10 would make it possible to focus on smaller scales, he says, which would help provide more targeted information to policymakers.

■ JOHN BARENTINE

Join the Globe at Night project: https://is.gd/GlobeatNight.

IN BRIEF

Observatories Not Immune

Light pollution is creeping up even on astronomical observatories. According to a study published in the February *Monthly Notices of the Royal Astronomical Society*, only a handful of all large observatories are in truly dark sites, with skyglow less than 1% brighter than assumed natural levels. And two-thirds have already seen their night skies brighten 10% over natural levels, report Fabio Falchi (University of Santiago de Compostela, Spain) and colleagues. Analyzing satellite data around major, historic, and potential observatory sites, the researchers computed skyglow at different altitudes above the horizon and compared it to natural levels. Even distant, seemingly inoffensive lights can be a bother. For example, a single highway 40 kilometers (25 miles) away contributes more than 50% of the overhead radiance in the otherwise dark desert skies over the Las Campanas Observatory, home of the twin 6.5-meter Magellan telescopes and future site of the Giant Magellan Telescope. Of course, remote astronomical observatory sites are the least affected by light pollution, which makes them the proverbial canary in the coal mine. "If we are not able to keep this canary alive," Falchi says, "then we can forget being able to solve the problem of light pollution as a global environmental issue."

■ JAN HATTENBACH

NOIRLAB / NSF / AURA / P. MARENFELD

GALAXIES

Fluffy Triangulum Has Hidden Two-Armed Pattern

THE TRIANGULUM GALAXY (M33) appears to the eye as a flocculent spiral, with many arm segments, but its older stars tell a different story.

Astronomers imaged M33 as part of a Hubble Space Telescope project called "Panchromatic Hubble Andromeda Treasury: Triangulum Extended Region," creating a mosaic of the galaxy's innermost 14,000 light-years from 54 fields. These images reveal some 22 million stars, which the team split into groups by age. Then they looked at the patterns each of these populations traced.

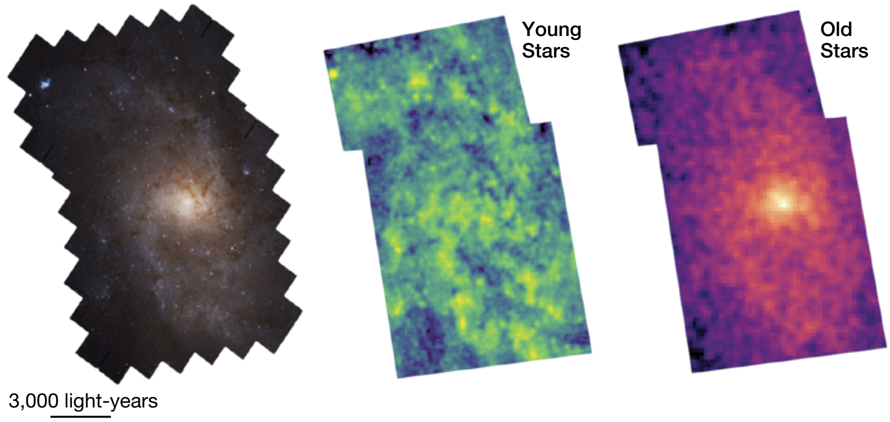
This is where things took an unexpected turn: While the youngest stars trace the familiar many-armed spiral, stars older than 1 billion years outline only two arms and a central bar.

"The structure of M33 really depends on the stellar population that you're looking at," Adam Smercina (University of Washington) summed up at the 241st American Astronomical Society meeting. The researchers first saw early signs of this hidden structure in 2021 and are now working on writing up a more detailed analysis.

The old stars might not have been born tracing the grander pattern, Smercina explained. Rather, a gravitational interaction could have sent waves rippling through the disk, spurring the formation of a two-armed spiral. Stars born long after the event wouldn't have been rejiggered, explaining why today's disk looks so different. Alternatively, the two-armed spiral could in fact be a long-lived, dominant pattern only recently obscured by the youngest stars.

Work that's under way to measure individual stars' motions might help decide between scenarios.

■ **CAMILLE M. CARLISLE**



▲ The woolly appearance of the Triangulum Galaxy *(left)* comes from its young stars *(center)*, but old stars *(right)* trace two arms and a central bar.

GALAXIES

Webb Telescope Finds Early Galaxies Too Numerous, Too Bright

MULTIPLE TEAMS REPORTED at the 241st meeting of the American Astronomical Society (AAS) that the James Webb Space Telescope is finding early galaxies to be more numerous and/or more mature than expected. The results may end up changing our understanding of how the first galaxies formed.

Speaking as part of the Cosmic Evolution Early Release Science (CEERS) collaboration, Jeyhan Kartaltepe (Rochester Institute of Technology) reported Webb's views of galaxies in a universe between 500 million years and 2 billion years old. The CEERS group found 850 early galaxies, measured the distance to each one using spectra, and then categorized them by shape.

Those shapes, it turns out, haven't changed much over cosmological time: The percentage of disk galaxies declines only slightly in the early universe, while the fraction of those with a central bulge or irregular shape stays roughly constant over time.

While disks are usually thought to form in more serene environments, Kartaltepe clarifies that early disks appear more turbulent and messy than modern ones. "I think the surprise is to see *so* many of them, to see that things were already fairly mature at these high redshifts," she says.

Also speaking at the AAS gathering, Haojing Yan (University of Missouri) reported galaxies from even earlier in cosmic history. Yan found 87 distant galaxies that appear to date to between 200 million and 400 million years after the Big Bang (corresponding to a redshift as great as 20).

◀ This patch of sky near the Big Dipper shows an intriguing mix of near and distant galaxies.

The distances to these candidates await spectroscopic confirmation, but so far, spectra have confirmed the majority of such preliminary distances. "Our previously favored picture of galaxy formation in the early universe must be revised," Yan concludes.

One of the theorists tackling this problem is Jordan Mirocha (McGill University, Canada), who also presented at the AAS meeting. He argues that multiple, interrelated factors — including star formation, stellar feedback, and the generation of dust — are probably at work in throwing off predictions.

"I think we have more to think about," he says.

■ **MONICA YOUNG**

VIEWS OF TRIANGULUM GALAXY: A. SMERCINA / M.J. DURBIN / J. DALCANTON / B.F. WILLIAMS / UNIVERSITY OF WASHINGTON / NASA / ESA; CEERS SURVEY: NASA / STSCI / CEERS / TACC / S. FINKELSTEIN / M. BAGLEY / Z. LEVAY

STARS

850-Year-Old Supernova Left White Dwarf Behind

A SUPERNOVA EXPLOSION recorded in the Far East almost 850 years ago has produced an unusual remnant. "I've worked on supernovae for [decades], and I've never seen anything like this," says Robert Fesen (Dartmouth College).

Fesen presented his observations at the 241st meeting of the American Astronomical Society (AAS). In other work presented at the meeting, Bradley Schaefer (Louisiana State University) suggested a possible origin for the centuries-old explosion. Both studies have been submitted for publication.

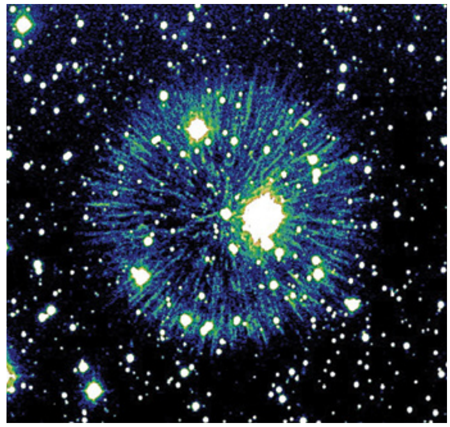
Amateur astronomer (and Fesen's second coauthor) Dana Patchick discovered the nebula in August 2013 in archived images from NASA's Widefield Infrared Survey Explorer (WISE). Originally, Patchick believed he had found a planetary nebula — his 30th find, hence the name Pa 30 — but later spectroscopic observations revealed that it's more likely a supernova remnant with a white dwarf at its center. The nebula lies some 7,500 light-years away.

The nebula's measured expansion rate — some 1,100 km/s (2.5 million mph) — puts its age at around 850 years old. So astronomers are confident that the cloud comes from SN 1181, a zero-magnitude supernova that appeared in Cassiopeia in August of AD 1181. Chinese and Japanese observers recorded this "guest star" slowly fading over a period of six months.

The nebula doesn't produce the copious radio waves or X-rays that would be expected from a young supernova remnant, which suggests it's unusual. And the white dwarf at the center is what Schaefer calls "a whacko weird thing." Despite being hot and bright, it's fading rapidly, by 1.7 magnitudes over the past century. Most remarkably, it produces a wind of charged particles that travel outward at 16,000 km/s, or 5% the speed of light.

"It's insane," Fesen says. "Stars simply don't have 16,000 km/s winds."

Previous work has shown that SN 1181 was likely a supernova of the relatively rare type Iax. While "normal" Type Ia supernovae result from the catastrophic detonation of white dwarfs, in less luminous Type Iax supernovae the exploding star might somehow survive. Schaefer says the evidence points to one scenario: Two white dwarfs must have merged to make this less-than-catastrophic collision.

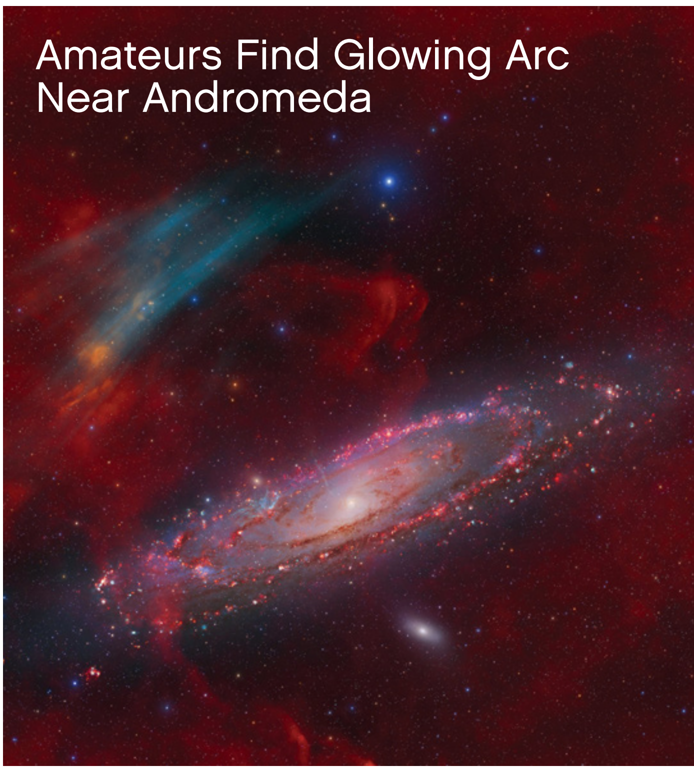


▲ The fierce wind from the central white dwarf eroded clumps of gas ejected by supernova SN 1181 to produce the fireworks-like filaments seen in the nebula today.

Fesen has already applied to both the Hubble and James Webb space telescopes to take further images of the remnant and the white dwarf at its center, which will help shed light on this rare type of supernova.

■ GOVERT SCHILLING

Amateurs Find Glowing Arc Near Andromeda



French and German amateur astronomers have discovered a mysterious nebulous arc close to the Andromeda Galaxy (M31), radiating solely the green light of doubly ionized oxygen ([OIII]). Xavier Strottner and Marcel Drechsler analyzed images obtained by Yann Sainty and stumbled upon a structure 1.2° southeast of the nucleus of M31. The arc extends over 1.5° and ends close to the naked-eye star Nu (ν) Andromedae (the blue star at the top of the photo at left). Sainty used a 4.2-inch Takahashi refractor and a large-format ZWO CMOS camera outfitted with a narrowband [OIII] filter. His wide-angle images added up to a total exposure time of 50 hours. Subsequent images, made with five different setups in France and the United States (including that of *S&T* Associate Editor Sean Walker), have confirmed the arc, now known as Strottner-Drechsler-Sainty Object 1 (SDSO-1). Previous surveys missed the arc due to its huge angular size and low surface brightness. The amateur astronomers reported their observations with professionals in January in the *Research Notes of the AAS*. It's still unknown whether the arc is associated in some way with Andromeda or is, in fact, in the Milky Way, but follow-up spectroscopic observations should help narrow down the arc's distance.

■ GOVERT SCHILLING

STRIATED NEBULA: ROBERT FESEN; GREEN ARC: MARCEL DRECHSLER AND YANN SAINTY

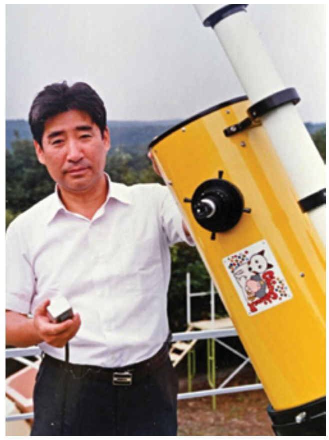
OBITUARY

Akira Fujii (1941–2022)

ACCLAIMED ASTROPHOTOGRAPHER Akira Fujii passed away on December 28, 2022, at age 81. As a Contributing Photographer to *Sky & Telescope* since 1991, he worked almost exclusively with large-format color film. Fujii's wide-field views of the constellations, each with impeccable star images, have been a hallmark of this magazine for nearly four decades.

Astronomy enthusiasts in Japan, however, have come to know Akira Fujii in a more expansive way. Born in 1941 in Yamaguchi City, he enrolled as a young man in the Design Department of Tama Art University in Tokyo, graduating in 1961. With this background he embarked on a lifelong career as publisher, layout artist, and author of books and periodicals about the night sky.

These publications included a popular quarterly magazine, a set of six children's books about the stars, and 12 hardcover books, issued monthly during 1994, that promoted sky-watching through the seasons. A common feature in these publications was the heartwarming caricature of a panda-like puppy named Chiro. The real-life Chiro had been Fujii's beloved canine companion for many years.



From 1974 through 1984, Fujii hosted his "Invitation to Starlit Skies" star party on Mount Azuma. This event often drew 2,000 participants, many of whom brought homemade telescopes, and it inspired other, similar events (*S&T:* July 2002, p. 64).

When Halley's Comet appeared in 1986, Fujii toured the length of Japan with his trailer-mounted 24-inch reflector, offering views of the comet and other sights to the general public. He also appeared frequently in NHK TV broadcasts.

Although his home for many years was Kōriyama, Fukushima prefecture, Fujii spent much of his time in the neighboring town of Shirakawa. There, he built Chiro Observatory, which soon became a gathering spot for dozens of followers, each with their own observing specialty.

In the mid-1990s, Fujii built his Chiro Southern Observatory outside Perth, in Western Australia, thereby putting the rest of the celestial sphere within his photographic grasp.

A profoundly humble man, Akira Fujii attracted many friends with his dedication. In 1993 the International Astronomical Union named minor planet 3872 Akirafujii in his honor.

■ **ROGER W. SINNOTT**

Read Roger Sinnott's personal remembrances at https://is.gd/AkiraFujii.

STARS

Astronomers Discover Giant Blinking Star

LONG AFTER IT HAPPENED, astronomers discovered that a distant Milky Way star had dimmed for seven years.

Between 2012 and 2018, the bloated red giant star, located some 26,000 light-years away in the constellation Sagitta, the Arrow, had become more than 60 times fainter (a drop of 4.5 magnitudes) than before.

"Stars typically don't do this," says Anastasios Tzanidakis (University of Washington), who reported the find at the 241st meeting of the American Astronomical Society. He and colleagues think that the extremely long and deep dimming happened when a slowly orbiting companion, surrounded by a huge disk of absorbing dust, blocked the red giant's light.

The European Space Agency's Gaia mission (*S&T:* Feb. 2023, p. 34) first detected the star's strange behavior. In 2017, Gaia saw the star (now known as Gaia17bpp) begin to brighten, and it issued an automated alert. Last year, Tzanidakis and colleagues followed up on that alert, using archived data from other telescopes to confirm that the long and deep eclipse had begun in 2012. Older observations show no other unexpected behavior back to 1950.

According to the team, the only viable explanation for the long dimming is that a huge disk of absorbing material, spanning 200 to 500 million kilometers (100 to 300 million miles), surrounds a faint companion star. The disk might consist of dust blown into space by the giant star and subsequently captured by its companion, or it could be a debris disk belonging to a white dwarf star. "We need to do more modeling," explains Tzanidakis.

Similar long eclipses have been reported for other stars, such as Epsilon Aurigae (*S&T:* July 2010, p. 16), but those have repeated within human lifetimes. The long duration of Gaia17bpp's eclipse indicates the orbital period of the obscuring material must be on the scale of centuries. There could be many more similar systems out there, Tzanidakis notes, but we'll need long surveys of large regions of sky to find them.

■ **GOVERT SCHILLING**

▶ An artist's concept shows a disk-enshrouded white dwarf blocking some of the light from the red giant star Gaia17bpp.

FUJII: ROGER W. SINNOTT; DUSTY DISK IN FRONT OF RED GIANT STAR: ANASTASIOS TZANIDAKIS

ET on Earth?

The search for extraterrestrial intelligence should not exclude our own planet.

SINCE THE EARLY 1960s, SETI (the Search for Extraterrestrial Intelligence) has largely focused on detecting radio messages. Arguably this hunt has only begun. But how do we seek new civilizations that might not be beaming intentional signals our way?

A recent buzzword in SETI circles is *technosignatures* (*S&T:* Aug. 2022, p. 34). The term broadens the notion of *biosignatures* — signs of biological activity — to search for technological activity. This allows us to avoid having to define "intelligence," to tacitly acknowledge both that intelligence may not be biological and that some very intelligent creatures (think cetaceans on Earth) might not have technology, and to simply focus on observable technological signatures (radio signals being one small subset of these). The technosignatures approach opens SETI to searching for anything from unintended flashes from spacecraft-propelling lasers to vast engineering projects, such as *Dyson spheres* or other "alien megastructures" built by those seeking to rearrange their planetary systems to harvest maximum energy from their star.

◀ A widely circulated clip from a video shot in 2015 by a Navy aircraft showing an unidentified aerial object

U.S. DEPARTMENT OF DEFENSE / PUBLIC DOMAIN

If we're open to technosignatures elsewhere in the galaxy, what about within the Sun's orbital realm? Our infant civilization has already launched five spacecraft that will wander the galaxy, and we're trying to figure out how to send tiny spacecraft to nearby exoplanets. Imagine what an aged ET civilization might have achieved and what machines might have entered our solar system over billions of years. A recently published white paper by a group of astronomers (including me) argues that as we explore the solar system, we should be on the lookout for artifacts (**https://is.gd/SSartifacts**).

This was highlighted when 'Oumuamua, the first-ever interstellar visitor found in our solar system, exhibited a peculiar shape and acceleration. Could it be an artifact? Almost surely not — astronomers have found more prosaic and more likely explanations. Yet there's value in such a false alarm, which invites us to ask, "Why not?"

Just as the galaxy doesn't stop inside the Oort Cloud of comets, the solar system doesn't stop at Earth's upper atmosphere. This brings us to the possibility of finding ET technology in our skies.

Admittedly, when it comes to *unidentified anomalous phenomena*, or UAPs, astronomers often reflexively dismiss the subject, explaining to people we meet that we're scientists, not UFO enthusiasts. There are many explanations — from lost balloons to internal camera reflections — for why people may see stuff in the air, and most of those explanations seem more likely than visitors from beyond our planet. Much obvious bullpucky also surrounds this topic, and anyone in astrobiology or SETI is so used to being bombarded with unhinged claims (you should see my inbox on any random week) that it's easiest to dismiss all of it.

But this response is intellectually lazy, and we back it up with rationalizations as to why we don't have to worry about it, e.g., aliens would never spend all the energy needed to actually visit Earth; they'd surely just stay home and send messages instead. Yet we must admit that, given the unpredictability

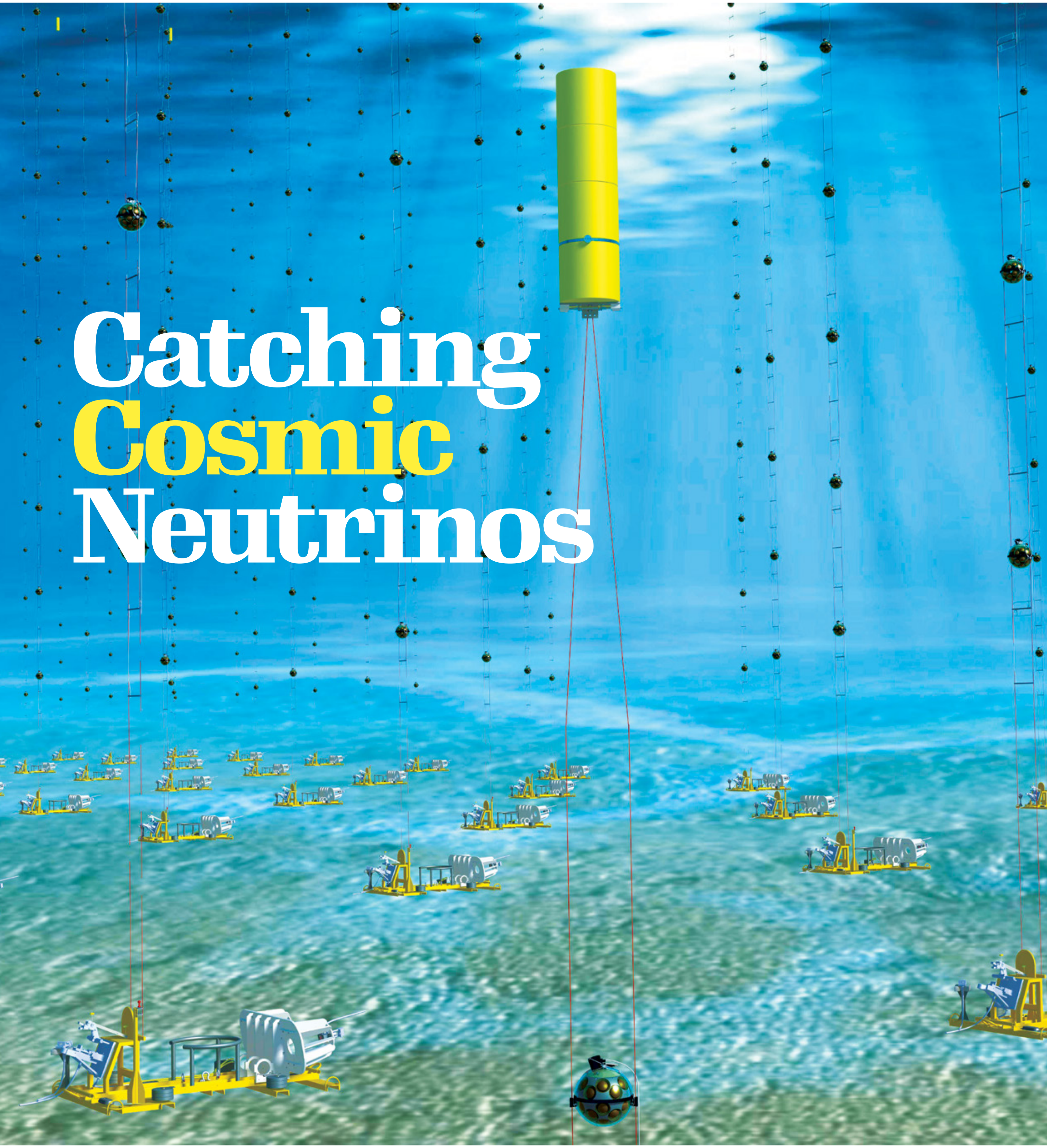
> We need to follow the data wherever they lead and be open to all possibilities. Otherwise we might miss something really important.

of advanced ET culture and technology, we have no idea what they'd value or be capable of.

We also don't really know what we should be searching for. And astronomy, which assumes an objectivity and consistency to natural phenomena, is ill-equipped to study something that might be aware of and deliberately avoiding or confusing our observations, or even studying us. Nevertheless, there's a logical continuity between extrasolar technosignatures, solar system SETI, and possible extraterrestrial UAPs. If we admit the worth of one, we cannot dismiss the others.

It's a tricky balance, especially with a topic that's so emotionally loaded for so many. But we need to follow the data wherever they lead and be open to all possibilities. Otherwise we might miss something really important.

■ **DAVID GRINSPOON** serves on a 16-member NASA committee that is exploring ways that scientists should go about studying UAPs.



Catching Cosmic Neutrinos

Scientists are building two vast "observatories" to help them study elusive particles.

Lined up along the wet and slippery deck of the landing craft *Castor 02* are four great spheres, each about 2.5 meters (8 feet) across. Wrapped in silver-colored material, they resemble the EVA pods in Stanley Kubrick's science fiction movie *2001: A Space Odyssey*. But these Launchers of Optical Modules (LOMs) will not take off into deep space. Instead, they are bound for the bottom of the Mediterranean Sea, some 2,450 meters below the ship.

Paschal Coyle, director of research at the Center for Particle Physics of Marseille, peels away part of the protective wrapping on one of the giant spheres, to reveal some of the 18 shiny Digital Optical Modules (DOMs) that are hidden inside. As large as a typical beach ball, each spherical DOM is outfitted with 31 photomultiplier tubes, devices sensitive enough to detect individual photons. At 9-meter intervals, the DOMs are attached to 200-meter-long cables that will vertically unroll from an anchor on the seafloor once deployed. Marie-Noëlle Fabre, a support engineer for the company that provides sonar navigation equipment, stresses the impressive precision of the underwater operation. "At a depth of almost 2.5 kilometers, we succeed in positioning the detector lines with an accuracy of just two meters," she says.

Neutrinos

Neutrinos come from nuclear reactions and particle interactions. When atomic nuclei join together or break apart, for example, they make neutrinos. Even a banana emits neutrinos: Bananas are rich in potassium, a small fraction of which is the radioactive isotope potassium-40. As the potassium-40 decays, it emits neutrinos.

In early September 2022, Coyle and Fabre were among a small group of scientists and engineers on the 11th deployment mission of the French part of KM3NET, a European "observatory" designed to detect and study *neutrinos*. Neutrinos are uncharged and nearly massless elementary particles that hardly interact with other forms of matter. As a result, they are able to zip through entire planets at near-light speeds, carrying with them unique information about the violent cosmic environments and events — such as supernovae — that create them.

KM3NET (Cubic Kilometre Neutrino Telescope) does not detect neutrinos directly. Instead, the 3D array of DOMs registers the faint flashes of light given off by electrons and,

◀ **A DIFFERENT KIND OF TELESCOPE** Artist's concept of a KM3NET detection unit. Each sphere contains photomultiplier tubes and is strung along cables suspended between buoys and anchors on the seafloor. (There would be no sunlight at these depths; the light is for clarity.)

EDWARD BERBEE / NIKHEF

in particular, *muons* (the heavy cousins of electrons) that are produced by rare collisions of neutrinos with atomic nuclei in the deep sea. The muons generate this *Cherenkov radiation* because they travel faster than the speed of light in water, which is much slower than the speed of light in a vacuum. Measuring the arrival time of the Cherenkov light at the individual photomultipliers to the nearest nanosecond makes it possible to reconstruct the muon's path through the detector. This, in turn, tells you which direction the original neutrino came from. Meanwhile, the number of detected photons reveals the energy of the incoming neutrino.

Ultimately, the observatory will include two groups of detectors — one here, and another a kilometer deeper down off the southeastern coast of Sicily. But the construction of KM3NET is demanding and time-consuming. So far, less than 15% of the French part's planned 115 detector lines have been put into place, spaced 20 meters apart on the seafloor. In a makeshift control center on board the *Castor 02* (basically a converted sea container), Coyle opens his laptop computer to show colorful computer animations of the deployment process, the final configuration of KM3NET, and the expected detections. Through the small windows, the distant horizon keeps going up and down, despite the sunny weather — the waves are still too high to start lowering new detector lines. "You just have to be lucky with the weather, as too much swell might break the cables during deployment," he says. "Hopefully the sea will become calmer later in the day."

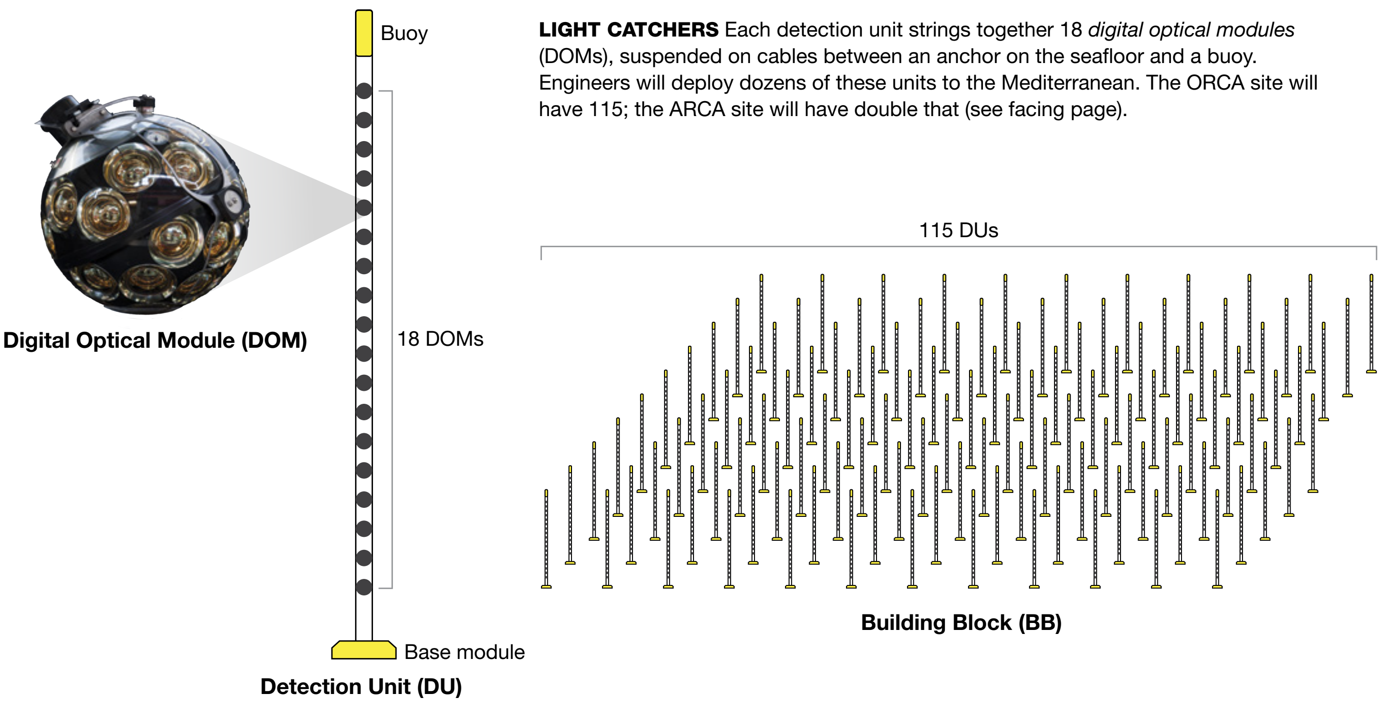
It will take at least another couple of years before the "facility" is completed. But once up and running, KM3NET will shed light on some of the most extreme phenomena in the universe.

Elusive Particles

Austrian physicist Wolfgang Pauli first predicted the existence of an uncharged, massless particle in 1930, but scientists didn't actually detect the neutrino until 1956. It hardly interacts with other particles, and it doesn't feel the electromagnetic force at all. As a result, neutrinos travel through space in perfectly straight lines, zapping right through everything in their path as if the universe is completely transparent to them. Which, incidentally, is the reason they are so incredibly hard to detect.

Over the past decades, physicists have discovered that neutrinos come in three types (electron neutrinos, muon neutrinos, and tau neutrinos) and that they can change from one of these *flavors* to another while speeding through the cosmos — a process known as oscillation. This implies that neutrinos are not completely massless, although we know they weigh at least a million times less than an electron. It's one of the big mysteries of science, as the well-established Standard Model of particles and forces predicts zero mass for the neutrino. (Unfortunately, the particle is much too lightweight to be a viable candidate for dark matter, another unsolved riddle of fundamental physics.)

As every gee-whiz astronomy book dutifully notes, many billions of neutrinos pass through every square centimeter of your body each and every second. The vast majority of them were produced during the Big Bang phase, when the universe was just 0.1 second old. However, thanks to the expansion of the cosmos, these *relic neutrinos* carry so incredibly little energy that they have never been directly observed — although an international collaboration is working on a small prototype of an experiment that would be sensitive enough to



LIGHT CATCHERS Each detection unit strings together 18 *digital optical modules* (DOMs), suspended on cables between an anchor on the seafloor and a buoy. Engineers will deploy dozens of these units to the Mediterranean. The ORCA site will have 115; the ARCA site will have double that (see facing page).

finally detect this cosmic neutrino background.

Much easier to spot is the steady stream of neutrinos from fusion reactions in the core of the Sun, first detected in 1968 by American physicist Raymond Davis. Yet another astronomical source of neutrinos was identified in February 1987, when facilities in the United States and Japan discovered a handful of neutrinos produced by Supernova 1987A in the Large Magellanic Cloud, a small galactic companion of our own Milky Way. More likely than not, astronomers realized, other energetic phenomena in the universe would also produce neutrinos, maybe at even much higher energies. But for sources at much larger distances, the expected flux would be relatively low.

Still, even a handful of neutrinos could give scientists important information about hard-to-access physical processes. The most energetic things in the universe — including jet-shooting supermassive black holes, neutron star collisions, and tidal disruption events (in which stars are torn up and swallowed by black holes) — should all produce a barrage of high-energy radiation and particles, including neutrinos. But surrounding material absorbs a significant fraction of the X-rays and gamma-rays, and the paths of charged particles, called *cosmic rays*, are bent by interstellar and intergalactic magnetic fields. Only neutrinos make the journey unscathed. That's why astrophysicists are so keen to study high-energy neutrinos from deep space — they are the ideal messenger particles to shed light on cosmic violence, their properties revealing details about how the photons and cosmic rays are made.

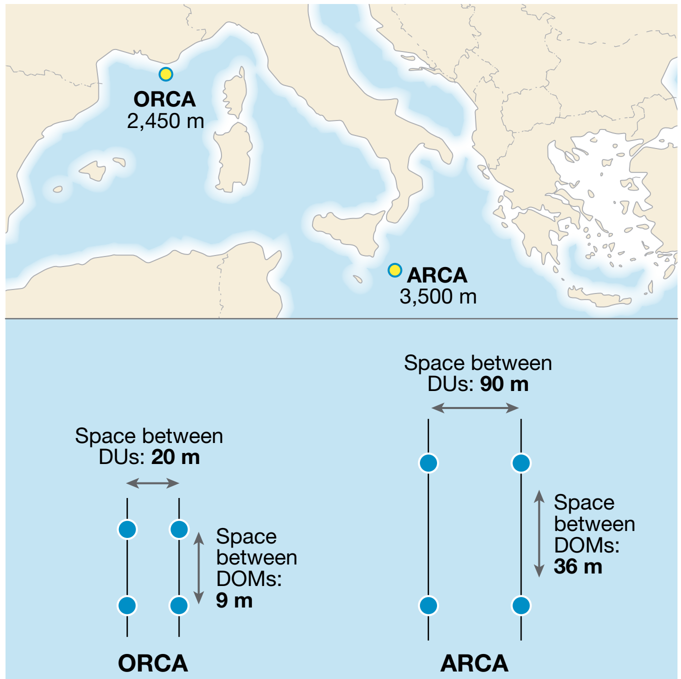
Yet given how rare neutrinos are, and that most of them pass through any instrument without leaving a trace in the first place, how do you go about detecting them?

IceCube

The answer is straightforward: To increase your chance of success, you need to increase the size of your detector. That's how IceCube was conceived — the first really large Cherenkov-based neutrino detector. Constructed at the geographical South Pole and completed in late 2010, IceCube features 5,160 photomultiplier tubes spread throughout a volume of one cubic kilometer of Antarctic ice, between 1,450 and 2,450 meters below the surface (*S&T:* Jan. 2014, p. 18). Every now and then, one of the myriad neutrinos passing through the detector collides with an atomic nucleus in the ice, producing a muon in the process. If this muon traverses the detector volume, IceCube's photomultipliers will register its faint flash of Cherenkov radiation, as the surrounding ice is both dark and transparent.

