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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

FEBRUARY 2023

Create Stunning Nightscapes

Pages 54 & 60

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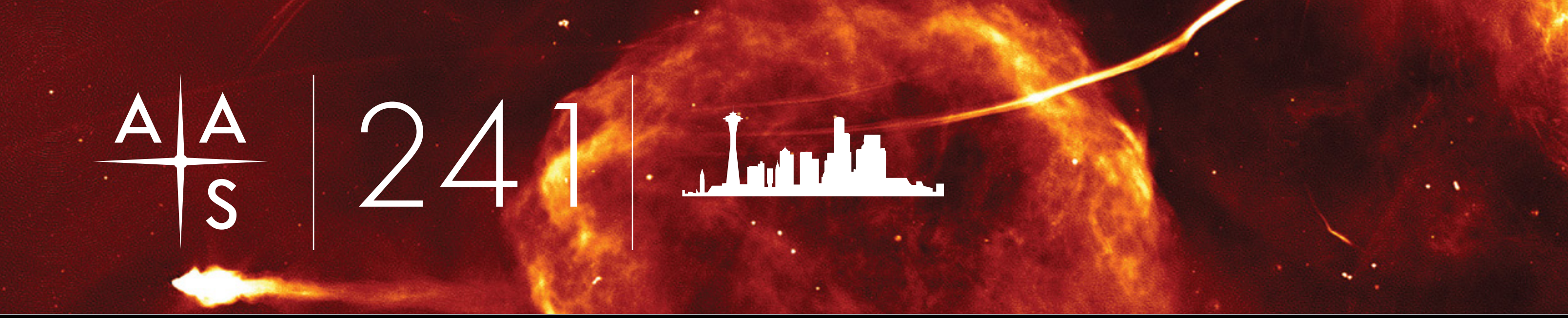

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Image: Supernova remnant G359.1-0.5. Credit: I. Heywood / SARAO

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THE ESSENTIAL GUIDE TO ASTRONOMY

NPS / WILLIAM PEDRO

February 2023 VOL. 145, NO. 2

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ON THE COVER

The Milky Way over the Saskatchewan Summer Star Party

PHOTO: ALAN DYER

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Take Your Pic

IN EVERY ISSUE of *S&T*, we aim to appeal to a wide spectrum of readers, from those just getting started in the hobby, or some aspect of it, through skilled practitioners. Our two articles this month on nightscape astrophotography exemplify this objective.

The title of Tony Puerzer's piece on page 54 — "The Simplest Astrophotography" — should catch the eye of beginner astro-imagers. But even adept night-sky shooters might enjoy the article, for it advances a minimalist philosophy that might entice, say, a planetary imager as a change of pace.

Alan Dyer's cover story on page 60 is arguably for the more experienced astrophotographer. Yet, like Puerzer's piece, it provides all anyone might need to start creating panoramic nightscapes even with basic equipment. You may not achieve right away what Dyer achieves — after all, he's one of the best in the business — but like many of the more in-depth treatments we publish, his work can leave you feeling aspirational: "Maybe someday I, too, can . . ."

▲ Inspirational and aspirational: a 360° panorama by Alan Dyer (see pages 66–67)

Whatever your level, inclination, or goals, these two articles essentially cover the gamut of steps needed to capture striking skyscapes. In both articles, the degree of expertise the author shares is optimal for his topic. It's a kind of Goldilocks zone each hits for the reader: neither too basic, nor too sophisticated, but just right.

Whatever image you're after, you needn't soldier your way through without help; they'll guide you. The writers suggest equipment they deem helpful or even vital to the task at hand, from a remote cable release or intervalometer (Puerzer) to a leveling head and indexing pan head (Dyer). They provide valuable tips, like "the 500 rule" Puerzer explains, or when Dyer notes that while a 30% overlap of images when assembling panos can work, he typically aims for about 50%.

They also specify things to watch out for that could throw you off track. Because camera models differ, Puerzer suggests experimenting with various shutter speeds and ISO settings on yours to determine the right balance between image brightness and noise. Dyer, for his part, warns that panoramas can be so large — tens of thousands of pixels wide and many gigabytes in size — that they might tax a computer not built for serious image processing.

Unsurprisingly, these articles also remind you of engaging vistas to photograph, such as mutiple-planet conjunctions or the grand arc of the Milky Way, Earth's blue shadow or the pink Belt of Venus. Go get 'em.

Peter

Editor in Chief

SKY & TELESCOPE
The Essential Guide to Astronomy

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An amateur astronomer guides onlookers through the night sky with a green laser at a star party hosted by the Craters of the Moon National Monument and Preserve.

JACOB W. FRANK / NPS / PUBLIC DOMAIN

Space for Beginners

I cannot express how thankful I am for your new monthly department, Beginner's Space (*S&T:* Sept. 2022, p. 74).

Having a new interest in astronomy but absolutely no background can be as challenging as it is frustrating. It's been more than 40 years since I attended high school, and I'm now newly retired. Any astronomical knowledge that might have been taught has long been pushed out of my brain by limited time, my career, and raising kids.

Now that I have more time, no career, and the kids are grown, I can devote myself to a new interest. Your magazine helps spark that interest. So thank you for the new department and recognizing that some of us need help.

Ruben Navarro
Wheatland, Wyoming

I am pleased that *S&T* is launching a monthly Beginner's Space column. I own a telescope but use it infrequently, mostly because every time I set it up to observe, I am not impressed with the results of my efforts. I appreciated the observing-aid illustrations on the sky maps on pages 59 and 60 of the September 2022 issue. But I was frustrated and disappointed that the illustrations on pages 24, 25, 45, and 56 lacked the same helpful identifiers. If I can't find Cassiopeia in an illustration, how will I ever find it in the night sky? I look forward to your efforts to enlighten me, particularly in checking the collimation of my Newtonian.

Thanks for a great publication!

Bill Edwards
Toms River, New Jersey

I like the idea of reviving Beginner's Page. When I got into observing, I started without optical aid. My mother, being a Girl Scout leader, helped. She showed me the most obvious asterisms, and we bought a device I haven't seen since, even in advertisements: an illuminated, one-eye viewer that overlaid the outlines of constellations around the actual stars viewed with the other eye. It was a great beginner device.

Then I was totally distracted by my discovery of telescopes and pestered my neighbor to get his out whenever I saw a star. Go To is a terrible idea for beginners. Scout and 4-H manuals are worth looking at. I used to read comic books and the *Junior Woodchucks' Guide* is what we all need.

Good luck.

Terry Herlihy
Chicago, Illinois

Beginner's Space is an excellent addition to *Sky & Telescope*. I've been a subscriber for over 50 years (since high school), and I was quite daunted by the articles back then. The initial article on the ecliptic is clear and informative for beginners, and for those of us who have been amateur astronomers for scores of orbits about our star, it enhances our perception of where we are in our solar system. I don't recall ever having seen a graphic representation of the inclination of all the planets relative to the ecliptic before. It just goes to show that there is always more to learn, particularly in the infinitely rich subject of astronomy.

In the astronomy club to which I have belonged for 40 years — Treasure Coast Astronomical Society, based at Indian River State College in Fort Pierce, Florida — we have a wide range of levels of astronomy-related understanding. Beginner's Space will be informative and helpful for all in our club, to whom I will heartily recommend it. Well done. I'm looking forward to future Beginner's Space articles.

Lawrence Crary
Stuart, Florida

The Sky Is Falling

"The sky is falling" is an expression from a fable about a chicken who was hit on the head by an acorn and went to tell the king that the sky was falling. Today, the term is used to define an irrational conviction that a disaster is imminent. For too long, other engineers and I have been treated like that chicken, as our decade-long crusade for a planetary defense system has been ignored.

We need a commercial transportation system that provides rapid access to space. Reusable launch vehicles and space-based tugs can be developed with existing technology. The space-based tugs can be equipped with sensors to detect near-Earth asteroids, and the reusable launchers can provide rapid response to deter the threat.

I am the coordinator of a group known as the Concerned American Aerospace Engineers. Please visit our website at **http://caae.space**.

"It's the squeaky wheel that gets the grease" is another expression that applies. Planetary defense will remain a concept until those of us riding Spaceship Earth speak out!

Don A. Nelson
Concerned American Aerospace Engineers
Alvin, Texas

One Man's Trash . . .

I agree with the points raised by David Grinspoon in his essay "Crash as Trash" (*S&T:* Sept. 2022, p. 12). We need to clean up after ourselves. However, the historical significance of such artifacts shouldn't be overlooked. Otherwise, someday we may read, "Accepting bids on a lot of three slightly used lunar rovers, a bit dusty, but very low mileage." Ad astra cum lucrum?

Greg Konesky
Hampton Bays, New York

I read David Grinspoon's "Crash as Trash" column in the September issue. We should continue to explore Mars, but we should also consider our impact on Mars from the beginning. The presence of our discards on the Martian surface will affect future science results. As we explore and use other worlds, we should develop the habit of taking better care of them than we have of Earth. We should also use these new habits to greatly improve our care of Earth as well!

James W. Scott
Vernon, New Jersey

A Solid Magazine

As a subscriber to *S&T* and an owner of various telescopes and binoculars, I certainly enjoy the magazine's various feature articles. It covers everything a beginner needs to enjoy the hobby of astronomy and observing. I especially like the pull-out section, which includes a planisphere for the month and the Binocular Highlight column. I also enjoy the various articles covering the Moon, planets, stars, and constellations. And I'm particularly fond of the 75, 50 & 25 Years Ago column by Roger W. Sinnott and the *S&T* Test Reports. All in all, *S&T* is a must-have for anyone interested in the hobby of astronomy.

Roger M. Gould
Great Neck, New York

FOR THE RECORD

- The team of Brazilian observers mentioned in "Understanding Lunar Eclipses" (*S&T:* Nov. 2022, p. 34) is the Rede de Astronomia Observacional (Observational Astronomy Network), which has been led for many years by Hélio C. Vital (**rea-brasil.org**).
- The graph on page 52 of the September 2022 issue contains errors in the vertical axis. A corrected version appears at **https://is.gd/errata2022**.

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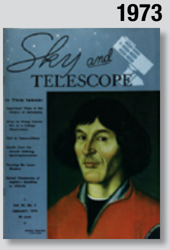
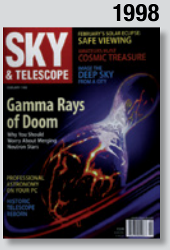
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1948

1973



1998



◖ February 1948

Startling Sight "Astronomical history tells of many 'great comets' which have appeared to our parents and grandparents. But not since 1910, when Comet 1910a and Halley's blazed across the sky, have any spectacular comets been seen — comets which could attract the gaze of the man in the street without any encouragement or advice from his astronomical friends. Now the Southern Hemisphere and the tropics have been treated to the sight of what surely deserves to be called the Great Comet of 1947, although its present designation is Comet 1947n.

"This spectacular object was first seen in South Africa on the evening of December 8, 1947, by practically everyone who happened to be out in the open under a clear sky [writes J. S. Paraskevopoulos of Harvard's Boyden Station] . . . [My] staff and I agreed that the tail was *not less* than 25 degrees."

◖ February 1973

Star Diameters "When a bright star of late spectral type is occulted by the moon, the duration of the star's fading at disappearance or of brightening at reappearance provides an accurate measure of its angular diameter. The high-speed photometric technique needed for such observations was developed some years ago by David S. Evans at the Royal Cape Observatory . . .

"[A] remarkable observation has been made of the Mira-type variable star R Leonis . . . '[G. Neugebauer and coworkers] made observations with three telescopes at Mount Wilson at wavelengths of 3.5, 4.8, and 11 microns. Observations at the two shorter wavelengths are consistent with a disk diameter of 0.05 arc sec, as predicted from [its] temperature and luminosity . . . At 11 microns, the occultation measurements show that the radiation originates from an area 0.3 arc sec in diameter, thus supporting the concept of thermal emission from a cloud of dust particles surrounding the star.'"

The early 1970s saw two pioneering techniques just coming into their own: high-speed photometry and observations in the infrared.

◖ February 1998

Comet Origins "Recent ultraviolet observations of Hale-Bopp suggest that the comet formed relatively close to the Sun before being tossed out into the Oort Cloud — where it remained for ages before returning . . . in 1995 . . . More evidence for a solar-system origin now comes from measurements at much longer wavelengths. Millimeter-wave spectra from the James Clerk Maxwell Telescope have established isotope ratios for the comet's carbon, nitrogen, and sulfur. From these ratios David C. Jewitt (University of Hawaii) and his colleagues infer that 'the cometary volatiles . . . show no evidence for an interstellar component.' This contrasts with Hale-Bopp's brilliant precursor, Comet Hyakutake (C/1996 B2), whose properties are suggestive of the interstellar medium."

ASTRONOMY & SOCIETY

National Science Foundation Won't Rebuild Arecibo

WHEN THE NATIONAL SCIENCE FOUNDATION (NSF) announced a new educational center at Arecibo Observatory in Puerto Rico, one line of an otherwise innocuous statement sent shock waves through the community: "The solicitation does not include rebuilding the 305-meter telescope or operational support for current scientific infrastructure, such as the 12-meter radio telescope or Lidar facility."

The NSF has been the steward of Arecibo Observatory since its construction was completed in 1963. But when a suspended receiver collapsed on the iconic 305-meter dish at the observatory's heart in 2020 (*S&T:* Mar. 2021, p. 8), it became clear that any replacement would be years in the making. The contract for the University of Central Florida (UCF) to manage Arecibo Observatory was already set to expire in March 2023, and the NSF announcement put the writing on the wall.

"We're entering a transition phase to ramp down scientific and technical activities and hand over to the future STEM education center managers," says Julie Brisset, who directs the Florida Space Institute at UCF.

What the new education center would look like is still unclear; NSF is still soliciting proposals as of press time. The center would supplement significant education and outreach programs already happening at the observatory.

Despite the lack of support for existing science facilities, it's still up in the air whether the observatory would continue operations in some form. "I'm pretty sure they would not disregard the opportunity to have science going on — they're just not going to fund it," Brisset says.

In fact, the NSF announcement states, "Teams seeking to utilize existing scientific infrastructure or proposing for new projects can submit proposals that are complementary to the scope of the new center." An NSF spokesperson confirmed that such proposals would be coordinated with the Foundation as well as with the new managers of the reimagined center.

But the instruments are fragile. "If there's, say, one month or so when an instrument is not used and maintained, then usually it doesn't work when you show up again," Brisset notes.

The NSF announcement came as a surprise to many in the community. "I was not expecting the NSF announcement," says Tracy Becker (Southwest Research Institute), who got her start via the Research Experience for Undergraduates program at Arecibo. "Like many other scientists, I have always remained optimistic that the gravitas of the iconic telescope, plus the incredible and diverse scientific research being conducting there, and could be conducted there in the future with a modest investment, would be enough to warrant rebuilding the telescope."