Unfortunately, most high-energy neutrinos "seen" by a detector like IceCube do not originate in outer space but in our own atmosphere. They are produced when energetic cosmic rays (mainly protons and electrons) slam into nitrogen or oxygen nuclei, generating a cascade of secondary particles, some of which decay into muons and (muon) neutrinos. While these atmospheric neutrinos may be interesting in and of themselves, they constitute an annoying background noise against which scientists have to search for genuine astrophysical neutrinos. It's a bit like discerning the sound of distant explosions while attending a rock concert. But at least researchers more or less know how many atmospheric neutrinos to expect from various directions.

In 2017, IceCube detected an extremely high-energy neutrino that coincided — both in timing and in direction — with a rare flash of gamma rays from TXS 0506+056, an extremely active galaxy called a blazar that lies 3.7 billion light-years away in the constellation Orion. And last November, the IceCube collaboration announced convincing evidence for a continuous outpouring of high-energy neutrinos from the active nucleus of the Squid Galaxy (M77), just 46 million light-years away in Cetus, the Whale (*S&T:* Mar. 2023, p. 10). In fact, most high-energy astrophysical neutri-



Two-Part Observatory

The European neutrino observatory KM3NET, which is under construction in the Mediterranean Sea, consists of two parts. The French part, known as ORCA (Oscillation Research with Cosmics in the Abyss) is located some 40 kilometers south of the harbor town of Toulon, at a depth of 2,450 meters. It mainly focuses on the properties of relatively low-energy neutrinos, including their "flavor-switching." The Italian part (ARCA, or Astroparticle Research with Cosmics in the Abyss) is located some 100 kilometers offshore of Portopalo di Capo Passero on the southeastern tip of Sicily, at 3,500 meters below sea level. ARCA is going to be even larger than ORCA. Its more widely separated optical modules will be better for studying the longer muon tracks resulting from higher-energy neutrinos.

LEAH TISCIONE / S&T

nos in the universe may well originate in rather inconspicuous active galactic nuclei (AGN) like M77, which are powered by supermassive black holes.

Such studies might help solve the riddle of the origin of the most energetic cosmic rays. Astronomers suspect that these "Mike Tyson particles," which carry as much energy as a powerfully pitched baseball, are produced in the cores of remote AGN. The idea is that strong magnetic fields or shock waves in the vicinity of a central supermassive black hole accelerate the particles. But since cosmic rays cannot be traced back to their source, observers need to find neutrinos produced in the same environments to confirm their suspicions. The TXS 0506+056 and M77 results suggest that blazars and AGN do indeed produce most ultra-high-energy cosmic rays.

Friendly Competition

But if there's a large, successful neutrino observatory operational in Antarctica, why bother to build another one on the bottom of the sea? While enjoying the Mediterranean sun and keeping an eye on the slowly subsiding waves, Paschal Coyle, who is also the spokesperson of the KM3NET collaboration, explains the need for both cooperation and "friendly competition" between different groups: Findings by one facility need to be corroborated — or falsified! — by other instruments, using different equipment and applying different analysis techniques. (A third cubic-kilometer-size detector known as Baikal-GVD, for Gigaton Volume Detector, is under construction at the 1,240-meter-deep bottom of Lake Baikal in eastern Russia.)

KM3NET also has its own unique selling points. In particular, the European observatory will be able to pinpoint the arrival direction of neutrinos much more precisely. "We expect to achieve a directional accuracy of less than a tenth of a degree," says Coyle. "That's about 10 times better than IceCube, which is more prone to light scattering due to tiny bubbles in the ice."

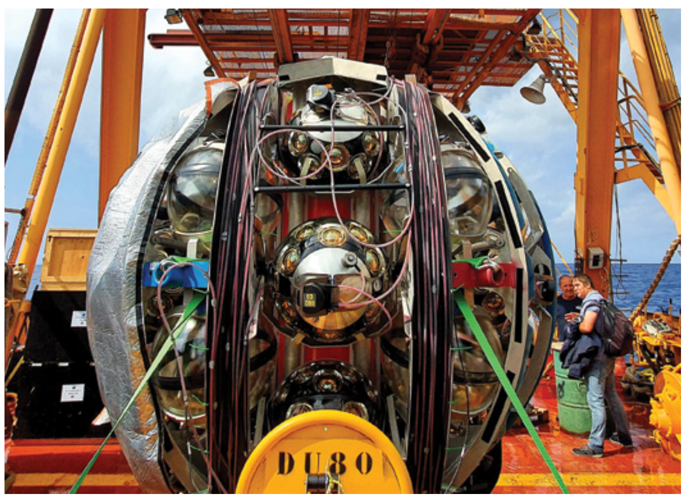
In addition, because of its location in the Northern Hemisphere, KM3NET will be able to study a different part of the universe than IceCube. Surprisingly, the section of sky each detector specializes in lies below, not above, the sensors. Here's why. Not all muons observed by IceCube or KM3NET result from neutrinos smashing into atoms. As mentioned before, muons are also produced when cosmic rays hit our planet's atmosphere. These atmospheric muons can traverse at most a few kilometers of rock, ice, or ocean before they decay. But neutrinos fly right through Earth. Only for a muon traveling "upward" through the detector can you be sure it was created by a neutrino, not by a cosmic ray hitting the planet's atmosphere. As a result, IceCube and KM3NET are most efficient in detecting rare astrophysical neutrinos when they look "downward."

Action Time

Around four o'clock in the afternoon, there's a sudden burst of activity aboard ship. The waves that prevented the deployment of new detector lines earlier in the day have finally subsided, and it's time for action. But first, an old line has to be hoisted up to solve an issue with the power supply. From the deck of *Janus II* (a nearby research vessel that is part of the KM3NET sea operation), an underwater robot is lowered down in a special cage and disappears beneath the surface. Meanwhile, on the *Castor 02*, crew members wearing safety helmets and life jackets are preparing a heavy lifting hook, which they attach to a kilometers-long steel cable on a giant reel. Soon enough, and with a lot of noise, the cable is unwinding over large pulleys, and the hook starts its 90-minute descent to the seafloor, some 2,450 meters below.

At the end of the afternoon, people gather to follow the activities of the underwater robot live on a TV screen in the small mess room of the *Castor 02*. Coyle and his team members can't take their eyes off the screen. It feels like watching a science-fiction movie. The propellers of the remotely con-

▼ **DEPLOYMENT** *Left:* The landing craft *Castor 02*, with the huge portal crane used to deploy the detector modules. *Center:* The DOMs are carefully coiled up inside a spherical cage, shown here on deck. *Right:* An underwater robot is lowered from the neighboring research vessel *Janus II*.



GOVERT SCHILLING (2)

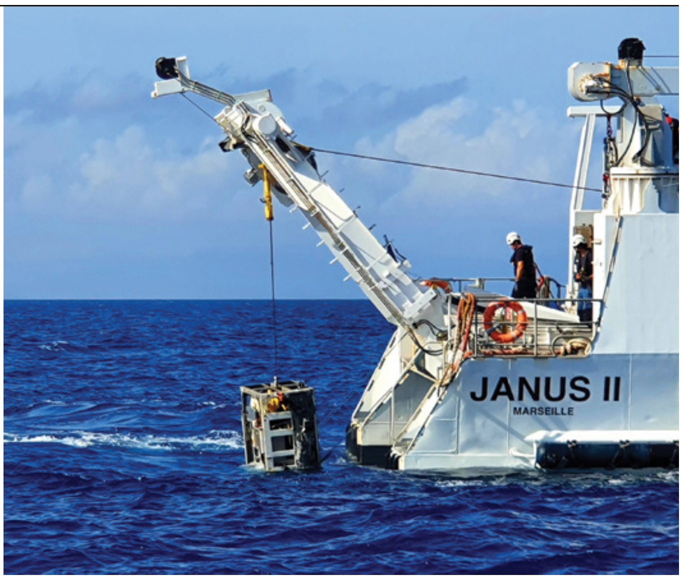
trolled robot stir up clouds of sand, which slowly swirl in the harsh light of the robot's floodlights. Mechanical claws grope around the anchor platform of the detector line that needs to be hoisted up, and they succeed in disconnecting its power and data cables.

Finally, the large hook comes down in exactly the right spot, thanks to Marie-Noëlle Fabre's navigation equipment. The robot attaches the hook, and then some hours later, late in the evening (and long after Coyle's journalist guests have already returned to the shore), the malfunctioning detector line is hoisted up. In the middle of the night, the first of the four new spherical modules with its delicate cargo of photomultipliers is lowered to the seafloor and connected to the array by the underwater robot.

Back in bustling Toulon, after an exciting day at sea, it's hard to imagine that countless neutrinos continuously zap right through buildings, cars, and people — 24/7, unhindered and unnoticed. Some of the tourists walking across the Place de la Liberté are probably on their way to the harbor, to take the ferry to the French isle of Corsica. They will sail high above KM3NET, unaware of the tiny flashes of Cherenkov light deep beneath their feet, let alone the high-tech equipment on the seafloor that astrophysicists use to untangle the mysteries of the cosmos. As Coyle puts it: "We're building the largest 'telescope' in the world, but no one will ever see it."

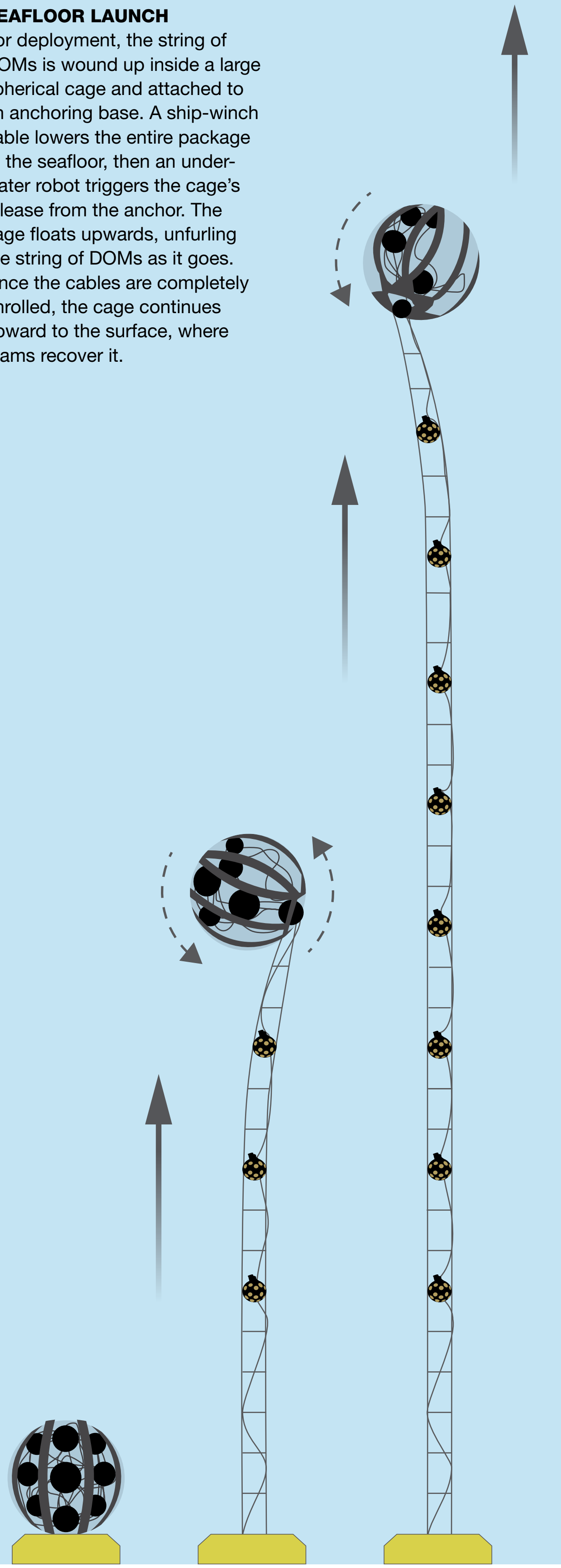
■ *S&T* Contributing Editor **GOVERT SCHILLING** thanks Paul de Jong of the Dutch National Institute for Subatomic Physics (Nikhef) in Amsterdam (a major partner in KM3NET) for helping him to organize his visit to the KM3NET deployment operation, and Nikhef's Daan van Eijk for helpful comments on the draft of this story.

Learn more about neutrinos from the Fermi National Accelerator Laboratory's All Things Neutrino site: https://neutrinos.fnal.gov.



SHIP: GOVERT SCHILLING; UNFURLING DIAGRAM: BEATRIZ INGLESSIS / *S&T*

SEAFLOOR LAUNCH
For deployment, the string of DOMs is wound up inside a large spherical cage and attached to an anchoring base. A ship-winch cable lowers the entire package to the seafloor, then an underwater robot triggers the cage's release from the anchor. The cage floats upwards, unfurling the string of DOMs as it goes. Once the cables are completely unrolled, the cage continues upward to the surface, where teams recover it.



The Great Edge-On Galaxy of Spring

Let's explore springtime's stunning sideways galaxy.

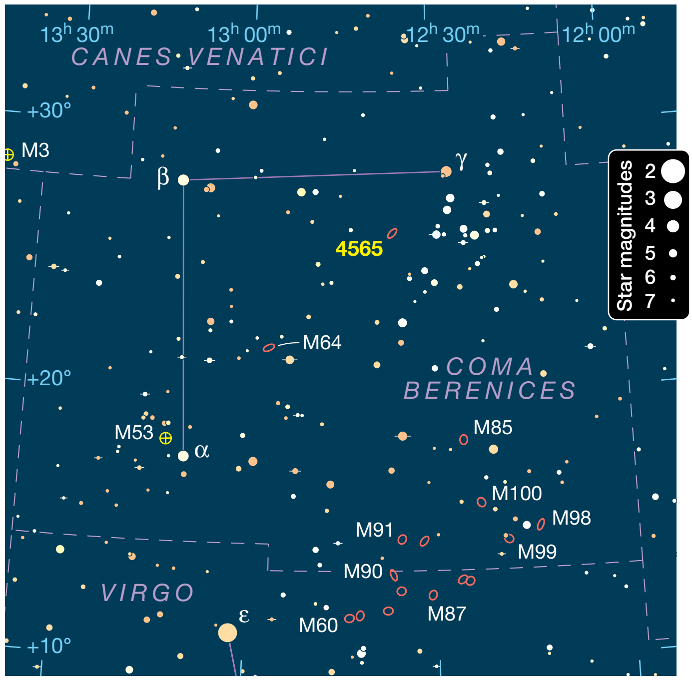
▲ **EDGE-ON BEAUTY** There's a lot to admire in this beautiful galaxy beyond the obvious, so look carefully and see how many subtle details you can pick out. Note the two companion galaxies — starting from NGC 4565's bulge, IC 3572 is the small irregular galaxy about 5′ due north, and larger NGC 4562 is about 12′ southwest. Besides NGC 4565, only NGC 4562 is within visual reach of most amateur scopes. North is up.

BOB FRANKE

Last November we visited the beautiful edge-on galaxy in Andromeda, NGC 891. Now it's time to look at springtime's equivalent, **NGC 4565**. Like its autumn counterpart, this galaxy is big and bright enough that many observers have wondered how Charles Messier failed to include it in his foundational deep-sky object catalog. The quick answer is that the sky is vast, and he just never happened to point his telescope in its direction. So, Messier's loss is the *NGC*'s gain, and the galaxy is magnificent either way.

Compared to NGC 891, NGC 4565 appears slightly longer and significantly brighter. That gives it more contrast with the night sky, meaning it can be seen more readily in light-polluted conditions. Not only that, a significantly smaller scope will bag it, too. For instance, I can easily find it with

▶ **IN THE COMA I GROUP** Look for NGC 4565 and its companion galaxies about 3° southeast of Gamma (γ) Comae.



my 80-mm finderscope under a dark sky, while NGC 891 is a no-show under the same conditions. That's a useful comparison, but let's examine NGC 4565 on its own merits.

At magnitude 9.6, NGC 4565 is one of the brightest members of the Coma I group of galaxies. It's an intrinsically large spiral that's even more luminous than M31, the Andromeda Galaxy. It also has more globular clusters than the Milky Way and is around 38 million light-years away.

Our view of NGC 4565 is not quite perfectly edge-on, so we see the nearly starlike core peeking over (or under) the central dust lane. We nevertheless get a wonderful glimpse of the central bulge, which is not only rather dramatic-looking but also gives us vital clues to the galaxy's morphology.

The professional literature describes the central bulge as "boxy" — it looks like a fat peanut from our perspective. This is a characteristic of barred spiral galaxies seen edge-on. A faint X also runs through its bulge, another indication of its barred spiral morphology. In addition, research has shown that NGC 4565 has an inner ring. Our sideways view of NGC 4565's spiral arms reveals that they're elegantly warped at each end, probably the result of a close pass by one of its companion galaxies.

Is there a bright face-on galaxy with similar morphological characteristics that could give us an idea of what NGC 4565 might look like if we could flip it by 90°? As it turns out, there is: **M95**, which, at magnitude 9.7 is not only as bright as NGC 4565, it's even in the springtime sky at the same time. (Look for it 8¾° east of Regulus in Leo.) M95's apparent diameter is less than half that of NGC 4565's, and given that it's at about the same distance it's therefore an inherently smaller galaxy.

All in all, NGC 4565 is a fascinating object, and we're lucky to see its gorgeous side profile while having a good idea as to what it probably looks like face-on. Conversely, this gives us an idea what M95 might look like from an edge-on perspective. Sweet!

Observations

NGC 4565 was one of the first non-Messier deep-sky objects I ever tracked down. Although that was 40 years ago, I think it's a good indication of what most observers today can expect to see from their suburban backyards on a clear, moonless night:

> *Bright edge-on galaxy — great sight at all powers — 240× best. Dark lane vaguely seen. I'll come back here — no doubt awesome in real dark skies. (12.5-inch f/7.8 Dobsonian, June 1983)*

I've had many wonderful views of NGC 4565 since then, but two stand out because they revealed aspects of this magnificent galaxy I'd never seen before. The first was in March 2021 under an utterly dark and very transparent sky in Eastern Oregon with my 28-inch scope. The second was in West

▲ **FROM ANOTHER ANGLE** Our view of M95 suggests what NGC 4565 might look like if we could view it face-on.

M95: KPNO / NOIRLAB / NSF / AURA / MICHAEL MCGUIGGAN / ADAM BLOCK

Texas with Jimi Lowrey and his 48-inch scope in April 2022. What did I see? Wonderful things!

Dark Lane

NGC 4565's most distinctive feature is its dark lane. It comprises the obscuring clouds of interstellar dust and gas that populate most galaxies that have spiral arms, and because we see NGC 4565 almost exactly edge-on, we observe this gas and dust where it's thickest. In most face-on spirals, detecting this material visually is usually quite difficult because we're looking through its thinnest section.

With the exception of the view through my 80-mm finderscope, I've always been able see NGC 4565's dark lane — even in poor transparency and so-so darkness, it presents sufficient contrast with the rest of the galaxy. This is a big part of NGC 4565's visual appeal, because in the eyepiece it looks a great deal like it does in images.

I've often tried to spot irregularities along the edges of the dark lane and have succeeded only once. Not surprisingly, that was with Jimi's 48-inch scope in April 2022. I was observing galaxies far in the background (see page 24) while keeping the dark lane near the core of NGC 4565 in the field of view. And that's when I noticed how ragged the edges of that feature appeared — I'd looked for signs of this raggedness for years, and here I was seeing it without even trying! (Well, that's not counting being barely able to get my eye to the eyepiece, but I'll get into that later.)

Bulge/Bar

The bulge sits at the center of the galaxy and appears as a cen-

▼ **EYEPIECE SKETCH** This is how I saw NGC 4565 through my 28-inch f/4 scope in March 2021 under ideal conditions. Notice the boxy shape of the bulge/bar, and the partial X on the southern half of the bulge — the two rays seemingly emanating from the core/pseudobulge. I saw the warp on both ends of the galaxy as well as the companion galaxy NGC 4562, in the bottom-right corner. Notice also the line of stars from the western end of NGC 4565 that trickle south toward NGC 4562, making it easy to find. I used magnifications of 155×, 253×, and 408× to make this sketch. The Sky Quality Meter reading was 22.05 — as dark as the night sky can get!

HOWARD BANICH

tral, slightly oblong dome on either side of the dark lane. It's the brightest feature besides the starlike core, which is also known as the *pseudobulge*. Research has shown that the bulge is actually the central bar of NGC 4565 seen from the side, a finding I think is absolutely fascinating. Scientists haven't yet determined its orientation, as measurements indicate a value between 0° and 45° from end-on. Visually, the bulge/bar appears nearly spherical through many amateur telescopes.

Understanding that the bulge is actually the central bar is an extraordinary nugget of knowledge, but I never thought I'd see any of its features visually. To my enormous surprise I saw both the boxy shape and the faint X on an exceptional night in March 2021 with my 28-inch scope. This was a night when my Sky Quality Meter (SQM) was giving readings slightly higher than 22.00 so often that I changed its batteries to make sure it was working properly. (A reading of 22.00 is the theoretical maximum darkness of the night sky).

The SQM was working just fine, though, and the view of the bulge/bar was astounding. Not only could I see the boxy shape, but I also noted two subtle fan-shaped spotlights radiating from the core to the rounded corners of the boxy bulge in its northern half. There was no trace of this feature in the southern half of the bulge, but I could scarcely believe my eyes because I wasn't looking for either — they were obvious enough to be seen at first glance.

So, quite remarkably, I was able to visually confirm NGC 4565's boxy bulge/bar — complete with a partial X — and see for myself that it's a barred spiral viewed from the side. This is one of the most satisfying observations I've ever made, and I sincerely hope you have the opportunity to experience this, too.

Warp

During this same observation I also detected the warped ends of NGC 4565 for the first time. They're pretty easy to see in photographs, but I never succeeded visually until that special night in March 2021 with my 28-inch scope. The warp jumped right out as if mocking me for never having noticed it until then. I remember thinking "how could I have missed this before?" I think the key is contrast between the faint ends of the galaxy and the sky background.

▲ **INFRARED VIEW** This four-filter Spitzer/IRAC image of NGC 4565 shows both its inner ring and pseudobulge, and hints at the central X, a characteristic of barred spirals when seen edge-on.

Because the sky was as dark and transparent as it could get, the galaxy extended a bit farther visually than I'd been able to see before. This made the warps on both ends appear gratifyingly prominent, especially with averted vision. Helping this was the overall straightness of the dark lane and its slight tilt with respect to the edge-on spiral disk. As such, the straightness of the dark lane accentuates the warp as it approaches each end of the galaxy.

The overall result was that NGC 4565 looked longer than usual, making the elegant twist at the extremities rather easy to see. Just lovely!

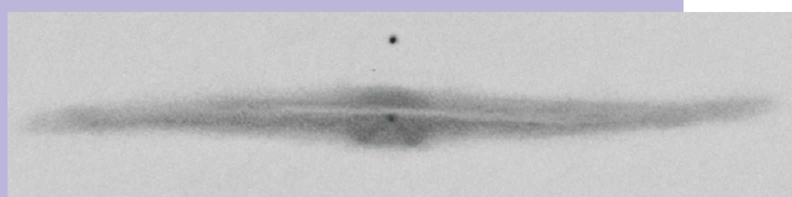
Companion Galaxies

The brightest of NGC 4565's companion galaxies is **NGC 4562**. At magnitude 13.4, its soft glow is visible in a semi-dark sky using a big scope, but its low surface brightness means the sky needs to be quite transparent for it to be visible in smaller instruments. The galaxy's ever-so-slightly brighter center can be seen on the best nights, but mostly it's just a subtle, oval glow that gradually fades away toward its edges. A line of four 11th- through 13th-magnitude stars runs from the northwestern end of NGC 4565 leads directly south to NGC 4562. The smaller galaxy is oriented about 90° to NGC 4565. This orientation is visually striking but doesn't indicate a close interaction between the two galaxies.

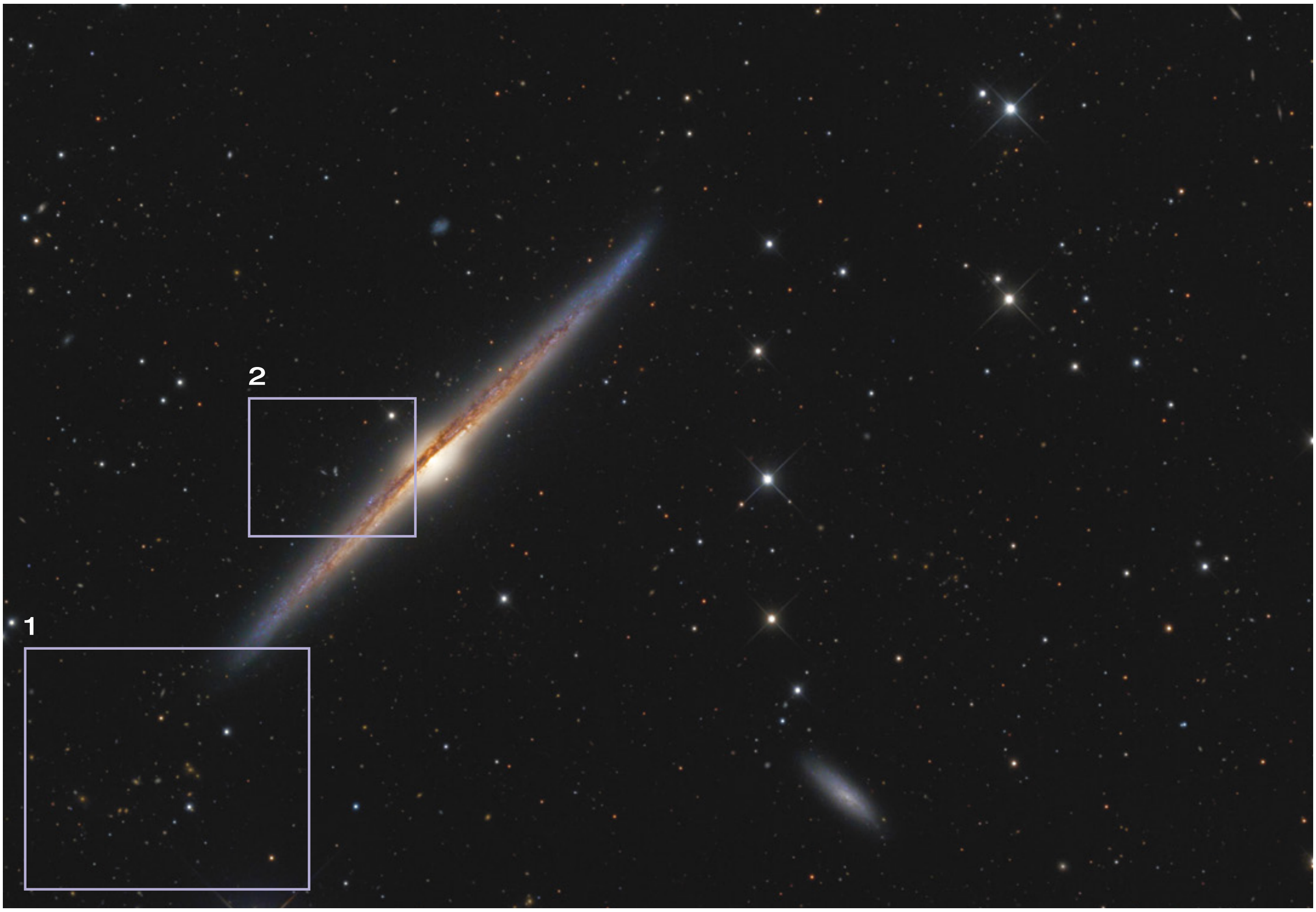
The Shapes of Galaxies

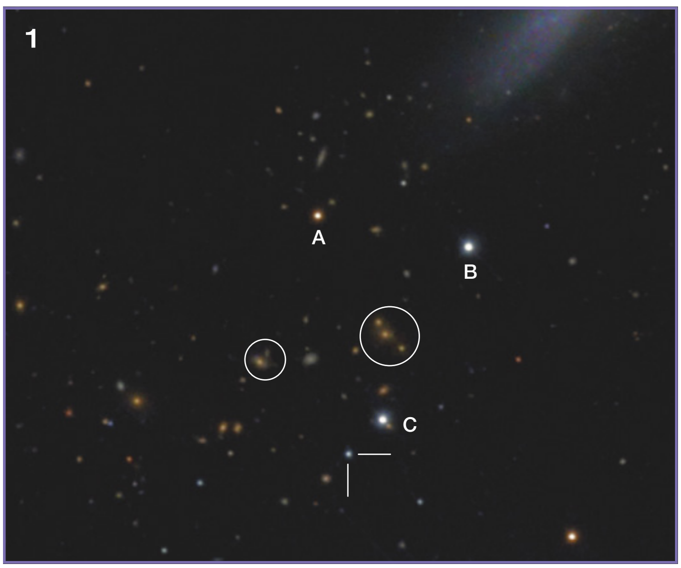
In his revised classification scheme for galaxy morphologies (published in 1963), French astronomer Gérard de Vaucouleurs listed NGC 4565 as SA(s?)b. Here, "SA" signifies it's an "ordinary spiral," "(s?)" indicates a probable "S-shape," while the lowercase "b" at the end identifies it as an early to mid-intermediate spiral. More recent versions of this classification move the "?" to after the "b" — but this still doesn't acknowledge NGC 4565's bar or ring.

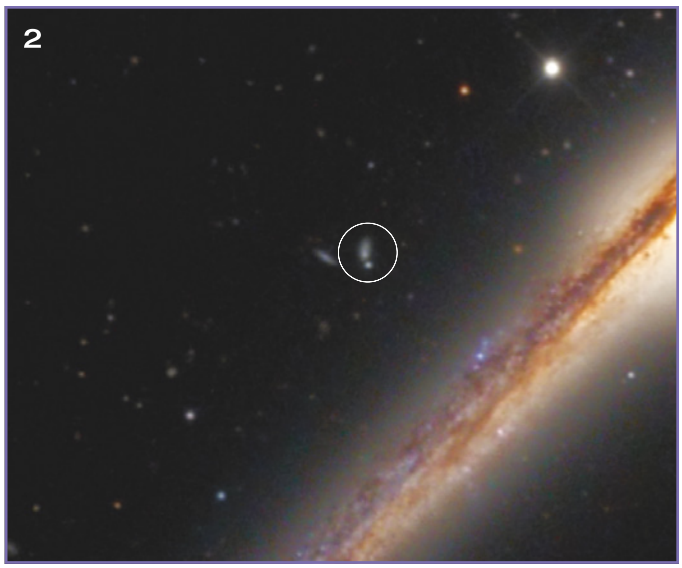
Based on our current knowledge, perhaps a more accurate classification would be SB(r)b, with "SB" denoting a barred spiral galaxy, and the small "r" in parenthesis indicating the central ring.



▲ **WARPED SPIRAL** Tilting NGC 4565 horizontally makes the warp on each end easier to see — note how straight the dark lane (white, in this negative) appears by comparison. The boxy bulge/bar and the core/pseudobulge are more evident in this crop from my larger sketch, as are the two "rays" of the partial X that I observed emanating from the pseudobulge. Also note how the dark lane doesn't extend all the way to the ends of the edge-on spiral disk and is most vivid near the bulge. It's also not perfectly centered within the disk.







▲ **BACKGROUND SPECKS** The zoom above shows the galaxy group RX J1236.9+2550. I was able to see two of its members with Jimi Lowrey's 48-inch telescope, which are circled. Both are 18th magnitude. The stars labeled A, B, and C are visible in my sketch on page 22 and are between 15th and 16th magnitude. The faint star between the brackets, which I mistakenly thought was another galaxy at the time of the observation, is also 18th magnitude.

▲ **BACKGROUND GALAXIES** The circled galaxy (NGP9 F378-0021738) above is the background galaxy I saw with the 48-inch scope in April 2022. I didn't spot either the star within the circle or the galaxy just outside it to the left (east), both at 19th magnitude. An exciting bonus during this observation was seeing irregularities in the dark lane for the first time! The magnification we used was 488×, and the sky was quite dark with an SQM reading of 21.70 (for both observations shown in 1 and 2).

BOB FRANKE (3)

However, the small, irregular galaxy **IC 3571**, which is about 10′ due north of NGC 4565's central bulge, does indeed shows signs of interaction — and is probably responsible for NGC 4565's elegant warp. Studies have shown a trail of neutral hydrogen between it and NGC 4565, indicating a close approach, but not close enough to create a tidal bridge of material between them.

At magnitude 16.9 this small, low-surface-brightness galaxy is really difficult to see. Even though I can't find an entry of it in my notes, I remember barely detecting it once. Too bad I didn't think to try for it during that great night in March 2021.

Background Galaxies and Clusters

I mentioned earlier that while observing NGC 4565 with Jimi's 48-inch f/4 scope, it was a challenge simply getting my eye to the eyepiece. The reason is that the scope was pointing nearly straight up at the time, which meant standing near the top of the 14-foot-tall observing ladder — and not being able to hold on to it. To look in the eyepiece required twisting to the left, using my left hand to adjust the focus and directional controls of the scope, while my right hand was helping steady the scope from the gusting wind.

Although that sounds dangerous, we (Contributing Editor Steve Gottlieb and fellow observer Akarsh Simha) do it all the time when observing with Jimi, so it feels normal — even though it does impart an extra zing of exhilaration to these near-zenith observations . . . but don't try this at home.

What we were able to see was more than worth the small potential danger. There are two distant galaxies in the line-of-sight due east of the bulge, and I was able to see the brightest of the pair, 17.7-magnitude **NGP9 F378-0021738**, fairly well as an elongated glow. The other galaxy, **NGP9 F378-0021761**, wasn't visible, but at 19th magnitude — and given my somewhat precarious perch — that's not too surprising.

How far in the background are they? I haven't been able to find a robust redshift for either galaxy, but data generated by the Sloan Digital Sky Survey give a light-travel time of approximately 1.1 billion years.

When examining the image on page 24, you may notice a faint smattering of tiny, orangey-yellow galaxies scattered off the southeastern end of NGC 4565, looking like small puffs of galactic fuzz. This galaxy group, designated **RX J1236.9+2550**, has a light-travel time of 2.3 billion years, putting it even farther away than the two background galaxies discussed earlier.

Through the 48-inch, I saw three tiny, very faint glows, two of which turned out to be galaxies. (I discovered later that the third was a faint star.)

Although the only reason we went after these tiny, dim galaxies was their line-of-sight proximity to NGC 4565, I was excited that we could see any members of this distant cluster because of the immense light-travel time. The sky is full of faraway objects like this, and being able to see any of them always makes the universe feel even more vast than it normally does.

And the Winner Is . . .

I could go on about all the other faint galaxies scattered around NGC 4565, but that's a separate observing program that would probably take us through the Coma I Group. That's a wonderful adventure all its own, but we'll put that epic journey aside for another time.

If you're anything like me, NGC 4565 will tug at your imagination every time you observe it, regardless of how dark or transparent the sky is. You'll just have to take a look, even if it's only a quick peek. And why not? It's an exquisite edge-on galaxy that can be enjoyed in almost any telescope. And as I found out, even if you've seen it a million times, you never know what your next observation might reveal.

■ Contributing Editor **HOWARD BANICH** gives NGC 4565 the "edge" over NGC 891 as his second-favorite edge-on galaxy — with the Milky Way, of course, being his favorite. You can reach him at **hbanich@gmail.com**.

NGC 4565 and Companions

Object	Type	Surface Brightness	Mag(v)	Size/Sep	RA	Dec.
NGC 4565	Barred spiral	13.3	9.6	15.8′ × 2.1′	12^h 36.3^m	+25° 59′
M95	Barred spiral	13.5	9.7	7.4′ × 5.0′	10^h 44.0^m	+11° 42′
NGC 4562	Barred spiral	14.0	13.4	2.4′ × 0.7′	12^h 35.6^m	+25° 51′
IC 3571	Irregular galaxy	14.1	16.9	0.3′ × 0.3′	12^h 36.3^m	+26° 05′
NGP9 F378-0021738	—	—	17.7	—	12^h 36.5^m	+25° 59′
NGP9 F378-0021761	—	—	~19	—	12^h 36.5^m	+25° 59′
RX J1236.9+2550	Galaxy cluster	—	—	—	12^h 36.9^m	+25° 51′

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.

The Past and Future of Star Names

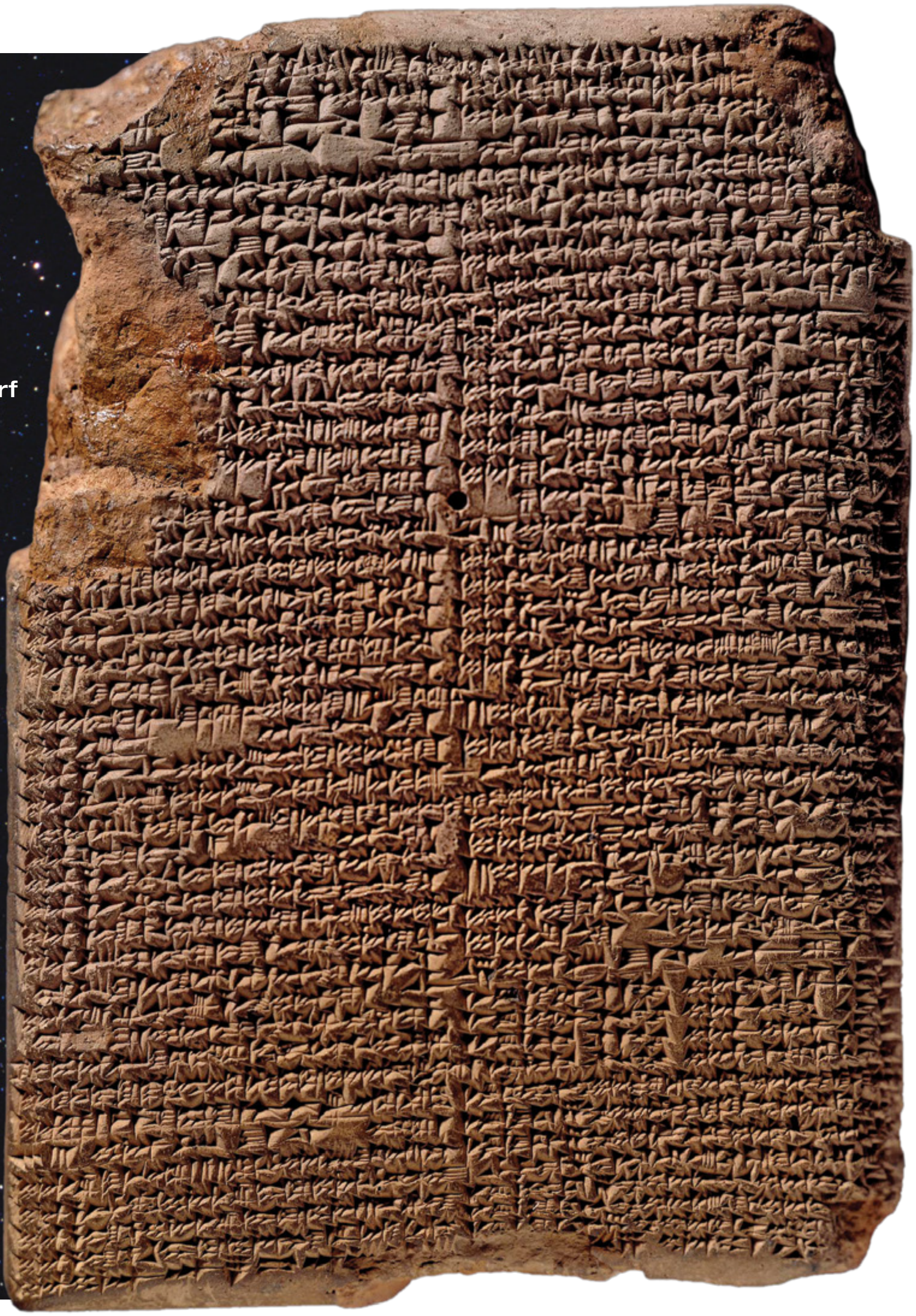
Star names trace the diverse roots of modern astronomy.

Sirius, Betelgeuse, Vega, and Altair — these names are familiar to anyone interested in astronomy. Yet they had no official status until the 21st century, when the International Astronomical Union (IAU) stepped in. At the end of 2022 the IAU had approved colloquial names for 450 stars, from Absolutno and Acamar through Zubenelgenubi and Zubeneschamali, and 20 more are expected in 2023. Where do these IAU names come from?

Only about 20 of the recently approved names are widely used both by professional and amateur astronomers. These include all first-magnitude stars visible from mid-northern latitudes, plus a few special cases like Polaris, the Pole Star. Professionals denote most other stars with a constellation or catalog name, plus a somewhat arbitrary sequence of numbers and/or letters. The majority of bright stars are covered by the Greek-letter designations that Johannes Bayer introduced in his 1603 star atlas, *Uranometria*. Academic journal authors almost always use Alpha Librae in preference to Zubenelgenubi, but even they call the night sky's brightest star Sirius rather than Alpha Canis Majoris.

Amateur astronomers, who are more likely to embrace a star's aesthetic and cultural dimensions, often use a few dozen additional names that appear rarely in the professional literature. For example, Albireo and Denebola are familiar to

AKIRA FUJII



◀◀ A MOTLEY CREW This photo shows all the stars in northern Leo with IAU-approved names. Regulus can be traced back more than 3,000 years, whereas the 6.5-magnitude star Formosa, orbited by the exoplanet Sazum, only received its name in 2019. It's sheer historical accident that faint Rasalas and Alterf have standard names whereas the much brighter star between them does not.

◀ ANCIENT IMPORTS The names Regulus and Spica can be traced back to the Mesopotamian *Mul Apin*, the first extant comprehensive astronomy textbook. Probably compiled around 1,000 BC, *Mul Apin* survives in several different copies dating from 700 to 300 BC. One of its cuneiform tablets is shown at left.

many enthusiasts. The remaining 100-plus IAU star names with traditional roots, such as Atik and Nihal, are mostly used by star-name aficionados, while the final 128 names were coined during IAU-sponsored contests.

Let's go back in time to see how we got here.

The Glory That Was Greece

It's impossible to overstate the role of ancient Greece in the development of the modern world. Poets still emulate Homer, philosophers argue about Plato and Aristotle, and Claudius Ptolemy's *Almagest* dominated the study of astronomy from its publication around AD 150 well into the 17th century.

In the *Almagest* Ptolemy summarized everything the Greeks had learned about astronomy over the course of seven centuries — and made one huge contribution of his own. He developed a detailed geometric model of the motions of the planets that could be used to predict their positions among the "fixed" stars indefinitely far into the future — a staggering achievement considering how complex planetary motion really is.

Although the book's main focus is the Sun, Moon, and planets, the *Almagest* also includes a catalog of more than 1,000 stars divided among 48 constellations. Ptolemy cited colloquial names for several of those stars, and a handful more star names appear elsewhere in Greek literature. But few as they are, those dozen or so Greek names include most of the sky's brightest stars, and many of them are still in use today.

Like the degree-minute-second system for measuring angles — another surviving vestige of the *Almagest* — some Greek star names actually date back to ancient Mesopotamia, the world's first civilization. For instance, Regulus (in Leo) and Spica (in Virgo) are Latin translations of Ptolemy's *Basilikos* and *Stachys*, meaning Little King and Spike of Wheat. (Regulus is a diminutive of Rex, meaning King in Latin.) These are derived in turn from the Mesopotamian

▲ **EARLY GREEK STAR NAMES** Arcturus and Sirius are probably the oldest star names that remain unchanged except for minor tweaks in spelling and pronunciation. Both appear in the didactic poem *Works and Days*, written around 700 BC by the Greek poet Hesiod, thought to be the subject of the Roman bust shown above.

▲ **STARS IN STONE** The Farnese Atlas, probably carved around AD 150, is the oldest known depiction of the Greco-Roman constellations. Some scholars surmise that the cusps of the constellation figures were intended to denote stars, but the stars themselves are not shown. This echoes the fact that Greco-Roman literature includes more than 50 names for constellations and asterisms but fewer than 20 star names.

names *Lugal* (King) and *Absin* (Ear of Grain), respectively (*S&T:* Jan. 2018, p. 66).

Some popular star names do appear to be native to Greece rather than Mesopotamia. For instance, Sirius is a Latinized form of *Seirios*, Greek for Scorcher. That presumably reflects the belief that when this star first appears in the predawn sky, the combination of its heat with the Sun's is responsible for the hottest days of the year. Even today these are sometimes called the "dog days of summer," a reference to *Cyon*, the Dog, another common Greek name for the star.

Most of the entries in Ptolemy's star catalog include only their celestial coordinates, magnitudes, and positions within the constellations; for instance, he noted that Denebola marks the tail of Leo, the Lion. These descriptions ended up supplying a large number of our modern star names after being translated into Arabic and then transliterated into Latin. Let's turn to that story now.

The Golden Age of Islam

The Roman Empire, which replaced Greece as the dominant power in the Mediterranean starting about 200 BC, had two main languages. Latin, the mother tongue of Rome, became the common language in the western half of the empire, while Greek continued to be used in the east and prevailed as the primary language of science and scholarship throughout.

During the empire's heyday all cultured people were bilingual in Latin and Greek, so scholarly texts were rarely translated. But knowledge of Greek was lost in the Western Roman Empire when it came under pressure from barbarian invasions around AD 400, making life untenable for educated urban elites. What we now call Western Europe was cut off from Greek culture, marking the beginning of the Dark Ages, when written records from Western Europe dried to a trickle.

Meanwhile, the ancient civilizations of the Middle East came under the sway of Islam. In the late 700s Islamic caliphs funded large-scale efforts to translate Greek, Persian, and Sanskrit classics into Arabic, the language of the holy Koran. Thus was born the Golden Age of Islam, when scholars synthesized the best of the older cultures and added their own distinctive contributions.

When Europe started to reawaken from its long intellectual slumber, it naturally looked to the Islamic world for instruction. Scholars flocked to Spain, which had been conquered by Islam during its initial military expansion. Cultural diffusion got a big boost after AD 1085, when Christians repossessed the ancient Spanish city of Toledo and its huge library, which housed Arabic translations of the Greek classics. Successive archbishops of Toledo encouraged local and visiting scholars to translate those books at first into Spanish and later into Latin, which became the primary language of science for the next six or seven centuries. As a result, Western Europe first encountered the *Almagest* through Gerard of Cremona's Latin translation of an Arabic translation of the Greek original. The title *Almagest* is in fact Arabic; the original Greek name was *Mathematike Syntaxis*.

▲ **DEEP-SKY DEVOTEE** This glorious chart of Leo comes from the oldest known manuscript of *The Book of the Fixed Stars*, written by Abd al-Rahman al-Sufi (903–986). Al-Sufi re-observed Ptolemy's stars, corrected their magnitudes, and noted many cases in which Ptolemy's positions were wrong. He also added many stars and deep-sky objects that Ptolemy missed, including the first known description of the Andromeda Galaxy.

The prefix "al," roughly equivalent to the English "the," reveals the tome's Arabic origin.

Many of our modern star names come from Arabic translations of the *Almagest*. For instance, according to Ptolemy, Libra's two brightest stars mark the Southern Claw and the Northern Claw, reflecting the fact that Libra was considered both a constellation in its own right and also as the claws of Scorpius, the Scorpion. In Arabic the Southern and Northern Claws became *al-zubana al-janubi* and *al-zubana al-schamali*, which morphed into the modern Zubenelgenubi and Zubeneschamali.

Frequently, the translators truncated the original Arabic phrases while Latinizing them. Denebola preserves most of the original *dhanab al-asad*, Tail of the Lion, but *dhanab al-dajaja*, the Tail of the Swan, lost the Swan and became simply Deneb, the Tail. Conversely, *ras al-ghul*, Head of the Ghoul, lost the Head and became Algol, the Demon.

Arabic culture already had a large body of astronomical poetry before it came into contact with Greek science. *The Book of the Fixed Stars*, written around 964 by Abd al-Rahman al-Sufi, was the most successful of many attempts to reconcile the Arabic and Greek traditions. The core of al-Sufi's book is a verbatim translation of Ptolemy's star catalog, but this is surrounded by a body of commentary and charts (see above) much bigger than the catalog itself. Al-Sufi included hundreds of traditional Arabic star names, many of which ended up being adopted in Europe. For instance, people all across Arabia had long called Taurus's brightest star *al-dabaran*, thought to mean the Follower, because this star follows the Pleiades across the sky. This was later Latinized as Aldebaran.

Not all Latin translators were fully fluent in Arabic, so many mistakes crept in as well. A classic example is the star Betelgeuse (*S&T:* Jan. 1983, p. 20). This started out as *yad al-jawza*, Hand of Jawza, that being the traditional Arabic name for Orion. The letters "y" and "b" look similar in Arabic, so this was mistakenly transliterated as Bedalgeuze, which morphed into the modern name after being copied over by subsequent scholars.

Few of the 100-plus traditional Arabic star names in the IAU list are as mangled as Betelgeuse, but it's rarely possible to reconstruct the original based only on the modern name. Who would guess that Vega and Altair started out as a matched pair? They in fact come from *al-nasr al-waqi*, the Swooping Eagle, and *al-nasr al-tair*, the Soaring Eagle, respectively. Vega, the Swooper, makes a V with Epsilon and Zeta Lyrae, like the upswept wings of a bird in mid-dive, whereas Beta and Gamma Aquilae, the wings of Altair, the Soarer, stretch out straight like a soaring bird.

The Scientific Revolution

Astronomers of the Islamic Golden Age and their successors in Europe's High Middle Ages made great strides in mathematics, paving the way for the development of calculus, the foundation of modern physics. But progress in astronomy was held back by the assumption that Earth was at the center of the universe. Quite a number of ancient and medieval astronomers speculated that Earth itself rotates rather than having the whole universe revolve around it once per day as Ptolemy stated, but very few were willing to contemplate the possibility that Earth actually moves in space.

That changed in 1543 when Nicolaus Copernicus published a detailed model of planetary motion with the Sun at the center. Then Kepler showed that planetary orbits are elliptical rather than circular, Galileo scanned the heavens with telescopes, Newton derived the universal laws of motion, and the next thing you know we have spaceflight and smartphones.

Throughout this time the number of star names continued to increase. Johannes Bayer included hundreds in the catalog that accompanied his 1603 atlas — the same work that introduced the Greek-letter system that's still widely used today. But Bayer made a number of errors, which became accepted because they appeared in such an important source.

A much worse offender was Giuseppe Piazzi, the discoverer of Ceres, the first asteroid. In the second edition of his *Palermo Catalogue*, published in 1814, Piazzi introduced about 100 star names that had Middle Eastern roots but had never before been used for the stars in question. Piazzi — or his assistant Niccolò Cacciatore, who took over the work as Piazzi's eyesight failed — often applied traditional asterism names to individual stars. For instance, Piazzi slapped the

▼▲ **ASTRONOMER ROYAL** Three madrasas (Islamic universities) flank Registan Square (below), the heart of Samarkand, Uzbekistan. The one on the left was built by Ulugh Beg (1394–1449), grandson of the Turco-Mongol conqueror Tamerlane. Ulugh Beg (above) was also the last great astronomer in the Islamic tradition and the first person to re-measure (and greatly improve) the positions of Ptolemy's stars. With star positions as accurate as those later obtained by Tycho Brahe as well as al-Sufi's dramatically improved magnitude estimates, Ulugh Beg's star catalog was arguably the best produced before the late 1600s, well into the telescopic era. Thomas Hyde's 1665 Latin translation gave rise to many modern star names.

ULUGH BEG PORTRAIT: ULUGH BEG OBSERVATORY / WIKIMEDIA COMMONS / CC BY-SA 4.0; REGISTAN SQUARE: BENJAMIN GOETZINGER / WIKIMEDIA COMMONS / CC BY-SA 4.0

name *al-nath* (Butting Animal) onto the Beta star of Taurus, the Bull, even though it originally denoted two stars in Aries, the Ram. The spelling has since been changed to Elnath.

Applied Imagination

Two of the names in the *Palermo Catalogue* are pure fabrication: Sualocin and Rotanev, for Alpha and Beta Delphini, respectively. Read backwards, these become Nicolaus Venator, a Latinized form of Niccolò Cacciatore. Apollo astronaut Virgil Ivan (Gus) Grissom pulled a similar stunt by smuggling his own middle name spelled backward as Navi to denote Gamma Cassiopeiae on the star charts used to navigate to the Moon. The IAU approved Sualocin and Rotanev because they have been widely used for two centuries, but it has not yet made a decision on Navi.

Plenty of other star names have been coined without any hidden agenda, first in Latin and most recently in English. Two obvious Latin examples are Polaris, which marks the north celestial pole, and Mira (Latin for amazing), which varies in brightness 100-fold every year.

Surely the most unimaginative English star name is Peacock, applied to the Alpha star of Pavo, the Peacock. However, the name does the job beautifully — it's a short, easily recognized label on charts for celestial navigators in the Southern Hemisphere. The star has no traditional Western name because it's too far south to be visible from Greece, Mesopotamia, or Egypt.

When European navigators ventured south of the equator in the 1500s, they needed names for all the uncataloged stars they encountered. One ploy was simply to move an existing name to one of the new stars. The name Achernar, from *akhir al-nar* (River's End), originally denoted the star Theta Eridani, which was the southernmost end of Eridanus, the River, in ancient times. In the late 1500s celestial cartographers extended Eridanus south to dazzling Alpha Eridani, and the name Achernar was quite logically then transferred to Alpha, the new River's End. That left Theta anonymous until it acquired the name Acamar, a different abbreviation of the same Arabic phrase.

There are many other cases in which a single name has been used for two different stars. Conversely, most star names have spelling variants, and quite a number of stars have two or more unrelated names. To take one prominent example, 20th-century star atlases and catalogs are split roughly 50-50 with respect to the Beta star of Cetus, the Sea Monster. Some call it Deneb Kaitos, from *dhanab qaitus*, the Sea Monster's Tail, while others call it Diphda, from its folk-Arabic name *al-difdi al-thani*, the Second Frog. The IAU endorsed Diphda in 2016, so with any luck that name will be used in all future atlases.

21st-Century Star Names

Lack of standardization is rarely a problem in casual conversation or writing since all languages are chock-full of words with many meanings and meanings with many words. But when telescopes with Go To capability became practical, manufacturers rashly chose to identify stars by name rather than designation. That can be a problem if you're looking for Deneb Kaitos in your star atlas, but the scope calls it Diphda instead. The situation could have been avoided if star names had been standardized much sooner.

As worthy a goal as standardization is, that's not why the IAU got into the star-name game. "It all started with the desire to name exoplanets," explains Eric Mamajek, chair of the IAU Working Group for Star Names (WGSN). There are well-established procedures for naming newly discovered solar system objects, but not for planets orbiting other stars. This becomes a problem whenever a newsworthy exoplanet is discovered, because news media and the general public much prefer names to convoluted designations. So far, they've made do with phrases like "the diamond planet" for the carbon-rich planet around 55 Cancri, or "the Tatooine planet" for Kepler-16b, which, like the eponymous Star Wars planet,

▲ **THE DAWN OF MODERN OBSERVING** Like Ulugh Beg 150 years earlier, Tycho Brahe (1546–1601) was a wealthy nobleman who built an observatory to measure planet and star positions. But whereas Ulugh Beg was an enlightened outlier in an increasingly fundamentalist society, Brahe worked at a time when scientific inquiry was in full flower. His data set a new standard for observational excellence and prompted Kepler's insight that planetary orbits are elliptical.

TYCHONIS BRAHE *ASTRONOMIÆ INSTAURATÆ MECHANICA* / WIKIMEDIA COMMONS / PUBLIC DOMAIN orbits a binary star. But what happens when the stakes are higher, and someone finds an exoplanet that's suspected to harbor life? That could happen any decade now. (The first exoplanet *proved* to have life is an entirely different matter; we might not see that in our lifetimes, or ever.)

The Way Forward

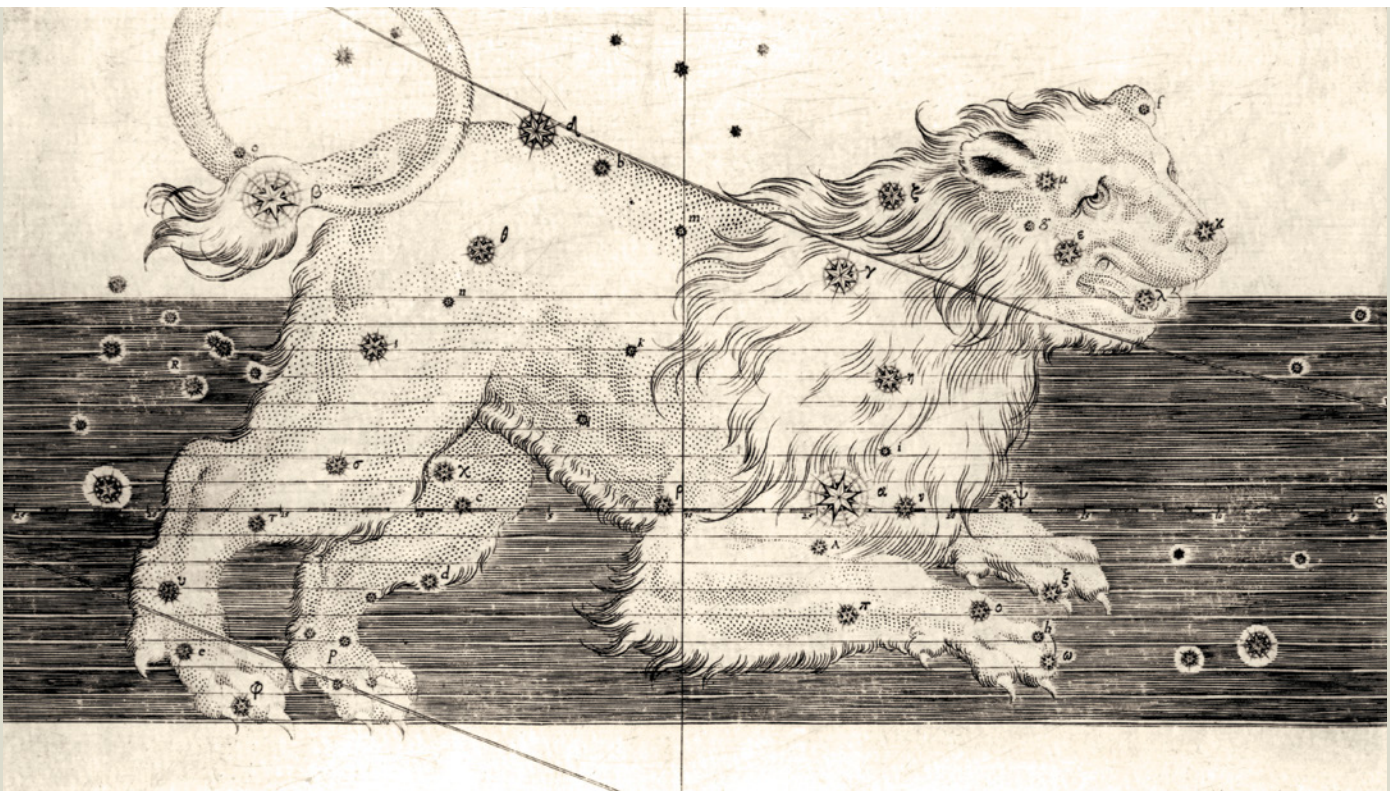
To test the waters while simultaneously popularizing exoplanets and forestalling private companies from selling exoplanet names, the IAU announced a public contest in 2014 to nominate and vote on names for the stars and exoplanets in 20 different systems.

Two of the host stars already had names that couldn't be changed. "Nobody was going to mess with Fomalhaut or Pollux," Mamajek says, "but most people assumed that Ain was up for grabs." Mamajek, a backyard astronomer and professional exoplanet researcher, informed the contest's organizers that three other host stars already had entries in the authoritative work *A Dictionary of Modern Star Names* by Paul Kunitzsch and Tim Smart. So, the first five traditional star names that the IAU approved were Fomalhaut, Pollux, Ain (Epsilon Tauri), Edasich (Iota Draconis), and Errai (Gamma Cephei).

The IAU decided that it should never replace a traditional name with a made-up name. But there is no definitive catalog of traditional star names, so the organization convened a panel of experts (the WGSN) for advice.

After endorsing the first five star names, the IAU obviously had to continue — it would be crazy to approve Pollux without its twin Castor, to say nothing of skipping Sirius, Betelgeuse, and all the rest. So in 2016 the IAU authorized 212 of the most common Western star names. In subsequent announcements, the IAU made official many other traditional names,

▲ **O BRAVE NEW WORLD** The existence of planets orbiting stars other than our Sun — long suspected but only proved in the 1990s — has revolutionized our view of the universe. The La Silla Observatory in Chile, shown here, is the most prolific ground-based exoplanet facility, with more than 100 discoveries to date.



LA SILLA OBSERVATORY: ESO / JOSÉ FRANCISCO SALGADO; *URANOMETRIA* LEO MAP: ROYAL ASTRONOMICAL SOCIETY / SCIENCE PHOTO LIBRARY; *URANOMETRIA* PAGE: HISTORY OF SCIENCE COLLECTIONS / UNIVERSITY OF OKLAHOMA LIBRARIES / PUBLIC DOMAIN drawing on non-Western sources such as China, which until recently was ahead of the West in many aspects of astronomy, and Polynesia, whose navigators plied the open oceans by starlight long before Columbus. Now, Mamajek says, the WGSN is in a process of consolidation rather than expansion; the next priority is documenting the origins of the existing names. It's a daunting job for a group of volunteers, even one that includes several eminent science historians.

A Is for Absolutno

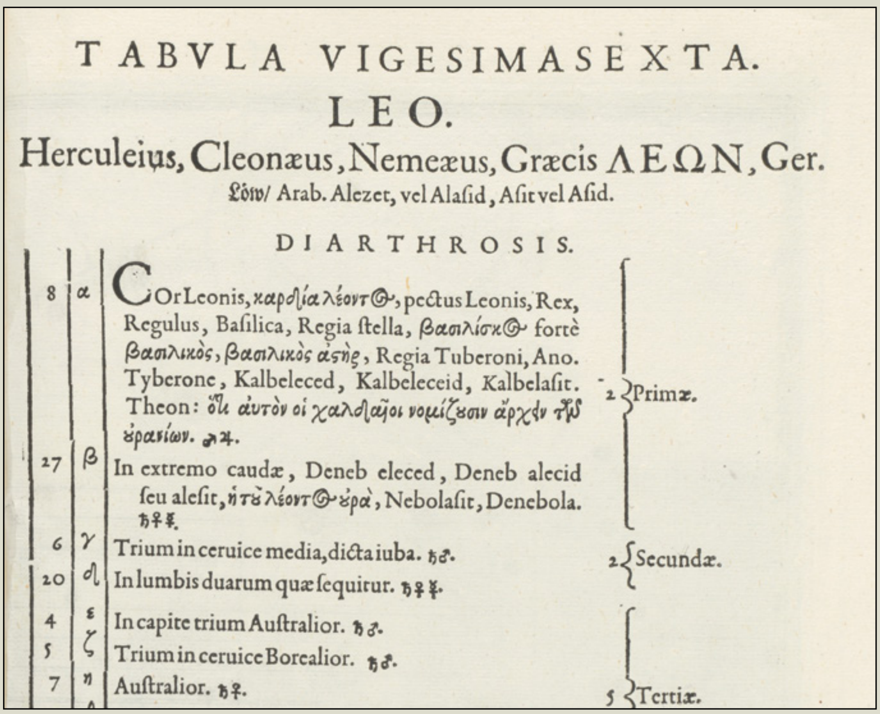
Let's end with Absolutno, alphabetically the first name in the IAU list. It was the Czech Republic's entry in a 2019 campaign in which every country got to nominate names for one exoplanet and its host star. This star's name comes from the novel *Továrna na absolutno* (*The Absolute at Large*) by the science-fiction titan Karel Čapek, best known for introducing the word "robot" in the sense we now use it. (I felt obliged to read this brain-teasing, mock-apocalyptic novel as background for writing about the star, and I'm very glad that I did.)

But just because the name Absolutno deserves a star, does it necessarily mean the star deserves a name? One way to get a handle on that question is with a telescope. At magnitude 12.1, Absolutno is one of the faintest of the named stars — it's barely visible through my 70-mm refractor, though quite prominent through my 12.5-inch Dobsonian. The view in the bigger scope turns out to be unexpectedly rewarding because Absolutno lies just 4 arcminutes north of the interacting galaxy pair NGC 2445/2444, also known as Arp 143, which is fascinating both astrophysically and visually. No doubt if you studied all the named stars, each one would prove remarkable in some way. Just as no two people have identical life stories, each star is unique when you look closely enough.

Having said that, several million stars appear brighter than Absolutno, and most of these likely have worlds orbiting them. The only reason Absolutno ended up with a name is that its planet, Makropulos, happened to be detected in time for the contest. A hundred years from now, when the number of known exoplanet systems will presumably be in the billions, it will no doubt seem strange that Absolutno was honored with a name while a million other 12th-magnitude exoplanet hosts were not. But that's no stranger than the stories behind many of the traditional star names that we all take for granted.

TONY FLANDERS has a long-standing fascination with naked-eye astronomy; he loves to note each star's name when it first appears in evening twilight. He contributed to *Sky & Telescope's Pocket Sky Atlas* and authored the magazine's internal style guide for star-name usage.

RELATED READING The most important secondary sources for this article are *A Dictionary of Modern Star Names* by Paul Kunitzsch and Tim Smart (available from **shopatsky.com**); *The History and Practice of Ancient Astronomy* by James Evans; and the IAU WGSN website (**iau.org/public/themes/naming_stars/**). Richard Hinckley Allen's *Star Names: Their Lore and Meaning* is very entertaining but not always reliable on non-Western sources.



TABVLA VIGESIMASEXTA.

LEO.

Herculeius, Cleonæus, Nemeæus, Græcis ΛΕΩΝ, Ger. Löw/ Arab. Alezet, vel Alaſid, Aſit vel Aſid.

DIARTHROSIS.

8	α	COr Leonis, καρδία λέοντος, pectus Leonis, Rex, Regulus, Baſilica, Regia ſtella, βασιλίσκος fortè βασιλικὸς, βασιλικὸς ἀστὴρ, Regia Tuberoni, Ano. Tyberone, Kalbeleced, Kalbeleceid, Kalbelaſit. Theon: ὅτι αὐτὸν οἱ χαλδαῖοι νομίζουσιν ἄρχειν τῶν οὐρανίων. ♂♃.	
27	β	In extremo caudæ, Deneb eleced, Deneb alecid ſeu aleſit, ἡ τοῦ λέοντος οὐρὰ, Nebolaſit, Denebola. ♄♀☿.	2 Primæ.
6	γ	Trium in ceruice media, dicta iuba. ♄♂.	
20	δ	In lumbis duarum quæ ſequitur. ♄♀☿.	2 Secundæ.
4	ε	In capite trium Auſtralior. ♄♂.	
5	ζ	Trium in ceruice Borealior. ♄♂.	
7	η	Auſtralior. ♄♀.	5 Tertiæ.

◀◀ **ARCHETYPAL STAR CHART** Johannes Bayer's *Uranometria* was the first star atlas made with accurate positions, made possible by improved cartography and Brahe's data. As this depiction of Leo illustrates, Bayer labeled stars with letters (mostly Greek), which take up less space on charts than Ptolemy's two-digit numbers. This was the right book at the right time — published in 1603, just before the dawn of telescopic astronomy. Bayer's lettering scheme is still in use today.

◀ **STAR NAME MISHMASH** The catalog accompanying Bayer's *Uranometria*, part of which is shown at left, displays Ptolemy's numbers and descriptions in the first and third columns, with Bayer's letters in between. The third column also includes hundreds of names for the brightest stars. Note that the now-official names Regulus and Denebola are not distinguished in any way from their numerous Latin, Greek, and Latinized Arabic aliases.

 by Knicole Colón

Exoplanets EVERYWHERE

AWASH IN EXOPLANETS
The Southern Hemisphere sky, with candidate (orange) and confirmed (blue) exoplanet systems found by TESS, as of late 2022

NASA / MIT / TESS AND ETHAN KRUSE (UNIVERSITY OF MARYLAND, COLLEGE PARK)

The TESS space telescope is expanding our knowledge of exoplanets, helping us focus on those orbiting stars that are the smallest and closest to Earth.

Over the past few decades, there has been an exoplanet revolution. Thirty years ago, we only knew of a handful of planets outside our solar system. Today, we know of more than 5,000 of these distant worlds, with some similar in size to Earth and some orbiting stars like the Sun. A major player in this exoplanet revolution was NASA's Kepler space telescope, which was retired in 2018. More than 50% of all exoplanets discovered to date have come from searching through Kepler data.

But our planet-hunting days are far from over. NASA's Transiting Exoplanet Survey Satellite (TESS) launched in 2018 and quickly picked up where Kepler left off (*S&T:* Mar. 2018, p. 22). Its mission: to search the entire sky for the nearest exoplanets.

One of Kepler's main goals was to determine how common exoplanets are in our galaxy, the Milky Way. Kepler surveyed a single part of the sky for several years to search for exoplanets via the *transit method*, in which periodic dips in a star's brightness reveal a planet passing in front of that star. The exquisite data Kepler collected during this initial mission, which lasted from 2009 to 2013, showed us that exoplanets are indeed abundant in our galaxy. We can now say with confidence that there are more planets than stars in the galaxy and so, on average, every single star in the galaxy hosts at least one planet. Of course, this does not mean every star actually hosts a planet. Rather, some stars host no planets and some stars host multiple planets.

However, there is more to the story than simply counting how many exoplanets there are. We want to know what exoplanets are made of and what their atmospheres are like. To find that out, we need to take a close look at these worlds. But the systems Kepler surveyed predominantly orbit faint, distant stars — poor targets for detailed study.

This is where TESS comes in. TESS is the only space observatory capable of surveying the entire sky to discover many of the closest, most accessible exoplanets in the Milky Way. Because TESS discoveries are predominantly around small, bright, nearby stars, astronomers can readily use other observatories to follow up and determine the exoplanets' masses and the composition of their atmospheres. With its discoveries, TESS is thus moving us further along in our journey to determine what exoplanets are made of and whether there is any other planet out there like Earth.

The Story Behind TESS

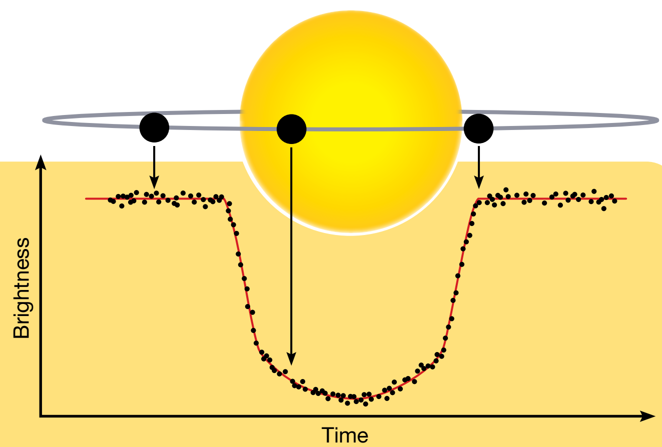
While TESS and Kepler both use the transit method to discover exoplanets in our galaxy, they differ in a few key ways. Kepler was a 0.95-meter telescope with a field of view about 12° wide, capable of detecting the change in brightness caused by an Earth-sized planet passing in front of a faint, distant, Sun-like star. In its primary mission, Kepler surveyed just one region of the sky for about four years. For another four and a half years after that, it stared at a series of patches of sky along the ecliptic plane as part of its "K2" mission.

TESS, on the other hand, has four CCD cameras each with 10.5-cm apertures that together cover an area of 24° by 96° on the sky — more than 20 times greater than Kepler's field of view. TESS's observations step around the sky every 27 days or so to produce a nearly all-sky survey over the course of two years. With these characteristics and approach, TESS is capable of detecting the change in brightness caused by Earth-size planets passing in front of bright, nearby stars similar in size to the Sun or smaller.

While TESS has relatively small camera apertures compared to Kepler's large mirror, it is very efficient. It observes millions of stars in order to find the kinds of systems we're looking for. TESS focuses on relatively small planets and small, bright, nearby stars for a few reasons. First, such

CANDIDATE VS. CONFIRMED

The process of discovering and confirming bona fide exoplanets is quite involved, which is why there are so many more candidate exoplanets compared with confirmed exoplanets. The confirmation of an exoplanet requires astronomers to determine with extremely high confidence that the only object that could be causing the tiny periodic dip in starlight is a planet. The alternatives include a binary star system, where one star eclipses another star periodically, or a false alarm, in which the "transit signal" is actually due to something like starspots or instrumental artifacts mucking up the data.



▲ **TRANSIT METHOD** When a planet passes in front of its star from our perspective, it blocks a small fraction of the star's light, which appears as a dip in starlight. The graph of how the star's brightness changes with time is called a light curve.

LEAH TISCIONE / *S&T*, SOURCE: NASA

planets and stars are common. Planets smaller than 4 Earth radii are the most common type of planet in our galaxy. Red dwarf stars — typically at most 60% the size and temperature of the Sun — are similarly the most abundant. Red dwarfs (also known as *M* dwarf stars) make up most of the nearest neighbors to our solar system (*S&T:* Jan. 2019, p. 34).