There also remains the question of how to replace Arecibo's lost radar capabilities, which scientists had used for detailed characterization of near-Earth asteroids. It's possible that additional investments in existing facilities can recover some capabilities. NSF is also exploring next-generation radar needs, with a report expected later in 2023.

Perhaps the biggest impact will be on the local community. "To me, there is irony in creating a STEM education center in Puerto Rico through the closure one of the largest facilities on the island that actually employs people with STEM careers," Becker says. "The engineers and scientists who operate the Arecibo Observatory instruments will need to look for different jobs, and many will likely be driven to leave the island of Puerto Rico."

Brisset agrees. "This is a big loss for the Puerto Rican community," she says. "I mean, it's great to have a STEM education center there, but a STEM education center always benefits from active science."

■ MONICA YOUNG

▲ *Left:* Arecibo Observatory as it appeared during its heyday. *Right:* This photo shows the damage to the 305-meter telescope at Arecibo Observatory shortly after its collapse.

BEFORE COLLAPSE: NAIC ARECIBO OBSERVATORY / NSF; AFTER COLLAPSE: MICHELLE NEGRON / NSF

STARS

New Observations Add Fuel to Fast Radio Burst Debate

UNTIL RECENTLY, there were dozens of ideas for what powers *fast radio bursts* (FRBs), ultra-bright flashes of radio waves visible from billions of light-years away. But when astronomers found multiple FRB-like bursts coming from a nearby highly magnetic neutron star, or *magnetar*, the question of FRB origins seemed to be largely settled (*S&T:* Sept. 2020, p. 10).

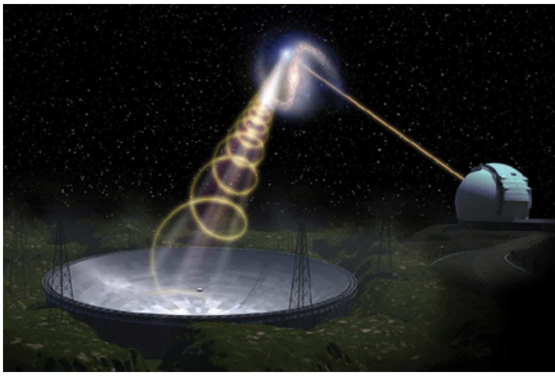
However, studies published September 21st in *Nature* and *Nature Communications* on FRB 20201124A disagree on its origin.

Over several months in 2020, Heng Xu (Peking University, China) and colleagues detected 1,863 bursts from the source using the Five-hundred-meter Aperture Spherical radio Telescope (FAST) in China. The FAST data included polarization, which, to the team's surprise, revealed that the magnetic field and/or the plasma density around the source sometimes changed dramatically over only a few days.

Team member Fayin Wang (Nanjing University, China) led a team in proposing that there is a magnetar at the heart of this FRB. But this magnetar has a companion: an extremely luminous blue *Be* star surrounded by a gas disk. As the two stars dance around each other, the magnetar's radio bursts pass through different parts of the *Be* star's disk to reach the observer, resulting in apparently quick changes.

"I think this is an excellent model that neatly explains the observed properties of the burst," says Adam Lanman (McGill University, Canada), who wasn't involved in the study. "But it's certainly not the end of the story!" For one, the repeating flashes from FRB 20201124A aren't as regular as would be expected from a binary system.

Another major wrench in the *Be*/magnetar scenario is where the FRB resides: The *Nature* study presents observations with the twin 10-meter Keck telescopes on Mauna Kea in Hawai'i, showing that the FRB source lies between the arms of a barred spiral galaxy. "That position is not particularly attractive for young stars," says team member Bing Zhang (University of Nevada). And if there are few young stars there, then it's unlikely the source comes from a fledgling magnetar.



▲ A stylized depiction shows a fast radio burst's circularly polarized emissions traveling toward the FAST and Keck telescopes. Keck's observations pinpointed the source's location: in between the arms of a barred spiral galaxy.

Zhang says he for one is back to the drawing board, at least for this particular source. "We need to really rethink everything," he says. "Start over."

■ **BENJAMIN SKUSE**

SOLAR SYSTEM

Asteroid Deflection Worked Even Better Than Expected

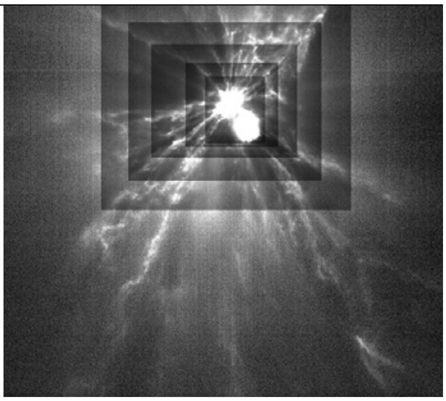
THE DOUBLE ASTEROID REDIRECT TEST'S (DART's) attempt to alter the path of an asteroid moon succeeded beyond expectations. Before the DART spacecraft slammed head-on into Dimorphos, the moon of asteroid 65803 Didymos, the moon orbited its primary in about 11 hours, 55 minutes. Post-impact, it now takes only 11 hours, 23 minutes (plus or minus 2 minutes) to complete its orbit. The large change — 32 minutes — was within the range predicted before the impact but at the top end of what was possible.

The plumes of ejecta streaming out from the head-on impact likely contributed to the moon's recoil. For every action, there is an equal and opposite reaction: By launching material toward Dimorphos' direction of motion, Dimorphos' momentum changed just as much in the opposite direction.

The mission confirmed the measurement using visible light and radar. With both ground- and space-based optical telescopes, the team recorded light curves of the Didymos system as the two components alternately eclipsed each other. The cadence of eclipses changed as the orbital period of Dimorphos shortened.

In addition, radio telescopes like those at Goldstone in southern California and Green Bank Observatory in West Virginia broadcast radar waves at the Dimorphos system and watched for the reflected signal. The new orbital speed derived from the radar data closely matched the ones measured from visible-light observations.

Many questions remain: How much momentum did the impact transfer? How much mass was ejected? How big were the particles? Was the impact large enough to introduce a wobble into Dimorphos' spin pole? Scientists are still analyzing the dramatic ejecta plumes and long, comet-like dust tail that the impact caused. It will take years to reap the full harvest of science!



▲ After the impact, plumes of ejecta streamed away from Dimorphos. Each rectangle here represents a different level of contrast in order to resolve fine structure in the plumes.

■ **EMILY LAKDAWALLA**

See more post-impact images at https://is.gd/DARTimpact.

FRB: JINGCHUAN YU; CUBESAT VIEW OF DART IMPACT: ASI / NASA / APL

HISTORY

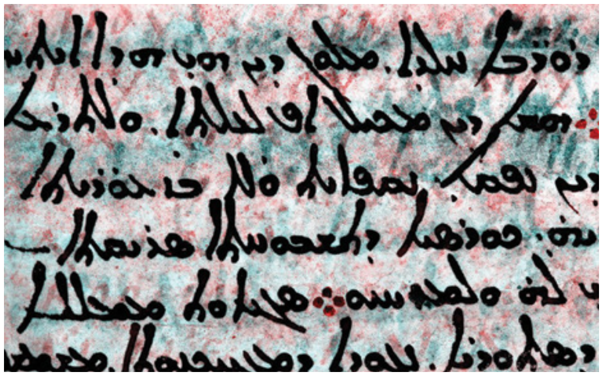
Lost Star Catalog Brought to Light

THE GREEK ASTRONOMER Hipparchus drew up the very first star catalog of the western world sometime between 162 and 127 BC, recording names, descriptions, and coordinates of some 850 stars. At least, that's what later sources say. No one has found copies of Hipparchus' list — until now.

Writing in the November 2022 *Journal for the History of Astronomy*, three European scientists claim to have uncovered a small part of the long-lost catalog. "I felt nothing short of awe when I first heard about it," says astronomy historian William Sheehan.

"[The find] illuminates a crucial moment in the birth of science, when astronomers shifted from simply describing the patterns they saw in the sky to measuring and predicting them," astronomy historian James Evans (University of Puget Sound) told *Nature*.

Peter J. Williams (Cambridge University, UK) and Victor Gysembergh and Emmanuel Zingg (Sorbonne University, France) studied the *Codex Climaci Rescriptus*, a 9th- or 10th-century manuscript from Saint Catherine's Monastery on the Sinai Peninsula in Egypt. The codex, now kept at the Museum of the Bible in Washington, D.C., contains Christian texts in Syriac.



◀ This multispectral detail of the palimpsest enhances Greek undertext in red, below the Syriac overtext in black.

Beneath the visible text on one of the folios is a *palimpsest* — the almost indiscernible imprint of an older text that medieval copyists had scraped off in order to re-use the costly parchment. Multispectral images revealed the older text, which probably dates from the 5th or 6th century A.D.

The Greek palimpsest text describes Corona Borealis, the Northern Crown, noting its extent on the sky and coordinates for four of its stars. These coordinates agree with the stellar positions around the time Hipparchus drew up his catalog.

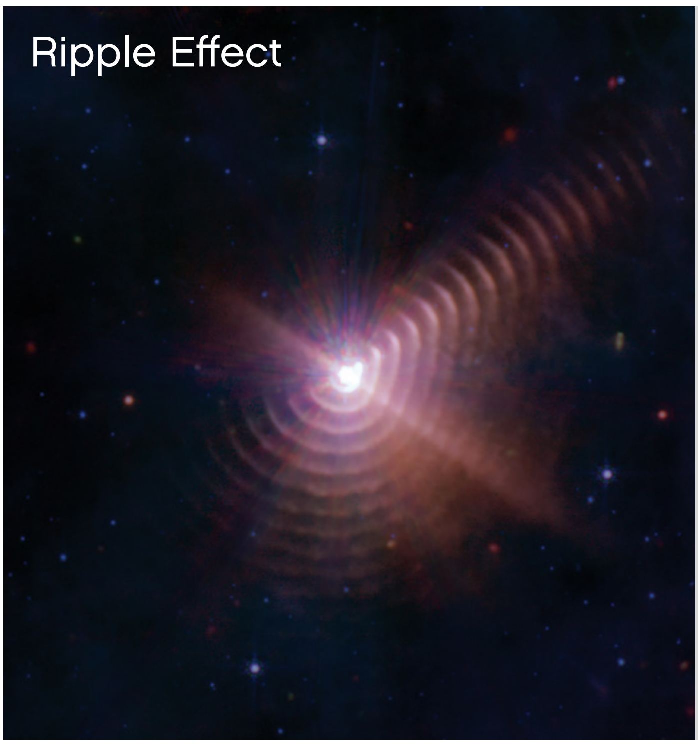
The discovery shows that Hipparchus used equatorial coordinates, and that his measurements were accurate to within one degree.

"The 'style' and coordinate system of the brief text in the palimpsest is similar to that used by Hipparchus in *The Commentaries*," says Bradley Schaefer (Louisiana State University), referring to the sole surviving text by Hipparchus. "So the palimpsest might plausibly have a Hipparchan heritage." However, he warns that this is "far from proven."

Still, many are delighted that part of the oldest star catalog in history might finally have come to light. "It is one of the most thrilling things to happen in astronomy history for a while," says Sheehan. "What else remains out there to be found out from one of the ancient palimpsests?"

■ GOVERT SCHILLING

Ripple Effect



The James Webb Space Telescope's mid-infrared observations have revealed unprecedented detail in the bizarre system known as WR 140. Two massive stars dance at its center: an *O* star emitting a weaker wind and a Wolf-Rayet star (see page 12) blowing off a stronger, carbon-enriched wind. For a few months every eight years, when the two stars come closest together in their mutual orbit, their winds slam into each other to make carbon-enriched dust, the building block of planets and possibly life itself. Previous images have shown two nested dust shells around the stars. In the new images, Webb revealed 17 nested shells of dust, representing 130 years of close approaches and dust-forming events. Ryan Lau (NSF's NOIRLab) and colleagues published the results October 12th in *Nature Astronomy*. They also took a spectrum of the second-innermost dust shell, where they found a signature of complex organic molecules known as *polycyclic aromatic hydrocarbons* (PAHs). "The conclusion that they are likely seeing spatially resolved evidence of PAHs is strong, and really amazing," says Joshua Thomas (Clarkson University). "This is definitely something to be excited about."

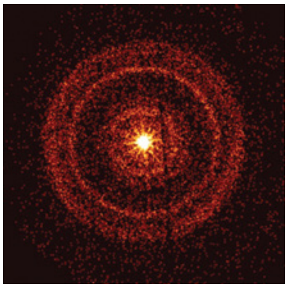
■ MONICA YOUNG

Read details at **https://is.gd/dustripples.**

VISIBLE/UV IMAGE OF PALIMPSEST: MUSEUM OF THE BIBLE 2021 / *JOURNAL FOR THE HISTORY OF ASTRONOMY* 2022; WR 140: NASA / ESA / CSA / STSCI / NASA-JPL / CALTECH

STARS

Brightest Gamma-ray Burst Yet



◀ GRB 221009A's X-ray afterglow has a ring-like appearance because some of these distant photons scatter off dust in our own galaxy.

AN UNPRECEDENTEDLY BRIGHT gamma-ray burst (GRB) lit up the sky on October 9th. Cataloged as GRB 221009A, it exploded in a galaxy 1.9 billion light-years away, which is close for a GRB.

This event likely belongs to the class of *long GRBs*, the end-of-life phase of rare, rapidly rotating massive stars. As such a star goes supernova, it ejects material into jets at speeds just shy of the speed of light. If one of those jets points toward us, we see a minutes-long burst of gamma rays. A longer-lived fading afterglow, observable at other wavelengths, often follows.

This explosion is the brightest and among the most energetic GRB yet detected, so intense that it temporarily blinded multiple sensitive gamma-ray detectors in space. China's Large High Altitude Air Shower Observatory also reported several tera-electron-volt photons pre sumably originating from the GRB. Among them is the most energetic photon from any GRB detected to date.

Such high-energy photons usually don't survive long treks through space, but when they do, they offer a unique glimpse into the physical processes that occur in extreme environments that we can't replicate on Earth.

The burst's high-energy photons even impacted Earth, ionizing its upper atmosphere and modifying the radio-propagation properties of the ionosphere.

Even after the initial burst, the X-ray afterglow remained about 1,000 times brighter than typical GRBs. Observatories have also detected the afterglow all the way down to radio waves — it will likely shine for months to come.