Second, it is generally easier to detect and study small planets around small stars with the transit method than around large stars, because what astronomers measure is the ratio of the size of the planet (and its atmosphere) relative to the size of the star. Correspondingly, it's more difficult to detect a small planet around a Sun-like star than it is around a red dwarf.

While Kepler has provided us with a bounty of small planets, the mission focused on Sun-like stars, and they for the most part lie far away from Earth. In fact, less than 1% of Kepler planetary systems are located within 200 light-years, a distance range well-suited for further follow-up.

Small Exoplanets Close to Home

TESS has brought our focus closer to home. We've discovered 285 confirmed exoplanets to date, with more than 4,000 additional candidate exoplanets awaiting confirmation (see tipbox, page 35). At first glance, TESS's discoveries so far match the expectations that we had before launch. TESS was specifically designed to discover 50 planets with radii smaller than 4 times that of Earth whose masses we could then measure with ground-based observatories. We've far exceeded this goal, with 174 small planets discovered to date, 116 of which have measured masses.

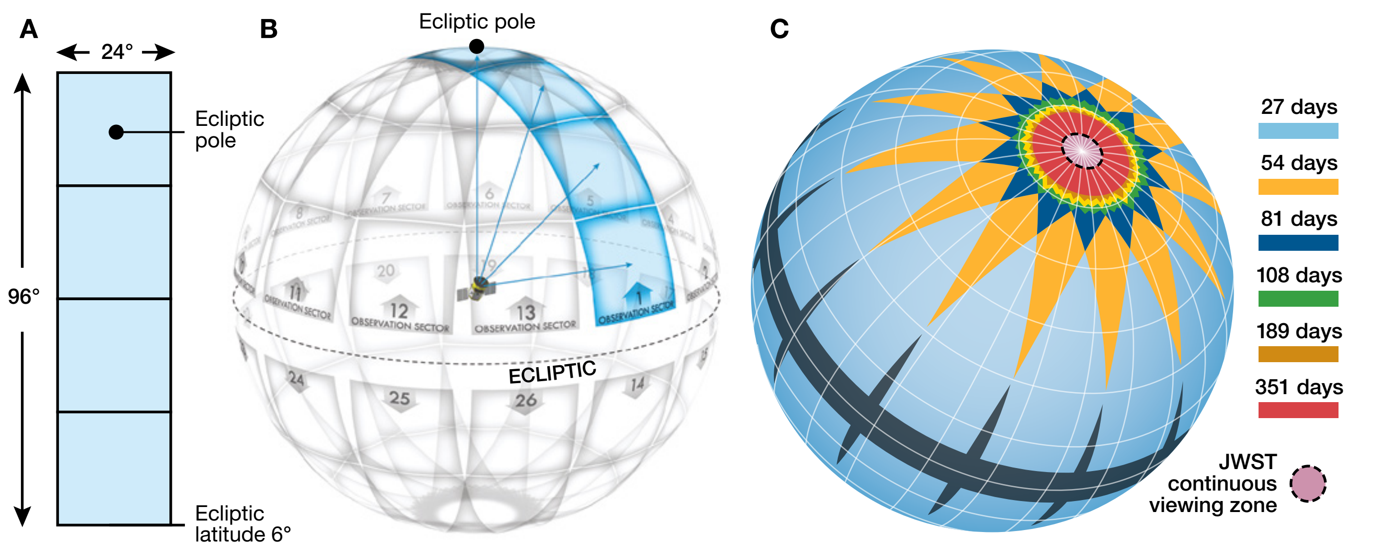
Mass measurements are possible for so many TESS exoplanets because the worlds orbit relatively bright stars, in whose starlight we can more easily detect the tiny wobble caused by the planet's gravitational tug on the star. More than 70% of all TESS exoplanets are found around stars brighter than a visible magnitude of 12. In Kepler's case, just 8% of discoveries are around such bright stars. TESS planetary systems are also located relatively close to home, with 40% found within 200 light-years of Earth. And more than 20% of TESS exoplanets orbit red dwarfs, compared to just a few percent of Kepler exoplanets.

One of the first planets TESS discovered, Pi Mensae c, orbits a star bright enough that it can be seen with the naked eye — at least if you find yourself in a location with an extremely dark sky and you have pretty good vision to boot. While you can see the star Pi Mensae with your own eyes on a clear night, it is not possible to see the planet with the naked eye because it is only about twice the size of Earth and it orbits very close to its star, with a period of just over 6 days.

WHAT'S IN A NAME?

TESS exoplanets have a variety of names, simply because there is no strict naming scheme employed by the mission team. TESS exoplanets typically receive a name that follows from an established star catalog, particularly for bright stars, e.g., Pi Mensae c. Otherwise, TESS targets are normally named as TOI-<insert number here>, where TOI stands for "TESS Object of Interest." This indicates the mission team flagged the object (star and planet) as a viable planetary system and assigned it a TOI number, e.g., TOI-257.01. Once a planet candidate is confirmed as a bona fide planet, we often change the number into a letter, in this case TOI-257b.

▼ **OBSERVING SECTORS** The combined field of view of TESS's four cameras spans a long, 24° × 96° strip of sky (A). Every 27 days or so, the spacecraft will observe a different strip of sky (B), slicing the celestial sphere into 26 sectors (13 per hemisphere). These sectors overlap near the ecliptic pole (C). The dashed circle around the pole shows the region that JWST can observe uninterrupted.



LEAH TISCIONE / *S&T*, SECTORS SOURCE: C. BEALS / MIT, COVERAGE MAP SOURCE: D. DEMING / TESS TEAM

Another planet, a gas giant on a much longer orbit discovered before TESS observed the system, also exists around this star.

The discovery of Pi Mensae c really opened the floodgates of what was to come from TESS. And flood it did! TESS has mostly discovered small planets that are within a few times the size of Earth, with around 50% of TESS exoplanets landing in a "super-Earth" or "mini-Neptune" category — a fraction roughly similar to previous discoveries, and contrary to what we see in the solar system. Super-Earth planets that are within about 80% of Earth's size are large enough that we cannot declare them to have rocky surfaces; instead, they may have a variety of compositions (*S&T:* Feb. 2022, p. 21). One of the expected compositions is that of a water world, which is just what TOI-1452b may be. This planet is approximately 70% larger and has about five times more mass than Earth. From the size and mass, astronomers can calculate the planet's density, which suggests it may have a very deep ocean.

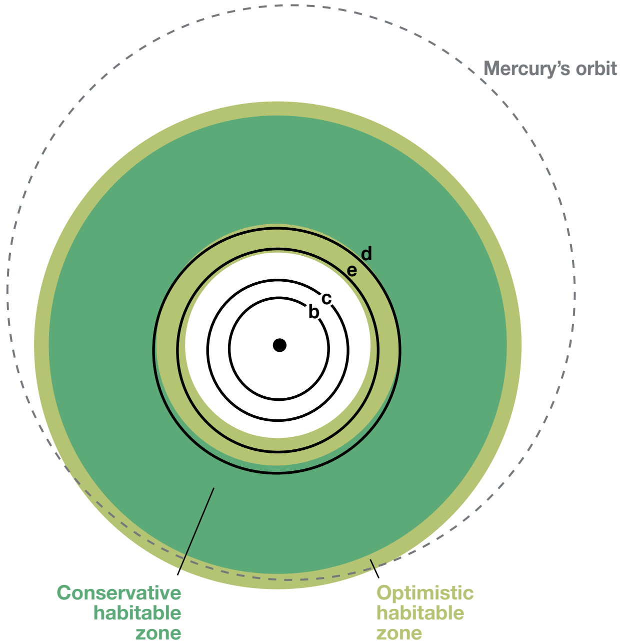
TESS is also making great strides in finding presumably rocky planets as small as (or smaller than!) Earth, with 11 such planets discovered so far. These include HD 21749c and L 98-59b. Both of these planets are quite a bit warmer than Earth, rendering them uninhabitable to life as we know it. However, TESS has found a few planets at the right distance from their stars such that, given the right atmosphere, the worlds might have temperatures similar to Earth and be able to sustain liquid water on their surfaces. TOI-700 d is a prime example of a TESS-discovered exoplanet found in the habitable zone of its star. The planet is also just 20% larger than Earth, making it more likely to have a rocky surface.

That said, even if TOI-700 d were just like Earth in size and temperature, that would not make it precisely Earth-like. One of the key differences is that TOI-700 d orbits a red dwarf — TOI-700 is approximately 40% of the Sun's size and about half as hot. In fact, the planet actually orbits around this cool star every 37 days, but it still has a temperature similar to Earth because the star is so much cooler than the Sun. Because red dwarfs are also typically more active than the Sun, planets like TOI-700 d on relatively short orbits will suffer from higher levels of radiation over their lifetime. Such radiation surely impacts the formation and evolution of life in ways we have not been able to fully explore yet (*S&T:* Dec. 2022, p. 34).

As exciting as it is to think about the prospects of finding potentially habitable planets, TESS was not designed to find perfectly Earth-like planets. And that is okay. TESS has clearly been enormously productive in its own right, finding plenty of small planets around small, bright, nearby stars.

Revealing New Secrets of Exoplanets

TESS is going well beyond its original mission goals and is making unexpected discoveries, too. We already knew from Kepler that the average exoplanet in the galaxy is around 2 to 3 times the size of Earth, and TESS has confirmed this trend extends to the worlds around cooler stars. However, a real



▲ **NOT QUITE EARTH-LIKE** The star TOI-700 has two planets in its habitable zone: d and a newly discovered planet, e (announced in January 2023). But because the star is a red dwarf, the habitable zone lies closer to the star than Mercury does to the Sun.

BEATRIZ INGLESSIS / *S&T*, SOURCE: NASA EXOPLANET CATALOG

surprise is that TESS has found more of these planets in tight orbits than predicted. This close-in region, where a planet only takes a few days to circle its star, is known as the "hot-Neptune" desert, because Kepler's discoveries had indicated that Neptune-size or smaller planets on close-in orbits were exceedingly rare.

Another surprise is that TESS is finding more giant planets than might be expected. Giant planets make up just 4% of the discoveries from Kepler. Yet, around 27% of TESS discoveries are roughly Jupiter-size or larger. Giant planets are common enough that astronomers discovered them with ground-based all-sky surveys long before Kepler launched, so it is not necessarily surprising that TESS's space-based all-sky survey would reveal additional giant planets as well as small planets. It does come as a surprise, however, that ground-based surveys did not already discover all the giant planets around bright stars in their scans of the sky. Notably, TESS is finding a population of giant planets around small stars (like TOI-1899b). We thought such a configuration would be rare, because it's difficult for the cloud that forms a small star to have enough material left over to make a big planet.

Together, these discoveries are further evidence that our solar system apparently has a rare architecture. Other ongoing searches for exoplanets around Sun-like stars will give us even more insight into just how unique our solar system is.

Clearly, by surveying the entire sky and observing millions of stars of all different types (from red dwarf to Sun-like to evolved stars), TESS is proving capable of discovering all kinds of planetary systems. A key example is its discovery of the Jupi-
(continued on page 40)

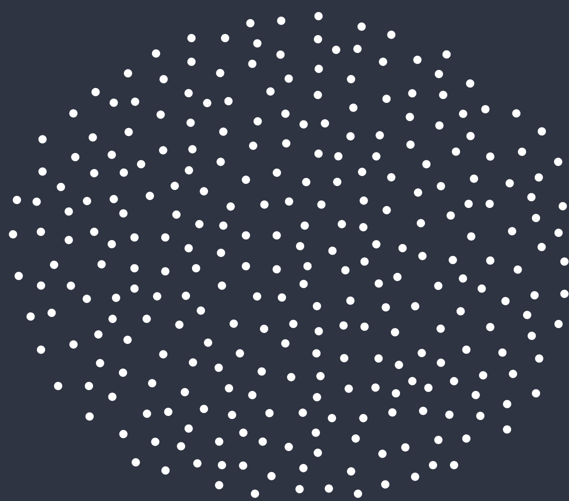
TESS'S EXOPLANETS

Using TESS, astronomers have discovered 5% of all confirmed exoplanets. But for nearby terrestrial planets and planets around the smallest stars, its impact is much larger. (These numbers are for January 1, 2023.)

TESS

Total Number of Exoplanets Discovered

285



50%

Fraction of all known terrestrial planets within 200 light-years of Earth that were discovered by TESS

TESS STELLAR HOSTS BY TYPE*

*some stars have no published temperature

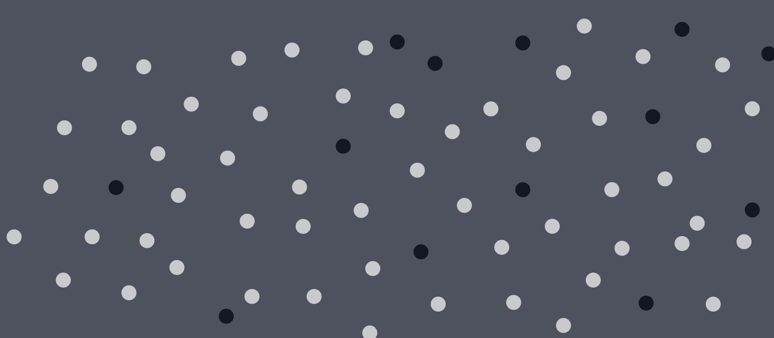
TESS PLANETS BY SIZE*

R_e = Earth radii
*some planets have no published radius

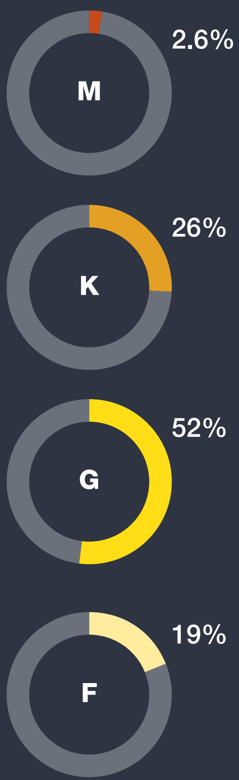
- Mars 0.3–0.7 R_e
- Earth 0.7–1.2 R_e
- Super-Earth 1.2–1.9 R_e
- Sub-Neptune 1.9–3.1 R_e

PLANETS DISCOVERED WITHIN 200 LIGHT-YEARS OF EARTH

- TESS
- Kepler



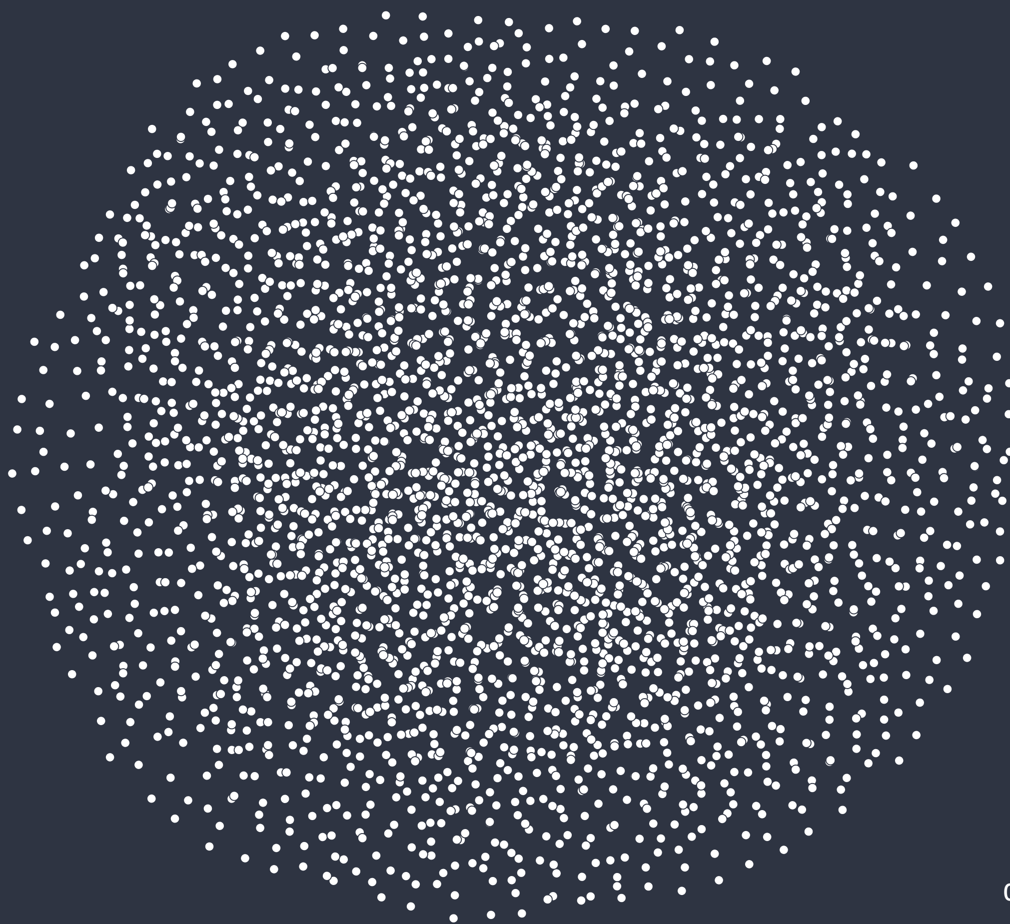
KEPLER STELLAR HOSTS BY TYPE



Kepler

Total Number of Exoplanets Discovered

3,253



KEPLER PLANETS BY SIZE

- Neptune 3.1–5.1 R_e
- Sub-Jupiter 5.1–8.3 R_e
- Jupiter 8.3–13.7 R_e
- Super-Jupiter 13.7–23.5 R_e

112
TESS

29
Kepler

INFOGRAPHIC: TERRI DUBÉ / S&T; EARTH
ICON: MARTIN VANCO FROM NOUN PROJECT

(continued from page 37)
ter-size planet WD 1856+534b, found in orbit around a white dwarf star. This is the first intact exoplanet known to orbit a stellar remnant. Worlds are often destroyed once a Sun-like host star evolves to the red giant phase and sheds its outer layers, eventually leaving behind a dense white dwarf (*S&T:* Jan. 2023, p. 14). Finding an intact exoplanet that evidently survived this stage of stellar evolution requires us to revisit what we know about the life and death of planetary systems.

On the flip side, TESS is also finding newly formed planets around young stars like AU Microscopii. AU Mic is a nearby red dwarf that is only around 25 million years old (compared to the Sun's more mature 4.6 billion years). AU Mic has been an excellent laboratory for astronomers for years, since it is young enough that it still has a disk of gas and dust around it left over from its formation. Astronomers expected that young exoplanets would exist in this disk, given the presence of a gap between the inner disk and the central star. So far, TESS has found not one but two planets in this gap, a pleasant but not wholly unexpected surprise. Establishing the presence of exoplanets around young stars like AU Mic is critical for understanding the time scale over which planets can form around different types of stars.

But wait, there's more! TESS is finding planets on ultra-short-period orbits — like GJ 367b with an 8-hour orbit — and planets that orbit multiple stars, like TOI-1338b (*S&T:* July 2022, p. 34). These worlds highlight the intriguing diversity of exoplanet systems, greatly complementing results from other surveys. All of the individual and collective discoveries that TESS is making serve to fill gaps in our knowledge of exoplanets and how they form, evolve, and die.

What's Next for TESS?

The TESS prime mission formally ended in July 2020, at which point its extended mission began. With operations now continuing until at least 2025, TESS is continuing to survey the sky and observe as many stars as possible, covering a longer stretch of time that will enable us to discover additional exoplanets, particularly those with longer orbital periods.

A key goal for the TESS mission continues to be discovering exoplanets orbiting stars bright enough to enable the measurement of planetary masses and atmospheric compositions using other telescopes. Observers have measured masses with ground-based telescopes for nearly 80% of TESS exoplanets so far, compared to just 11% of Kepler exoplanets.

TESS discoveries are already making themselves known in the realm of atmospheric observations. Because many TESS exoplanets orbit small, bright, nearby stars, we have a vastly improved ability to detect the tiny amount of starlight that filters through these planets' atmospheres to reveal their compositions. TESS worlds make up nearly 37% of the transiting exoplanets that the James Webb Space Telescope (JWST) is observing in its first year of science operations. With JWST, we will search for evidence of water, carbon dioxide, methane, and other molecules in these planets' atmospheres.

CITIZEN SCIENTISTS

TESS discoveries are made possible largely thanks to the work of professional astronomers, but citizen scientists play a key role as well. Citizen scientists work on projects like Planet Hunters TESS (https://is.gd/zooniverse_tess), Exoplanet Watch (https://is.gd/exoplanetwatch), and UNITE (science.unistellaroptics.com) to find new signals that automated search algorithms cannot easily find in the data, and also to vet candidate exoplanet signals to verify their planetary nature. These programs take advantage of the fact that all TESS data are publicly available, enabling citizen scientists to contribute to the discovery of hundreds of TESS candidate exoplanets so far.

What we learn about the compositions will add another piece to the puzzle of how exoplanets form and evolve.

It was only a few decades ago that we had to rely on the imagination of astronomers and authors and filmmakers alike to picture what types of exoplanets might exist (if any). Now here we are today, knowing that exoplanets outnumber stars in our galaxy and, by extrapolation, in our universe. And thanks to TESS, science fiction keeps turning into fact with the variety of extrasolar worlds that we are discovering close to home. TESS is continuing to uncover new surprises along the way that reveal just how vast the exoplanet landscape is. With every discovery, we're changing our understanding of how planets form and evolve — and getting closer to answering the ultimate questions of what our place in the universe is and how we got here.

■ **KNICOLE COLÓN** is the TESS Project Scientist at NASA's Goddard Space Flight Center. She also has roles on JWST and the Pandora SmallSat and studies extreme exoplanets in her spare time.


FOUR EYES Artist's concept of TESS in space, showing its solar panels and four cameras

NASA GODDARD SPACE FLIGHT CENTER

OBSERVING
May 2023

3 **EVENING:** The waxing gibbous Moon gleams high in the south-southeast, in Virgo, about 2° above left of Spica. See page 46 for more on this and other events listed here.

5 **ALL NIGHT:** A penumbral lunar eclipse will be visible across much of Europe, most of Africa, Asia, Australia, and New Zealand.

6 **MORNING:** The Eta Aquariid meteor shower peaks. The Moon will be just past full and will severely hamper the display.

7 **MORNING:** Early risers will see the waning gibbous Moon some 2½° right of Antares in the south-southwest.

9 **EVENING:** Mars is in Gemini 5° lower left of Pollux. Venus blazes to the pair's lower right. Look toward the west-northwest to catch this sight.

13 **MORNING:** Face east-southeast to watch the Moon, one day past last quarter, rise in tandem with Saturn. Around 5° separates the pair.

17 **DAWN:** The waning crescent Moon and Jupiter climb above the eastern horizon with less than 1° between them. An occultation will be visible from some locations (go to page 48).

21 **DUSK:** Look toward the west to see Venus, Castor, and Pollux arranged in a triangle. The Moon hangs lower right of this tableau.

22 **EVENING:** The waxing crescent Moon and Venus are some 5° apart in Gemini, low in the west-northwest. Catch this sight before it sets.

23 **EVENING:** The Moon is 2° lower left of Pollux, while Venus poses 5½° below the pair.

24 **DUSK:** Turn to the west to see the lunar crescent in Cancer, equidistant (around 4°) from both Mars and the Beehive Cluster (M44). Binoculars will tease out the cluster stars.

26 **EVENING:** The Moon, one day shy of first quarter, is less than 3½° from Regulus, in Leo. Face west to watch the pair sink toward the horizon.

28, 29 **DUSK:** Venus and Pollux are 4° apart above the west-northwestern horizon.

31 **MORNING:** The waxing gibbous Moon and Spica descend toward the west-southwestern horizon, with 4° between them.

31 **EVENING:** Mars hovers on the outskirts of the Beehive Cluster. Look to the west after sunset to take in this sight.

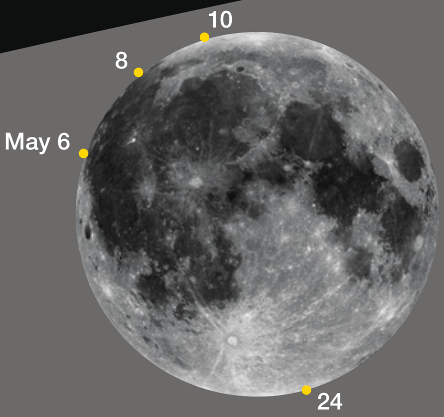
— DIANA HANNIKAINEN

▲ Spica, also known as Alpha (α) Virginis, is the brightest star in the constellation Virgo (it shines at top left in the image). You'll note it's often mentioned in this column — since it's on the ecliptic, the Moon and the planets pay it a visit on a regular basis. BOB KING

MAY 2023 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

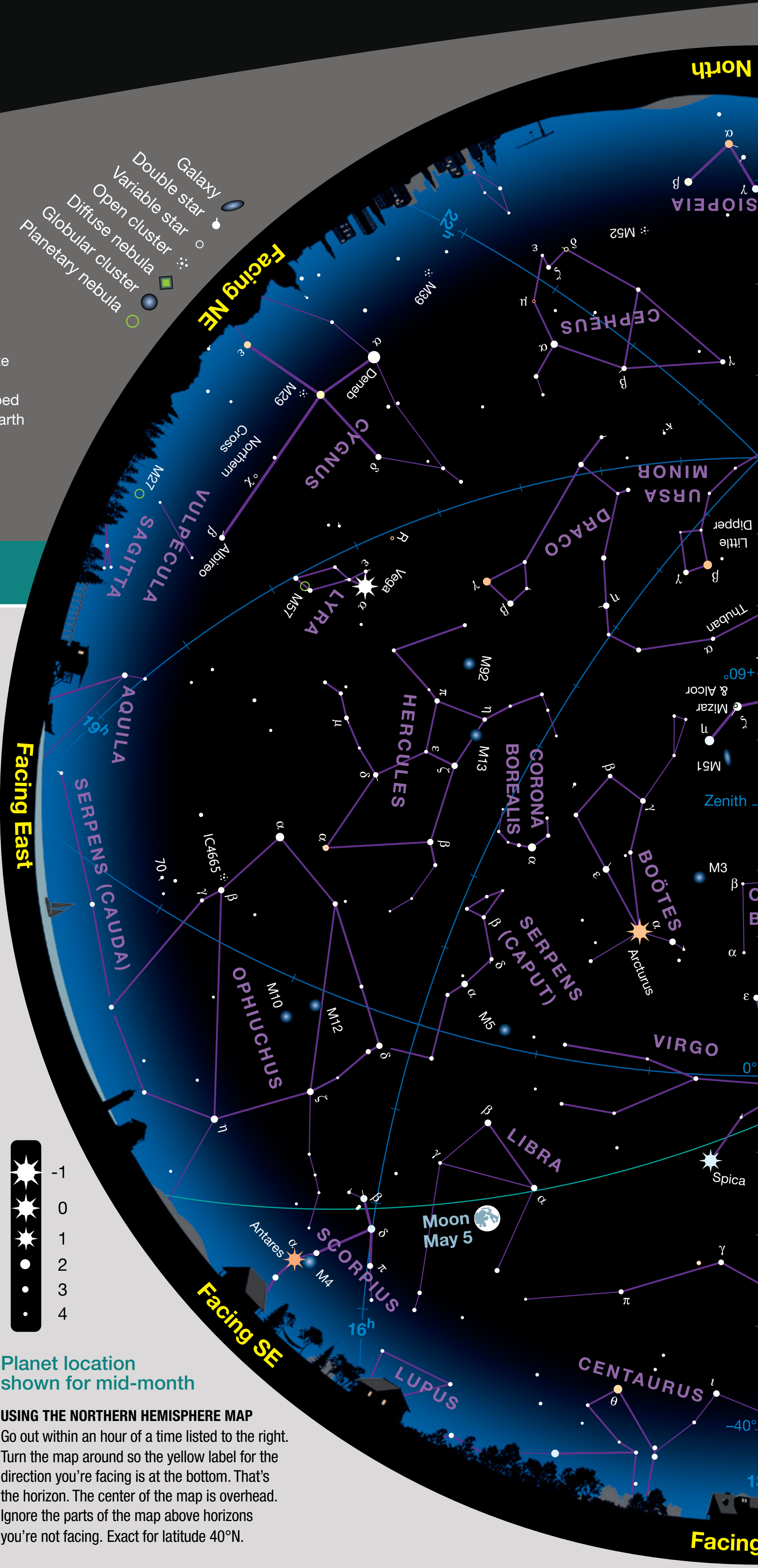
FULL MOON	**LAST QUARTER**
May 5	May 12
17:34 UT	14:28 UT
NEW MOON	**FIRST QUARTER**
May 19	May 27
15:53 UT	15:22 UT

DISTANCES

Perigee	May 11, 05^h UT
369,344 km	Diameter 32′ 21″
Apogee	May 26, 02^h UT
404,508 km	Diameter 29′ 32″

FAVORABLE LIBRATIONS

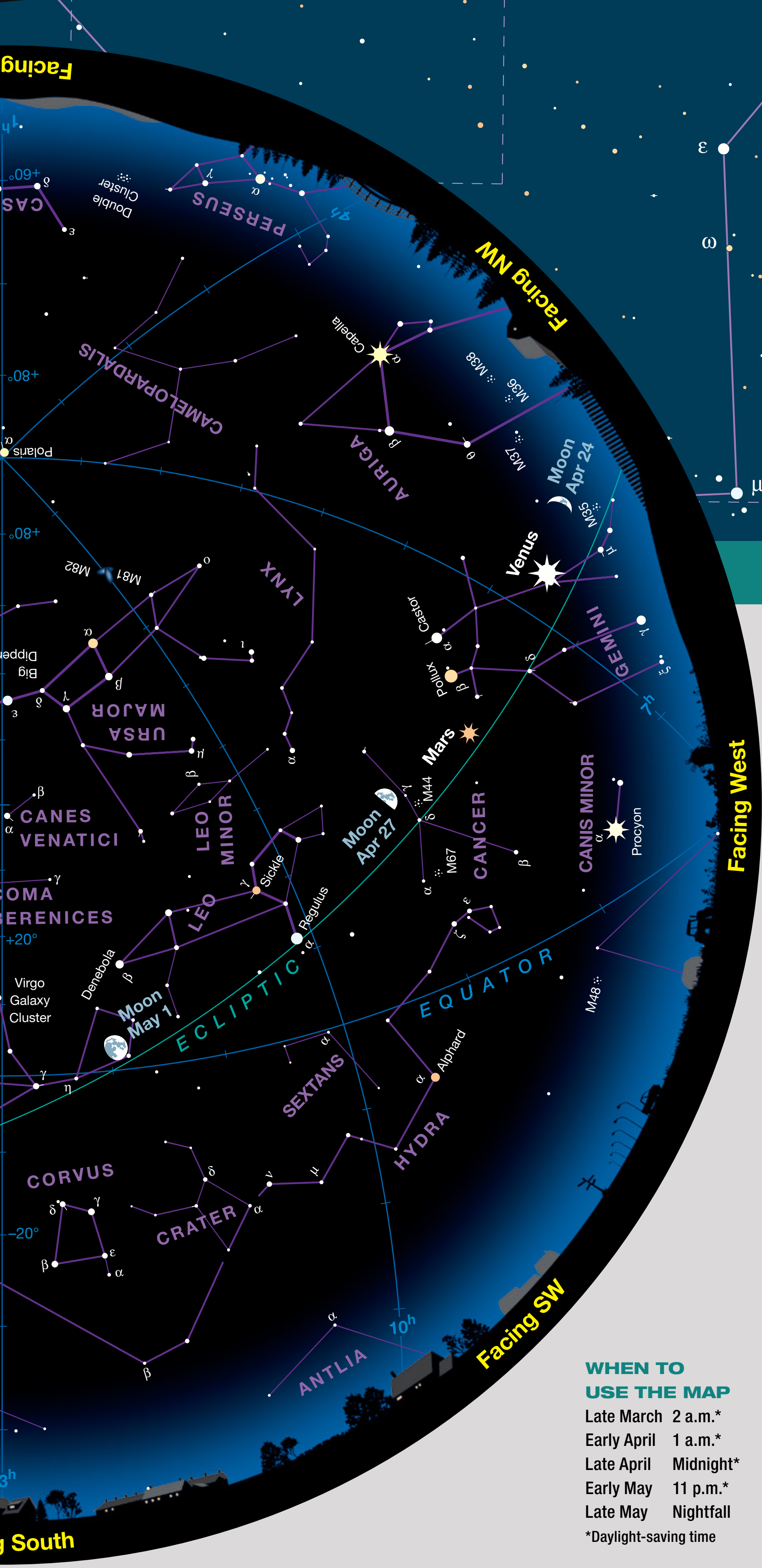
• Vasco da Gama Crater	May 6
• Gerard Crater	May 8
• Brianchon Crater	May 10
• Hale Q Crater	May 24

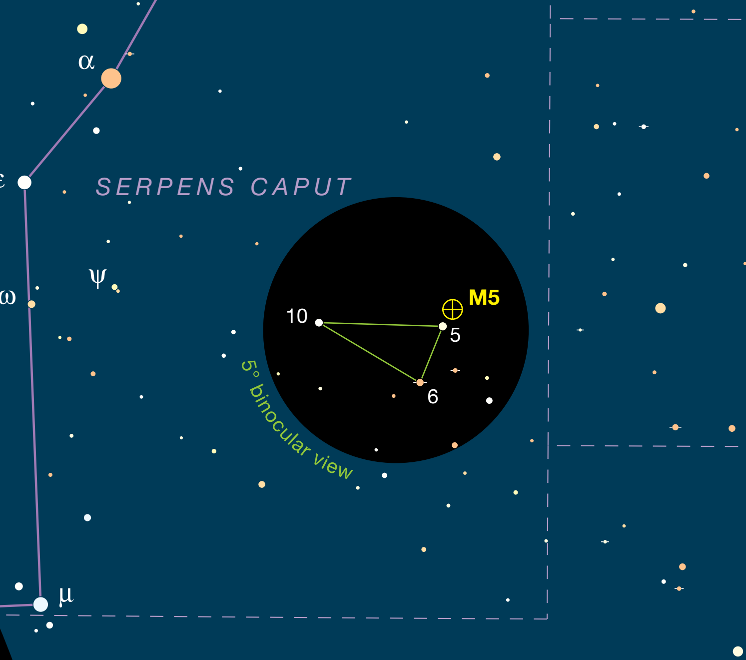


Planet location shown for mid-month

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.





Binocular Highlight by Mathew Wedel

The Serpent's Gem

Our target this month is the globular cluster **M5** in the constellation Serpens Caput, the head of the celestial serpent. My favorite route to the cluster involves a couple of triangles. Imagine 3.7-magnitude Epsilon (ε) and 3.5-magnitude Mu (μ) Serpentis as two points of an equilateral triangle and M5, 8° to the west serving as the third point, completing the shape. I see another triangle: The stars 5, 6, and 10 Serpentis form a shape like a pizza slice, with the globular lying just off its northwestern corner. I fancy that M5 is a glittering jewel protected by the serpent rearing to the north.

With a visual magnitude of 5.6, M5 is naked-eye visible under good conditions. The cluster itself is a marvel, with a compact core and a ragged periphery spangled with bright outlying members. Not all of this detail will be visible in conventional binoculars — like most globular clusters, M5 really starts to take on personality at a magnification of 15× and up. But it's still fun and rewarding to see how much of the cluster's character you can tease out in handheld instruments.

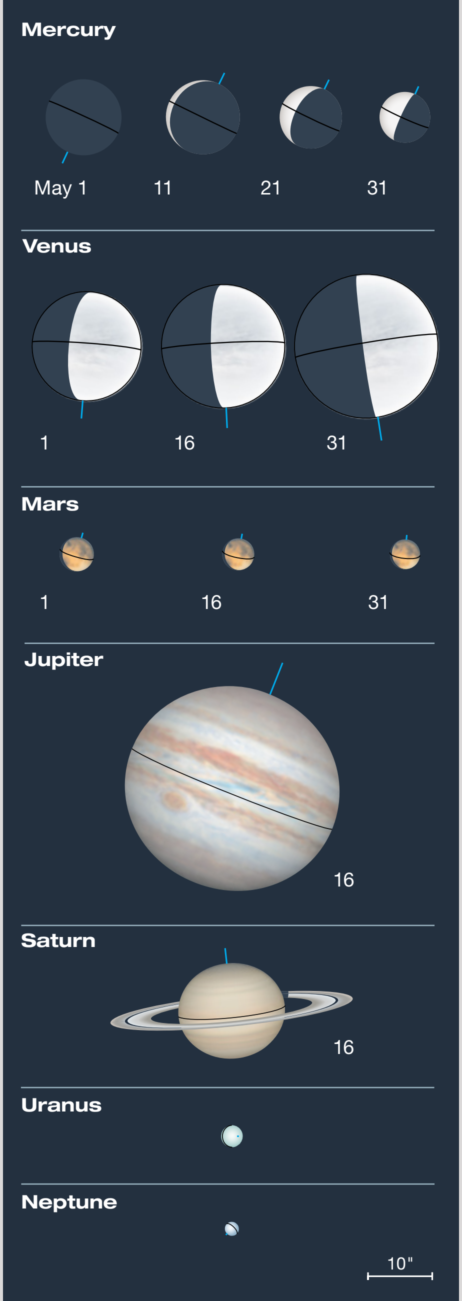
M5 is about 24,000 light-years away and well above the plane of the Milky Way. The more famous globular M13 in nearby Hercules lies at a similar distance, so the visual differences between the two clusters are mostly real, rather than artifacts of distance. I love comparing them — to me, M13 appears larger but less detailed in binoculars. It's a fine cluster, to be sure, but to my eyes the bright core and uneven periphery of M5 give it a little more character, even in 7×50 or 10×50 binoculars. And both deliver the frisson of excitement that comes with drinking in light from a time when woolly mammoths and saber-toothed cats roamed the Earth.

■ **MATT WEDEL** likes to go big-game hunting, tracking down globular clusters in the halo of the Milky Way.

WHEN TO USE THE MAP

Late March	2 a.m.*
Early April	1 a.m.*
Late April	Midnight*
Early May	11 p.m.*
Late May	Nightfall

*Daylight-saving time



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

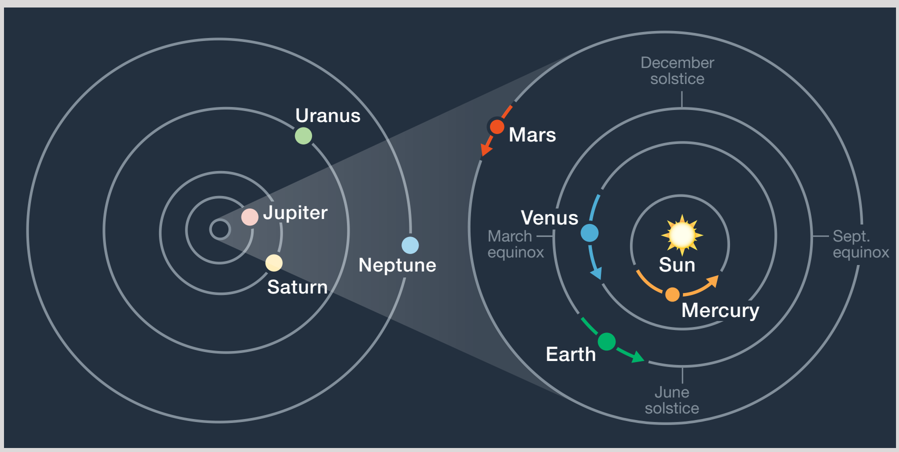
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during May. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** invisible all month • **Venus** visible at dusk all month • **Mars** high in the west at dusk and sets in the predawn • **Jupiter** emerges at dawn starting on the 6th • **Saturn** visible at dawn all month.

May Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 30.6^m	+14° 50′	—	–26.8	31′ 45″	—	1.007
	31	4^h 29.2^m	+21° 48′	—	–26.8	31′ 33″	—	1.014
Mercury	1	2^h 35.6^m	+16° 15′	2° Ev	—	11.8″	0%	0.567
	11	2^h 17.9^m	+11° 53′	14° Mo	+3.1	11.5″	7%	0.583
	21	2^h 22.5^m	+10° 36′	23° Mo	+1.2	9.7″	24%	0.690
	31	2^h 52.0^m	+12° 52′	25° Mo	+0.3	7.9″	42%	0.850
Venus	1	5^h 26.1^m	+25° 38′	42° Ev	–4.2	17.0″	66%	0.981
	11	6^h 15.1^m	+26° 05′	44° Ev	–4.2	18.4″	62%	0.905
	21	7^h 02.4^m	+25° 29′	45° Ev	–4.3	20.2″	57%	0.826
	31	7^h 46.7^m	+23° 54′	45° Ev	–4.4	22.4″	52%	0.746
Mars	1	7^h 22.0^m	+23° 53′	69° Ev	+1.3	5.4″	91%	1.739
	16	7^h 57.7^m	+22° 20′	62° Ev	+1.5	5.0″	92%	1.870
	31	8^h 33.5^m	+20° 18′	57° Ev	+1.6	4.7″	93%	1.992
Jupiter	1	1^h 38.0^m	+9° 03′	14° Mo	–2.0	33.3″	100%	5.925
	31	2^h 04.1^m	+11° 27′	36° Mo	–2.1	34.4″	100%	5.738
Saturn	1	22^h 29.8^m	–10° 58′	65° Mo	+1.0	16.3″	100%	10.188
	31	22^h 35.8^m	–10° 29′	92° Mo	+1.0	17.1″	100%	9.702
Uranus	16	3^h 06.4^m	+17° 10′	6° Mo	+5.9	3.4″	100%	20.655
Neptune	16	23^h 50.2^m	–2° 22′	58° Mo	+7.9	2.2″	100%	30.436

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**.



Appreciating Coma Berenices

What the constellation lacks in luster, it makes up for in wonder.

Stand under a Moon-free country sky on a clear May evening and look fairly high in the south for a thin scattering of dim stars gathered in a delightfully irregular arrangement. What you are seeing is the second-closest open star cluster in the entire sky. But there's more here than meets the eye. That collection of stars (cataloged as Melotte 111) lies within the boundaries of Coma Berenices — a small constellation that occupies an important piece of celestial real estate and is also the subject of an enchanting myth.

On paper, the stars forming Coma Berenices are faint enough to discourage urban or suburban stargazers from taking the time to look. Its brightest lights are a trio of stars forming a right-angle: Alpha (α), Beta (β), and Gamma (γ) Comae Berenices. All three register as 4.3-magnitude, but Beta is (by the tiniest margin) brightest of all. However, none of them is thought to be a true member of Melotte 111, though some sources list Gamma as a possible outlier.

The brightest cluster star is in fact 4.8-magnitude 12 Comae Berenices, located just a bit more than 2½° south-southwest of Gamma. The cluster itself is thought to be less than 300 light-years distant, which is roughly twice as far away as the Hyades in Taurus — the nearest open cluster to Earth.

While none of the stars in Coma Berenices stands out under light-polluted conditions, they aren't especially difficult to identify in reasonably dark country skies. Indeed, if your sky has a limiting magnitude of 5.5, a half-dozen Coma stars are within reach. If you get the chance to enjoy pristine conditions far from city lights, you could see as many as 10 constellation members.

In mythology, the constellation's beautifully irregular arrangement of stars represents the wavy locks of

▲ **HAIR FIT FOR A QUEEN** The tresses of Queen Berenices II grace the May evening sky. The constellation is both modest in size and dim. Of the 88 officially recognized constellations, Coma Berenices ranks as the 42nd largest, and none of its stars shines brighter than magnitude 4.3.

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

Berenice's hair. But how did her hair get up there? Queen Berenice II was co-regent of Egypt with King Ptolemy III, who reigned from 246 to 222 BC. The Queen prayed that her husband would come back from war safely, and to help ensure that outcome she cut off her beautiful amber tresses and took them to the temple of Aphrodite at Cape Zephyrion, in Alexandria. Her husband survived the war, but at some point, her lock of hair mysteriously vanished. The temple priest claimed that the gods had accepted the Queen's tresses and lifted them up to the heavens, where they now glitter as the collection of stars we know today as Coma Berenices ("coma" meaning "hair" in Latin).

On a less fanciful note, the constellation is also where we find the north galactic pole, located just south of a line connecting Beta and Gamma. This point on the celestial sphere is 90° perpendicular to the galactic equator — essentially the central line in the hazy band of the Milky Way that we see so well on summer evenings.

When we look towards the north galactic pole, we're gazing through a thin cross-section of the Milky Way into the depths of space. Unsurprisingly, this line of sight brings into view many, many distant "island universes" — including members of the Coma Cluster, thought to be home to more than 1,000 individual galaxies.

A nearby open cluster, an enchanting legend, and a clear view to the great beyond — I'm sure you'll agree that Coma Berenices is much more than a generous smattering of faint stars!

■ **FRED SCHAAF** recalls getting a good view of Coma Berenices from a rural location, despite the presence of a first-quarter Moon lighting the sky.

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

The Moon Welcomes Jupiter

This month is full of striking conjunctions at dusk and at dawn.

WEDNESDAY, MAY 3

The **Moon** has a busy month, starting this evening when it partners up with **Spica**, in Virgo. As darkness falls, the two are high in the southeast and roughly 2½° apart; however, the Moon is still approaching the 1st-magnitude star. When they're closest a few hours later (at 12:40 a.m. EDT, on May 4th), the gap between them will have narrowed to just a bit more than 2°. As we've noted here before, the Moon zips along at an impressive pace, moving its own diameter ever hour. By the morning of the 7th, it will have crossed Virgo and Libra to sit in Scorpius, about 2½° right of that constellation's brightest star, **Antares**. But even more illustrative of the Moon's pace is the fact that it ends the month as it began, with another Spica encounter. This time the twosome set together (about 4° apart) in the predawn hours of the 31st.

MONDAY, MAY 15

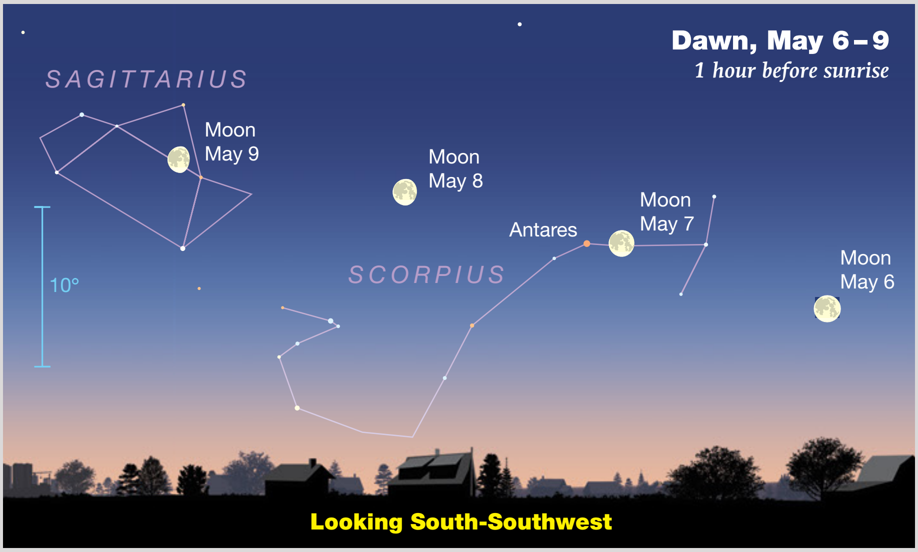
The current **Mars** apparition just keeps going and going and going . . . Thanks to the Red Planet's steady eastward motion along the ecliptic, it manages to keep a healthy distance between itself and encroaching evening twilight. Indeed, Mars advances roughly ½° east per *day* — the same amount the Moon traverses in an *hour*, as it happens. Tonight, the planet's travels bring it in line with **Castor** and **Pollux**, in Gemini. The three dots form a more-or-less straight line that spans some 11°. It will be a delightful naked-eye sight. The alignment will be most perfect for observers on the West Coast, who can watch the trio set late at night in near-perfect alignment. All three are within half a magnitude of one another: Mars glows a ruddy magnitude 1.5, Pollux shines at magnitude 1.1, and Castor's dual suns (appearing as a single dot to the naked eye) add up to magnitude 1.6.

But the most attention-grabbing light in this part of the sky is **Venus**, which gleams at magnitude –4.3 roughly 14° below the threesome. And Venus is moving along at a pretty good clip as well. On June 1st, it will sit roughly where Mars is now, creating an even more impressive sight than this evening's conjunction.

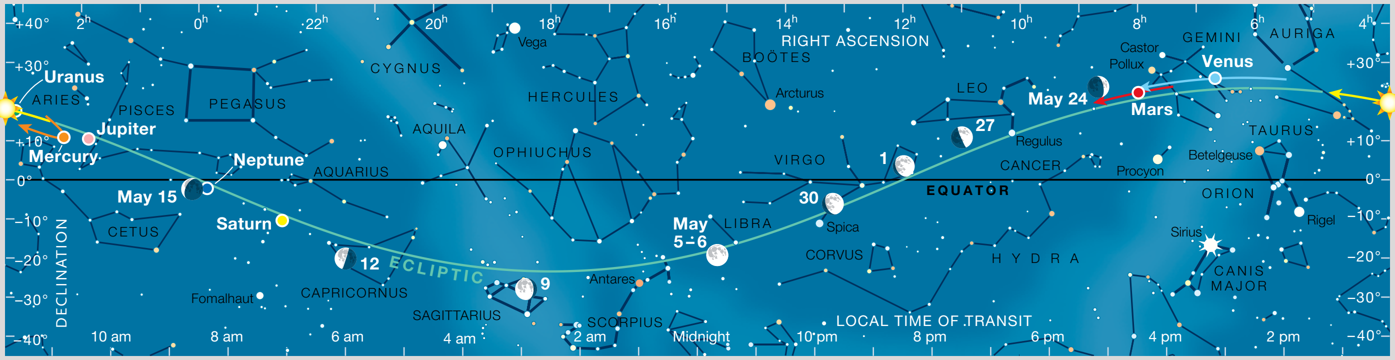
WEDNESDAY, MAY 17

While a lot of the planetary action occurs during evening hours this month, there are a couple of morning events of note as well. Most exciting is a remarkable, but slightly challenging, pairing of the waning crescent **Moon** and **Jupiter**. The "challenge" (such as it is) arises from the fact that the two rise together less than 70 minutes ahead of the Sun and so are awash in bright twilight. Half an hour before sunrise, they stand just 6° above the eastern horizon. But what a sight they are! Depending on your location, much less than 1° separates Big Jove from the narrow, earthlit lunar crescent. Binoculars or a small, wide-field telescope will show them together nicely. As the morning wears on, the Moon edges closer and closer to Jupiter, until roughly 7:40 a.m. EDT when it covers the planet in full daylight, as seen from the East Coast. (For details, turn to page 48.)

This dawn event might be your first glimpse of Jupiter as it begins its new apparition. The planet is emerging from its April 11th conjunction with the Sun and in the coming months climbs higher



▶ 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 Sun and planets are positioned for mid-May; 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.

each morning as it ascends toward its November opposition. Between now and then, it encounters the Moon each month — but none of those meetings will be as close as this one.

MONDAY, MAY 22

Tonight, the waxing crescent **Moon** begins a series of wonderfully attractive conjunctions. Its first dancing partner is the reigning Evening Star, **Venus**. Because the Moon is still approaching Venus, the later you look (and the farther west you are), the smaller the gap between the two will be. The earthlit lunar crescent will be roughly 5° below and right of Venus. Of course, you can use the Moon as a guide to spotting Venus with binoculars even before the Sun sets. Seeing the planet's silvery glint set against a deep-blue sky is one of visual astronomy's most alluring treats.

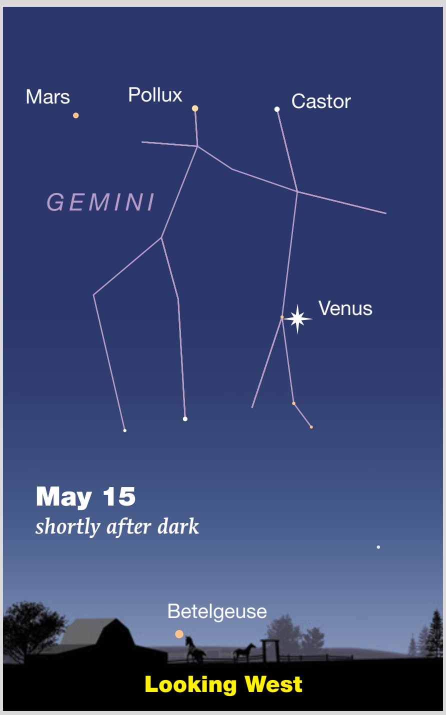
On the following night (the 23rd) the Moon is about 2° below left of **Pollux**, where it sits between Venus and **Mars**. And one night later (the 24th), the crescent is about 4° above the Red Planet.

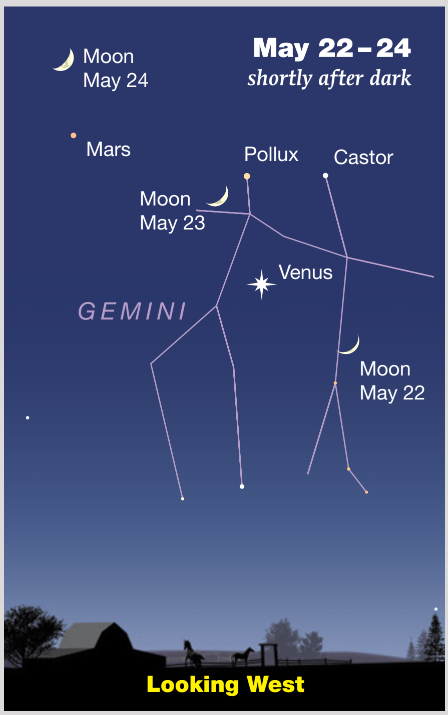
MONDAY, MAY 29

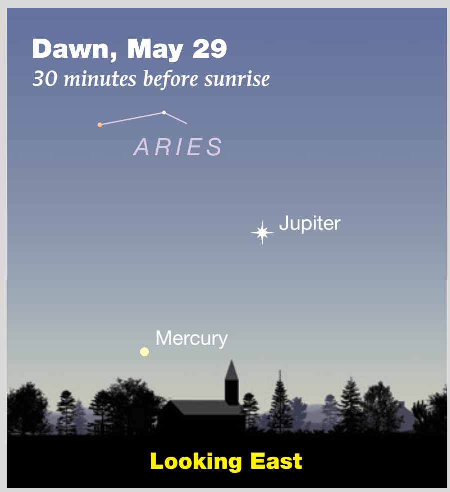
Mercury has its greatest elongation from the Sun this morning. Normally that'd be prime time for catching the little planet, but this is its least favorable apparition of the year. And you're actually better off waiting another week. Why? Because later on, Mercury will be both brighter and very slightly higher. This morning it shines at magnitude +0.4, whereas a week later (June 5th) it achieves a magnitude of –0.1.

Given that the planet will be only 5° above the east-northeastern horizon during this stretch, you're going to need your binoculars to claim it. If you enjoy a challenge, have a try — some of my most satisfying observations have been those I was unsure I'd actually be able to make. And don't despair if you come up empty-handed. In mid-September you'll get a substantially better chance to enjoy views of Mercury.

■ Consulting Editor **GARY SERONIK** always welcomes the start of a new Jupiter apparition.







Jupiter Hides Behind the Moon

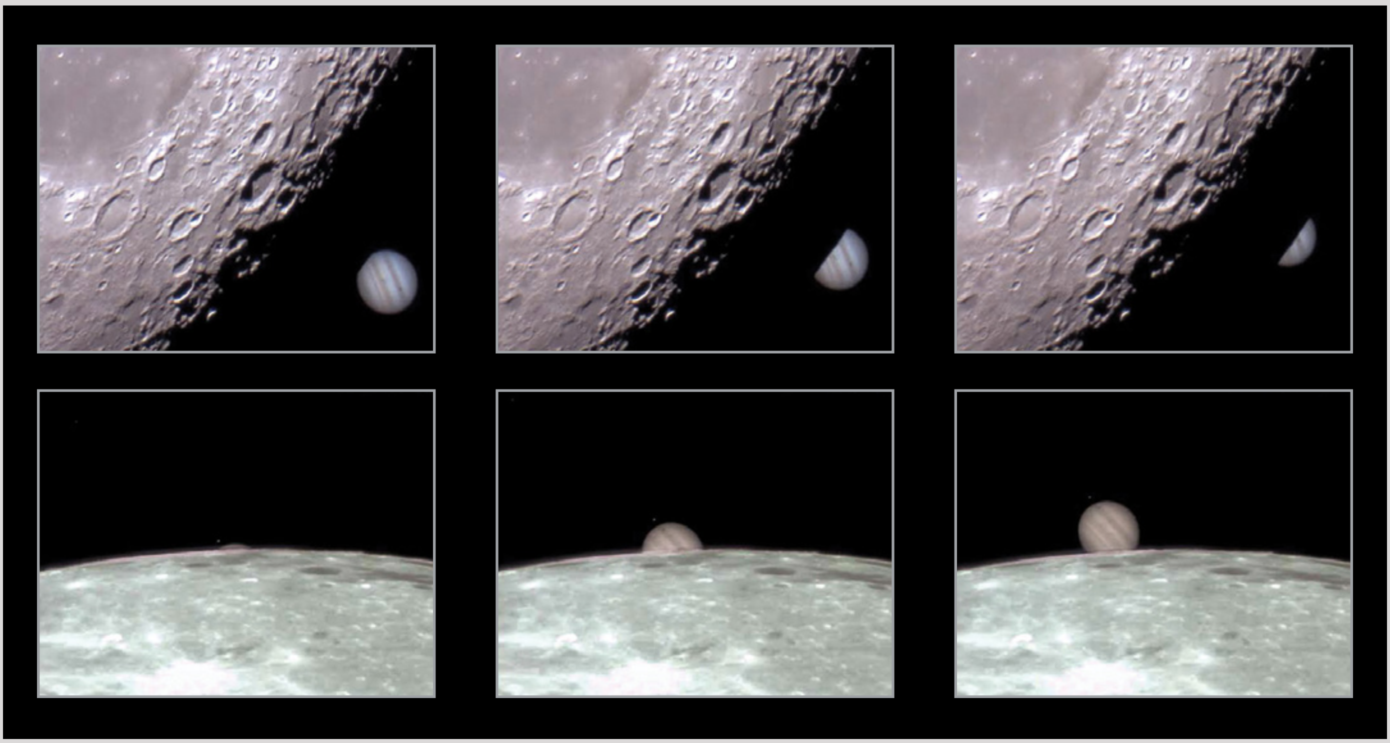
Catch a rare occultation of the solar system's biggest planet.

If you saw either of last winter's Mars occultations, you know how exciting it can be to watch the Moon cover a planet. Traveling along in its orbit at approximately 1 kilometer (0.6 miles) per second, the Moon slid closer and closer to Mars until it appeared to touch the planet — an electric moment. When viewed with a telescope, the Red Planet quickly "set" behind the approaching lunar limb. Some time later (the duration of the event depended on your location) the Moon released Mars, and it appeared to "rise" from behind the trailing lunar limb.

During the December occultation, I keenly sensed our Moon's orbital motion. Watching Mars reappear, in my imagination I visualized a red exomoon rising above the surface of a cratered, alien landscape as the event concluded. The Martian globe's small apparent size compared to the mammoth Moon thoroughly reinforced the illusion — if only for a few minutes.

That observing session whetted my appetite for more. If you feel the same way, or if you've never seen a planetary occultation before, this month presents a great opportunity. On the morning of May 17th, a 5%-illuminated, waning crescent Moon will occult Jupiter in the morning for observers across much of the U.S., Canada, and Central America, and in the afternoon as seen from northern Europe.

For the eastern half of the Americas, the Moon covers the planet after sunrise, in full daylight. However, observers in the western U.S. will see the occultation take place low in the eastern sky during morning twilight. Jupiter reappears after sunrise, except for more northerly locations. In Seattle, Washington, for example, Jupiter disappears at 4:52 a.m. PDT and reappears from behind the Moon at 5:28 a.m., right after sunrise at 5:27 a.m. As the event begins, Jupiter's altitude will be just 2½° and will climb to 9° by the time the occultation wraps up. Skywatchers in



▲ This sequence of images shows the December 25, 2012, occultation of Jupiter as imaged from São Bernardo do Campo, Brazil. During this May's event, Jupiter disappears behind the Moon's bright limb and reappears on its dark limb — the opposite of the 2012 occultation presented above.

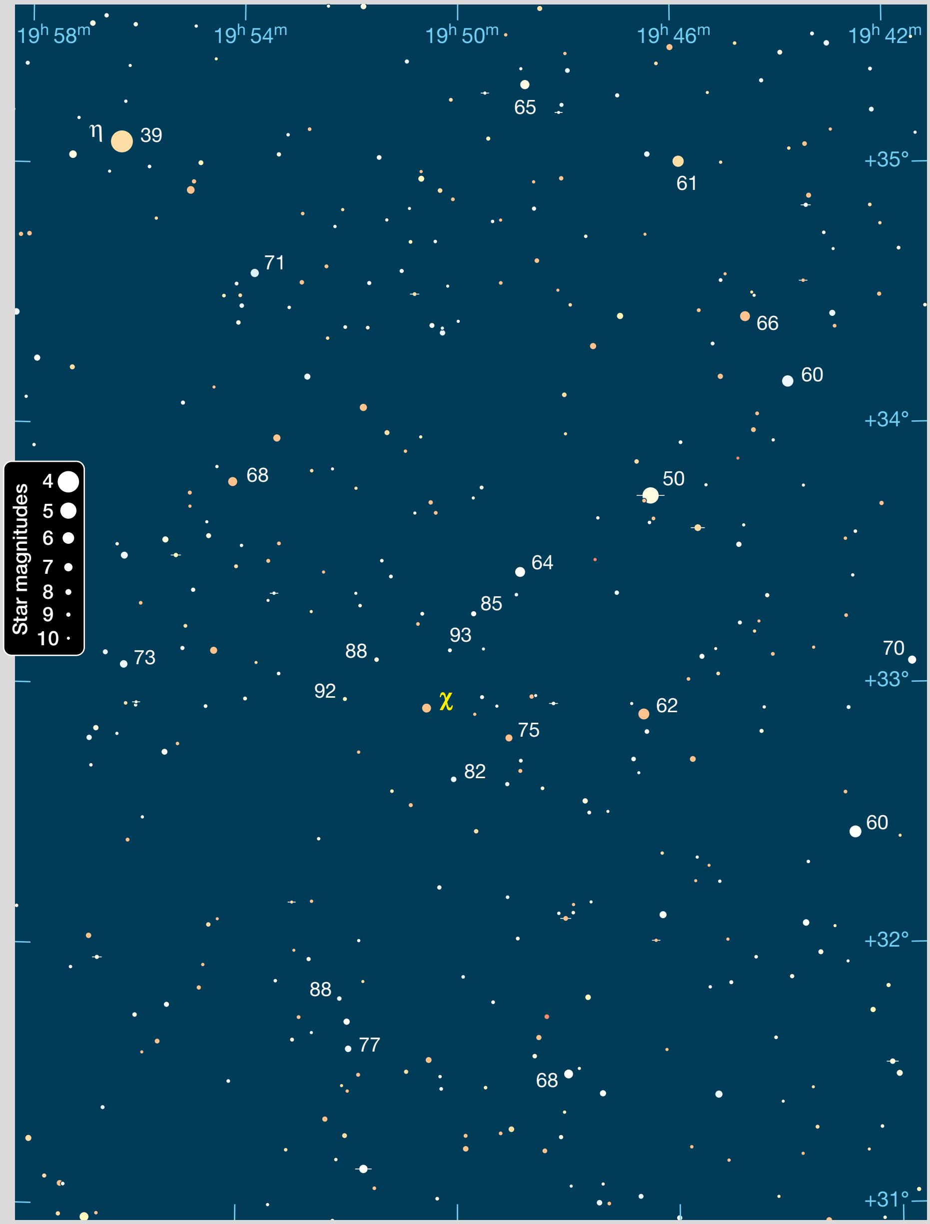
RAFAEL DEFAVARI

Anchorage, Alaska, are afforded the possibility of seeing Jupiter re-emerge at 4:48 a.m. AKDT (right at moonrise), with the Sun peeping above the horizon 19 minutes later.

Observers in the western regions of North America will have the darkest twilight skies, making it easier to view the event in binoculars. For most of the rest of us, the key will be finding the very old Moon (two days before new) in daylight. If you have a very clear, blue sky you can just use your eyes and a stargazing app to guide you to the Moon's position relative to the eastern horizon. Otherwise, a telescope with a Go To mount or setting circles will get the job done. Once you fix the crescent in view, Jupiter will be faintly visible as a small disk immediately east of the Moon. The gas giant will appear very pale but will reveal its most prominent markings, the North and South Equatorial Belts.

Keep in mind that Jupiter returns to view along the Moon's dark limb in daylight, making for a magical sight as the planet seems to materialize from blue nothingness. Coincidentally, a double shadow transit unfolds smack in the middle of the occultation. Europa's shadow begins its Jovian passage at 6:34 a.m. EDT (10:34 UT) followed by Io's shadow at 7:51 a.m. EDT (11:51 UT). Will you be able to see the tiny black dots? Perhaps. Discerning the two moon shadows in the light of day and with the planet at such a low altitude will require exceptional seeing conditions and high magnifications.

To find precise details for your location, I recommend simulating the occultation with a stargazing app, such as *SkySafari* or the free program *Stellarium*. One tip for *Stellarium* users: Select the Sky and Viewing Options button (F4) and reduce the relative scale to 0.25 under Stars on the right side of the Sky tab. This will display Jupiter and its satellites plainly at low zoom levels more naturally than the software's default settings will.

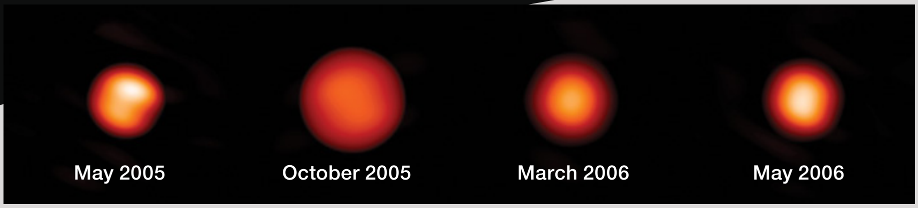


Keeping an Eye on Chi

WE JUST MIGHT SEE a "new" naked-eye star in the Northern Cross this month. The Mira-type variable Chi (χ) Cygni, located about 6½° northeast of Albireo, is expected to reach peak brightness around May 2nd, when it tops out at around 4th magnitude — or possibly even brighter.

Glowing like a tiny shard of sun-struck garnet, Chi Cygni should be unmistakable in either a telescope or binoculars. The star has a range that would make an opera singer jealous — climbing as high as magnitude 3.3 before plummeting to 14.2. That's a 23,000× brightness swing! Chi Cygni is full of surprises, too. In 2006, it reached magnitude 3.8, its brightest peak since the mid-1800s. But eight years later, in the summer of 2014, the star only managed magnitude 6.8. During its most recent maximum in April 2022, it maxed out at around 5.0.

▲ Use this map to estimate Chi (χ) Cygni's brightness. Labeled stars show magnitudes with the decimal point omitted. North is up.



▲ This sequence of infrared images, made in 2005 and 2006 with the Infrared-Optical Telescope Array optical interferometer, reveals the changing shape and brightness of the pulsating red giant star Chi (χ) Cygni, located approximately 520 light-years from Earth. Images show up to a 40% variation in the star's diameter as well as hot spots and changes in the amount of limb darkening.

One of my favorite stories about Chi Cygni concerns its discovery. Johann Bayer recorded the star in his 1603 *Uranometria* atlas, but the first person to recognize its variability was German astronomer Gottfried Kirch, in 1686. While observing the nova known today as CK Vulpeculae (in the neighboring constellation, Vulpecula), Kirch noticed that Bayer's Chi Cygni was missing. Several months later it returned, establishing the star's variable nature.

Most long-period variables are of spectral type *M*, but Chi belongs to the rarer spectral type *S*, whose stars are richer in carbon as well as zirconium. Convection currents dredge these elements from the star's interior and deposit them in the outer layers.

Spectrographs show lots of dark absorption bands in Chi's light caused by zirconium oxide and other molecules in its cool, distended atmosphere. Like all Mira-type stars, Chi's outer layers expand and contract as it seeks (and fails) to reach equilibrium.

The star's cyclic palpitations affect both its luminosity and size. Over its 408-day cycle, Chi's diameter varies from approximately 195 million kilometers (121 million miles) at maximum brightness to as large as 464 million kilometers at minimum. That's 140 to 333 times the diameter of the Sun! Picture that when you lay eyes on Chi Cygni this month.

Occultation Rehearsal

THREE MORNINGS BEFORE it occults Jupiter, the Moon will take a swing at Psi^3 (ψ^3) Aquarii, a 5th-magnitude star that forms part of a compact trio in eastern Aquarius that also includes Psi^1 and Psi^2 Aquarii.

On May 14th, observers across the eastern two-thirds of the U.S. will witness some part of the occultation. From the East Coast, the bright limb of the waning lunar crescent covers the star in morning twilight, but the reappearance occurs close to or after sunrise and won't be visible.

Midwesterners will miss the ingress but catch sight of the star popping back into view on the Moon's dark limb in morning twilight. Psi^3 should be plainly visible in even the smallest telescopes and probably in tripod-mounted binoculars, too. Farther west in the Mountain states, the star reappears shortly after moonrise in complete darkness, but at low altitude. (The occultation won't be visible from the West Coast.)

For precise times for your location, run a simulation on your astronomical software of choice, as described previously.

◀ This simulated view shows the 5th-magnitude star Psi^3 Aquarii moments before it's covered by the advancing lunar crescent.

Action at Jupiter

AFTER A ONE-MONTH absence, Jupiter emerges at dawn from its April 11th conjunction with the Sun. As a new apparition begins, the planet will initially be a somewhat disappointing telescopic sight, owing to its low altitude for much of the month. From mid-northern latitudes, on May 6th (roughly the first morning it'll be visible to the naked eye) Jupiter sits just 1.4° above the east-northeastern horizon 30 minutes before sunrise. By the 15th, that figure has improved to 5.2°, and on the 31st to 13.3°. The planet reaches opposition in autumn, on November 3rd. For telescope users, the most rewarding span of this apparition is bracketed between August 22, 2023, and January 30, 2024. The first of those dates corresponds to when the planet reaches the meridian by the start of morning *civil twilight* (when the center of the Sun is 6° below the horizon). The second date is when Jupiter first crosses the meridian as evening civil twilight begins. Of course, that's simply a rule of thumb — the planet can be enjoyed well beyond those two dates.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for 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.)

INTERFEROMETRIC IMAGES: SYLVESTRE LACOUR, OBSERVATOIRE DE PARIS; OCCULTATION SIMULATION: STELLARIUM

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

SEAN WALKER

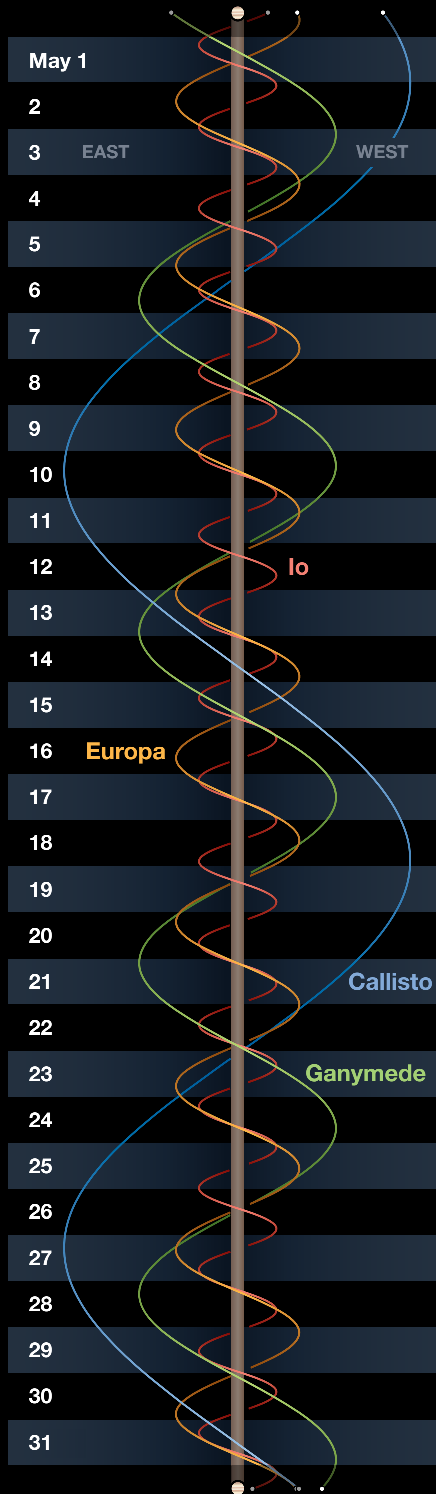
These times assume that the spot will be centered at System II longitude 38° on May 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 38° and $1\frac{2}{3}$ minutes later for each degree more than 38°.