■ JURE JAPELJ

MILKY WAY

Astronomers Map Our Galaxy's "Underworld"

ASTRONOMERS HAVE DRAWN the first map of the distribution of dead stars in and around our Milky Way. This stellar cemetery of neutron stars and black holes takes a different shape from the galaxy we can see.

The most ancient of these compact corpses are the most difficult to track down, both because of the complex changes the galaxy has undergone over billions of years, and because of the "kicks" these objects received when they were born. Uneven supernovae explosions can boot remnants out of the Milky Way's disk. While young remnants won't have moved far since their demise, older ones are long gone. Based on calculations, the team found that 40% of neutron stars and 2% of black holes get enough of a kick to leave the galaxy entirely.

The remainder are still caught in the Milky Way's gravitational clutches, and David Sweeney (University of Sydney) and his team set out to find out where they are. They constructed a simulated map of their current locations using a statistical model that factored in the birth, death, and ejection of ancient stars and their remains. They found that, rather than being confined to a disk, the compact stellar corpses occupy a nearly spherical cloud that stretches three times the disk's height. The results appear in the November *Monthly Notices of the Royal Astronomical Society.*

Astronomer Karen Masters (Haverford College) is impressed: "I think this work is a really clever use of well-established models to investigate the Milky Way," she says.

But actually observing ancient black holes and neutron stars is challenging. "The most exciting part of this research is still ahead of us," Sweeney says.

■ COLIN STUART

NASA / SWIFT / A. BEARDMORE (UNIVERSITY OF LEICESTER)

IN BRIEF

Amateur Finds New Images of Uranus Rings

Previous comparisons between Voyager 2's 1986 images of Uranus' dusty ring system and ground-based images from 2007 suggested that ring material might move around, with one of the rings possibly having changed in brightness and position. But it was hard to be sure because of the different points of view. Then Ian Regan, an image-processing enthusiast, asked himself whether Voyager might have captured the dusty rings in "lookback" images. By stacking data stored in NASA's Planetary Data System, he found three faint dust rings not previously observed in the 36-year-old images. Regan shared his newly processed images on Twitter, where they found their way to planetary-rings scientist Matthew Hedman (University of Idaho). Hedman presented the images (with Regan as coauthor) at October's Division for Planetary Sciences meeting. "These data not only confirm that the location of the peak brightness in the zeta ring did indeed change between 1986 and 2007," Hedman says, "but also indicate that the total amount of material in this ring changed substantially over that time."

■ EMILY LAKDAWALLA

See images and how-to details at https://is.gd/UranusRings.

SOFIA's Final Flight

The Stratospheric Observatory for Infrared Astronomy (SOFIA) has reached the end of its flight plan. Although SOFIA was designed to last 20 years, NASA decommissioned it after only eight, citing high cost and low scientific output. The abrupt end left scientists devastated and projects unfinished. SOFIA flew above 99% of the infrared-blocking water vapor in Earth's atmosphere, enabling, for example, the mapping of magnetic fields in stellar nurseries and distant galaxies (see **https://is.gd/MagneticGallery**) and the discovery of water on the sunlit portions of the Moon (*S&T:* Feb. 2021, p. 11). But the telescope cost NASA more than $80 million a year to run — nearly as much as the Hubble Space Telescope — and it didn't result in nearly as many findings. As such, the mission earned a low ranking in the 2020 Decadal Survey. "I think if we had known how much it would have cost when we started," says Paul Hertz (NASA), "we would have chosen to do this science some other way."

■ SHANNON HALL

 by Greg Bryant

The *Allure* of W

olf-Rayet Stars

These rare jewels in the galaxy create powerful winds and mesmerizing dust spirals.

Live fast and die young — it's a well-used phrase in many facets of our world. In astronomy it surely sums up the life story of Wolf-Rayet stars, one of the rarest of stellar types in our galaxy, yet increasingly recognized as wielding great influence on both the interstellar medium and star formation.

Estimated to shine for only 5 million years, and with exuberant stellar winds second to none, Wolf-Rayets enrich the surrounding interstellar medium with gas and dust as they dispel up to ten-millionths of a solar mass each year. They each end their lives in a supernova, perhaps even as a long gamma-ray burst — the most energetic form of supernova. Their luminosity is hundreds of thousands of times that of the Sun, thanks to their high temperatures and masses ranging from around 10 to more than 80 solar masses.

This find puzzled astronomers for more than half a century.

The first catalog of Wolf-Rayets, published in 1894, numbered just 54 members, and even by 1981 the count had only risen to 159. Since then, dedicated optical and infrared surveys have increased the Milky Way's tally to 667, according to the online Galactic Wolf-Rayet Catalogue maintained by Paul Crowther (University of Sheffield, UK). Some studies have suggested that only a thousand or so Wolf-Rayets should currently exist in the Milky Way, out of a galactic population of perhaps several hundred billion stars overall. It certainly makes them a treasured rarity.

The Nature of Wolf-Rayets

Our knowledge of Wolf-Rayet stars dates back to 1867. That year, French astronomers Charles Wolf and Georges Rayet were conducting a survey of the constellation Cygnus, using the 15.7-inch (40-cm) Foucault telescope at Paris Observatory to record the spectra of individual stars. Stellar spectroscopy, particularly for stars other than our Sun, was very much in its infancy at this time.

◀ **LOSING ITS COOL** Wolf-Rayet stars form from massive stars that shed their outer layers shortly before death. Here, WR 134 (second star from top in the central four-star string) appears with some of its lost gas, visible where it collided with surrounding gas to create the prominent blue arc. The star lies about 6,200 light-years away in Cygnus, the Swan.

T. A. RECTOR (UNIV. OF ALASKA, ANCHORAGE) AND H. SCHWEIKER (WIYN AND NOIRLAB / NSF / AURA)

During their survey, Wolf and Rayet's attention was drawn to three 8th-magnitude stars — HD 191765, HD 192103, and HD 192641. The spectrum of each of these stars displayed broad emission bands, rather than the thin absorption lines that had been seen in other stars.

This find puzzled astronomers for more than half a century. As late as 1929, the American astronomer Donald Menzel described Wolf-Rayet stars and their spectral characteristics as ". . . a door yet unopened and with a key so curious that we are not even sure how to insert it in the lock."

That same year, however, Canadian astronomer Carlyle Beals confirmed that the broad bands in the spectrum appeared to be Doppler-shifted emission, smeared out by the motion of a continuous outflow of material from the star. In a paper published in *Monthly Notices of the Royal Astronomical Society*, Beals presented spectra taken of known, northern-sky Wolf-Rayet stars brighter than 11th magnitude. He showed that several aspects of the emission bands' appearance matched what should arise if the emission came from atoms hurtling away from the stars, pushed out by the stars' own light.

An Evolving Picture

It would be many more decades before astronomers appreciated how Wolf-Rayet stars evolved to their current state. By the 1980s, though, astronomers generally accepted that these stars were once O-type supergiants, the hottest, brightest stars in the stellar menagerie. Commencing on the main sequence with masses equivalent to at least 25 Suns, the progenitors of Wolf-Rayets burn hydrogen for a few million years, forming a helium core.

Wolf-Rayet Subtypes

There are multiple kinds of Wolf-Rayet stars, split according to the star's spectral lines. Nitrogen-rich (WN) ones are dominated by nitrogen; WC ones are dominated by carbon and oxygen. In a rarer third class, WO, oxygen appears more prevalent than carbon.

Astronomers disagree about how exactly a star goes from this stage to being a Wolf-Rayet. Some think that as the core's hydrogen reservoir approaches empty, just before the helium becomes the star's fuel, there is a split in the star's evolution depending on its mass. For O stars below roughly 30 solar masses, the star proceeds through the red supergiant phase and on to the Wolf-Rayet stage. But if the star's mass is greater than 30 solar masses, then it may instead experience an intermediate stage as it approaches the helium-burning process: The star becomes somewhat unstable, ejects material, and transforms into a *luminous blue variable* (LBV). Eta Carinae and P Cygni in the Milky Way and S Doradus in the Large Magellanic Cloud are the most famous LBV examples.

LBVs are rare: Only a dozen or so LBVs have been catalogued in the Milky Way thus far, due in part to their spending less than 100,000 years in this phase of evolution. Eventually, they lose so much mass that essentially all that remains is their helium core. At this point, the star has become a Wolf-Rayet, typically weighing between 10 and 25 solar masses but with a few pushing 100. The star is now in its final stage of life; within a million years, it will head towards a violent end in a supernova.

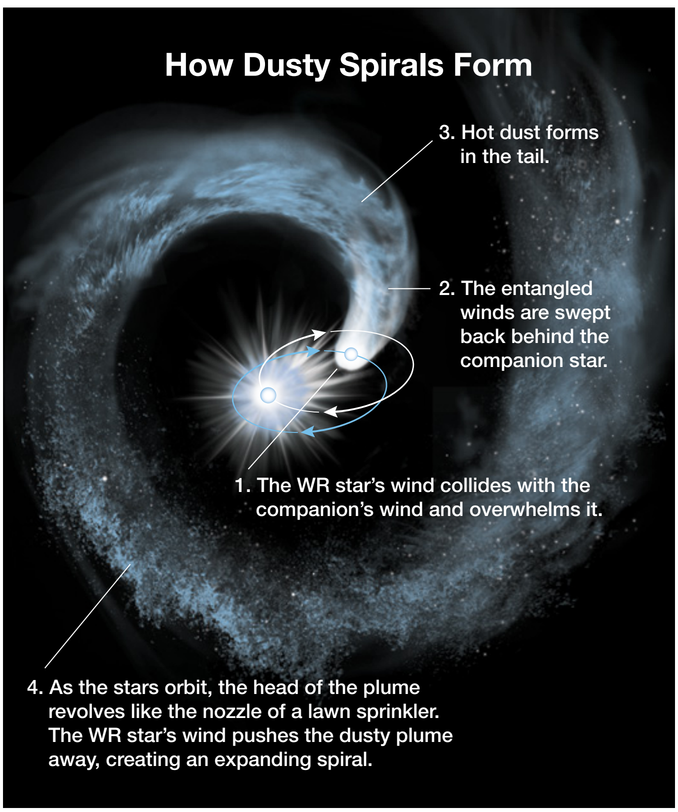
In 2017, however, a study by Nathan Smith (University of Arizona) drew attention to some possible problems regarding the categorization of LBVs as a step in the evolutionary chain between O-type stars and Wolf-Rayets. Whereas Wolf-Rayets occupy the same spatial distribution throughout the Milky Way's galactic disk as O-type stars do, LBVs are much more isolated from their presumed O-type brethren. This disconnect would suggest that LBVs are instead the result of smaller stars, which have become unstable after interacting with each other in a binary system, Smith posited.

Such interactions can influence how much mass a star loses and direct the star down evolutionary routes that a single star would not follow.

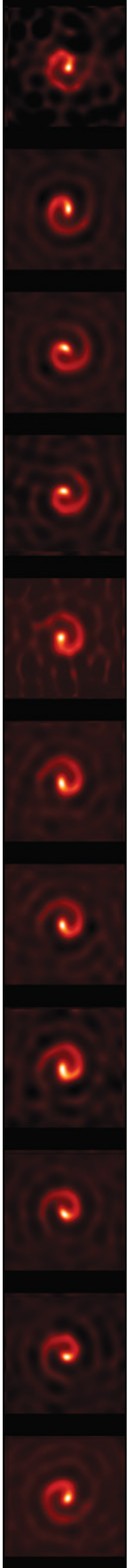
Others, such as Crowther, suspect the reality lies somewhere between these extremes: Perhaps the most luminous LBVs become Wolf-Rayet stars, while the least luminous don't.

We do think that a significant fraction of massive stars, including Wolf-Rayets, have close binary companions. Given that, binary interactions should be common for massive stars. Such interactions can influence how much mass a star loses and direct the star down evolutionary routes that a single star would not follow. For Wolf-Rayets, their presence in low-metallicity galaxies would be difficult to explain if they were single stars, because they lack the heavy elements that drive excessive mass loss and shouldn't easily expel their hydrogen envelopes. A metal-poor star in a close binary system, however, can lose enough gas to its companion to become a Wolf-Rayet.

▼ **ENDLESS SPIRAL** Astronomers used JWST to capture this mesmerizing image of WR 140's spiral, processed by amateur astronomer Judy Schmidt. The rings correspond to episodes of dust formation when the WR star and its companion approach periastron and their winds collide.



HOW DUSTY SPIRALS FORM: GREGG DINDERMAN / *S&T*; WR 140: JWST / MIRI / JUDY SCHMIDT



◀ **PINWHEEL** As WR 104 and its companion star orbit each other over eight months, their winds collide and form dust that draws an expanding spiral. These images capture the spiral at different times, showing a complete rotation.

PETER TUTHILL / UNIVERSITY OF SYDNEY

A Dusty Trail

Given cool and dense enough conditions, some of the constituents of a star's wind, such as carbon, can condense to form dust. The environment of a Wolf-Rayet star shouldn't meet these criteria, because the wind is extremely hot and energetic — hostile conditions for dust formation. Nevertheless, some Wolf-Rayet stars are known to produce dust, either periodically or persistently.

Dust plays an important role in the universe. Its presence shields interstellar clouds from high-energy radiation, enabling the gas to cool and collapse to form new stars. The individual grains also provide a surface where chemical interactions occur and ices build up. However, models of galaxies both local and in the distant universe can't account for the abundance of dust that astronomers see. It turns out that Wolf-Rayet stars — long overlooked in this regard — may be part of the solution to this problem.

The archetypal example of a periodic dust-producing system is WR 140, a binary some 6,000 light-years away in Cygnus and comprising a Wolf-Rayet star and an *O* star. In 1976, John Hackwell (University of Wyoming) and colleagues first noted the infrared variability of this star over the period 1970–1975. Two years later, a team led by Peredur Williams (Royal Observatory, Edinburgh), using a 1.5-m telescope at Cabezon Observatory in Tenerife, observed that WR 140 had brightened nearly three magnitudes in the near-infrared. They proposed that this temporary brightening represented the formation of a dust shell.

In 1985, the star again brightened from its normal level, this time based on observations from the U.K. Infrared Telescope on Mauna Kea. The 7.9-year gap between the two brightenings led to a re-examination of data from various observatories dating back to 1921, confirming that there was indeed a 7.9-year period, with the *periastron* of the orbiting *O*-star occurring shortly before infrared maximum.

Astronomers think that as the companion *O* star makes its closest approach, at a distance of 1.4 a.u., it passes through the Wolf-Rayet's stellar wind, and the collision between the stars' winds creates conditions suitable for carbon atoms to combine and form dust. Joshua Thomas (Clarkson University) and colleagues have noted in a recent paper that the precise knowledge about WR 140's orbit makes it "an important astrophysical laboratory for dust production and colliding-wind shock physics."