Phenomena of Jupiter's Moons, May 2023

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

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

Jupiter's Moons



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

The Ashen Light of Venus

Recent spacecraft images lend new credibility to a controversial planetary feature.

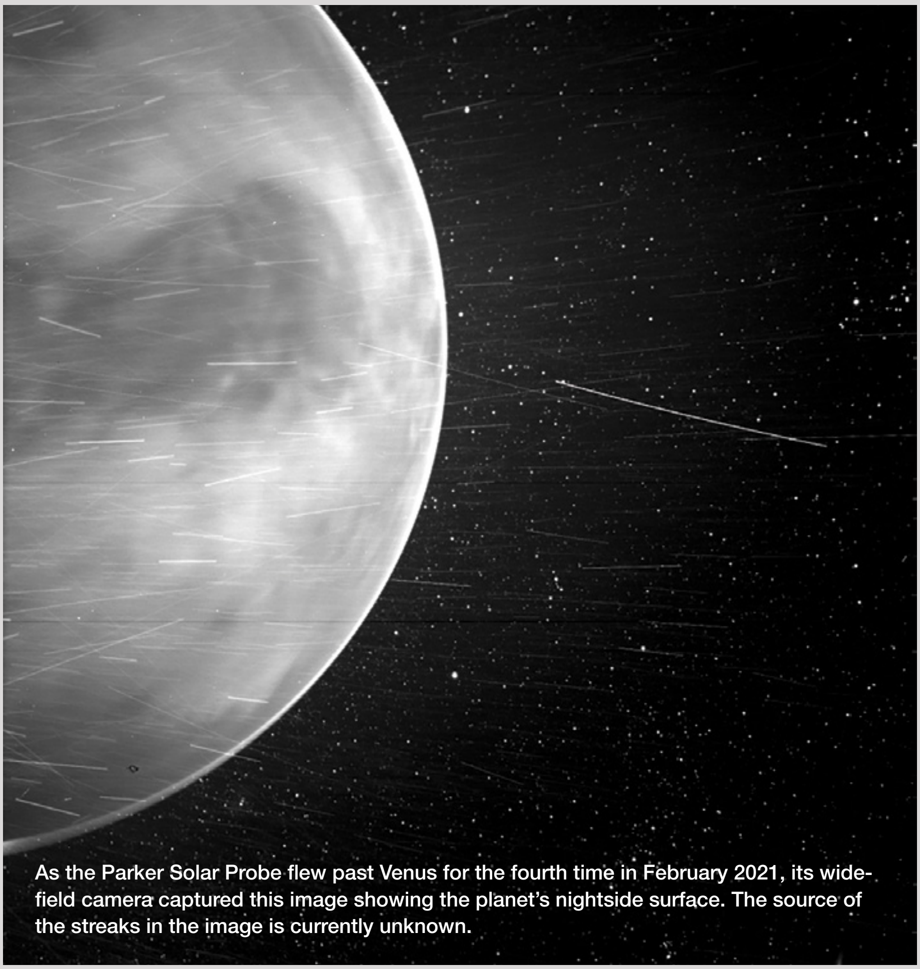
For more than three centuries, visual observers have reported a faint glow emanating from the nightside of Venus. Dubbed the *ashen light*, the elusive phenomenon is only sporadically visible and usually glimpsed when the planet appears as a slender crescent. In recent years, most authorities have written off the ashen light as an optical illusion. There's no denying that the human eye–brain combination has an insidious tendency to fill in or complete the figure of a crescent. Most reports of ashen light sightings should be taken with a boulder-size grain of salt.

Venus is invariably a disappointing target for telescopic observers because of an unbroken canopy of clouds and haze that conceals the planet's surface from prying eyes. During the early 1980s, astronomers discovered that this veil is partially transparent in the near-infrared region of the spectrum — wavelengths invisible to the human eye. In this spectral window at 800 to 1,100 nanometers it's possible to image the planet's nightside surface, which bakes at a furnace-like temperature of about 460°C (860°F) and glows like a piece of iron pulled from a forge. In the near-infrared, Venus's nightside has a dappled appearance that roughly corresponds to the surface topography mapped by NASA's Magellan spacecraft in the early 1990s. The slightly cooler highlands appear darker than the surrounding lowlands.

In 2006 Frederick Taylor of the Atmospheric, Oceanic, and Planetary Physics department at Oxford University speculated that the thermal glow of the surface might account for the ashen light if the layers of cloud and haze are sufficiently transparent in the visible region of the spectrum. Although the ashen light is usually described as uniform and colorless, some observers have described a mottled texture as well as a warm ruddy or coppery hue. That's exactly what images taken in 2020 and 2021 by NASA's Parker Solar Probe seem to reveal.

Launched in 2018, the Parker Solar Probe is using a series of seven gravity-assist flybys of Venus to shrink its highly elliptical orbit and gradually spiral closer to the Sun. The spacecraft's Wide-field Imager for Parker Solar Probe (WISPR) camera is designed to take images of the outermost reaches of the Sun's atmosphere and the solar wind in visible light.

Visible-light images of the nightside of Venus recorded during the third and fourth flybys of the planet look very similar to near-infrared images, albeit with subdued contrast. An estimated



As the Parker Solar Probe flew past Venus for the fourth time in February 2021, its wide-field camera captured this image showing the planet's nightside surface. The source of the streaks in the image is currently unknown.

NASA / JOHNS HOPKINS APL / NAVAL RESEARCH LABORATORY / G. STENBORG AND B. GALLAGHER

80% of the reddish thermal glow in the visible region of the spectrum is absorbed or scattered by Venus's dense atmosphere and low-lying clouds, but about 20% penetrates the blanket of gas and mist.

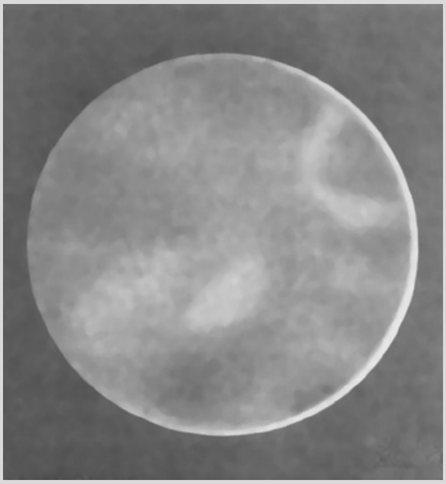
A decade ago, veteran NASA planetary scientist Dale Cruikshank calculated the intensity of the visible-light component of the dull-red thermal glow of the nightside of Venus and its apparent brightness as seen from Earth. His luminance value for red light (650 nanometers wavelength) exceeds the brightness of the Milky Way's star clouds by a factor of 20. So, if 80% of this light is absorbed or scattered, is it possible to see the remaining 20% in close proximity to the dazzling glare of Venus's sunlit crescent? Richard McKim, who served as Director of the British Astronomical Association's Venus Section from 2004 to 2019, believes it is. He suspects that the changing visibility of the ashen light is caused by variations in the thickness of low-level clouds and perhaps even in the level of Venusian volcanic activity.

Naval Research Laboratory astrophysicist Brian Wood hesitates to attribute the ashen light to thermal glow because the sensitivity of the human eye is highest in green light (around 555 nanometers) and falls off by a factor of almost 10 in red light. Wood suspects that a green emission feature recorded in Parker Solar Probe images may be a more plausible explanation.

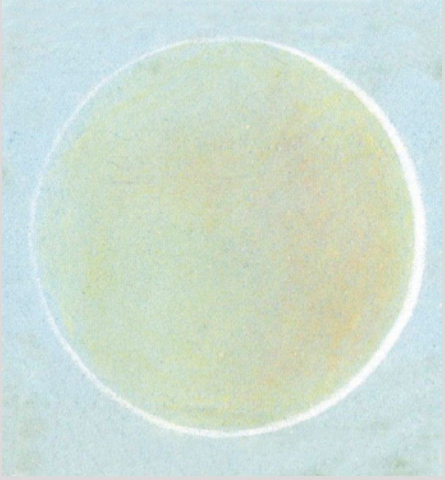
During the day, intense solar ultraviolet radiation breaks down molecules of carbon dioxide in the atmosphere of Venus high above the cloud deck, liberating atoms of oxygen. Fierce, 320 km/h (200 mph) winds rapidly transport these energized atoms to the night side of the planet, where they slowly combine to form diatomic oxygen molecules (O_2). The energy released by this reaction emits green light.

First detected during the 1970s by the Soviet Venera 9 and Venera 10 spacecraft, the brightness of this visible oxygen airglow fluctuates dramatically depending on the level of solar activity. In the Parker images it's very prominent right along the planet's limb, where

CHEVEAU DRAWING: PUBLIC DOMAIN



▲The ashen light is often described as a uniform glow emanating from the nightside of Venus. However, many observers have reported an irregular, dappled appearance similar to what is portrayed in this 1932 drawing by Robert Cheveau using a 7½-inch refractor.



▲This sketch by Dale Cruikshank depicts the appearance of the nightside of Venus during a daylight observation in 1962. This intriguing observation by a seasoned observer and eminent planetary scientist lends credence to the notion that the thermal glow of the planet's torrid surface may occasionally be visible in telescopes.

the depth of atmosphere along the line of sight is greatest. This feature may correspond to a narrow, glowing band outlining the planet's nightside limb that was seen on several occasions during the 1950s and '60s and dubbed "the woolen thread" by the British observer Valdemar Firsoff.

Wood points out that Venus's dense atmosphere is also very effective at refracting sunlight from the dayside and wonders if a perceptible amount reaches all the way to center of the nightside. "It's clearly there at some level in the [Parker] images and older Venus Express orbiter data," he says. "A lot more work has to be done to quantify it, but this light would certainly be at wavelengths the eye would be very sensitive to."

I've seen the ashen light only once — almost four decades ago — but I remain convinced that what I saw was no illusion. The Parker images seem to lend credibility to my eyepiece impressions of a ghostly light marred by a diffuse dark blotch that's still a vivid memory after so many years.

The Parker Solar Probe team plans to acquire more data during the spacecraft's final flyby of Venus in November 2024. Meanwhile, they encourage observers to gather more data as well: "It would be a worthwhile project for both amateur and professional astronomers to assess whether the optical surface emission seen by [Parker] might be sufficiently bright to be observable from the ground."

For observers in the Northern Hemisphere, evenings in the late spring and early summer of 2023 present an unusually favorable opportunity to attempt to image in visible wavelengths. From 40° north latitude, on June 16 the planet's 43%-illuminated crescent will stand 32° above the horizon at sunset. By July 17 the crescent will be only 18% illuminated, and the planet's altitude at sunset decreases to 15°.

Take advantage of this four-week observing window to carefully monitor the nightside of Venus for the ashen light. Comparing visual impressions with images taken through red and green filters combined with an infrared blocking filter may finally solve one of observational astronomy's oldest and most enduring mysteries.

■ Although Contributing Editor **TOM DOBBINS** has witnessed the ashen light only once, it made a lasting impression.

Aiming High for M97 and M108

Two faint Messier objects lie alongside the Big Dipper overhead at nightfall.

I live on the north side of a small city. My sky to the south is awful, and the view northward is . . . not quite awful. On a perfect night, I can count up all seven members of the Little Dipper.

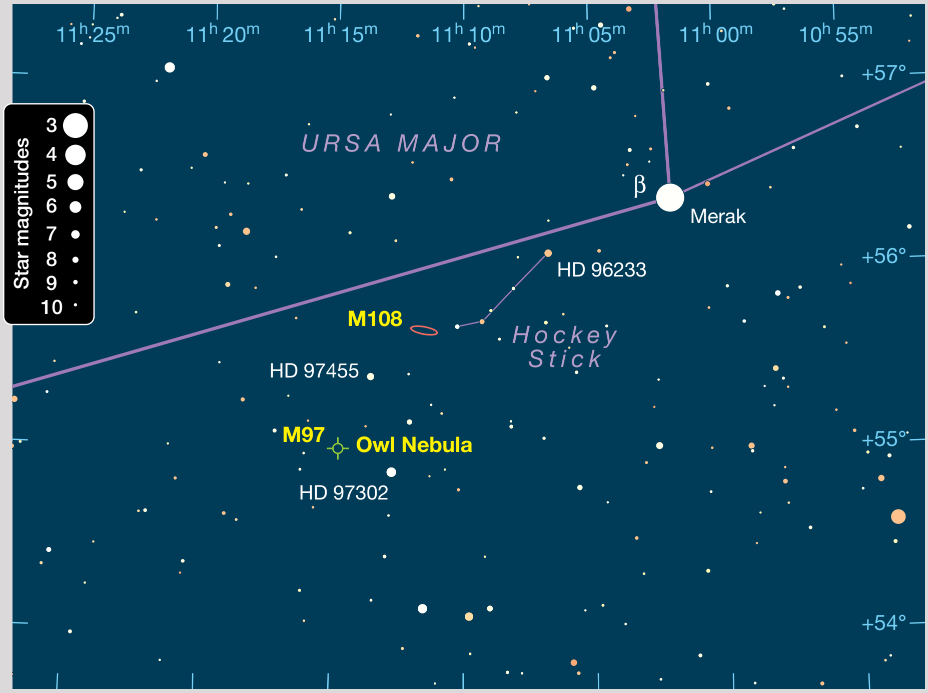
Alas, my suburban neighborhood is pocked with porch lights, some of them blinding. A few neighbors like to string up glaring party lights above their backyards and leave them on all night. Grrr. Needless to say, the delicate denizens of deep space don't look great in my backyard telescopes. But ever the optimist, I star-hop to Messiers and NGCs, no matter how long it takes. Glimpsing those faint fuzzies overhead often boils down to dogged determination and timing. The best time to view faint sights is when they're highest in the sky, where atmospheric dimming (and, typically, light pollution) is minimal.

Fortunately, not all star-hops are long and require you to be able to see faint stars — some don't even require an

RON BRECHER

▶ **DISPARATE DENIZENS OF THE DEEP**
Planetary nebula M97 and spiral galaxy M108 lie less than 1° apart and near Beta (β) Ursae Majoris, also known as Merak. However, appearances can be deceiving. Merak is 80 light-years from Earth. M97 is 2,600 light-years away, and M108 lurks at a distance of roughly 45 million light-years.

▶ **A SHORT STAR-HOP** A little ramble from Merak in the Big Dipper takes the careful observer southeastward past two 7th-magnitude stars to the nearly edge-on spiral galaxy M108 and the planetary nebula M97. The total distance traveled — as the Owl flies — is 2¼°.



optical finderscope. One quite manageable hop begins at 2.4-magnitude Beta (β) Ursae Majoris, or Merak, which marks the southwest corner of the bowl of the Big Dipper. From Merak, a few star-hops lead to a pair of challenging Messier objects worth tracking down.

My 10-inch f/6 Dobsonian reflector — my weapon of choice for stalking faint stuff — is equipped with an optical finderscope, but in this case I've used it only for locating Merak. The pale prizes are close enough to the star to permit star-hopping without lifting my eye from the eyepiece.

Almost Outta Sight

First up is **M108**, a nearly edge-on spiral galaxy lying 1½° east-southeast of Merak. I get underway by aiming my 10-inch Dob at the star, centering it in the field of view of a 24-mm eyepiece generating 64×. I could go as low as 48× (using a 32-mm eyepiece), but I'll explain in a moment why I opt for the modest 64× magnification.

I begin the search by shifting ¾° southeastward to HD 96233, a solitary, 7.3-magnitude star. That first hop gets me almost halfway to the target — except the path from Merak through the star to M108 isn't quite straight. To ensure success, I follow a ragged, 40′-long hockey-stick asterism outlined by HD 96233 plus four dimmer stars. The faintest star in the stick is magnitude 9.8, so it's an easy route to follow. The 8′-long blade aims eastward, very close to M108.

Easy pickings? Not exactly. The galaxy is a reasonable 8.6′ × 2.4′ in extent, oriented roughly east-west, and it's a respectable magnitude 10.0. However, because the object's light is spread across a relatively broad area, its surface brightness is a full three magnitudes fainter than its catalog figure. Moreover, the galaxy's slender form is interrupted by dark dust lanes. M108 is difficult to appreciate in a city sky; indeed, for me it's a missing Messier at low power. That's the reason I hop along the hockey stick carefully searching for a fuzzy "puck" beyond the blade.

Sometimes, I can spot M108 at 48×, but the galaxy is a barely perceptible thread of light. At 64×, I get a longer wisp that's easier to notice. Working at 90×, the scope picks up a 12.2-magnitude star off M108's western tip, and an extremely dim pinpoint overlying the galaxy just west of center. On the clearest nights the spindly mass appears a bit wider and brighter towards the middle.

With the Dob upped to 127×, I can pick up some mottling with averted vision — subtle evidence of the galaxy's thick dust lanes. The scene at 169× is problematic — all I see is the central bulge (the fuzzy puck I mentioned earlier). Threading a light-pollution reduction (LPR) filter into the eyepiece barrel improves the contrast between the smudge and the sky, but the LPR reveals no additional details.

Elusive Owl

Nearby is **M97**, a classic planetary nebula — a ghostly giant "planet" floating some 2,600 light-years away. Nicknamed the Owl Nebula, M97 sports a diameter of 2.8′, which is significantly larger than the similarly distant doughnut of the famous Ring Nebula (M57) in Lyra. However, M97 glows wanly at magnitude 9.9 (one magnitude dimmer than the Ring), and because its light spans such a big area, its disk is diffuse. Moreover, the pale visage of the Owl is unevenly illuminated; two holes in the disk form the owly eyes.

High in the Dipper

Object	Type	Mag(v)	Size	RA	Dec.
M108	Galaxy	10.0	8.6′ × 2.4′	11h 11.5m	+55° 40′
M97	Planetary nebula	9.9	2.8′	11h 14.8m	+55° 01′

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.

▲ **CELESTIAL SURFBOARD** M108 is nicknamed the Surfboard Galaxy due to its elongated shape, a result of it lying not quite edge-on. Note the irregular dust lanes cutting below center across the front of the galaxy, which is very slightly inclined to our line of sight.

▲ **MIDNIGHT OWL** M97 is a distended, atmospheric shell of gas ejected from a dying, shriveling star. Bipolar outflows from the central star are evident in this image, though the visual observer perceives only a diffuse disk — perhaps with two dark "eyes" embedded within.

RON BRECHER (2)

M97 is situated only a little more than ¾° southeast of M108. But capturing the Owl can be tricky because of its pallid complexion. Identifying it in my blanched city sky is a three-step process. First, staying focused on M108, I lower the magnification to 48×, then I shift the scope 23′ southeastward to a 7.5-magnitude star (HD 97455). Finally, I veer southeastward for another 23′ to the planetary.

Just one problem: I often sweep right past the ghostly object. It may seem counterintuitive, but the key to a quick catch is to nudge s-l-o-w-l-y. There's a 6.6-magnitude star, HD 97302, shining ⅓° southwest of M97. When I have both HD 97455 and HD 97302 in the low-power field, I know M97 is in there, too. With that in mind, I add the LPR filter, and a tiny, gauzy disk pops into view. Bingo! I'm amazed at how a basic LPR can lift M97 out of a city sky. An Ultra-High Contrast (UHC) or doubly ionized oxygen (O III) filter works even better. The UHC and O III narrowband filters block unwanted light from the sky while passing most (though not all) of the nebula's emission. The O III is especially efficient. If you want the Owl to hoot, give it oxygen!

Occasionally, I can make out M97 at 48× without a filter. As I increase magnification, though, the round cloud becomes terribly dim and diffuse. Much beyond 100×, it dissolves into nothingness. With the LPR in place at 127×, the Owl becomes slightly oblate and vaguely textured. The blotchiness gets me closer to perceiving the two dusky hollows in the disk. A UHC filter enhances the nebula, but the field of view itself is a bit darker. The O III view is darker still. Amid the ambient neighborhood light, I shield my eye in a bid to spy the eyes of the Owl. One? Two? Maybe, just maybe.

Small-Scope Challenge

I asked my trusted colleague David Rodger to give these disparate Dipper objects a try. David lives in North Vancouver, 100 km (62 mi) west of me. He observes from a north-facing patio and, like me, confronts a northern sky he charitably characterizes as "almost palatable." David can detect M97 in his 4.7-inch apochromatic refractor at 39× with the aid of an O III filter. His scope doesn't show M108 at any magnification, even with a LPR. David and I agree that the slender galaxy is a tougher challenge than the pale planetary.

It's fun trying to pick up M97 and M108 in the same low-power eyepiece. I can frame them in my 10-inch Dob on opposite sides of a 58× field. I use a LPR filter to enhance both the nebula and the galaxy. (Be aware that while a UHC or an O III will revive the planetary, either one will kill the galaxy.)

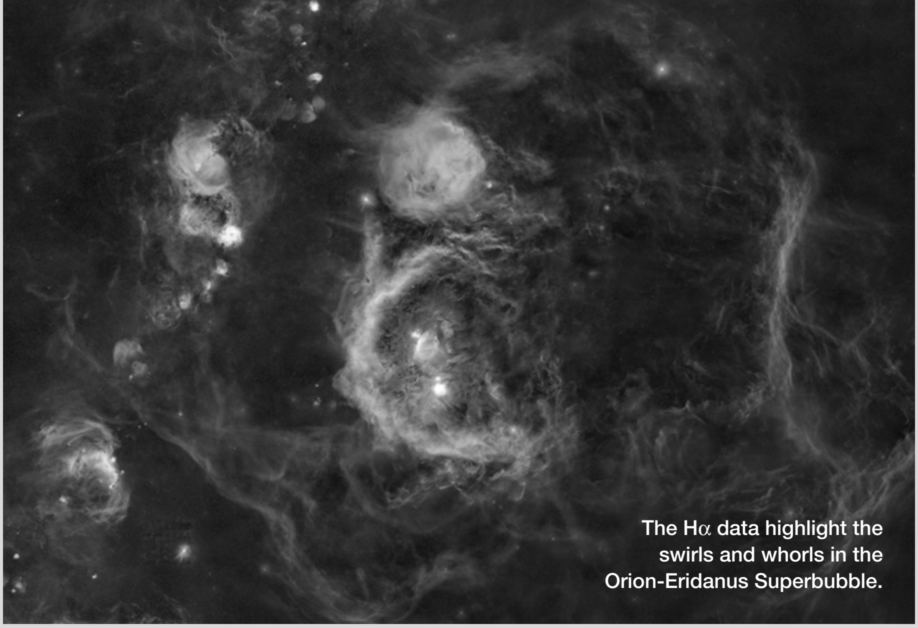
I consider all this a victory. Glimpsing these fragile deep-sky objects in a city sky gives me a sense of satisfaction — of winning against the odds. So, get outside on the next clear, moonless night and aim high!

■ A few years ago, Contributing Editor **KEN HEWITT-WHITE** actually heard an owl hoot in the distance while observing the Owl Nebula.

by Diana Hannikainen

Surveying the Neutral Hydrogen Sky

Researchers dip into *S&T* editors' survey data.


The Hα data highlight the swirls and whorls in the Orion-Eridanus Superbubble.

MDW HYDROGEN-ALPHA SKY SURVEY

The fascination of *Sky & Telescope*'s very own Dennis di Cicco with the hydrogen-alpha (Hα) sky dates to the 1960s, when he was still in high school. Back then, he'd shoot images of nebulae using photographic emulsions — light-sensitive materials, for those of you too young to remember. After Associate Editor Sean Walker joined the *S&T* staff in 2000, the pair — having discovered a mutual interest — experimented with imaging in Hα from Dennis's backyard observatory. Things really took off when they started dabbling in wide-angle imaging with camera lenses.

For an early project, Dennis and Sean tackled the huge, faint western edge of the Orion-Eridanus Superbubble. Night after night they acquired data, probing the limits of what they could image in Hα. Sean then assembled the results into a mosaic, which they published in the April 2009 issue of the magazine. The final image covered more than 4,000 square degrees (that's almost 10% of the whole sky visible from Earth!). The file size was a whopping 100 MB.

The survey begins. Shortly after that, the *S&T* duo joined forces with David Mittelman (1954–2017). Passionate about astronomy since college, he operated a couple of telescopes remotely in New Mexico. The three of them would meet regularly and talk all things astronomy — and process the data coming out of New Mexico. During these sessions, chats about Dennis and Sean's Hα work planted a seed in their collective minds: Could they possibly map the whole sky in Hα? One evening in late 2015, over dinner and wine, they decided they could . . . and thus the MDW Hydrogen-Alpha Sky Survey blossomed into being. (MDW stands for the first initial of the three gentlemen's surnames; the Survey is now part of the Mittelman Family Foundation.)

The trio had the talents and the abilities to fulfill this plan. Says Sean, "You don't have to be a visionary to think up a survey — it's just that we had the interests and resources to actually do it." And do it they did. They started building and testing the telescopes and, following the commissioning phase, officially launched the survey in May 2016.

Dennis and Sean expect to complete the northern campaign this year, which will cover the entire sky from declination −32° to +90°. This will consist of 3,179 fields; they already have 3,009. "When we finish the northern portion of the survey, we'll have covered 77% of the whole sky," says Dennis. They're currently in the process of shutting down and shipping one of the New Mexico scopes to Chile (the other is expected to follow within a year) so as to complete coverage of Southern Hemisphere skies, which will require some 900 fields and around three years of work.

Pros dip in. In 2017, the renowned website Astronomy Picture of the Day showcased an image from the Survey (**https://is.gd/mdw_apod**), which piqued the curiosity of researchers. Among the professional astronomers to get in touch with the trio was Robert Fesen (professor emeritus at Dartmouth College). Fesen, who's research focuses on galactic supernova remnants, used MDW data in several papers that he published in academic journals. He included Dennis, Sean, and Dave as coauthors.

But the MDW Survey isn't limited to observing in Hα. Recently, Fesen — as a member of a collaboration of amateurs and professionals — contacted Sean and Dennis and requested observations in O III. With these data, they confirmed the presence of a long filamentary feature near M31. The team presented this result in a recently published paper (**https://is.gd/M31_filament**).

Fesen, for one, encourages other researchers to explore the data coming out of the MDW Survey. And, if you're an amateur, why not consider borrowing a page from the team's playbook? "Amateurs taking dozens of images using narrow filters on telescope-and-camera systems can detect emission-line nebulae that can be hard to detect with much larger professional telescopes," he says.

■ Observing Editor **DIANA HANNIKAINEN** loves to lose herself in the swirls of the MDW Survey images.

ON THE SURVEY: Learn more about the project at **mdwskysurvey.org** and in *S&T:* Oct. 2019, p. 20.

Live-Stacking the Deep Sky

Latest-generation CMOS cameras make astrophotography easier than ever.

Deep-sky astrophotography sure has changed since the turn of the 21st century. Most readers are familiar with the rise of charge-coupled devices (CCDs) and how they displaced film as the primary method of taking pictures of the night sky (as well as all other types of photography). Thanks to their high quantum efficiency, electronic detectors could record fainter targets in less time than ever before, which quickly made them the tool of choice for amateur and professional astronomers alike.

In recent years, complementary metal-oxide semiconductor (CMOS) detectors, which have similar and slightly newer technology, have supplanted CCDs as the detector of choice. CMOS cameras are both cheaper to manufacture and continue to improve with virtually every new model released (see *S&T:* Mar. 2023, p. 58). Today, they have the potential to change the way amateurs approach deep-sky imaging by eliminating much of the complexity from the pursuit. The future has arrived. Here's how you can take advantage it.

Low-Noise Stacking

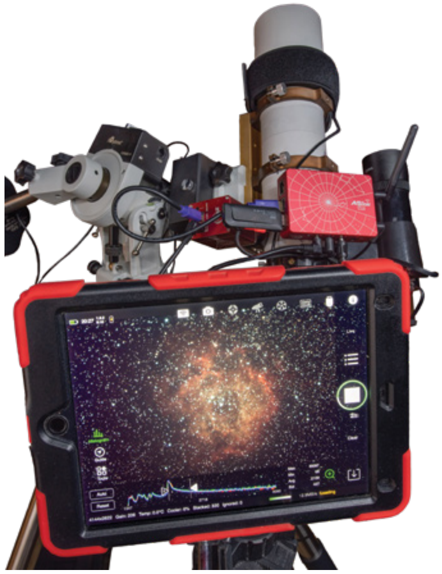
The big breakthroughs that allowed CMOS sensors to become the dominant technology for astro imaging are their infinitesimally low noise levels and their very high quantum efficiency. Indeed, some of the newest cameras are so good that it's becoming increasingly common to capture colorful images of galaxies, nebulae, star clusters, and comets with lots and lots of extremely short exposures, rather than several longer ones.

One way to take advantage of this capability is to pair these detectors with software that continuously aligns and

▲ **EASY ASTROPHOTOGRAPHY** By stacking hundreds of very short exposures recorded with a camera using the latest CMOS sensors, imagers can record deep, colorful pictures of targets like IC 434, the Horsehead Nebula (seen above at left) in Orion. The author captured this shot using 120 30-second exposures taken with the 92-mm Astro-Physics Stowaway refractor and Player One Uranus-C color CMOS planetary camera seen in the photo at right.

UNLESS OTHERWISE NOTED, ALL IMAGES COURTESY OF AUTHOR stacks short exposures, building up the photograph while you simply sit back and watch. This type of imaging is known as *live stacking*. It opens up a lot of possibilities for deep-sky photographers at any level of expertise and makes capturing impressive images much easier. Live stacking is long-exposure astrophotography approached a different way.

Several current programs include live-stacking capabilities: *AstroToaster* (**astrotoaster.com**), *Jocular* (**https://is.gd/jocular**), *SharpCap* (**sharpcap.co.uk**), and *TheSkyX* (**bisque.com**) as well as some programs tailored for specific cameras. (The ASIAir Plus reviewed in the May 2022 issue includes *ASI Studios* with a live-stacking feature.)



◀ **TABLET STACKING** Several manufacturers offer live-stacking programs that work with their cameras and other devices. Seen at left is the ASIAir Plus performing live stacking of hundreds of short exposures of NGC 2244, the Rosette Nebula in Monoceros.

Originally intended for *electronically assisted astronomy* (EAA), in which the image slowly builds up on the computer or tablet screen as you keep exposing, live stacking allows you to share the image with the public right at the telescope. This type of "observational imaging" has been around for quite some time. Manufacturers like Mallincam have long included it with their own cameras.

Live stacking isn't limited to outreach. It can simplify your astrophotography rig by eliminating the need for *autoguiding* — the tracking corrections typically required when taking exposures of several minutes or more. That means you can put away the guidescope, extra tube rings, and autoguiding camera as well as all the cables and additional power needs. At the most basic level, you only need four things to live-stack: your telescope, a tracking mount, a low-noise camera, and a computer or tablet to run the software.

Your choice of camera is important for live stacking. As noted, those with the latest low-noise CMOS sensors will yield the best results. Rather than seeking a specific detector, look for models that have low readout noise levels as well as high quantum efficiency.

You can live-stack with planetary cameras as well as cameras with active cooling designed specifically for deep-sky astrophotography. I've had great results with planetary cameras by ZWO, Player One Astronomy, and QHY while imaging during cool-weather months in the fall and winter. But bear in mind that uncooled cameras such as these will produce more thermal noise in warm conditions, so a cooled camera will give you better results year-round.

Another important factor to consider is the size of the camera's field of view. Models featuring small detectors may make it difficult to place your target within the frame. In addition, a good Go To mount will take the difficulty out of finding objects and help you image multiple targets in a single evening.

Tracking and Exposure

As with other forms of imaging, your telescope mount's ability to track the sky remains the most important factor to

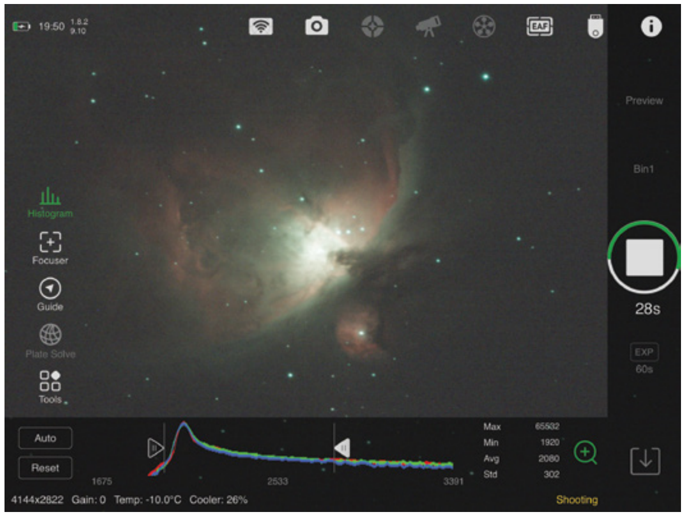
▼ **SLOW BUILD** *Left:* A single, 30-second exposure of NGC 891 in Andromeda reveals the galaxy amidst a field of noise. *Right:* After one hour of live-stacking 120 individual 30-second exposures, NGC 891 achieves a smooth appearance, and several background galaxies become visible.

STACKING: JOHNNY HORNE

make live stacking work. As long as your scope can track an object across the sky, you can live-stack. How long you can expose is determined by how accurately your telescope can track before stars become elongated. But unlike imaging with long exposures, it isn't necessary to use a polar-aligned equatorial mount. In fact, "observation stations" like the eVscope by Unistellar (reviewed in *S&T:* Dec. 2020, p. 66) and the Stellina by Vanois (*S&T:* Mar. 2020, p. 68) actually use live stacking to produce their images.

Let's look at imaging with alt-az tracking first. In this configuration the object remains centered in the field. However, since the telescope is moving in two axes as it tracks the sky, every image being stacked on the screen is slightly rotated compared to the previous one — an effect known as *field rotation*. You can avoid field rotation by limiting your subexposures to 30 seconds, and much shorter closer to the zenith. A good way to visualize how the frames stack in alt-azimuth is by taking a stack of playing cards and turning each individual card by 5 degrees — the middle of each card remains centered on each card, but the corners do not. So, with this type of live stacking, the corners of the frame do not overlap. This means you increasingly have to crop into the center of the field as the exposures add up to remove the unattractive edges of the frame.

One additional drawback of imaging in alt-azimuth mode is that it's difficult to track objects at the zenith because the mount reaches a point where it can't smoothly follow a target because Earth's rotation doesn't correspond to the mount's axes of motion. And that's where an equatorial mount really helps.



▲ **LIVE CONTROL** ZWO's ASIAir computers include its *ASI Studio* software, which does an excellent job of live-stacking images, though the app will only control ZWO cameras.

Equatorial Improvement

Live stacking with an equatorial mount makes everything much easier. Sure, it's more effort to set up and polar align,

▲ **ARCING NOISE** Live stacking can be accomplished with a telescope in alt-azimuth tracking mode. But long, cumulative live-stacked images may begin to show arcs in the field as the images are rotated and stacked. This picture of Cassiopeia's NGC 7635, the Bubble Nebula, has been stretched to reveal artifacts from live-stacking the target for 1 hour while tracking in alt-azimuth mode.

ASI STUDIO IN ACTION: JOHNNY HORNE

but your images will be far better. For one thing, everything within the camera's field of view stays in the same place from one exposure to the next, permitting you to take advantage of your detector's entire area.

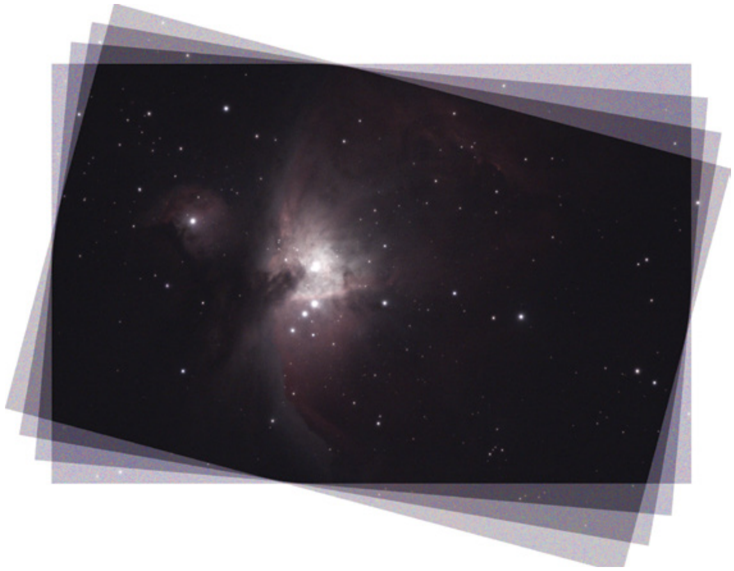
Tracking will still limit the length of your exposure, but that limit is based on two things: how good your polar alignment is, and how long you can expose before the mount's *periodic error* (a recurring oscillation in the right ascension drive) elongates the stars. However, this may not be a significant problem, particularly if your camera and telescope combination produce an image scale larger than your mount's periodic error (PE). Just limit your exposures so they are shorter than the point at which stars become elongated. The optimum exposure time may take a few minutes of trial and error to discover, but figuring it out will ensure you get good results your first night out. Some live-stacking programs have tools that measure the full-width, half-maximum (FWHM) stellar profile of images and reject frames that exceed the parameters you set.