Pinwheels of Dust

What about the small number of Wolf-Rayets that seemingly produce dust continuously? A European study published in 1996, for example, showed that dust formation around the Wolf-Rayet stars WR 104, WR 112, and WR 118 had remained relatively steady over two decades.

In 1998, Peter Tuthill (now at University of Sydney, Australia) and colleagues used the Keck I telescope to acquire infrared images of one of those stars, WR 104, a 13th-magnitude source in Sagittarius. Observations two decades earlier by David Allen and colleagues at the Anglo-Australian Observatory had measured the diameter of the star's dust shell to be around 200 a.u. Tuthill's team confirmed that diameter, but their observations revealed something remarkable — a dusty spiral, like a pinwheel, surrounding the star.

Astronomers had proposed WR 104 was a binary back in the 1970s based on a study of its spectra, but it was only in 1996 that they confirmed the presence of an *OB* companion from the detection of certain spectral features. (Observers announced a third stellar member of the system, located farther out, in 2002.) The Keck images, taken two months apart, showed the spiral plume revolves around the star every eight months. Tuthill's team proposed that the spiral shape is a result of the Wolf-Rayet's stellar wind colliding with that of the companion, overwhelming the companion's wind due to its more energetic nature, and sweeping the material into a plume that streams behind the *OB* star, where it forms dust. Because the stars are so close together — roughly twice Earth's distance from the Sun — dust is ever-present.

While dust is only a minute fraction of the Wolf-Rayet's total mass loss, its detectability makes it a valuable tracer, allowing studies of the stellar wind itself and providing insight into the system's mass loss.

The geometry of WR 104 is such that we view it from an almost pole-on perspective. That position generated greater attention in 2008, when Tuthill's team narrowed in on our viewing angle's exact value, determining that our line of sight is inclined roughly 12° from WR 104's pole.

As both stars in the binary system are expected to eventually explode as supernovae, and astronomers think that some stars can direct more energy along their rotational axis at the time of explosion, the team briefly examined the implications of our vantage point looking down the axis of this system. At a distance of 8,000 light-years from us, a core-collapse supernova would appear considerably bright but would not be threatening. On the other hand, if the explosion were a gamma-ray burst, then Earth could be in the firing line of the high-energy jet.

Fortunately for us, astronomers have since come to think that WR 104 is unlikely to generate a gamma-ray burst, as the Wolf-Rayet doesn't appear to be spinning quickly enough.

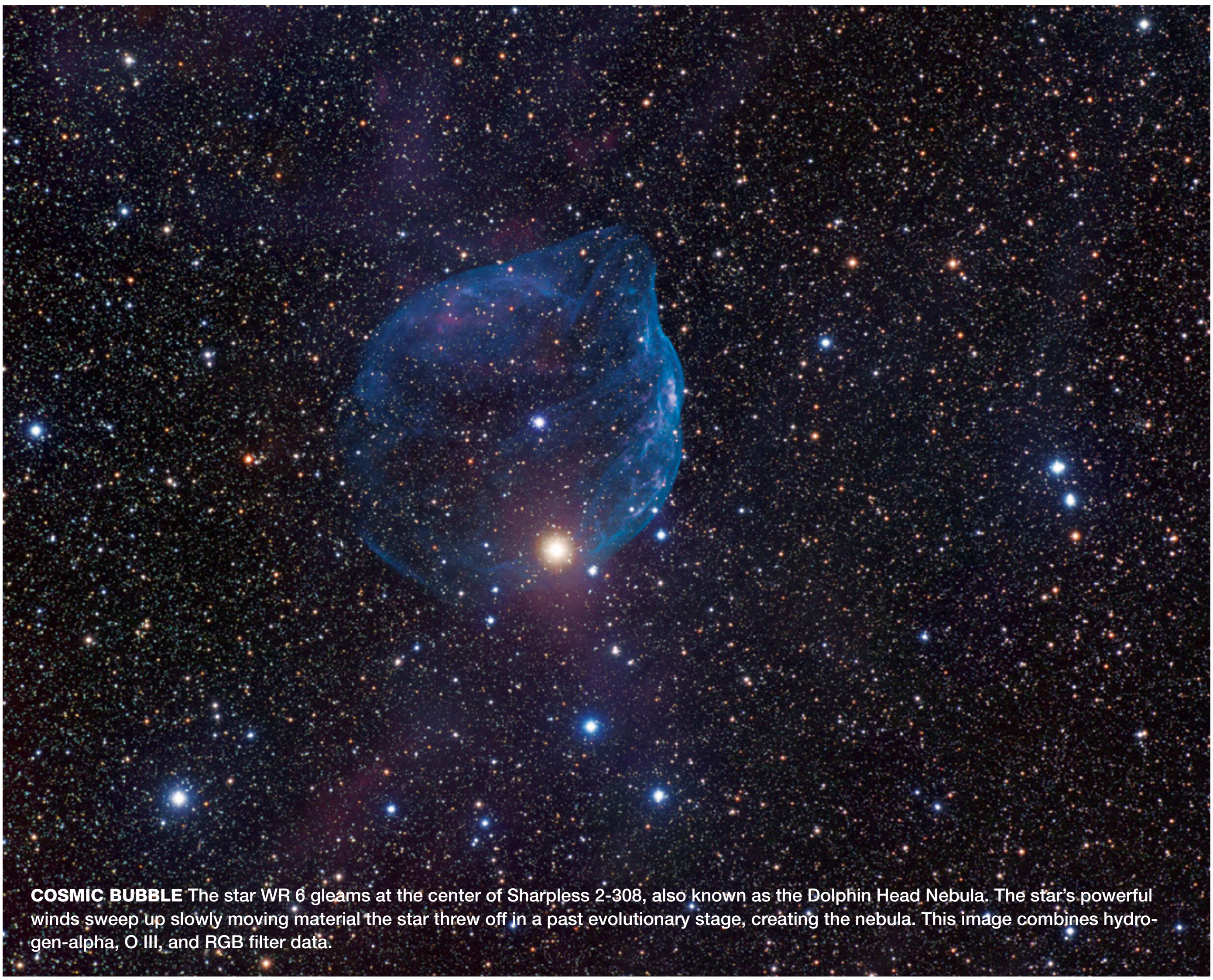
A Mystery Uncoils

Tuthill's team has imaged similar pinwheels around WR 98a and two Wolf-Rayets in the Quintuplet Cluster, and it's now generally believed that all dusty Wolf-Rayets have a giant companion. Interest in studying such Wolf-Rayet binaries has also heightened due to an unexpected discovery a few years ago. Australian astronomer Joseph Callingham (now at Leiden University, the Netherlands) was in the last year of his undergraduate degree at the University of Sydney when he came across a previously unstudied but cataloged source called 2XMM J160050.7–514245 in the southern constellation Norma, the Square. J1600 was considerably bright at X-ray and radio wavelengths, and also in the infrared. Fellow Sydney colleague Tuthill shared Callingham's suspicion that the object might be a *colliding-wind binary*.

Their team was able to image the source in the infrared in 2016 and 2017 with ESO's Very Large Telescope, revealing a spectacular colliding-wind binary with a dust plume similar to previously imaged Wolf-Rayet pinwheels. They nicknamed the system Apep after the serpent deity from Egyptian mythology, noting that Apep was the enemy of the Sun god Ra, and it was "an apt illusion to the image that evokes a star embattled within a serpent's coils."

Callingham and colleagues observed Apep again in 2019 with the VLT, revealing that both stars in the center of the system in fact are Wolf-Rayets, one with spectral lines dominated by carbon (a carbon-type Wolf-Rayet, or WC) and the other a nitrogen-type (WN). This was a surprising find, to see two Wolf-Rayets together, given the short lifetime of the Wolf-Rayet phase.

It was the 2017 image, however, that stumped the



COSMIC BUBBLE The star WR 6 gleams at the center of Sharpless 2-308, also known as the Dolphin Head Nebula. The star's powerful winds sweep up slowly moving material the star threw off in a past evolutionary stage, creating the nebula. This image combines hydrogen-alpha, O III, and RGB filter data.

SEAN WALKER / S&T

researchers. Unlike the quick motion that was apparent in dust plumes around other Wolf-Rayet binaries, the dust pattern surrounding Apep was hardly moving, in contrast to the measured speed of the gas in the system. Astronomers had expected that any new or recently formed dust would move in concert with the gas in which it was formed. Instead, Apep apparently had two winds moving at different speeds.

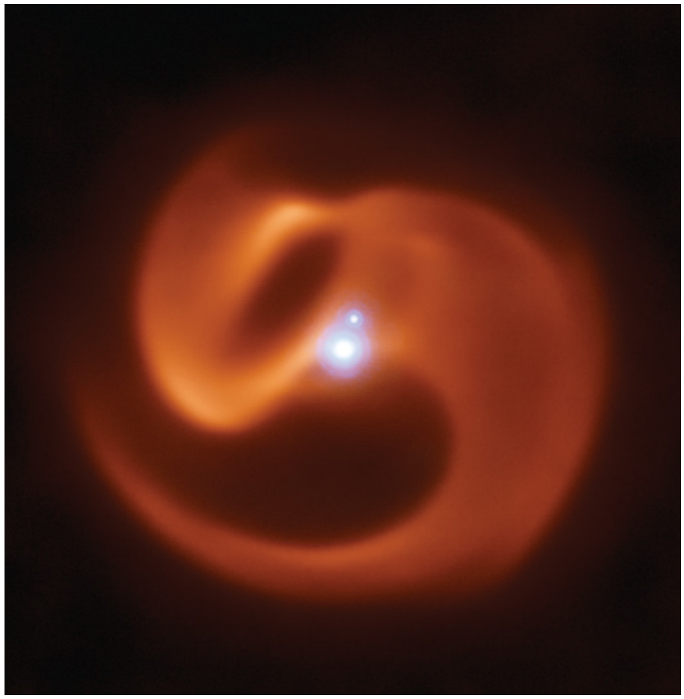
Callingham's team proposed that what we're seeing is a system in which the Wolf-Rayet star itself has both a slow equatorial wind and a fast polar wind. Such an anisotropic state can arise when a star is rotating at a near-critical rate. This discovery has led to Apep being regarded as the Milky Way's strongest candidate for one day exploding as a gamma-ray burst.

Future Studies

Supernovae aside, questions remain about Wolf-Rayets and their dust production. Thus far, astronomers have only observed dust formation in carbon-rich binaries and not in nitrogen-rich binaries. Yet modeling suggests that a carbon-rich environment is not a strict requirement for colliding winds to create dust.

Also, not all WC binaries produce observable dust. Gamma Velorum — which at magnitude 1.8 is the brightest Wolf-Rayet system in our night sky as well as the closest, lying some 1,000 light-years from us — is a tight binary, yet it displays none of the dust formation seen in other colliding-wind binaries.

Astronomers now think that Wolf-Rayets are a significant source of dust in the interstellar medium, particularly in galaxies where other prominent sources (such as aging *asymptotic giant branch stars*) haven't yet had the time to make their mark. Highlighting their importance, Ryan Lau (Institute of Space & Astronautical Science, Japan Aerospace Exploration Agency) and colleagues secured early science observation time with the James Webb Space Telescope to further explore the impact that these stars' dust has on the surrounding interstellar medium, and how that shapes the next generation of stars (image, page 14). Although they live fast and die young, Wolf-Rayets' legacy may last for billions of years.



▲ **APEP** This infrared composite image shows the stunning dust spiral nicknamed Apep. The lower "star" is the unresolved Wolf-Rayet binary that produces the coil of dust. The upper star is a companion star in the triple system.

■ Contributing Editor **GREG BRYANT** sometimes takes a long, hard look at the closest Wolf-Rayet star, Gamma Velorum, on clear nights from Sydney, Australia. His most recent *S&T* article was "Open Cluster Exoplanets" (July 2021).

WOLF-RAYET HUNT Here are eight WR stars worth seeking out, including Gamma Velorum, which is the closest known. The others on the list are all surrounded by associated nebulae; some may be sighted visually with filters, but all are rewarding imaging targets. Several entries may require Northern Hemisphere observers to travel to lower latitudes in order to bag them. The first three appear in the evenings in February and March.

The WR numbering system comes from the *Sixth Catalogue of Galactic Wolf-Rayet Stars*, published in 1981. The latest catalog of known WR stars in the Milky Way, from which these data have been compiled, is maintained at **https://is.gd/WRcatalog**.

Wolf-Rayet Hunt

WR No.	Other Name(s)	HD	Mag(v)	RA	Dec.
6	EZ CMa, Sh 2-308	50896	6.9	$06^h\ 54.2^m$	–23° 56′
7	NGC 2359	56925	11.4	$07^h\ 18.5^m$	–13° 13′
11	Gamma Velorum	68273	1.8	$08^h\ 09.5^m$	–47° 20′
18	NGC 3199	89358	10.8	$10^h\ 17.0^m$	–57° 55′
23	WR 23 Nebula	92809	9.1	$10^h\ 41.6^m$	–58° 46′
75	RCW 104	147419	10.9	$16^h\ 24.4^m$	–51° 32′
134	WR 134 Nebula	191765	8.0	$20^h\ 10.2^m$	+36° 11′
136	NGC 6888	192163	7.4	$20^h\ 12.1^m$	+38° 21′

Right ascension and declination are for equinox 2000.0.

Winter Outreach

Showing the public celestial sights through a telescope can be a wonderfully rewarding experience.

▲ **SPARKLES IN THE SKY** Most everyone has heard of the Pleiades and has likely admired the open cluster in Taurus with the naked eye. But not everyone has seen the cluster up close. If you're viewing through a low-power scope, you could ask your guests what familiar constellation the stars' arrangement reminds them of.

PLEIADES: SEAN WALKER / S&T; PERSON AT EYEPIECE AND TWO KIDS AT SCOPES: TED FORTE (2); TED FORTE AT OUTREACH EVENT: HALINA FORTE

What's the power of your telescope? Anyone who has shared their scope with the public has fielded this question, which they usually address by providing an explanation of magnification and dispelling the popular myth of its overrated importance. Yet, the question should perhaps bring something different to mind. For in a very real sense, the true power of your telescope is its power to astonish and inspire. Astonishment and inspiration are two critical elements of astronomy outreach.

Amateur astronomers the world over engage in outreach to bring astronomy to the public and to recruit new members to their clubs. It's a powerful tool for enlisting allies in the fight to preserve dark skies, which is probably essential to the survival of the hobby. And for many amateurs it's the most rewarding factor. Outreach events aren't only a benefit to the public, they can be a unifying and fun activity for club members. In my experience, astronomers who engage in outreach are more likely to remain active in their clubs and seem to get the most fulfillment out of their membership.

I've participated in astronomy outreach for about three decades, starting with the very night I joined my first astronomy club. Since then, I've shared my scope and fascination with the night sky hundreds of times, logging thousands of hours. In this tour, we'll visit some winter objects that I think make great targets for outreach. The factors that make them intriguing to the public vary. They may be well known — just having a popular "nickname" can arouse curiosity, or they might simply have a fascinating history, or be a particularly good example of their genre.

▲ **UP CLOSE AT THE EYEPIECE** The first sight of a celestial object through a big telescope in a dome such as the one shown here — the 20-inch f/8.1 Ritchey-Chrétien at Patterson Observatory in Sierra Vista, Arizona — is a thrill. The University South Foundation owns the observatory, which is operated by volunteers from Forte's club, the Huachuca Astronomy Club. Forte himself is the observatory's director. On January 31, 2020, middle-school students visited the site and admired a close-up view of Venus.

▶ **WAITING FOR THE GO-AHEAD** *Top:* These young gentlemen from Bella Vista Elementary in Sierra Vista are attending the Kid's World event in 2015. Forte set up his Coronado Personal Solar Telescope and 8-inch Celestron SCT with appropriate solar filters so they can admire the Sun. Once they got the word to look through the eyepiece, they enjoyed a sight like no other.

▶ **BRINGING THE SKY TO EVERYONE** *Bottom:* Outreach events also include daytime sessions, which is great for younger viewers with early bedtimes. Here, Forte is centering on the Moon with his 18-inch f/4.5 Obsession Dobsonian while eager guests line up to catch a glimpse.

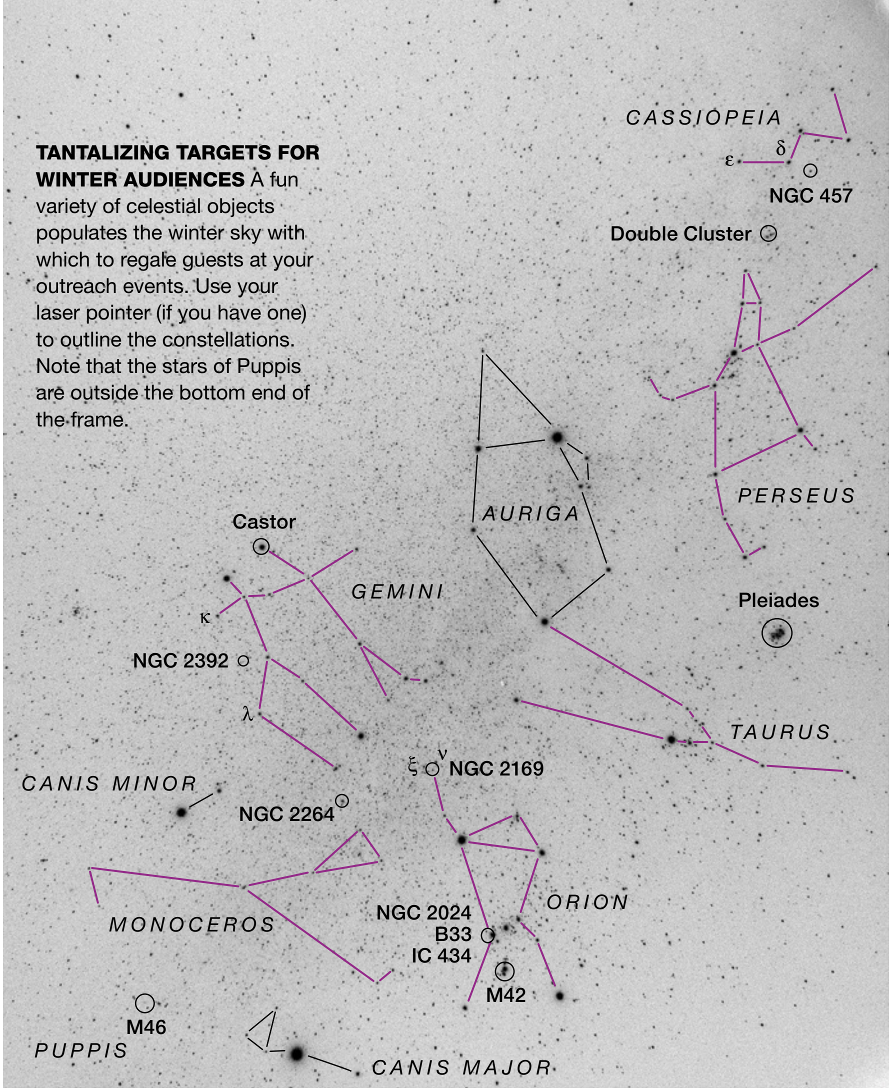
Double Delights

More often than not, outreach takes place under less-than-optimal conditions. The typical schoolyard, city park, or urban street corner will be too brightly lit to display your favorite deep-sky objects. These events also quite commonly begin during twilight. The Moon and the bright planets provide a ready solution when they're available — but when they're not, I like to begin with a double star.

My go-to winter double is **Castor**, or Alpha (α) Geminorum. It's bright enough to pop out in twilight and is easily split in a small telescope. It takes only a 60-mm aperture to see it as double. Apparent to the naked eye as a bright, single star, Castor demonstrates the ability of a telescope to reveal a star's double nature. As such, it's a fine example of the species, with a fairly well-known mythological connection. Those familiar with mythology will recognize Castor and Pollux as the twin sons of Zeus, king of the gods, and the Spartan queen, Leda, from the Greek legends.

So now that you've shown your guests the target, you'll want to regale them with some interesting facts. You could mention, for example, that in 1678 Giovanni Cassini discovered that Castor is a visual binary — the first recorded observation of a gravitationally bound object beyond our solar system. You'll also want to anticipate the almost inevitable questions you'll get. Once they've seen Castor for themselves, viewers will want to know how far away the stars are and how far apart they are from each other. So, arm yourself with these facts before you meet the public: Castor is about 51 light-years away, almost twice as distant as its mythological twin Pollux. The two component stars of the visual pair are about twice as far apart as the Sun and Pluto, with a mean separation of 104 astronomical units. And they take 460 years to orbit each other. You might also want to tell them that Castor is actually a system of six stars in three binary pairs — each member of the visual pair is itself a spectroscopic binary. A third spectroscopic pair consisting of two red dwarfs sitting 72″ to the south appears to be gravitationally bound to the other two pairs. If you relate facts like these, be prepared to explain terminology like "astronomical unit" or "spectroscopic." Even terms like "binary" may be unfamiliar to your audience.

Having answers at your fingertips to your guests' queries will bolster your confidence and enhance your audience's experience. Heed the sage words of Abraham Lincoln: "Give me six hours to chop down a tree, and I will spend the first four sharpening the axe."



TANTALIZING TARGETS FOR WINTER AUDIENCES A fun variety of celestial objects populates the winter sky with which to regale guests at your outreach events. Use your laser pointer (if you have one) to outline the constellations. Note that the stars of Puppis are outside the bottom end of the frame.

AKIRA FUJII

Captivating Clusters

Bright open clusters are usually a good choice for outreach targets. They're pretty and can be very impressive. I like to show clusters that have curious and recognizable patterns that make observing them fun and surprising.

One winter favorite is **NGC 457** in Cassiopeia. It's alternately known as the Owl Cluster, the E. T. Cluster, or the Dragonfly Cluster. Two bright stars give the impression of eyes and a scattered pattern of fainter stars represent a body with wings or arms spread wide. Asking an audience to use their imagination to see one of these suggested shapes is a good way to spark engagement and introduce a bit of whimsy.

This young star cluster contains about 100 stars, spans 53 light-years in diameter, and is around 9,100 light-years away. William Herschel discovered it in 1787. The 5.0-magnitude yellow supergiant Phi (φ) Cassiopeiae and 7.0-magnitude HD 7902 form the two eyes, but Phi Cassiopeiae is unlikely to be a cluster member. Most novice observers may not spy the fine red star V466 Cassiopeiae on the cluster's northern edge unless you point it out but will be impressed when they do spot it.

Imagining a line connecting Epsilon (ε) and Delta (δ) Cassiopeiae and extending it about another third of the distance between them will lead you to NGC 457.

I often employ a green laser pointer during my outreach sessions — they're useful tools that will usually grab the attention of a crowd. In fact, you might find some in your audience more impressed by the laser than by the view in the telescope! Once the novelty wears off, however, a laser is a great way to point out your target and guide your guests to it in the sky. Sometimes it's all you need to conduct a successful outreach event, as they're perfect for tracing out the constellations and identifying the named stars. Lasers can be dangerous, so a word of caution is in order here (see sidebar at right).

NGC 2169 in Orion is another example of an open cluster whose stars form an interesting asterism. This small group contains about 30 stars, and the brightest of them are arranged like the number 37 when viewed in a non-inverting scope. Many astronomers actually call it the 37 Cluster, and it's sure to amuse first-time viewers. Located a short hop from Betelgeuse in Orion's raised arm, it forms the apex of a triangle with Xi (ξ) and Nu (ν) Orionis at its base. The cluster is about ½° southwest of a line connecting the two stars.

Recognizable patterns add considerable interest to objects and encourage viewers to examine them more closely. At first, you may have to help the observer see a Christmas tree in **NGC 2264**, but once they recognize it, they'll have a sense of accomplishment. I like to describe it as a Christmas tree *cookie*, as the asterism resembles that shape very well. If the

▲ **WHAT DO YOU SEE?** Asking your audience what they see in patterns in the sky is a great way to stimulate their interest. Before you tell them that NGC 457 is also known as the Owl or E. T. Cluster, ask them what the open cluster looks like to them.

▲ **CELESTIAL DIGITS** If you've ever seen the open cluster NGC 2169 through a telescope, you'll likely remember your initial reaction. Eliciting a chuckle from your guests at the eyepiece can also be a satisfying experience for the scope owner.

viewer has trouble with it, try framing the cluster in your finderscope; it'll be more apparent in the wider field.

When groups of astronomers convene to do a public event, they often concentrate on the same celestial showpieces — this can become a little boring for your guests making their rounds between scopes. You'll do well to compile a collection of objects that make successful outreach targets by introducing some variety. Almost any of the Messier clusters are usually good choices. One of my favorites is **M46** in Puppis. You can challenge your observers to detect the planetary nebula **NGC 2438** that seems to float among the cluster's stars. The European Space Agency Gaia satellite's measurement of NGC 2438's distance puts it at 1,370 light-years, far closer than the star cluster, which lies about 5,000 light-years from us.

At *sidewalk astronomy* events, we often only get one chance to capture the interest of the casual passerby. The target you choose should be impressive. The Perseus Double Cluster, comprising **NGC 869** and **NGC 884**, is a sure-fire crowd pleaser. It's a particularly good target if your outreach setup includes a wide-field instrument like mounted binoculars or a rich-field telescope. You'll want at least a 1° field of view to adequately frame the pair of open clusters.

The western cluster, NGC 869, contains a beautiful asterism called the Diamond Ring. A 6.6-magnitude star near the center of the cluster is set off by an arc of five fainter stars that opens toward it, vaguely resembling an engagement ring. Asking viewers to seek this out will encourage them to look more closely and consider what they see.

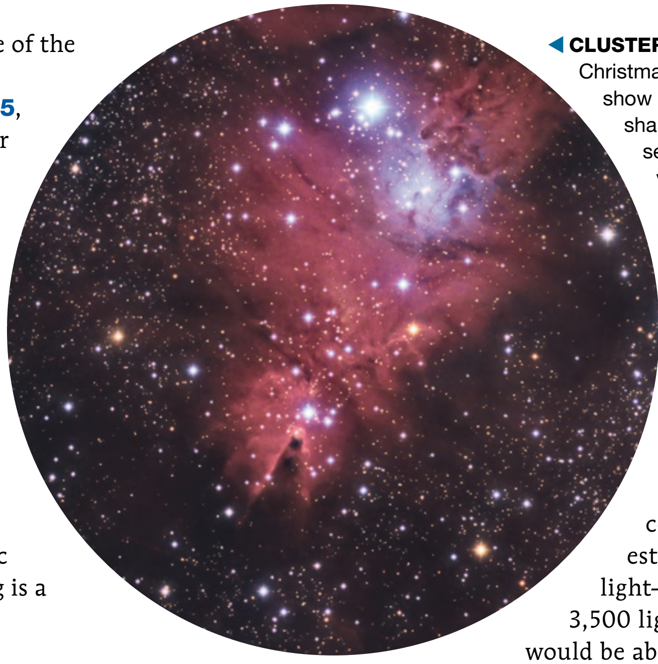
Pointing out that the Double Cluster is visible to the naked eye under dark skies and that it has been known since antiquity is a good segue into the subject of ancient stargazing and the lore surrounding the constellations. The Double Cluster marks the head of the Greek hero Perseus. In some depictions, it represents the scimitar with which he slew the Medusa, a winged female creature

Green Laser Pointers

Laser pointers can do considerable harm to eyes and skin, and they should not be considered toys or be used by minors. The greater the output power of your laser, the more likely it is to cause injury. Laser pointers must be less powerful than 5 mW — when they're brighter than that, they're known as *overpowered*. Consumers should be aware that many commercially available lasers are not labeled and may even be mislabeled. The Food and Drug Administration reports that 60% of lasers tested have greater output than their labels indicate. As a rule of thumb, if your pointer is small and runs on button batteries, it's probably less than 5 mW. A pen-size or larger laser that runs on AA or AAA batteries is likely too bright. Some states prohibit the use of green laser pointers by minors and in certain situations, like on school grounds. They should ***never*** be aimed at a passing aircraft or at a person. Many major star parties prohibit their use because of the danger of eye damage and the spoiling effect they can have on astrophotography. As the use of laser pointers is strictly controlled or even illegal in some jurisdictions, make sure to check with your local astronomy club to find out what rules apply locally. See **https://is.gd/laserpointers** for more tips.

NGC 457: RON BRECHER; NGC 2169: GARY IMM; GREEN LASER: NPS / WILLIAM PEDRO with snakes for hair (she was one of the three Gorgons).

Most people have heard of **M45**, also known as the Seven Sisters or the Pleiades, and someone will undoubtedly ask to see this cluster through the telescope. This inevitable request affords a good opportunity to demonstrate how little of the sky is captured in a typical telescope. It's also the perfect illustration of your finderscope's more expansive view. It's what would be justifiably described as a *teachable moment*. For many amateur astronomers, educating the public about the mechanics of observing is a major component of outreach.



◀ **CLUSTERS AND NEBULAE** NGC 2264, the Christmas Tree Cluster, is an excellent target to show how stars can be arranged in different shapes. For this one, you might want to select a scope that provides an inverted view, otherwise the Christmas tree figure will be upside down.