Still, periodic error may not even be a concern if your goal isn't high-resolution astrophotography. Wide-field, low-power telescopes will be much less sensitive to PE than long-focal-length instruments combined with the small pixels commonly found in CMOS sensors.

At the Telescope

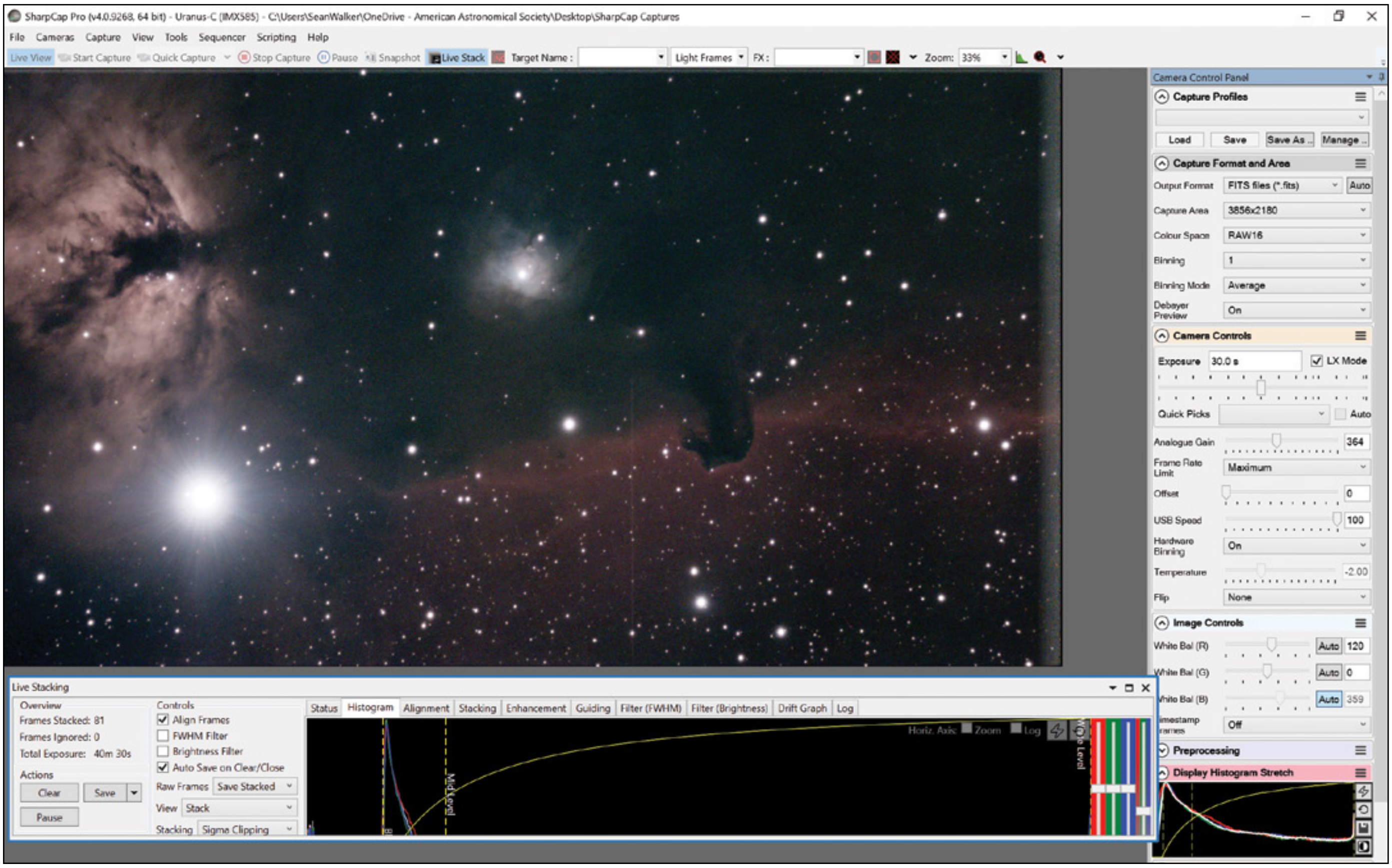
Once you get going, live stacking is quite easy. I use *SharpCap* for live stacking, but most programs that offer the feature have similar controls. My nights begin by aligning my mount, syncing the Go To on a known object. Next, I start *SharpCap* and connect my camera with the ***Camera*** pulldown menu. I then set an exposure of perhaps 2 seconds in the Camera Controls and open the program's focus assistant tool (***Tools > Focus Assistant > Multi-Star FWHM Measurement)***. This window measures the stellar profile of many stars in the field and produces an average value after each exposure. I adjust focus until I get the lowest average FWHM value. When I'm satisfied with focus, I then set the program to record several dark frames and flat-field calibration frames. *SharpCap* can apply these to the images as they are live-stacked if you input them in the ***Preprocessing*** section of the Camera Control Panel at the right side of the screen. The program does not save individual live-stacked frames with calibration applied, but I can also apply them later when processing the individual subframes in my preferred deep-sky image-processing program, if I so choose.

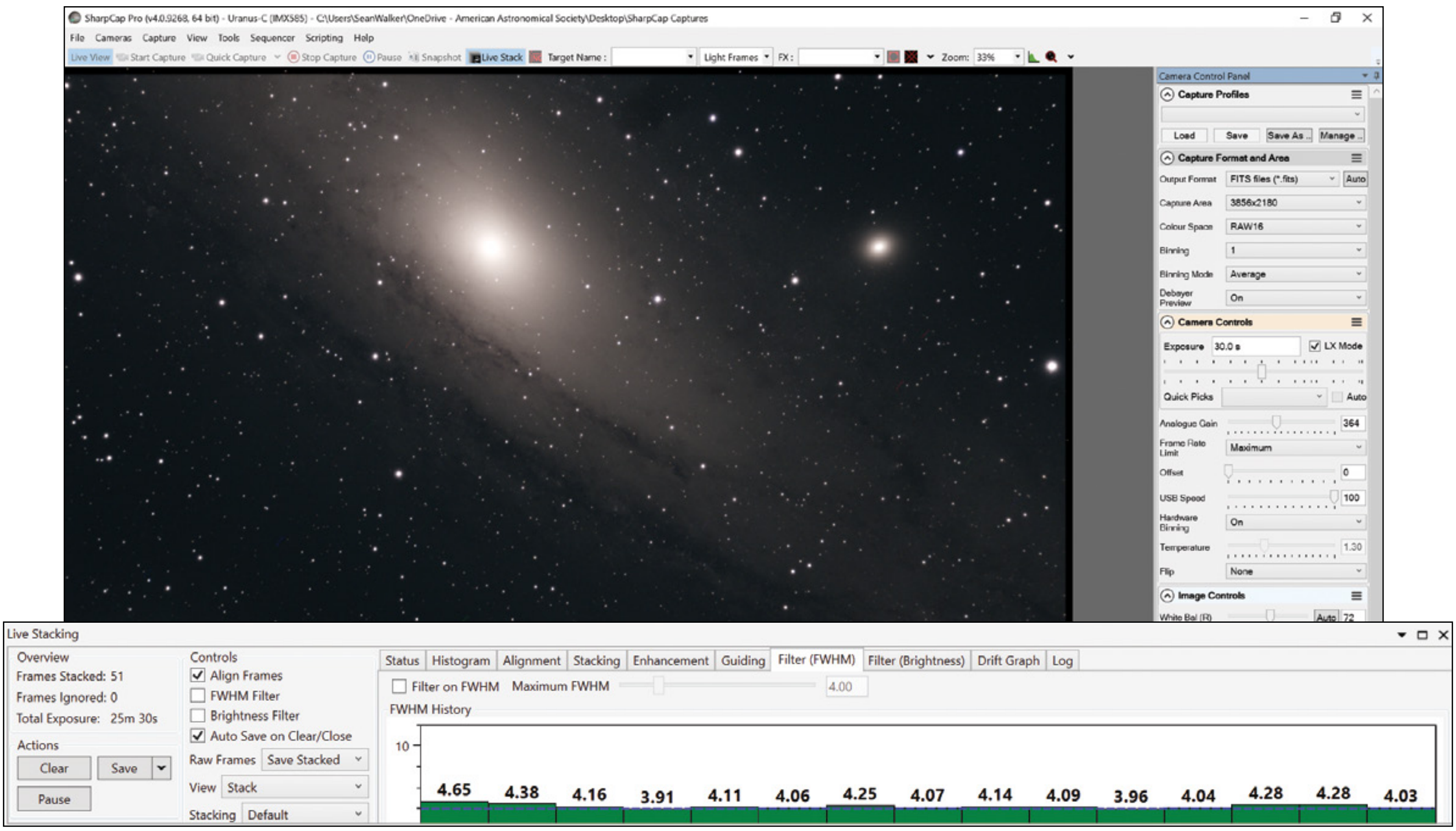
After the preliminary steps are out of the way, I slew to my first target and set the camera to take 5-second exposures. That's often enough to begin to show a galaxy, star cluster, or nebula in the field. Next, I tweak the framing and set the exposure time a bit longer, perhaps 10 or 15 seconds, and open the live-stack function in *SharpCap* (***Tools > Live Stack***) to begin the imaging process. Slowly, the object begins to appear. At first, it's fairly noisy. *SharpCap* includes some tools on the bottom of the window so that you can manually adjust the image to make it appear more attractive, which is par-



▲ **FIELD ROTATION** Images acquired with an alt-azimuth tracking scope will be slightly rotated as targets arc across the sky, resulting in non-overlapping corners of the frame, as the above simulation with the Orion Nebula, M42, shows. Imaging on a polar-aligned equatorial mount avoids this issue.

▲ **GUIDERLESS DEEP SKY** Live stacking allows you to create colorful images of deep-sky objects even when your mount isn't accurately polar aligned. The author recorded this image of M76 in Orion with his 92-mm refractor on an equatorial mount that was only roughly polar aligned. Although the stars are round, the poor polar alignment reveals itself in the red, green, and blue hot pixels that wiggle across the frame in this 40-minute accumulated exposure.


SharpCap Pro (v4.0.9268, 64 bit) - Uranus-C (IMX585) - C:\Users\SeanWalker\OneDrive - American Astronomical Society\Desktop\SharpCap Captures
File Cameras Capture View Tools Sequencer Scripting Help
Live View Start Capture Quick Capture Stop Capture Pause Snapshot Live Stack Target Name : Light Frames FX: Zoom: 33%
Camera Control Panel
Capture Profiles
Load Save Save As... Manage...
Capture Format and Area
Output Format FITS files (*.fits)
Capture Area 3856x2180
Colour Space RAW16
Binning 1
Binning Mode Average
Debayer Preview On
Camera Controls
Exposure 30.0 s
LX Mode
Quick Picks
Analogue Gain 364
Frame Rate Limit Maximum
Offset 0
USB Speed 100
Hardware Binning On
Temperature -2.00
Flip None
Image Controls
Preprocessing
Display Histogram Stretch
Live Stacking
Overview
Frames Stacked: 81
Frames Ignored: 0
Total Exposure: 40m 30s
Actions
Clear Save
Pause
Controls
Align Frames
FWHM Filter
Brightness Filter
Auto Save on Clear/Close
Raw Frames Save Stacked
View Stack
Stacking Sigma Clipping
Status Histogram Alignment Stacking Enhancement Guiding Filter (FWHM) Filter (Brightness) Drift Graph Log


SharpCap Pro (v4.0.9268, 64 bit) - Uranus-C (IMX585) - C:\Users\SeanWalker\OneDrive - American Astronomical Society\Desktop\SharpCap Captures
File Cameras Capture View Tools Sequencer Scripting Help
Live View Start Capture Quick Capture Stop Capture Pause Snapshot Live Stack Target Name : Light Frames FX: Zoom: 33%
Camera Control Panel
Capture Profiles
Load Save Save As... Manage...
Capture Format and Area
Output Format FITS files (*.fits)
Capture Area 3856x2180
Colour Space RAW16
Binning 1
Binning Mode Average
Debayer Preview On
Camera Controls
Exposure 30.0 s
LX Mode
Quick Picks
Analogue Gain 364
Frame Rate Limit Maximum
Offset 0
USB Speed 100
Hardware Binning On
Temperature 1.30
Flip None
Image Controls
Live Stacking
Overview
Frames Stacked: 51
Frames Ignored: 0
Total Exposure: 25m 30s
Actions
Clear Save
Pause
Controls
Align Frames
FWHM Filter
Brightness Filter
Auto Save on Clear/Close
Raw Frames Save Stacked
View Stack
Stacking Default
Status Histogram Alignment Stacking Enhancement Guiding Filter (FWHM) Filter (Brightness) Drift Graph Log
Filter on FWHM Maximum FWHM 4.00
FWHM History
10
4.65 4.38 4.16 3.91 4.11 4.06 4.25 4.07 4.14 4.09 3.96 4.04 4.28 4.28 4.03

◀ **ALL IN THE SCREEN** *Top:* Live stacking is mostly about how the image will look on your screen as it builds up. As soon as you launch Live Stacking in *SharpCap*, it opens the control window on the bottom of the screen where you can adjust the Black Level, Mid-Level, and White Level as well as the color balance with simple sliders at the right.

◀ **QUALITY CONTROL** *Bottom: SharpCap*'s Filter (FWHM) tab measures the brightness profile of stars during a live stack, allowing you to exclude images from the stack that exceed your chosen threshold.

ticularly useful if you're also sharing the view with onlookers. Controls include setting the Black Level, the Mid Level, and White Level, as well as three vertical sliders at the right for adjusting the color balance and luminance levels.

Once this is running, I can sit back and watch the image slowly get better. Setting up and getting everything working together doesn't take much time at all, which is why live stacking is becoming a popular tool for outreach — seeing a nice picture of, say, the Triangulum spiral M33 building up on the screen in full color is extremely impressive, no matter if you're an experienced observer or someone attending a public event for the very first time.

You can set *SharpCap* to save the individual frames recorded as well as the stacked version. There are several options for saving the stacked image when you click the arrow to the right of the ***Save*** button. These include ***Save as 16 Bit Stack, Save as 32 Bit Stack, Save with Adjustments***, and ***Save exactly as seen***. If you're happy with what's displayed on the screen, select the last option.

Depending on how good I'd like to make the final image, I can simply select ***Save exactly as seen*** and I'm done. But I find image processing to be half the fun, so I make sure to choose Save All in the Raw Frames pulldown menu and save the stacked image as a 32-bit unprocessed file.

This stacked image is already pretty good, though it may contain light-pollution gradients that may take some expert-level image-processing work to fix. If that's the case, then I'll re-stack the image using the flat-field calibration frames I recorded and correct these problems.

Re-stacking for Aesthetics

Live stacking makes for a great public outreach tool, which allows you to share the view as your selected target emerges more clearly with each added exposure. But the method also produces great data that you can then stack later on to make impressive pictures. You can treat these images just like you would with any other type of deep-sky imaging that you've read about in these pages over the years. The difference, though, is you'll likely be stacking hundreds of exposures to make your final image. This might require a fairly robust computer with a good amount of RAM.

Stacking is the most time-consuming aspect when combining hundreds of short exposures, especially if you shot with a color camera. Each frame will need to be converted into a color image first. That's because the detector is actually a grayscale device fitted with a red, green, and blue

RICHARD S. WRIGHT, JR.

▲ **NOT JUST FOR BRIGHT TARGETS** Live stacking isn't limited to color cameras or bright targets. This image of NGC 2264, the Cone Nebula in Monoceros, was recorded during a live-stacking session and processed later. The image uses 162 one-minute exposures recorded with a 92-mm refractor and Player One Poseidon-M camera controlled with *TheSky HD*.

Bayer filter matrix in front of it. After that, the frames still need to be aligned and combined.

I've had good luck performing all these operations in both *DeepSkyStacker* (**deepskystacker.fr**) and *PixInsight* (**pixinsight.com**). Other programs may struggle when aligning large numbers of files, but each worked well processing the live-stacked 32-bit FIT file produced by *SharpCap*.

Once you've stacked the images, it's simply a matter of stretching the result to display the full range of brightness, adjusting the color balance, and then applying some mild sharpening and noise reduction, if desired.

Live stacking is perhaps the easiest way to get into deep-sky imaging today. By taking advantage of the high-sensitivity and low-noise characteristics of the latest CMOS cameras, you can set aside much of the complexity of deep-sky astrophotography and concentrate on enjoying your time under the stars. You can even entertain family and friends by showing the image as it slowly comes together on your device's screen.

■ Associate Editor **SEAN WALKER** will embrace anything that takes the difficulty out of imaging the night sky.

The Star Adventurer GTi

Sky-Watcher has upgraded its popular camera platform to a full-fledged Go To mount.

◀ The Star Adventurer GTi is a lightweight German equatorial mount with dual-axis drives and Go To pointing. It's designed for small-scope visual use and astrophotography for amateurs who travel to dark-sky sites.

Star Adventurer GTi

U.S. Price: $640
With optional mount kit: $740
skywatcherusa.com

What We Like

Extremely portable

Built-in, illuminated polar-alignment scope.

What We Don't Like

Camera trigger requires constant wireless connection.

Daytime alignment routine difficult to locate.

IN RECENT YEARS, Sky-Watcher has rolled out several portable, light-duty mounts for observers on the go. I've used a few of them, including the original Star Adventurer mount. I've taken it along on several astrophotography adventures (*S&T:* Feb. 2017, p. 32), and while it's a good tracking platform, it's not suited to carrying small telescopes for astrophotography. Additionally, I often wish it had the Go To control included in the company's AZ-GTi Alt-azimuth mount, which I reviewed in the February 2019 issue (page 58). Fast-forward a few years and it seems that Sky-Watcher has listened to its customers with the introduction of a new mount aimed squarely at traveling imagers.

The new Star Adventurer GTi melds two previous-generation products — a small equatorial mount and the Go To power of the AZ-GTi. It works very well as a platform for cameras mated to telephoto lenses, and even for astrophotography with small, wide-field telescopes.

A Solid Package

The Star Adventurer GTi is compact enough to conveniently fit in your airline carry-on luggage or stow easily in a small duffel bag or backpack. It has a weight capacity of 5 kg (11 lb), which is adequate for most camera-and-lens combinations, or a small refractor and a camera. The GTi resembles the first Star Adventurer mount but with several additions. While the original is a single-axis tracking platform, the GTi includes declination axis with a miniature servo motor drive on both axes. Additionally, the GTi comes with a counterweight

▶ Above the polar scope is the communication pane. In addition to the power switch, it includes inputs for an ST-4-style autoguider cable and an optional SynScan hand paddle (not included), a USB port to connect external computers, a 2.1-mm female DC power input, and the SNAP port to connect DSLR and Mirrorless cameras.

ALL PHOTOS COURTESY OF AUTHOR

shaft and 2.3-kg counterweight as well as a built-in altitude adjustment platform — all of which were optional purchases with the original mount. We were loaned just the head for this review, and I mounted it on the tripod that came with the AZ-GTi — a combination that worked quite well together. Sky-Watcher also offers a kit that includes a tripod and pier extension for an additional $100.

The mounting saddle accepts Vixen-style dovetail mounting bars. Both the right ascension and declination axes have clutches that allow you to carefully balance the load. The right-ascension clutch is a knurled green knob on the side of the mount, while the declination clutch is a large, black ring with thumb spokes. Both were easy to manipulate in the dark. The counterweight shaft can be threaded into either of two available sockets to reposition the shaft for use anywhere from zero to 70° latitude without it colliding with the tripod legs.

One of the big additions to the Star Adventurer GTi is its Go To capabilities. I felt the manual version was more suited to use with camera lenses, but GTi does very well with long telephoto lenses and small telescopes, for which computer-assisted pointing is particularly helpful.

The Star Adventurer GTi is controlled wirelessly via the free *SynScan Pro* app (available for both iOS and Android devices) or a SynScan hand controller (available separately). The mount is powered by 8 AA batteries, which are inserted in two compartments on both sides of the polar finder. There's also a 12-volt power port located above the polar finder, in addition to inputs for an ST-4-style autoguider, the optional SynScan hand controller, a USB connection to connect to a computer, and a SNAP port to fire the shutter on your DSLR or Mirrorless camera. (Optional SNAP cables for several camera models are available on the Sky-Watcher website.) One night after a cable mishap disconnected the DC power, I discovered the GTi will keep functioning using the internal batteries without so much as a hiccup. Impressive!

Initializing the GTi is just like using any Sky-Watcher mount with SynScan support. After verifying your location, date, and time, you then select either one-, two-, or three-star alignment methods. I found one-star alignment was good enough for visual observing and placed targets within a low-power eyepiece field after each slew. When performing a three-star alignment, the app requires you to hit the up and right buttons in order to take up backlash in

▲ The mount accepts Sky-Watcher's V-style dovetail bars (similar to those produced for decades by Vixen Optics).

the motors before you can accept the star's centering and move on to the next alignment star.

I was disappointed that the Sun was not available as an alignment target when I wanted to use the GTi for solar observing. A Sky-Watcher representative later informed me the feature is available but must be enabled in advanced settings. My workaround was to simply skip the alignment and manually position the scope on the Sun and select the solar-tracking rate.

Aligning the mount took only a few minutes using its integrated polar scope. After leveling the mount head with its bubble level for reference, I then fired up *SynScan Pro*'s polar-scope utility, which shows precisely where to posi-

▼ The Star Adventurer GTi can be powered with 8 AA batteries. The batteries will power the mount in the event of failure from an external power supply.

▼ The mount can operate between 0° and 70° latitude. Knurled green knobs on the azimuth and altitude controls are used during polar alignment. The right ascension clutch knob is visible at top.

▼ The rear of the right-ascension axis contains the polar-alignment scope. A black plastic cover protects the polar scope's eyepiece when not in use.

tion Polaris (or the four-star asterism in Octans for Southern Hemisphere users) on the polar scope's reticle. The accuracy of this method proved sufficient to produce round stars in all of my tests.

One note about the polar scope: The red-light illuminator floods the entire field with light even on its lowest setting, reducing the view's contrast. While unexpected, it didn't make the alignment process noticeably harder.

▲ The Star Adventurer GTi includes two separate sockets for the counterweight shaft. Users at latitudes near the equator can use the outer socket (right) to ensure the counterweight shaft doesn't hit the tripod. A threaded plug keeps moisture and dirt out of the unused socket.

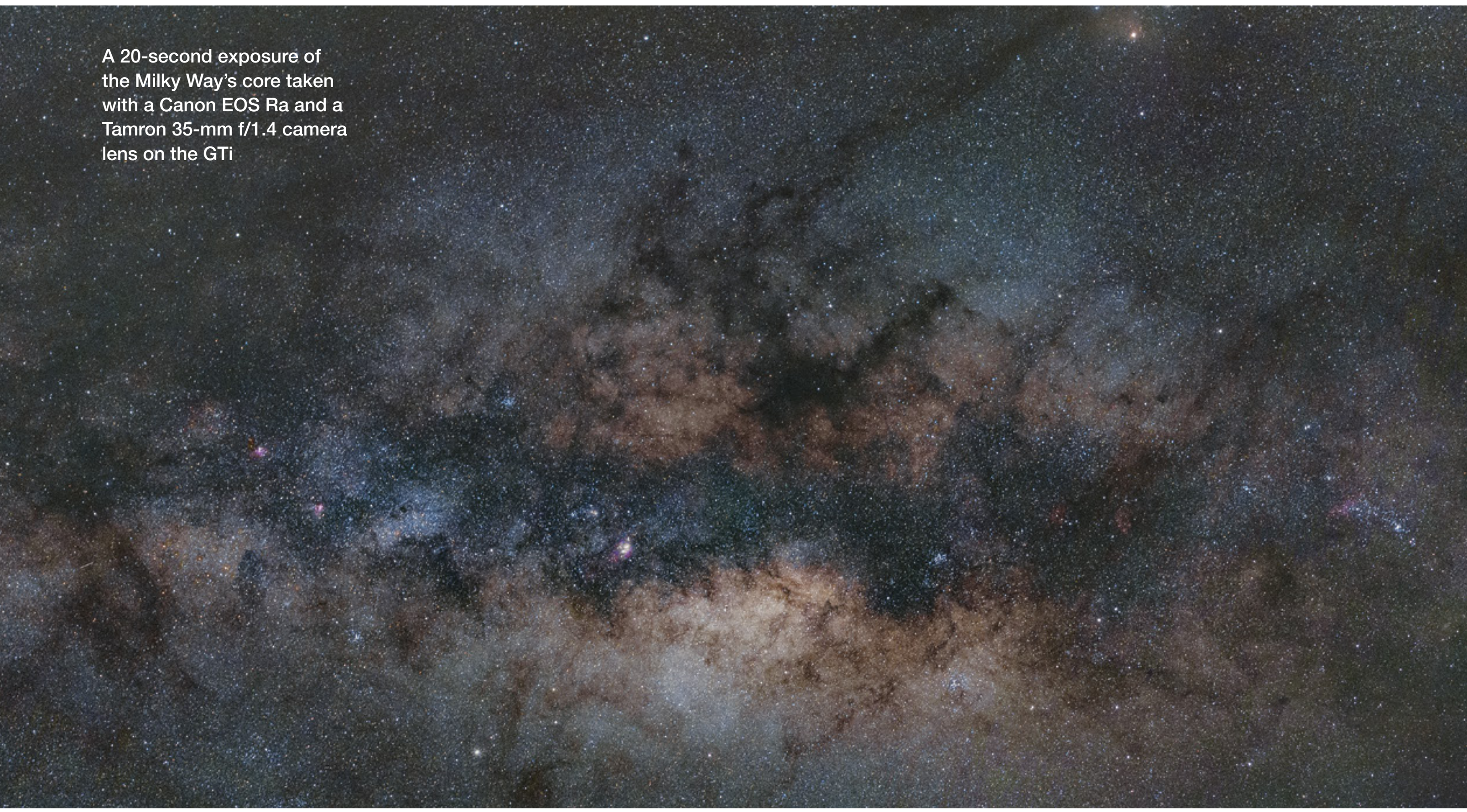
Small-Scope Use

There's a saying about children's eyes being bigger than their stomachs, and in the same vein, many people buy a telescope setup that's too big and too much trouble to set up regularly. With the Star Adventurer GTi and a small refractor, I could be up and running in less than 10 minutes to snatch a few minutes of observing before bed or see some sunspots in the morning before I start my workday.

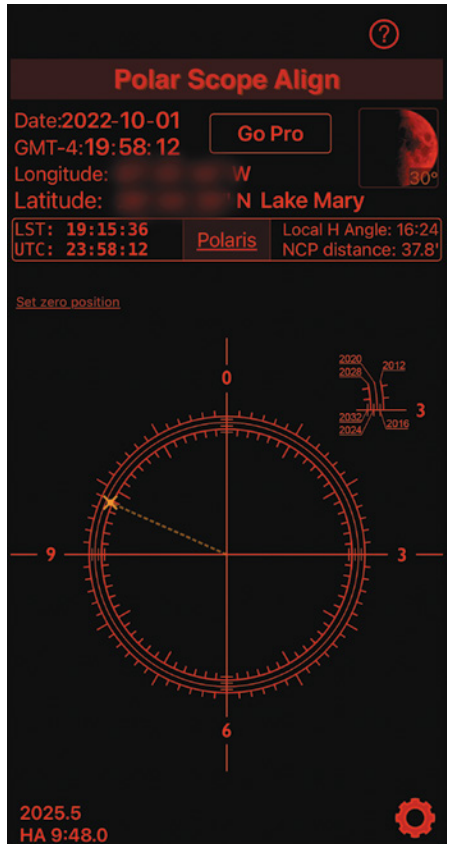
I have a large, semi-permanent mount in my backyard, but its location has very limited visibility of the sky (thanks to my neighbors' trees), especially along the ecliptic where the Sun, Moon, and planets are found. With the highly portable Star Adventurer GTi mount, I can quickly set up my 92-mm scope in my driveway or front yard to access that part of the sky.

When using the Star Adventurer GTi exclusively with the *SynScan Pro* app for imaging with a telescope, a three-star alignment is necessary to land objects within reach of my camera's limited field of view. With my Takahashi FS-60 f/5.9 refractor mounted on the GTi, targets were often perfectly centered after a Go To slew. Stepping up to my heavier 92-mm Astro-Physics f/6.6 Stowaway refractor's 2° field of view, targets were never perfectly centered and often were just outside of the camera's field and required re-centering.

I had much better luck running the mount with an external computer. The GTi is ASCOM-compatible and can be controlled with a variety of desktop planetarium programs. I ran the mount using *TheSkyX Professional*, which connects to the mount via the SynScan hand controller USB port. After that, the GTi worked like most other small Go To mounts. I also ran *TPoint* to improve its pointing accuracy, and afterwards it slewed and tracked targets just like any telescope mount.



A 20-second exposure of the Milky Way's core taken with a Canon EOS Ra and a Tamron 35-mm f/1.4 camera lens on the GTi



▶ The free *SynScan Pro* app that controls the GTi is available for both iOS and Android. Users connect their device to the mount through its internal Wi-Fi hotspot.

▶▶ A polar scope utility in the *SynScan Pro* mobile app displays exactly where to position Polaris (or stars in Octans in the Southern Hemisphere) for quick and precise polar alignment. Note that the app also has a red screen mode.

The *SynScan Pro* app acts as an intervalometer for DSLR or Mirrorless camera users with the appropriate SNAP cable connecting the mount to the camera to fire the shutter. After connecting my Canon EOS Ra camera to the GTi's SNAP port and setting it to Bulb mode, it was easy to program a sequence of images. One caveat to this feature is that the app must stay running and connected to the GTi to execute the entire sequence — you can't have your device go into power-saving mode while firing exposures. Make sure the tablet or smartphone you're using is fully charged before starting an imaging session.

The mount's unguided tracking performance was quite good with telephoto lenses up to 200-mm focal length. The mount consistently delivered round stars in exposures up to 90 seconds with this lens paired with my Canon EOS Ra. Stepping up to the FS-60 refractor and its 354-mm focal length, the mount's unguided tracking produced acceptable stars in exposures up to about 30 seconds duration. I also attempted unguided exposures with the 92-mm Stowaway at 494 mm and started seeing elongated stars in images longer than about 15 seconds. This scope is right up near the weight limit of the mount (and required a second counterweight). These might not sound like very long exposures, but they're more than adequate for live stacking many deep-sky objects (see page 58).

To improve the Sky-Watcher mount's tracking, users can utilize ST-4-compatible autoguiders and issue corrections in both axes — another big advancement over the earlier Star Adventurer models. Autoguiding with a 50-mm guidescope on top of my FS-60 yielded perfectly round stars in exposures of any length

▲ The Star Adventurer GTi easily accommodates the author's Takahashi FS-60 refractor and piggybacked EvoGuide 50ED guidescope (reviewed in our June 2022 issue, page 70). The combination is well under the 5-kg weight capacity of the mount.

▲ This image of M13 in Hercules was recorded with the author's Astro-Physics 92-mm Stowaway refractor on the GTi. One hundred 15-second unguided images were stacked to produce this result.

with my Canon camera. Although I wanted to use the 92-mm refractor for longer exposures, the 50-mm guidescope put the payload well above the weight capacity of the mount even before adding the necessary counterweights.

As with any equatorial mount, there is the issue of the meridian flip when slewing to targets on opposite sides of the sky. This little mount's Go To system understands when it needs to reorient itself when switching from targets in the east and west. However, it will happily track past the meridian until it runs the camera into the tripod if you allow it. This feature is both useful and a slight concern. It's desirable to be able to track past the meridian uninterrupted for hours, but you have to be careful not to let it impact the tripod and potentially damage the right-ascension gear.

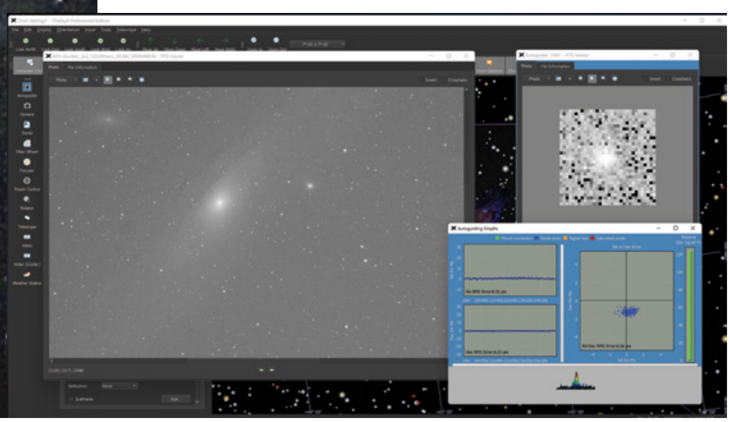
Using a small mount like this for imaging, I also had to be mindful of cable snags. Adding a guidescope meant I had two USB cables and a power cable for a cooled camera dangling from the back of the mount. Cable management is important with any mount, especially a small one for which it doesn't take much to impede its tracking abilities.

After comparing the use of the SynScan hand controller with the app-based approach, I became aware of the potential downsides of this new approach. It's an attractive way for the manufacturer to significantly reduce hardware costs, but I found making small adjustments to a telescope's position with a touch screen to be a clumsy user experience. I'd rather look in the eyepiece and have tactile buttons to feel and press while centering objects. I was very grateful that I could use the SynScan hand controller from another Sky-Watcher mount on the Star Adventurer GTi when I used it visually. However, I found the mobile app to be perfectly suitable for imaging.

And the Verdict Is . . .

The Star Adventurer GTi is an excellent, light-duty mount. Small and lightweight, it's ideal for both wide-field and telephoto lenses, especially if you like to travel light. It's also quite usable with a small telescope for long exposures under computer control. I also found the Star Adventurer GTi to be easy to use for quick observing sessions with my favorite small refactors. The Go To function is especially useful. It will be my newest companion on any future camping and dark-sky travel adventures.

■ After decades of lugging heavy gear to star parties, Contributing Editor **RICHARD WRIGHT** enjoys travelling light.



◀▼ Autoguiding the GTI produced nice round stars, as shown in this stack of 2-minute exposures of M31 captured with the setup shown on page 67. The author used the mount connected to Software Bisque's *TheSkyX Professional* to run both the autoguider and imaging camera (below).

Make a Plate-Solving Finder

Here's a finder for the 21st century.

I'VE WRITTEN SEVERAL columns about finders over the years. Most of them involve nothing more complicated than a simple lens or an LED with a dimming circuit. But there's a new type of finder that's taking the world by storm, and it's time we amateur telescope makers got in on the fun.

What kind of finder am I talking about? One that looks at the sky, recognizes where your telescope is pointed, and displays that position in a planetarium program. That's called plate solving, and until recently it's been the province of a dedicated website. You uploaded your image to **astrometry.net**, and after a few seconds it would tell you what part of the sky you'd given it. That was pretty cool, but turning that into a finder involves some fairly serious computer hackery.

Fortunately, Minnesota amateur Dale Eason has paved the way for us. Dale has spent quite a bit of his life programming computers. One of his proudest achievements is the *DFTFringe* program, which allows mirror makers to analyze the surface profile of a mirror in progress down to the gnat's whisker.

Dale became interested in plate solving after discovering an earlier effort called *PSWAI* (Plate Solved Where Am I) on a Cloudy Nights forum (**cloudynights.com**). Dale says, "I saw this post on CN, and it triggered my interest. I took that code and modified it and swapped out the camera for a Raspberry Pi camera. I added a more friendly user interface and created a device that I think is easier to make and use. But that idea is at the heart of the solution, and I could not have done it if the original programmer had not posted about his version."

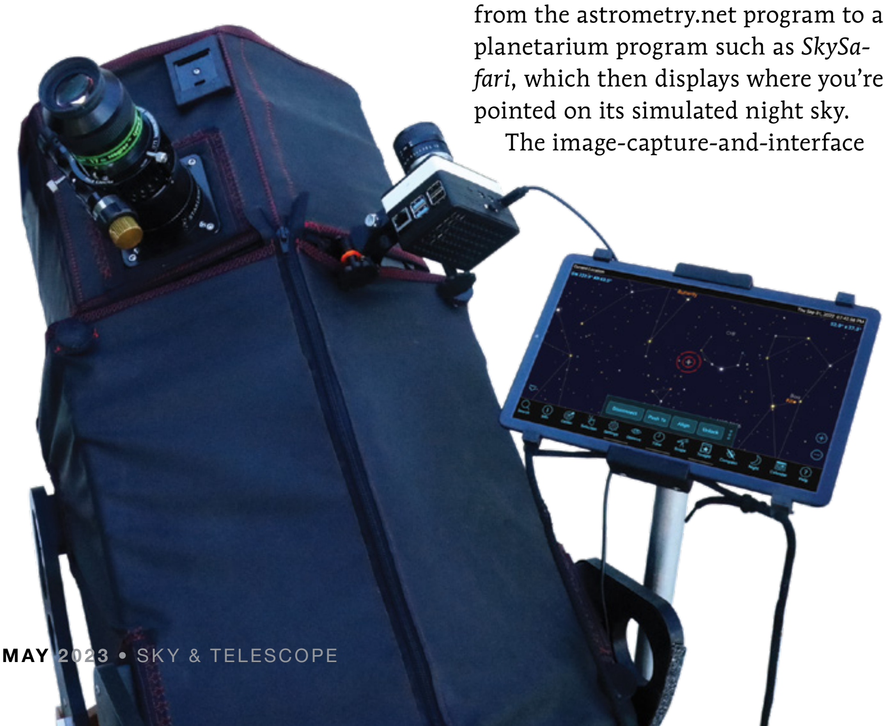
So what's involved in making your own plate-solving finder? You need a computer that's capable of running the astrometry.net software. Dale uses a Raspberry Pi. You need a camera capable of taking a reasonably fast photo of the night sky. Again, Dale uses a Raspberry Pi High Quality camera with a 25-mm C-mount lens. You need software to control the camera and send the data from the astrometry.net program to a planetarium program such as *SkySafari*, which then displays where you're pointed on its simulated night sky.

▲ The Raspberry Pi computer and the camera fit comfortably in a 3D-printed box measuring 2.5″ × 3.5″ × 2″.

The image-capture-and-interface software is where Dale put his effort. Dale's *SkySolve* software controls the exposure length, how often a solve operation is performed, how far from the original position to search (limiting this to nearby fields speeds up the recognition), whether the images are stored for later reference, and many other functions. It communicates with *SkySafari* via Wi-Fi, setting up its own network if none is available. And best of all, once you get it set up the way you want it, it gets out of the way, and you only need to pay attention to the *SkySafari* screen for the rest of the night.

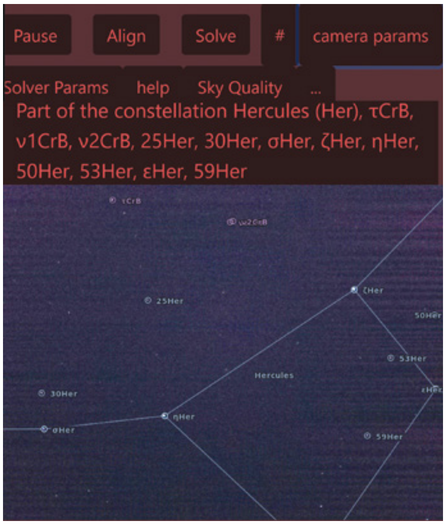
Dale says, "A typical-use case is to turn it on, wait a minute or so, and turn on *SkySafari* on a phone or tablet. Connect *SkySafari* using its telescope-connect feature. Once connected, *SkySafari* displays where the telescope is pointing. Now just push your scope around and wait a couple of seconds to see where it's pointing. Once you've done it a few times, it usually takes only 3 or 4 pushes to get to your target."

How long does the operation take?



◀ The *SkySolve* computer and camera, plus a tablet running *SkySafari*, fit comfortably on the side of Dale's computer. Note the empty bracket for the no-longer-needed reflex finder.

DALE EASON (2)



▲ The user interface for setting up the *SkySolve* program is simple, intuitive, and informative.

DALE EASON

Dale reports, "It never takes more than a minute to get from anywhere in the sky to some other object of interest. So now when a neighbor drops by and asks if I have anything he would like to see, I can say sure, it will just take a minute."

The whole works fits in a small project box (3D-printed, of course) and is powered by a small, 5-volt USB power tank. Raspberry Pi computers have become more expensive in the aftermath of the pandemic, but this system is still an order of magnitude cheaper than a full-on Go To setup, and if you don't mind pushing the scope yourself, it works just as well.

This is a great project for someone who wants the newest, best technology to help them find their way around the night sky. For more information, see Dale's Cloudy Nights topic at **https://is.gd/platesolve**, watch his video at **https://is.gd/platesolvevid**, or join his discussion group at **groups.io/g/skysolve**. The software is available on Dale's Github page at: **github.com/githubdoe/skysolve**, and the 3D-print files are available on Thingiverse at **thingiverse.com/thing:4920959**.

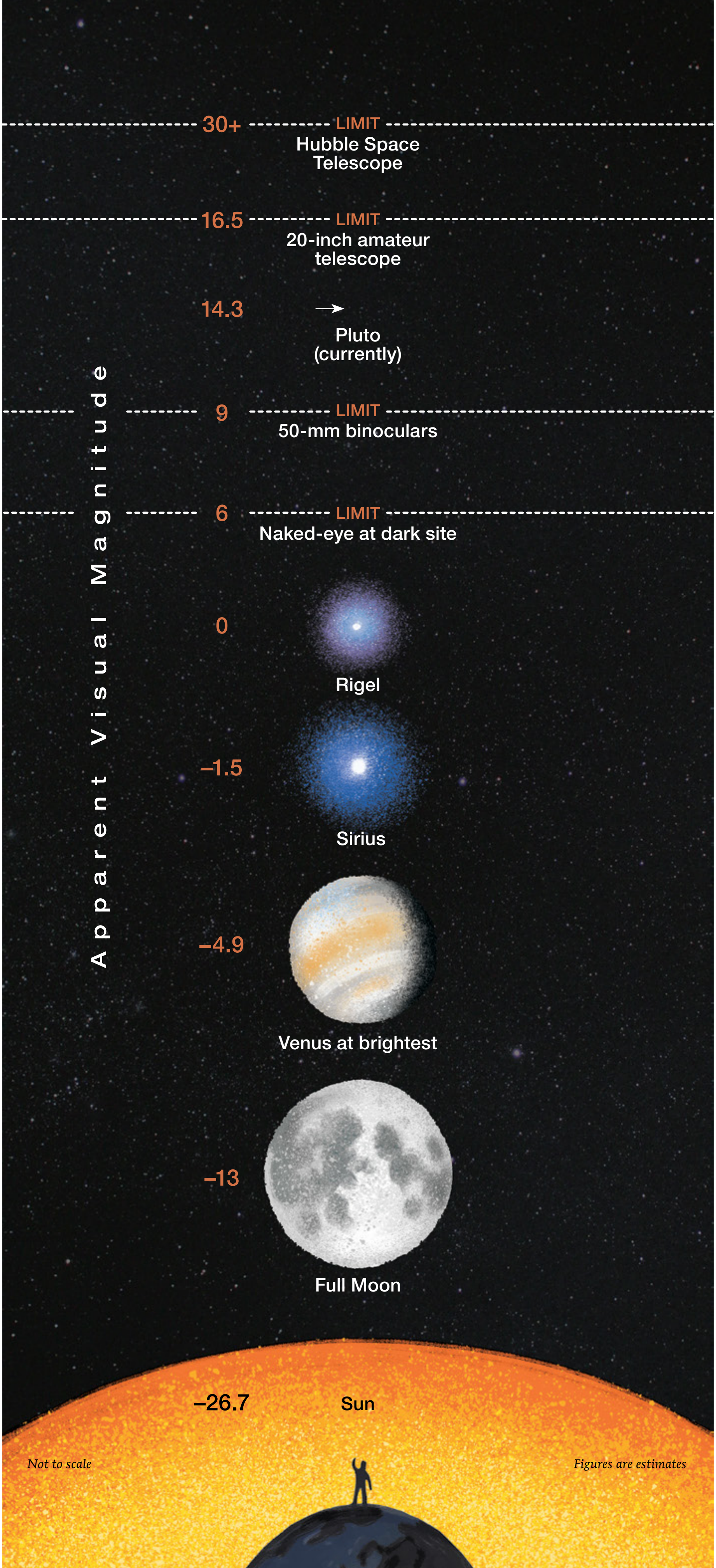
■ Contributing Editor **JERRY OLTION** solves the sky in his head most nights, but he's only good down to about 6th magnitude.

What Is the Stellar Magnitude System?

A SCALE OF THE brightnesses of stars, the stellar magnitude system arose in ancient Greek times. We still use today the scheme that Hipparchus devised in the 2nd century BC when he compiled the first well-known star catalog. Hipparchus denoted the brightest stars he could see "of the first magnitude," meaning "the biggest." Brighter stars seem to look larger to us than fainter ones, so basing his system on *magnitude* (from the Latin *magnus*, "great") made sense. Slightly fainter stars he designated "of the second magnitude," and the faintest stars he could see with the naked eye he labeled "of the sixth magnitude."

The Alexandrian astronomer Claudius Ptolemy took Hipparchus's system a step further in the second century AD. In his own star catalog, Ptolemy characterized some stars as "greater" or "smaller" *within* a magnitude class. Astronomers today now measure differences as small as 1⁄100 of a magnitude or smaller. Notwithstanding the scale's name, they also use it to gauge the brightnesses of planets, moons, and other nonstellar objects.

Ptolemy's work endured as the standard astronomy reference for the next 1,400 years. Only when Galileo turned his telescope skyward in the early 17th century did the scale take its next leap forward. Gazing at the heavens, Galileo instantly saw stars fainter than the naked-eye limit of sixth magnitude. "The largest [brightest] of these," he



LEAH TISCIONE / S&T

wrote in his 1610 work *Sidereus nuncius*, "we may designate of the seventh magnitude."

That was just the beginning of how deep into the night sky we could see, of course. As optics improved, astronomers observed stars and other objects bearing ever fainter magnitudes. Modern 50-mm binoculars will reach stars of about 9th magnitude, while a 6-inch telescope will show those down to around 13th magnitude. The Hubble Space Telescope, for its part, can reach as deep as magnitude 30 or fainter.

An Exact System

Even as late as the mid-1800s, however, assigning stellar brightness was still a judgment call. What one astronomer might consider a 1st-magnitude star, another might deem 2nd magnitude. Astronomers needed a more exact way to define the magnitude scale. So, in 1856, English astronomer Norman Pogson proposed that astronomers define a difference of five magnitudes as a brightness ratio of exactly 100 to 1. Thus, one magnitude corresponds to a brightness difference of the fifth root of 100 ($\sqrt[5]{100}$), which is roughly 2.5.

Don't worry about the math. Just know that the scale is logarithmic, so a 1st-magnitude star is about 2.5 times brighter than a 2nd-magnitude star, approximately 2.5^2 times brighter than a 3rd-magnitude star, around 2.5^3 times brighter than a 4th-magnitude star, and so on. The scale gives us an idea of just how staggering the differences in the brightness of stars in the night sky truly are. So, while a difference of five magnitudes (from, say, 1st to 6th magnitude) translates to a ratio in brightness of 100 to 1, a difference of 10 magnitudes is a ratio of 10,000 to 1, and of 20 magnitudes is 100,000,000 to 1!

Though astronomers quickly adopted Pogson's system, another problem remained: Some 1st-magnitude stars are brighter than other 1st-magnitude stars. And, of course, there's the Sun, which to us is obviously far brighter than any other star. What to do? The unavoidable solution was to continue the scale into negative numbers.

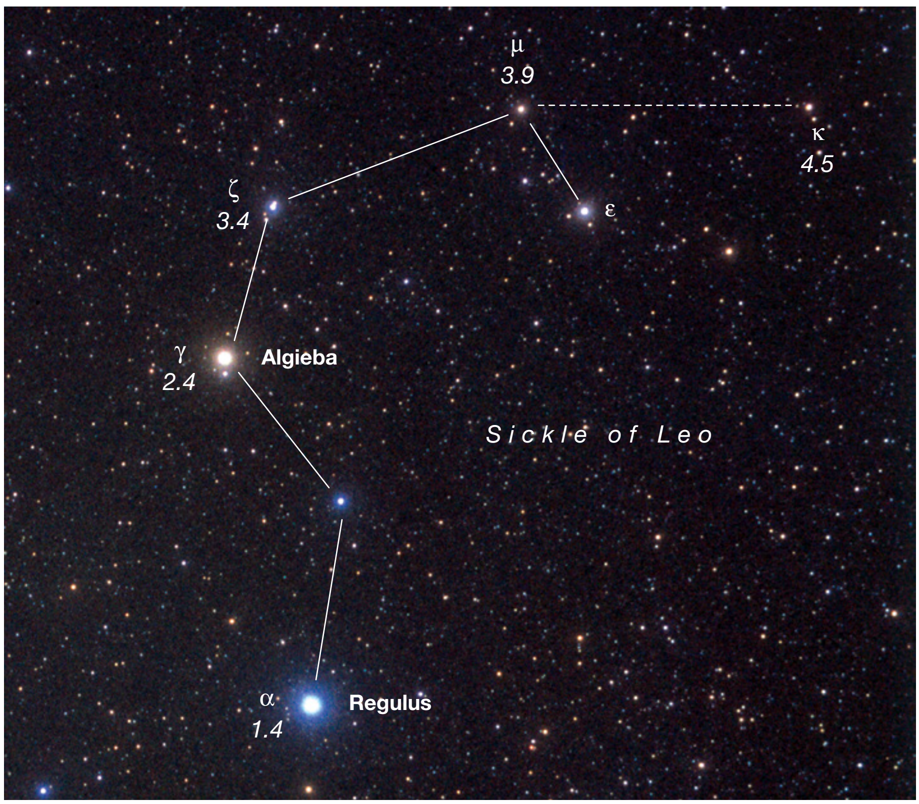
Thus, while the stars Vega, Rigel, and Arcturus are around magnitude 0 (that is, brighter than magnitude 1), Sirius shines at magnitude –1.5, Venus at its brightest gleams at –4.9, and the Sun blinds at –26.7. Going the other way, into fainter magnitudes, 14.3 is Pluto's current magnitude, while 16.5 is roughly the faintest magnitude visible using a 20-inch amateur telescope.

The Sickle asterism, or star pattern, in Leo provides a handy way to visualize stellar magnitudes (see image below). Starting with Regulus, or Alpha (α) Leonis, at magnitude 1.4, we move one magnitude fainter to Algieba, or Gamma (γ) Leonis, then another magnitude class each to Zeta (ζ), Mu (μ), and Kappa (κ) Leonis, respectively. (For why we use Greek letters in star charts, see Beginner's Space in the February issue.) Note that a magnitude class brackets the whole number, so a 5th-magnitude star can lie anywhere between magnitude 4.5 and 5.4. Thus, Kappa Leonis is a 5th-magnitude star.

Apparent versus Absolute Magnitude

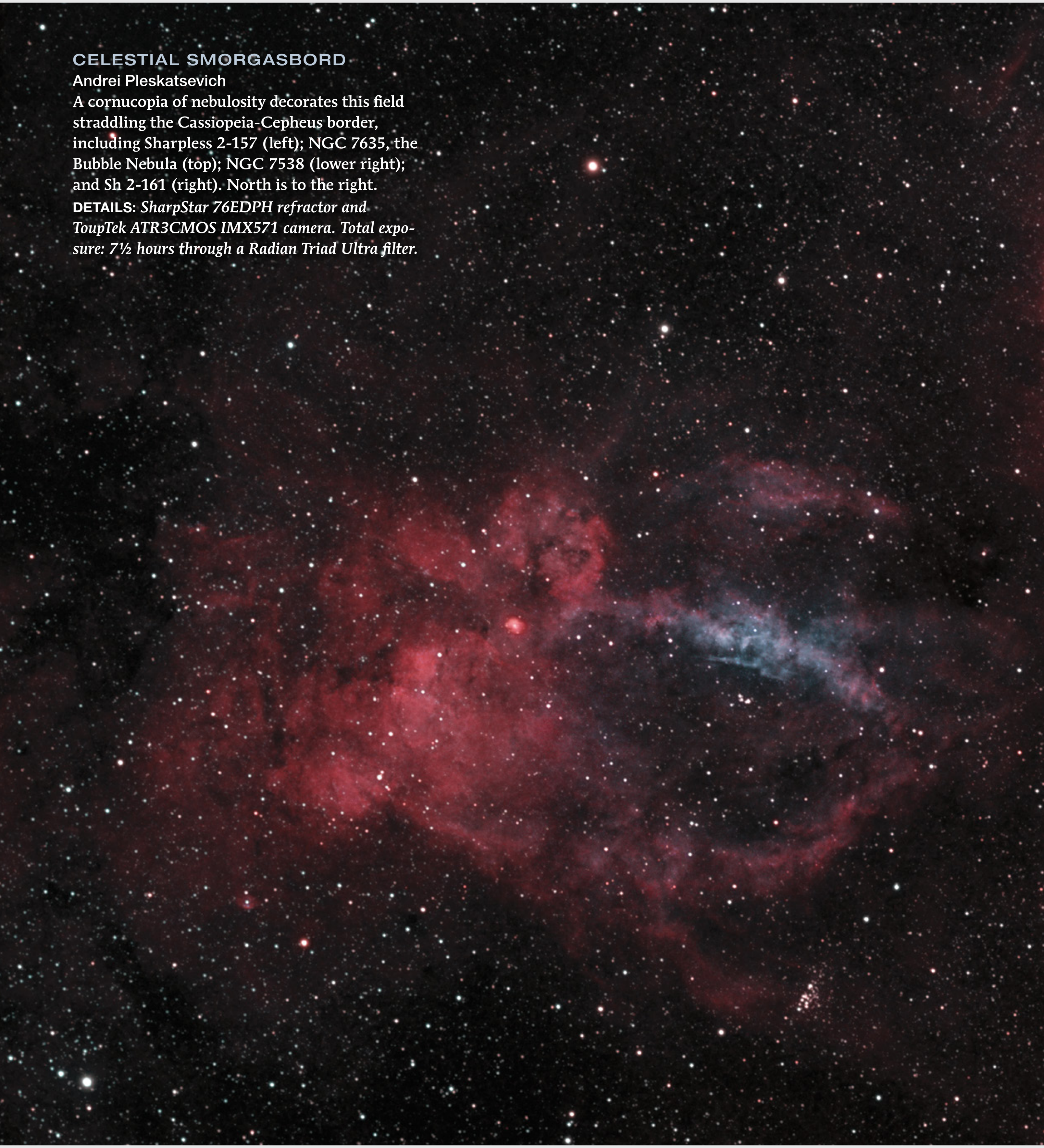
One last point: So far we've been talking about *apparent* magnitude — how bright objects *appear* from Earth. But to determine how bright a star *actually* is, we need to factor in its distance. For this, astronomers use the *absolute* magnitude scale, which indicates true stellar luminosity. A star's absolute magnitude is how bright it would appear if viewed at a distance of 10 parsecs. (A *parsec* is a standard distance unit astronomers use and is approximately 3.26 light-years, so 10 parsecs is 32.6 light-years.)

Observed from this distance, the Sun would shine at a mere 4.8 in absolute magnitude. Meanwhile, Rigel, the blue supergiant in Orion, would blaze at a dazzling –8. If we could put them side by side at a distance of 10 parsecs, our Sun would appear positively dim in comparison to Rigel. As with so much in astronomy, the seemingly straightforward question at the start of this article doesn't have a simple answer. ■



AKIRA FUJII

▲ **STELLAR MAGNITUDES AT A GLANCE** In this image of the Sickle asterism in the constellation Leo, the Lion, magnitudes of stars go up by one magnitude fainter from 1st-magnitude Regulus all the way out to 5th-magnitude Kappa Leonis (a star not part of the Sickle proper).

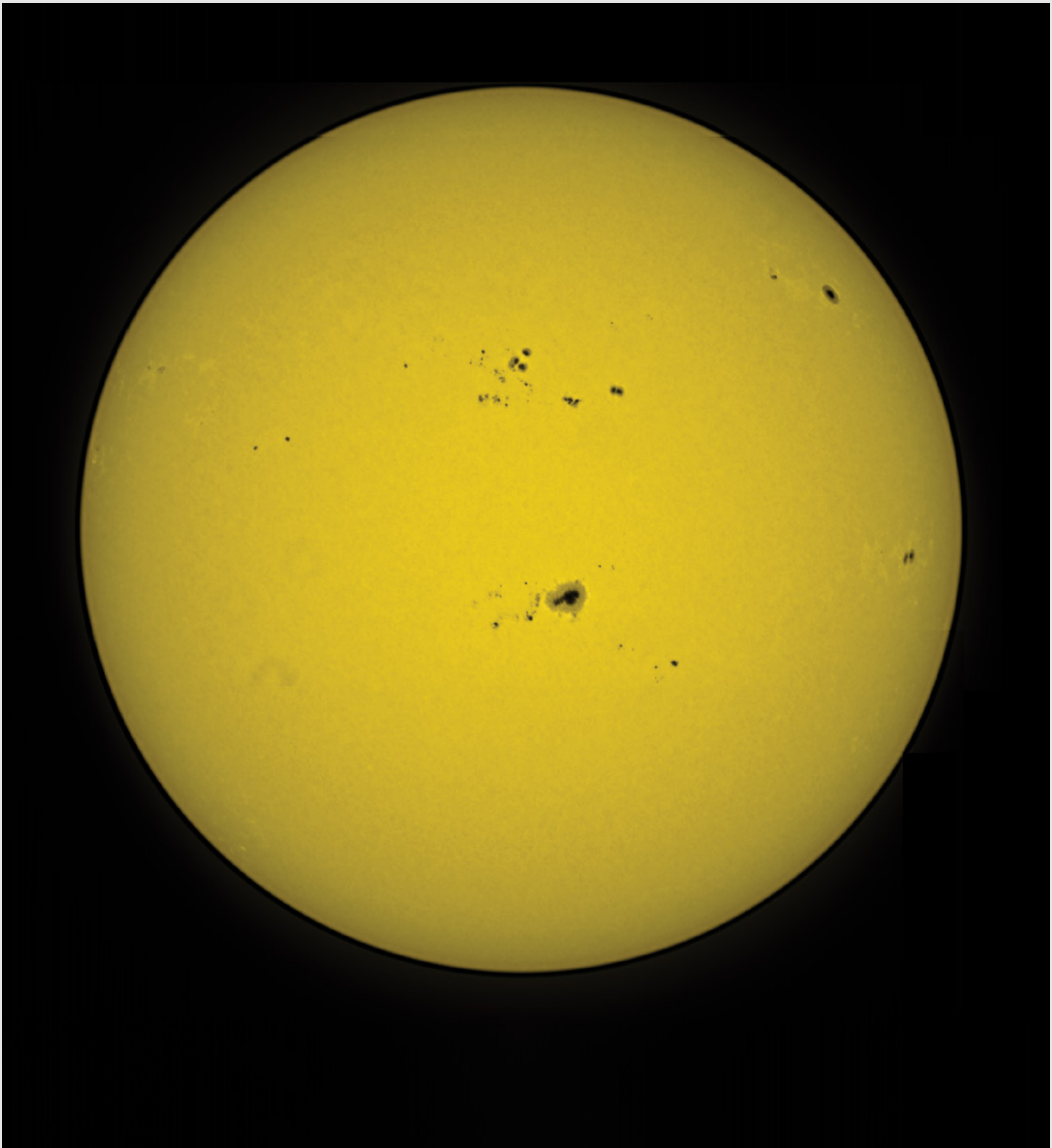


CELESTIAL SMORGASBORD

Andrei Pleskatsevich

A cornucopia of nebulosity decorates this field straddling the Cassiopeia-Cepheus border, including Sharpless 2-157 (left); NGC 7635, the Bubble Nebula (top); NGC 7538 (lower right); and Sh 2-161 (right). North is to the right.

DETAILS: *SharpStar 76EDPH refractor and ToupTek ATR3CMOS IMX571 camera. Total exposure: 7½ hours through a Radian Triad Ultra filter.*



SOLAR BEHEMOTH

Ricardo Sánchez

Several groups of dark sunspots adorned the Sun's disk on January 19, 2023, including AR 3190, a spot so massive it was visible through eclipse glasses without a telescope.

DETAILS: *Sky-Watcher BK MAK102 EQ2 Maksutov-Cassegrain telescope and ZWO ASI174MM camera. Stack of 1,000 frames, each through Solar Continuum and UV-IR cut filters.*

◁ DUSTY GALAXY

Bob Fera and Eric Coles

Edge-on spiral galaxy NGC 891 in Andromeda displays a dark dust lane and bright central bulge. Dusty filaments are seen extending hundreds of light-years above and below this galaxy's centerline.

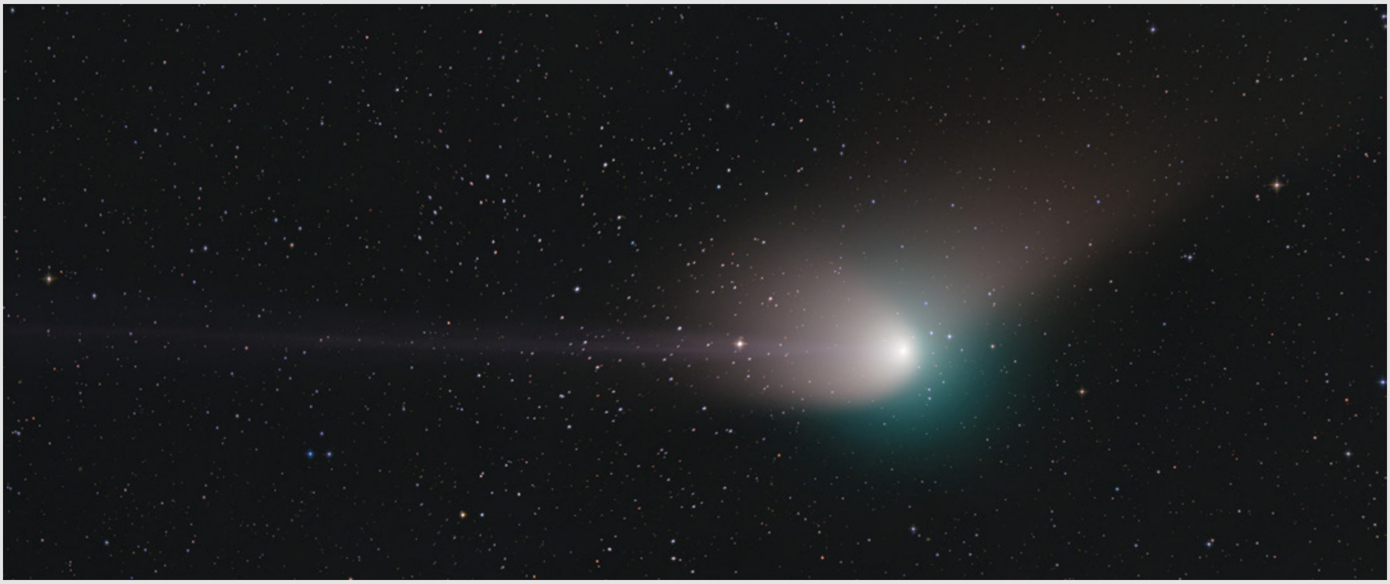
DETAILS: *PlaneWave CDK20 telescope and Moravian Instruments C3-61000 PRO camera. Total exposure: 15 hours through LRGB filters.*

▽ SHRINE TO THE STARS

Bob Horton

Stargazers gather beside the McGregor Observatory on Breezy Hill as a Perseid meteor cuts across the Milky Way during the 2022 Stellafane amateur telescope makers convention in Vermont.

DETAILS: *Nikon Df camera with 20-mm lens. Total exposure: 18.6 seconds at f/1.8, ISO 3200.*



△△ DASHING BETWEEN DIPPERS

Chris Schur

Comet ZTF (C/2022 E3) displays a thin gas tail and short, fan-shaped dust tail as it glides past Ursa Minor on January 27th. The dust tail appeared to have lined up with the ion tail a few days after Earth passed through its orbital plane.

DETAILS: *Orion 10-inch Newtonian astrograph and ZWO ASI071MC Pro camera. Total exposure: 2 hours.*

△ A TALE OF TWO TAILS

José J. Chambó

Solar-wind turbulence caused a disconnection event in the ion tail of Comet ZTF (C/2022 E3) on January 19th as it passed through Boötes. The break-up of diatomic carbon causes the comet to glow a striking blue-green color.

DETAILS: *TS-Optics GSO Photon 8 reflector and Atik 383L+ camera. Total exposure: 35 minutes through LRGB filters.*

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

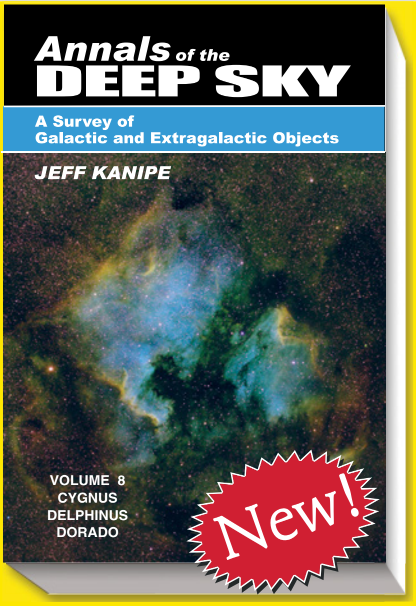
Bob's Knobs™
COLLIMATION THUMBSCREWS
www.bobsknobs.com

Your Custom Adapter is just a few clicks away
HOT PRODUCT 2011 SKY & TELESCOPE
www.preciseparts.com
305 253-5707
info@preciseparts.com
PRECISEPARTS®
CUSTOM PARTS FOR ASTRONOMY

www.lunaticoastro.com
wifi + optional **battery**
No cables!
Seletek LIMPET focuser controller
$149
✓ very small and easily attached to the telescope
✓ **Wifi** and **USB** connection
✓ Works with **most motors** in the market
✓ Optional **external temperature sensor**
✓ **ASCOM, INDIGO** and **INDILib** enabled

Read S&T!
skyandtelescope.org/subscribe

BOOKS



Much, much more than just a field guide. Annals is the observer's travel guide to the most recent scientific findings told with deep historical context and captivating illustrations.

Volume 8 — $34.95

Willmann-Bell

Get full details at shopatsky.com

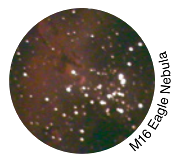
CAMERAS

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!



M16 Eagle Nebula

HOT PRODUCT 2017 SKY & TELESCOPE

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

REVOLUTION IMAGER
RevolutionImager.com

CLASSIFIEDS

• **FOR RENT:** 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500

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

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

skyandtelescope.org

ACCESSORIES

OBSERVATORIES/DOMES

MISCELLANEOUS

MISCELLANEOUS (cont.)

TELESCOPES

SOFTWARE

SKY&TELESCOPE

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

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

Celestron
»back cover
accessories / binoculars / mounts / telescopes
celestron.com

iOptron
»page 5
mounts / telescopes
ioptron.com

QHYCCD Light Speed Vision
»page 1
cameras
qhyccd.com

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

Stellarvue
»inside back cover
eyepieces / telescopes
stellarvue.com

Ad Index

To advertise in our Product Locator, please email Rod Nenner 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.

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/astrowithnoborders

April 15–16
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

April 15–22
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 19–22
MID-SOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 27–30
SOUTHERN STAR
Little Switzerland, NC
https://is.gd/Southern_Star

April 29
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

May 14–21
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 19–21
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org/index.php/msp13

June 10–17
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCStarParty

June 14–17
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brcasp

June 14–18
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

June 14–18
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 14–18
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
yorkcountystarparty.org

June 15–18
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

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

Seeking Canals on Mars

Using Percival Lowell's 24-inch refractor, could the author see what the astronomer saw?

WHEN I WAS 10 years old, nothing captured my imagination more than the canals of Mars and the magnificent (and rather tragic) story Percival Lowell told of a civilization of intelligent beings having built them to stave off extinction on their dying world. In his 1910 book *Mars as the Abode of Life*, Lowell described the canals as "Fine lines and little gossamer filaments only, cobwebbing the face of the Martian disk, but threads to draw one's mind after them across the millions of miles of intervening void."

Soon after I read this, Mars came to opposition in March 1965 — the first I ever observed. With my 60-mm refractor, I gazed with all my soul at the tiny, coppery pinhead of light that swam in the eyepiece. I didn't make out any canals; in fact, I could just barely discern Syrtis Major, one of the planet's largest features. And when, four months later, Mariner 4 flew past the planet, I saw, with the rest of the world, that while craters abounded, nary a canal was to be seen. It was one of the great disappointments of my life.

I've never stopped wondering about the canals, however. What were they? Illusions, surely, but even illusions have explanations.

I now live in Flagstaff, Arizona, and so sometimes I have access to Lowell's 24-inch Clark refractor at the nearby Lowell Observatory. During the opposition of Mars this past December, I was able, with help from observatory staff, to indulge in a bit of eyepiece archaeology. I wanted to duplicate as exactly as I could the observing conditions — aperture, magnifying power, and the like — that once revealed canals to Lowell.

That was straightforward enough. What I couldn't do so readily was regain the "innocent eye." I couldn't unlearn all that I knew of Mars from spacecraft and digital images, and look at the planet with the naïveté of a late-19th- or early 20th-century observer.

The white polar caps and broad, dark surface markings easily came into view in the 24-inch. One night I examined the Mare Tyrrhenum and Terra Sirenum regions. On another I studied the rather bland Tharsis region, distinguished by the faint, bright ring of Olympus Mons. On yet another, Mare Erythraeum and Margaritifer Sinus were visible. I relished the detail in these features, which came out in the steadiest moments, and I tried to capture them in careful sketches. What was not so simple was to shift my focus to the deserts, the preferred location of the canals.

When I did, though, the canals remained stubbornly not there.

Then, one magical night, a few threadlike lines suddenly appeared! They were off-center in the eyepiece field, and as soon as I attempted to focus on them, they were gone. Yet for a moment my heart skipped a beat. Though I was unable to suspend disbelief for long, I did for an instant, and I felt a little of the wonder I experienced so many years ago with my little telescope. Instead of Mars being as we know it today, it hung as a golden globe on gossamer threads of "what if" and momentarily revived the vivid if fading memory of my childhood.

■ Contributing Editor **BILL SHEEHAN** is coauthor, with Jim Bell, of *Discovering Mars* (University of Arizona Press, 2021).

Percival Lowell's 24-inch refractor at Lowell Observatory, with Mars visible through the dome's slit

WILLIAM SHEEHAN


CELESTRON
MASTER the SKY
Try Celestron's legendary, top-rated astronomy binoculars
Immerse yourself in the night sky with Celestron binoculars.
▪ See the Moon's craters in lifelike depth
▪ Take in wide-field objects like the Orion Nebula, the Pleiades, and comets
▪ Or simply get lost panning the Milky Way
There's no setup time, no distractions, just you and the Universe.
SkyMaster Series
▪ The world's bestselling astronomy binocular
▪ Available in a variety of sizes (60mm-100mm) and up to 35x magnification
SkyMaster Pro Series
▪ Features an RSR (Reflex Sight Ready) rail so you can attach your red-dot finder
▪ Fully multi-coated optics, BaK-4 prisms, waterproof
SkyMaster DX Series
▪ Features a 7mm exit pupil, ideal for viewing with dark-adapted eyes
▪ Fully multi-coated optics, BaK-4 prisms, waterproof
Echelon
▪ Assembled in the USA
▪ Fully multi-coated optics, BaK-4 prisms, waterproof
▪ Independent focus design
TrailSeeker ED Series
▪ Extra-low dispersion (ED) glass
▪ A compact choice perfect for handheld observing
★★ Cornell Lab of Ornithology's ★★
Top Pick for Affordable Full-size Binoculars
celestron.com
CELESTRON PREMIER SELECT DEALERS
B&H Photo – 800.947.9970 – bhphotovideo.com
High Point Scientific – 800.266.9590 – highpointscientific.com
Optics Planet – 800.504.5897 – opticsplanet.com
Astronomics – 800.422.7876 – astronomics.com
OPT Telescopes – 800.483.6287 – optcorp.com
Woodland Hills – 888.427.8766 – telescopes.net
Adorama – 800.223.2500 – adorama.com
Focus Camera – 800.221.0828 – focuscamera.com
Agena AstroProducts – 562.215.4473 – agenaastro.com