Pleasing Planetaries

Planetary nebulae are my favorite type of celestial object, and I try to include at least one example (besides NGC 2438) of a planetary at any event I attend. Showing objects that you're passionate about is sure to translate into an energy that will boost interest in your listeners. It's also what makes outreach so much fun for the astronomer.

One of the best winter planetaries, **NGC 2392** in Gemini, is always a good choice. To find it, point your scope about midway between Kappa (κ) and Lambda (λ) Geminorum. The planetary has a bright central star and an easily visible disk that stands out in stark contrast to a nearby field star (8.3-magnitude HD 59087). We haven't constrained its distance, but estimates vary from 2,800 to 5,000 light-years. Adopting a distance of 3,500 light-years, the 40″-wide object would be about 0.7 light-year across.

Oohing at Orion

The prime showpiece of the winter sky is undoubtedly the Orion Nebula, **M42**. Its beauty is unmatched by any object in the sky. Legend has it that the renowned observer William Herschel began his observing career by viewing the Orion Nebula, and he was so amazed that it sparked his lifelong study of such objects. I like to reserve it for the evening's grand finale. It's a hard act to follow, after all. Young and old alike are usually amazed to learn that, when viewing the nebula, they're witnessing the act of starbirth. In the poetic words of author Robert Burnham, Jr., ". . . it creates, as does no other vista of the heavens, the single overpowering impression of primeval chaos, and transports the imaginative observer back to the days of creation." Astronomers using the Hubble Space Telescope have identified about 150 *proplyds* (protoplanetary discs) that are presumed to be nascent solar systems. (See, e.g., *S&T:* Feb. 2021, p. 57.)

The Orion Nebula is visible to the unaided eye as a fuzzy patch in Orion's Sword, so it's rather puzzling that there's no mention of it in any ancient texts. Even Galileo failed to notice it. French astronomer Nicolas-Claude Fabri de Peiresc is credited with the discovery of the nebula in 1611. It was the first nebula ever photographed (in 1880 by Henry Draper), and it's quite often the first object newly minted astrophotographers attempt to capture today.

About 1,350 light-years distant, it's one of the closest large star-forming regions to the Earth, and it spans some 16 light-years. Approximately 700 stars have formed within the nebula.

◀ **PEEKABOO PLANETARY** If your scope is powerful enough to capture the planetary nebula NGC 2438 seemingly floating in front of the open cluster M46 in Puppis, you'll want to point it out. This is a terrific opportunity to discuss the three-dimensionality of the universe, as the planetary lies several thousand light-years closer to Earth than the cluster does. The star at lower right is 5th-magnitude HD 61772.

NGC 2264: RON BRECHER; M46: BERNHARD HUBL

Viewers should easily see the pattern of the four brighter stars that constitute the Trapezium and will be interested to know that they're hot young stars that are primarily responsible for lighting the nebula. The Orion Nebula has enough mass to create about 10,000 stars the size of our Sun; it's fun to imagine the brilliant star cluster that will greet future stargazers here.

Generation III night-vision devices are a new tool available to amateur astronomers that seem poised to revolutionize our vocation. The enhancement they bring to emission objects is incredible. I've started employing my PVS-14 night-vision monocular at outreach events, and it has afforded me the opportunity to share objects that I used to think unsuitable. One night-vision favorite is the Horsehead Nebula.

The Horsehead, or **Barnard 33**, is one of the most photographed objects in the sky and so is rather well known, but it's also notoriously difficult to observe except under the darkest skies. That all changes with night-vision enhancement. In my 10-inch Dobsonian, coupled with a 65-mm Super Plössl eyepiece and a hydrogen-alpha filter, the PVS-14 shows the Horsehead in remarkable fashion. The subtle glow of **IC 434**, the faint emission nebula that backlights B33, is greatly enhanced, making the inky-black nebula stand out in stark contrast. The wide field — the combination yields more than 2° — can encompass both the Horsehead and the Flame Nebula, **NGC 2024**, in a single field of view. Such a striking vista is sure to impress. Night-vision enhancement will allow you to add other remarkable but often hard-to-see nebulae to your outreach repertoire, such as the Rosette Nebula in nearby Monoceros and even Barnard's Loop, besides adding a new dimension to more familiar favorites like the Orion Nebula.

▲ **TWO FOR ONE** Open clusters are showpieces at any outreach event, but the Double Cluster in Perseus is doubly so.

Night-vision devices are useful, but the most important tool at your disposal is your enthusiasm. It's every bit as vital to effective outreach as is sharing your telescope. A keen attitude is infectious, so don't shy away from expressing your own excitement. It's only because we ourselves are astonished and inspired that we can astonish and inspire others.

■ Contributing Editor **TED FORTE** continues to be active in outreach activities and derives his biggest pleasure from guiding his guests to fascinating targets in the sky.

Tantalizing Targets

Object	Name	Type	Constellation	Mag(v)	Size/Sep	RA	Dec.
Alpha Geminorum	Castor	Double star	Gemini	1.9, 3.0	5.4″	$07^h\ 34.6^m$	+31° 53′
NGC 457	Owl Cluster	Open cluster	Cassiopeia	6.4	20′	$01^h\ 19.5^m$	+58° 17′
NGC 2169	37 Cluster	Open cluster	Orion	5.9	6′	$06^h\ 08.4^m$	+13° 58′
NGC 2264	Christmas Tree	Open cluster	Monoceros	4.1	40′	$06^h\ 41.0^m$	+09° 54′
NGC 2437	M46	Open cluster	Puppis	6.1	20′	$07^h\ 41.8^m$	–14° 49′
NGC 2438		Planetary nebula	Puppis	10.8	76″	$07^h\ 41.8^m$	–14° 44′
NGC 869	Double Cluster	Open cluster	Perseus	5.3	18′	$02^h\ 19.1^m$	+57° 08′
NGC 884	Double Cluster	Open cluster	Perseus	6.1	18′	$02^h\ 22.1^m$	+57° 08′
M45	Pleiades	Open cluster	Taurus	1.5	120′	$03^h\ 47.5^m$	+24° 06′
NGC 2392	—	Planetary nebula	Gemini	9.1	54″	$07^h\ 29.2^m$	+20° 55′
M42	Orion Nebula	Bright nebula	Orion	4.0	40′ × 35′	$05^h\ 35.3^m$	–05° 23′
Barnard 33	Horsehead Nebula	Dark nebula	Orion	—	6′ × 4′	$05^h\ 40.9^m$	–02° 28′
IC 434	—	Bright nebula	Orion	—	60′ × 10′	$05^h\ 41.0^m$	–02° 24′
NGC 2024	Flame Nebula	Bright nebula	Orion	—	30′ × 30′	$05^h\ 41.9^m$	–01° 51′

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

RON BRECHER

WIKIMEDIA COMMONS / PUBLIC DOMAIN

The Constellations of Petrus Plancius

A little-known astronomer introduced 16 of our 88 constellations. Who was he?

Since 1930, the International Astronomical Union (IAU) has officially recognized 88 constellations. The saga of how we got there is an interesting one that involves a colorful cast of characters — some familiar, some not.

Many cultures have their own star lore, but the constellations we use today are largely derived from Western sources, starting with the 48 groupings that Claudius Ptolemaeus (Ptolemy) described in his 2nd-century *Almagest*. Ptolemy didn't draw any celestial maps that we know of — but the *Almagest* contained a catalog listing the constellations and their associated stars. There were no set boundaries, so some stars were shared by neighboring constellations.

Shortly after Johannes Gutenberg invented the printing press in the 15th century, terrestrial maps, globes, and atlases began to appear. These efforts were later expanded to include celestial works based on the *Almagest*. Of course, Ptolemy himself relied on earlier works, but those are mostly lost to us. The *Almagest* survived through the ages, and in early 16th-century Renaissance Europe astronomers considered it the ultimate authority for nearly all celestial knowledge. It's therefore not surprising that the earliest examples of celestial cartography almost exclusively referred to Ptolemy's work.

▲ **NEW SKY** In 1660, Andreas Cellarius produced his celebrated atlas *Harmonia Macrocosmica*. The planisphere at left shows the Northern Hemisphere sky, the chart at right the Southern Hemisphere. In addition to the 48 constellations of Ptolemy, these charts include the 21 constellations Petrus Plancius introduced in 1598 and 1612. They also include Coma Berenices and Antinous (near Aquila), which Ptolemy had mentioned and Caspar Vopel introduced on a celestial globe in 1536, as well as Columba, introduced by Plancius in 1592.

So, where did the other 40 constellations come from? Just as terrestrial cartographers filled the oceans with sea monsters to make their works more interesting and attractive, their celestial counterparts began to fill the empty spaces in the heavens with new constellations.

Many of these were created to honor people (such as Taurus Pionatovii, described in the August 2022 issue), or places. Following the invention of the telescope in 1608, charts began to include fainter stars, which also contributed to the invention of new constellations. Some of these were widely adopted and remained popular for decades, while others were short-lived and failed to gain widespread acceptance. The constellations themselves didn't have formal boundaries until 1801, when German astronomer Johann Elert Bode introduced the concept in his great celestial atlas, *Uranographia*. Previously, cartographers had been free to carve out areas between existing figures using "unformed stars" — those not used in Ptolemy's constellations — to fashion new creations.

Inventing constellations became so popular that more than 100 new ones were introduced by the early 19th century. This tally doesn't even include schemes to replace existing constellations with biblical figures — a subject covered in the January 2021 issue. In a number of cases, new entries supplanted earlier creations. Celestial atlases by Johann Bayer in 1603, Johannes Hevelius in 1687, and Bode's

1801 opus each introduced or included numerous new constellations (see my article on page 58 of the January 2022 issue). These greatly influenced cartographers producing celestial charts in subsequent years. With Bode's *Uranographia*, the heavens had become very crowded indeed. His atlas portrayed 107 constellations, most of which persisted until the end of the 19th century.

To end the chaos, the IAU undertook an effort to create a formal list of celestial figures. They adopted a list of 88 constellations in 1922 and set their official boundaries in 1928. They published all this in 1930, giving us our current heavenly menagerie. The IAU collection includes all but one of Ptolemy's original 48 constellations (Argo Navis was very large and was divided into smaller components; see *S&T:* Mar. 2020, p. 22) and 41 new ones. Of these, 16 come to us courtesy of an individual most readers of this magazine probably have never heard of.

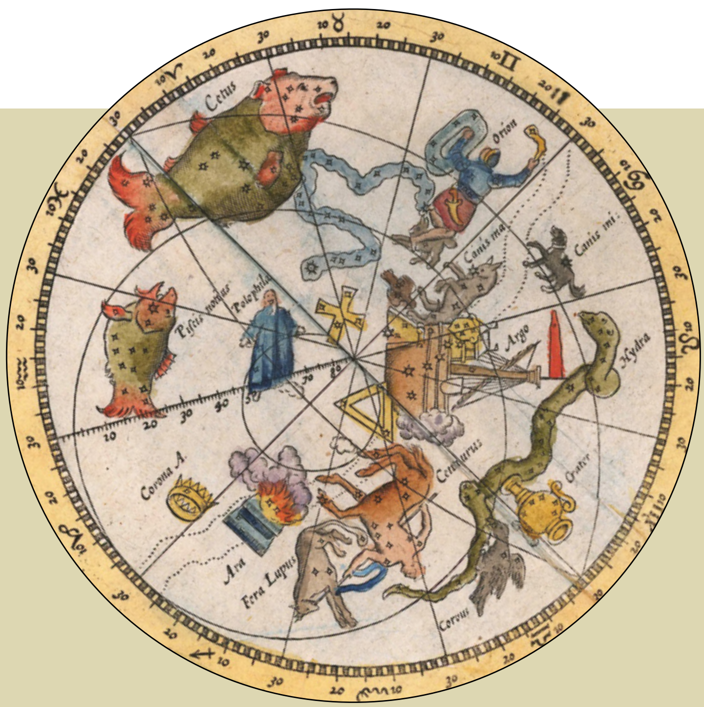
◀ **CELESTIAL CARTOGRAPHER** Working in Amsterdam in the late 1500s, Petrus Plancius trained two Dutch navigators to map the southern skies. Beginning in 1598, he populated his celestial globes with new constellations, filling the empty area around the south equatorial pole and giving us 14 of our official constellations. In 1612 he introduced eight more constellations, but only two of these have survived.

Meet Petrus Plancius

Petrus Plancius (1552–1622) was born Pieter Platevoet in the Dutch-speaking Flanders region of what is now Belgium. His family was wealthy, and young Petrus was educated in a variety of disciplines, including astronomy and theology. In 1576 he was ordained a minister in the Calvinist church, but Spanish control of the region and the Inquisition forced him to flee to Amsterdam in 1585. His fascination with astronomy and navigation led him to become a cartographer for the powerful Dutch East India Company, producing more than 100 terrestrial and celestial maps and globes to aid the company's vast network of explorers and traders. Plancius wasn't actually a cartographer himself, but Amsterdam was known for its excellent map houses, and he collaborated with several prominent map- and globe-makers there.

Up until this time, celestial *planispheres* (maps that show an entire hemisphere) and globes based on Ptolemy's constellations exhibited a large blank area around the south celestial pole. This was simply because that area of the sky was too far south to be visible from Mediterranean latitudes. Since the southern sky had been out of reach to Europeans, there had been no impetus to populate that part of the celestial sphere with constellations. Plancius set about to correct this

▲ **BLANK CANVAS** In 1515, German artist Albrecht Dürer produced the first printed planispheres. These depicted the 48 constellations of Claudius Ptolemy's 2nd-century *Almagest*, which were limited to those visible from the Mediterranean. Dürer's planisphere of the southern sky (above) clearly shows gaps in constellations surrounding the south celestial pole — gaps that future cartographers would eagerly fill.



▲ **FILLING THE VOID** In 1589 and 1592, Petrus Plancius introduced four new constellations into the region that isn't visible from Mediterranean latitudes. Of these, only Columba has survived. In 1598 he replaced the Crux south of Eridanus, Triangulus Antarcticus, and Polophilax with newer constellations.

PETRUS PLANCIUS: J. BOYS / R. VINKELES / WIKIMEDIA COMMONS / PUBLIC DOMAIN; 1515 CHART: J. STABIUS / J. SCHÖNER / WIKIMEDIA COMMONS / PUBLIC DOMAIN; PLANCIUS CHART: WIKIMEDIA COMMONS / PUBLIC DOMAIN omission, since accurate maps of the southern sky would be essential to ships navigating in the far southern oceans.

Charting the Southern Sky

Plancius began filling in this celestial void in 1589 when he added a constellation he called Crux (south of Eridanus) and another designated Triangulus Antarcticus (near the south celestial pole). Sailors and explorers such as Andrea Corsali, Amerigo Vespucci, and Francisco de Medina had previously reported the stars in these groupings — but they lacked accurate coordinates. Plancius folded them into new constellations, which he placed in distinctly different locations than our current Crux and Triangulum Australe. In 1592, Plancius added two more southern constellations: Columba, the Dove, and Polophilax, the Guardian of the Pole. Columba is the first truly non-Ptolemaic constellation to have survived. (German cartographer Caspar Vopel introduced Coma Berenices and Antinous in 1536, but Ptolemy had previously described these, though he didn't treat them as separate constellations.)

Plancius set about improving knowledge of the southern sky by training several Dutch sailors and navigators, including Pieter Dirkszoon Keyser and Frederick de Houtman. Tasked with making accurate celestial observations during their voyages, Keyser and de Houtman provided coordinates for more than 120 southern stars. Based on their efforts, in 1598 Plancius collaborated with a local cartographer to produce a celestial globe that included a whole new southern menagerie. He retained Columba and introduced 12 new figures: Apis, Apus, Chamaeleon, Dorado, Grus, Hydrus, Indus, Pavo, Phoenix, Tucana, Triangulum Australe, and Volans. To these, Plancius also added Crux, today's familiar Southern Cross — Ptolemy's asterism south of Centaurus. Apis (the Bee) quickly morphed into Musca (the Fly). This Musca appeared as early as 1603 on a globe designed by Dutch cartographer Willem Janszoon Blaeu and has survived to the present. Apis, however, did reappear from time to time, including on German astronomer Johann Gabriel Doppelmayr's planisphere of 1741, where the constellation was labeled "Musca Apis." As we'll see later, Plancius introduced another bee, this time in the Northern Hemisphere.

These new figures were apparently intended to honor discoveries by recent explorers. Some historians seem unsure as to whether it was Keyser, de Houtman, or Plancius who bundled these stars into constellations. But Plancius did include drawings of a toucan, a bird of paradise, and a chameleon on a terrestrial map dated 1594, which strongly argues in favor of the idea that their celestial counterparts were his creations.

Regardless of their origins, Bayer embraced these new constellations in *Uranometria*, his highly influential celestial atlas of 1603. Largely as a result of Bayer's exclusion, celestial cartographers quickly abandoned Polophilax, Triangulus Antarcticus, and the version of Crux south of Eridanus. Of the 17 constellations Plancius introduced prior to 1600, fourteen are still in use today. It appears that following this burst of activity, Plancius took a break from cartography. But he wasn't quite finished.

Plancius Constellations

Constellation	Original Source	Status
Apes (Northern Musca)	1612 globe	Last appearance 1899
Apis (Southern Musca)	1598 globe	Adopted by IAU
Apus	1598 globe	Adopted by IAU
Camelopardalis	1612 globe	Adopted by IAU
Cancer Minor	1612 globe	Last appearance 1660
Chamaeleon	1598 globe	Adopted by IAU
Columba	1592 map	Adopted by IAU
Crux (below Centaurus)	1598 globe	Adopted by IAU
Crux (south of Eridanus)	1589 globe	Last appearance 1607
Dorado	1598 globe	Adopted by IAU
Gallus	1612 globe	Last appearance 1660
Grus	1598 globe	Adopted by IAU
Hydrus	1598 globe	Adopted by IAU
Indus	1598 globe	Adopted by IAU
Jordanus Fluvius	1612 globe	Last appearance 1730
Monoceros	1612 globe	Adopted by IAU
Pavo	1598 globe	Adopted by IAU
Phoenix	1598 globe	Adopted by IAU
Polophilax	1592 map	Last appearance 1607
Sagitta Australis	1612 globe	Last appearance 1660
Tigris Fluvius	1612 globe	Last appearance 1730
Triangulum Antarcticus	1589 globe	Last appearance 1607
Triangulum Australe	1598 globe	Adopted by IAU
Tucana	1598 globe	Adopted by IAU
Volans	1598 globe	Adopted by IAU

Constellations of 1612

In 1612, Plancius, in collaboration with Flemish globe-maker Pieter van den Keere, produced a celestial globe on which he introduced eight new constellations. Many of these filled gaps in the northern sky. They included Apes (a bee, the northern counterpart to his Apis from 1598), Camelopardalis, Cancer Minor, Gallus (a rooster surrounded by Monoceros, Canis Major, and Argo Navis), Jordanus Fluvius (the Jordan River), Monoceros (the Unicorn), Sagitta Australis (the Southern Arrow), and Tigris Fluvius (the Tigris River).

Two of these new constellations, Camelopardalis (the Giraffe) and Monoceros, were immediately popular and appeared on just about every subsequent celestial chart and are included in the IAU's official list. The other six didn't survive, but most managed to persist for decades. Although they're not familiar to today's stargazers, 17th-century astronomers knew them well. Let's trace them out.

▲ **TRADE ON THE WAVES** This painting, dated 1677, shows the returning fleet of the Dutch East India Company. Founded in 1602, the Company employed cartographers such as Petrus Plancius, who helped create maps to facilitate expanding trade routes through previously uncharted waters. Toward the end of the 17th century, it had grown to become the richest private company in the world and boasted nearly 200 ships and some 50,000 employees.

The two most northern of Plancius's six lost constellations celebrated important rivers. Tigris Fluvius meandered its way from Pegasus to Ophiuchus then flowed south of Cygnus and Lyra (but north of Delphinus, Sagitta, and Aquila). Another river, Jordanus Fluvius, originated from its sources in "Jor" and "Dan" under the tail of Ursa Major, then flowed south of the Great Bear and around to its snout. Many globes and planispheres portrayed these two rivers, including those published by Strasbourg astronomer Isaac Habrecht II in 1621 and 1628, German astronomer Jacob Bartsch in 1624, German-Dutch cartographer Andreas Cellarius in his highly celebrated atlas of 1660 (shown on pages 24 and 25), and French cartographer Augustin Royer in 1679. Tigris Fluvius was rendered with an additional tributary, the Euphrates, in Cellarius's atlas.

▼▶ **LOST AND FOUND** The Cellarius atlas plates were purchased by another publisher, who reprinted the atlas in 1708. Then, in 1804, an Ottoman publisher produced planispheres modeled on those in the Cellarius atlas, presented below. These charts provided a final (but obscure) reprise for the lost Plancius constellations of 1612.

In 1687, Hevelius's great celestial atlas, *Firmamentum Sobiescianum*, was published. The work presented several new constellations, seven of which survive to the present day. He adopted all 14 of Plancius's southern constellations that were included in Bayer's 1603 atlas, as well as Camelopardalis and Monoceros. However, Hevelius abandoned Tigris Fluvius in favor of his own new constellation, Vulpecula. Likewise, he dropped Jordanus Fluvius to make room for Leo Minor and Lynx.

The Hevelius atlas, like Bayer's, was highly influential. His new constellations battled with Plancius's rivers over the next four decades, all appearing equally often. A handful of planispheres and globes portrayed the rivers, including those by Italian cartographer Vincenzo Coronelli in 1692 and 1693, Jean Le Febure in 1700, Dutch printmaker Carel Allard in 1706, Vasilii O. Kipriyanoviji in 1707, and German globemaker Johann Ludwig Andreae in 1724. The rivers were effectively presented for the final time in a celestial atlas that Salzburg cartographer Corbinianus Thomas published in 1730. But they did have a revival of sorts in 1804 on a pair of obscure Ottoman planispheres based on Cellarius's 1660 charts.

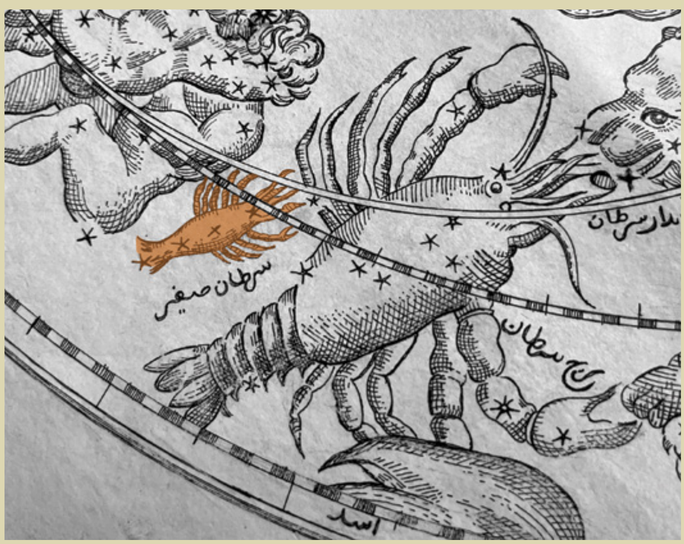
Of Roosters, Bees, and Flies

Planispheres in the Cellarius atlas of 1660 included the remainder of the constellations Plancius introduced in 1612. However, with the exceptions of Camelopardalis and Monoceros, that was to be their last hurrah. Gallus (the Rooster) also appeared in the globes and planispheres Habrecht published in 1621 and 1628, and in Bartsch's

SHIPS: PRISMA ARCHIVO / ALAMY STOCK PHOTO; CHART DETAILS: RAY HARRIS PRIVATE COLLECTION (4)

Apes

Cancer Minor



planispheres in 1624. However, Cancer Minor (between Cancer and Gemini) and Sagitta Australis (between Sagittarius and Scorpius) were not widely adopted and only showed up on the Cellarius planispheres and the 1804 Ottoman works based on these.

Plancius's constellation Apes (the Northern Bee) has a more intriguing legacy. It was formed from an asterism of four stars above Aries and below Triangulum. Apes shows up on the 1621 Habrecht globe and in his 1628 planispheres. In the 1624 Bartsch planispheres, Apes the bee morphed into Vespa, the Wasp. The Northern Bee reappeared in the Cellarius planispheres but was replaced by Musca (the Northern Fly) on charts by Stanisław Lubieniecki in 1665, and then was repurposed as Lilium, a fleur-de-lis honoring the king of France on Royer's planispheres of 1679. Of these competing options, Hevelius ultimately selected Musca for his famous and influential 1687 atlas. But this didn't immediately settle matters.

From 1687 to 1730, most planispheres presented either Lilium or Musca. Those featuring Plancius's rivers portrayed Lilium, while works that had Hevelius's constellations instead included Musca. Lilium made its near-final appearance (along with Plancius's rivers) in the Thomas atlas of 1730. Thereafter, Hevelius's constellation choices dominated almost all celestial works into the 20th century. Lilium popped up again on two planispheres published in 1785 and 1789, but Musca was present in nearly everything else after 1730, though its popularity began to wane by the end of the 19th century.

Poor Plancius tried to introduce both a southern bee (Apis) and a northern one (Apes), only to have them both ultimately morph into flies — one of which survives as today's Musca. Since the IAU chose to only include the southern version, it neatly avoided having to designate one Musca Borealis and the other Musca Australis.

◀ **GLOBAL EFFORT** Plancius collaborated on several celestial globes, including this one dated 1625, which was produced a few years after his death in 1622. It depicts all the constellations he introduced from 1598 to 1612, as well as Columba from 1592, Coma Berenices, and Antinous.

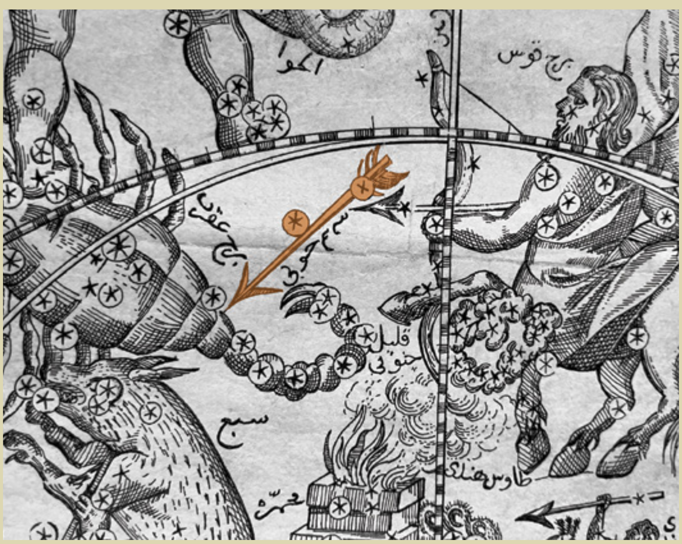
SCIENCE MUSEUM GROUP / PUBLIC DOMAIN

Plancius's Legacy

Notwithstanding the fact that nine of the 25 constellations Petrus Plancius introduced failed to survive, 16 of them continue to grace our modern skies. That's no small achievement. He was the first astronomer to supplement Ptolemy's constellations with wholly new inventions. His efforts to map the stars around the south celestial pole made a lasting contribution, as evidenced by the rapid and universal adoption of all 13 of the constellations he drew up in 1598. Thanks to Plancius, the atlases and charts we use to explore the night sky include a toucan, a giraffe, a unicorn, a chameleon, a couple of fish, and a host of other creatures. But no bees.

■ **RAY HARRIS** has been collecting and studying antique celestial charts and atlases since 1987 and has lectured widely on the art and science of early star atlases.

Sagitta Australis



Gallus

The Cepheus Spur

A newly named feature in our galaxy drapes distant luminaries across the northern sky from Cepheus and Camelopardalis to Auriga, Gemini, Taurus, and Orion.

A spectacular spiral galaxy is a majestic sight. The galaxy's rapid rotation whips up spiral arms where interstellar gas and dust spawn new stars, setting the arms aglow with blue and red supergiants as well as pink clouds of ionized hydrogen gas. In the greatest spirals, like the Whirlpool (M51), arms wrap around the entire galaxy.

But take a closer look at an excellent image of the Whirlpool and you'll also see plenty of irregularities, especially in the galaxy's outskirts: A spiral arm splits in two; spurs and feathers sprout from the arms; bridges of stars connect one spiral arm to another. It's easy to discern all these details on a Hubble image taken from M51's distance of 28 million light-years, but it's a lot harder for any astronomers trapped inside that galaxy to do the same.

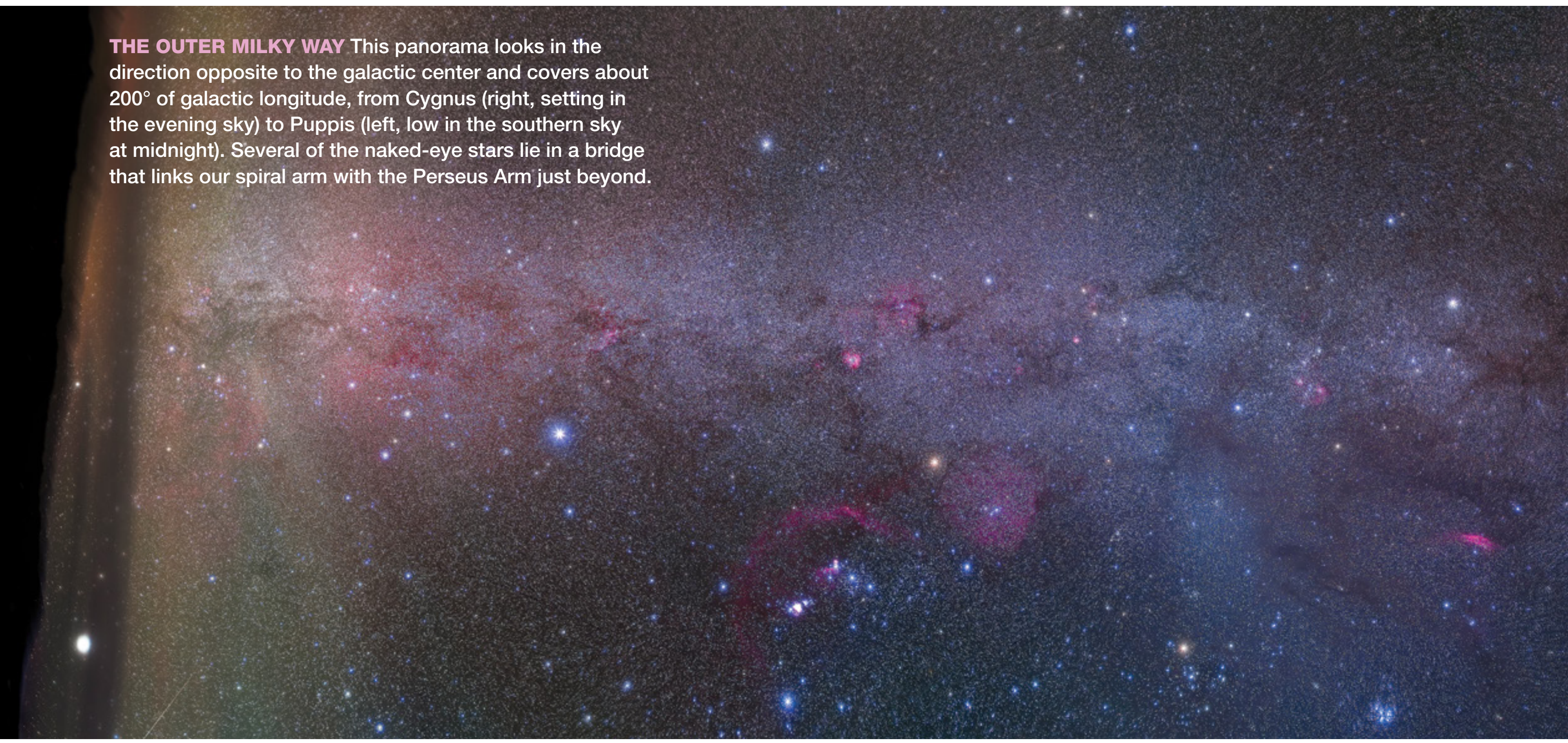
Which brings us to the eternal problem of the Milky Way, whose structure we cannot see from the outside. Because of our location, astronomers discovered spiral arms in our galaxy only in 1951, a full century after seeing them in the Whirlpool. Even today, no one knows whether the Milky Way is a stunning grand-design spiral like the Whirlpool, a beautiful multi-arm spiral like M101, or a less impressive flocculent spiral like M33.

We do know, however, that we live near the inner edge of the Local Arm. This arm supplies almost every star the naked eye can see (*S&T:* Nov. 2019, p. 16). Just as Earth lies between the orbits of Venus and Mars, so the Local Arm lies between the Sagittarius and Perseus arms. It's in these and other spiral arms that the Milky Way Galaxy mints most of its stars.

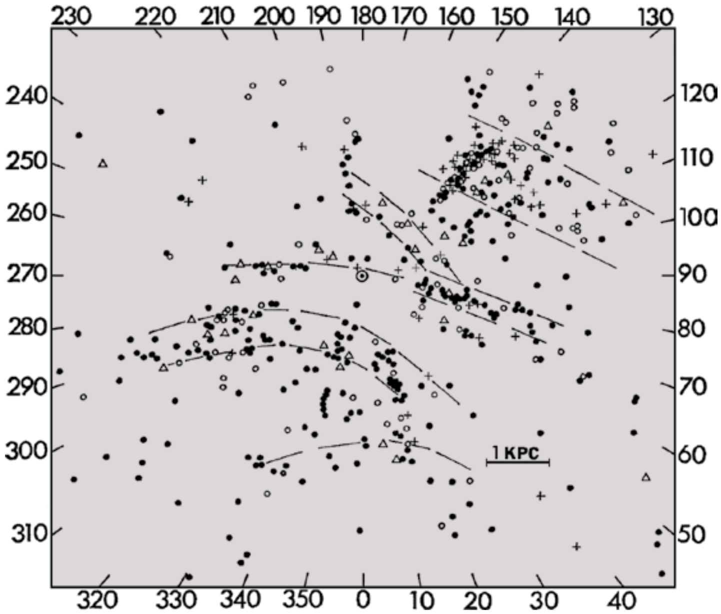
But as in the Whirlpool Galaxy, there are exceptions, because new stars can arise in interarm regions, too. Using the Gaia spacecraft to obtain precise parallaxes and distances of luminous blue *O* and *B* stars (see page 34), astronomers in Spain, Chile, and the United States recently mapped a long bridge of stars that stretches from the Local Arm out toward the Perseus Arm. The astronomers named this 9,000-light-year-long feature the Cepheus Spur in their 2021 paper. At its heart are six *OB* associations, which are loose groups of massive young stars bearing spectral types *O* and *B* as well as the white, yellow, orange, and red supergiants that have evolved from such stars.

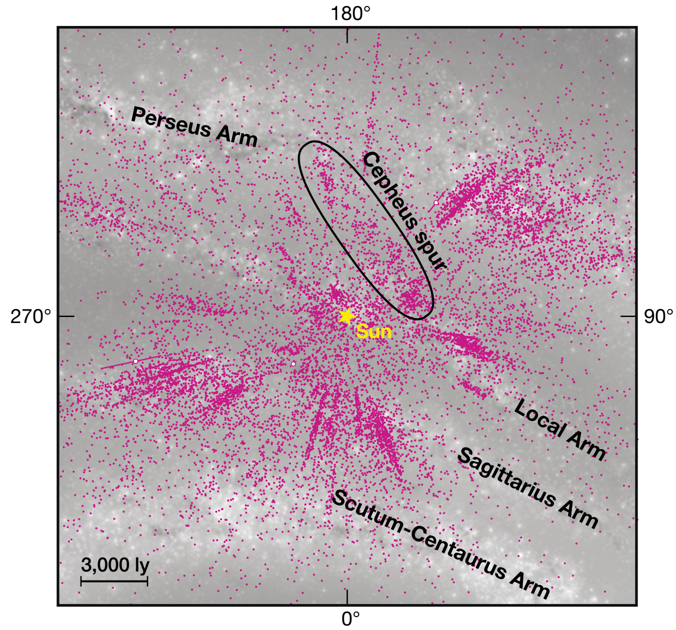
The six *OB* associations "are connected like a chain of beads, connecting these two arms," says Michelangelo Pan-

ALAN DYER



THE OUTER MILKY WAY This panorama looks in the direction opposite to the galactic center and covers about 200° of galactic longitude, from Cygnus (right, setting in the evening sky) to Puppis (left, low in the southern sky at midnight). Several of the naked-eye stars lie in a bridge that links our spiral arm with the Perseus Arm just beyond.





▲ **THE LOCAL GALAXY** *Left:* A 1970 map of supergiants delineated several spiral arms and a branch off the Local Arm (center). The dot surrounded by a circle marks the Sun's position; other symbols indicate different spectral types. *Right:* Gaia positions for OB stars show the same branch, now called the Cepheus Spur. The background image is an artist's illustration of the Milky Way (see page 34).

1970: R. M. HUMPHREYS / *ASTRONOMICAL JOURNAL* 1970; 2021: M. PANTALEONI GONZÁLEZ ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY* 2021

taleoni González, an undergraduate working with Jesús Maíz Apellániz (both Spanish Astrobiology Center, Madrid). The six groups defining the Cepheus Spur are the Cepheus OB2, Cepheus OB3, Cepheus OB4, Camelopardalis OB1, Auriga OB1, and Gemini OB1 associations. Despite their great distances from us, their brightest stars are dimly visible to the naked eye.

The Spur of the Moment

Although Pantaleoni González and his collaborators were the first to name the feature, they weren't the first to see it. In 1953 William Morgan (Yerkes Observatory), who had just discovered the Milky Way's spiral nature, saw the feature on galactic maps he made and interpreted it not as a spur but instead as a branch from the spiral arm containing the Sun.

In 1965 Stewart Sharpless (U.S. Naval Observatory), who had worked under Morgan, called the feature a "bifurcation" of the Local Arm.

Then Roberta Humphreys (now University of Minnesota) plotted the positions of nearby supergiants and delineated the same structure. "I just called it a spur," she says. Her maps appeared in the March 1970 issue of *Sky & Telescope* and later in *The Astronomical Journal*; the maps were part of her PhD thesis at the University of Michigan. "Academically I'm Morgan's granddaughter," she says, because her PhD advisor — William Bidelman — had earned his doctorate under Morgan. Humphreys wrote that the spur might eventually join with the Perseus Arm. The problem, she says, is that "the Perseus Arm kind of sputters out" where the two would join, the sort of irregularity that spiral galaxies often exhibit in their outer regions.

That early work, of course, didn't utilize the power of the Gaia spacecraft. "As always, the answer has been in plain sight if only you allowed yourself to believe the distances," says Robert Benjamin (University of Wisconsin, Whitewater). "'Believing the distances' is what Gaia is all about when it comes to galactic structure."

The Gaia data have revealed that the far tip of the Cepheus Spur — the Gemini OB1 association — is more distant than previously thought. Whereas both Morgan and Humphreys had estimated its distance to be 4,900 light-years, Gaia implies a figure around 6,000 light-years. On the new maps the spur therefore makes a steeper angle with the Local Arm.

The 2021 study notes another intriguing trait: "The Cepheus Spur is above the galactic plane," Pantaleoni González says. The spur's stars are typically a few hundred light-years above the plane of the Milky Way's disk. That, he says, suggests the stars formed because the galaxy's disk is oscillating, perhaps in response to the gravitational disturbance of a passing satellite galaxy.

See the Cepheus Spur

Despite lying partly between two spiral arms, the Cepheus Spur boasts some of the most luminous stars known, many of which are naked-eye. One likely member is renowned for its

GARNET STAR Mu Cephei (top) glows with its distinctive red hue beside the emission nebula IC 1396 in this RGB and hydrogen-alpha composite.

MDW SKY SURVEY

beauty, the red supergiant Mu Cephei —"one of my favorite stars," Humphreys says. German-born English astronomer William Herschel named it the Garnet Star for its deep red hue. The color results from both the star's cool surface and interstellar dust that further reddens the starlight. The dust also absorbs so much light that Mu Cephei looks two magnitudes fainter than it otherwise would.

Frustratingly, this 4th-magnitude gem is too bright for Gaia to provide a reliable parallax. In 1978, Humphreys assigned the star to the Cepheus OB2 association, which she placed at 2,700 light-years from Earth. A 2019 study determined the star's distance to be 1,600 to 2,600 light-years from us, while a 2020 paper put Mu Cephei at 2,900 to 3,500 light-years away. If the star is indeed 2,700 light-years distant, then it's about 200 light-years above the galactic plane.

Another famous red supergiant, VV Cephei, is also part of the Cepheus Spur. A blue companion orbits the big red star every two decades. At 5th magnitude, VV Cephei is dimmer than Mu Cephei, and the Gaia parallax indicates a distance of 3,300 light-years from Earth and a height above the galactic plane of 400 light-years.

Both stars are among the largest in the galaxy, surpassing the better-known red supergiants Antares and Betelgeuse. Make the Sun as large as either Mu Cephei or VV Cephei and it would engulf Mercury, Venus, Earth, Mars, Jupiter, and maybe even Saturn.

Other naked-eye members of the Cepheus Spur in its namesake constellation are 4th-magnitude Nu Cephei, a white *A*-type supergiant like Deneb, and 5th-magnitude Lambda Cephei, one of the few *O*-type stars visible to the naked eye. The Gaia data indicate Nu Cephei is 3,600 light-years from Earth, while Lambda Cephei is 2,800 light-years from us. Lambda Cephei is a likely runaway: It was once part of the Cepheus OB2 or OB3 association, but either a close companion star exploded and expelled Lambda at high speed or else other massive stars ganged up on it and tossed it out via their gravity. In addition to this menagerie of stars, the Cepheus OB2 association contains the young star clusters Trumpler 37 and NGC 7160.

The Cepheus Spur runs through neighboring Camelopardalis, the faintest constellation that never rises or sets for observers at mid-northern latitudes. The brightest star in this constellation, Beta Camelopardalis, is in the foreground, but the second-brightest star, the 4th-magnitude blue supergiant CS Camelopardalis, belongs to the Camelopardalis OB1 association and thus to the Cepheus Spur. Ditto for somewhat fainter CE Camelopardalis, an *A*-type supergiant. Both stars light up reflection nebulae. If these stars were as close to us as those of the Big Dipper, they'd far outshine Sirius, making Camelopardalis the standout of the northern sky. The double *B*-type star 1 Camelopardalis, shining at 6th magnitude, is also a member of the Camelopardalis OB1 association, as is the young star cluster NGC 1502.

In Auriga the Cepheus Spur juts farther away from us, as reflected by the distance of 5th-magnitude Chi Aurigae, 4,700 light-years. It's a blue supergiant in southern Auriga, near Taurus, and belongs to the Auriga OB1 association. But the best-known member of this association is the open star cluster M36, which is some 4,000 light-years from Earth. The cluster was born 15 to 30 million years ago.

▲ **MESSIER 36** The Pinwheel Cluster contains hundreds of stars and gleams in Auriga, the Charioteer. Binoculars or a small telescope should pick it up.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

The farthest group in the Cepheus Spur is the Gemini OB1 association. So you'll need binoculars to glimpse the red supergiant 6 Geminorum and the blue supergiant 9 Geminorum, both being slightly dimmer than the nominal naked-eye threshold of magnitude 6. Red 6 Geminorum is 5,700 light-years from Earth and 200 light-years above the galactic plane, whereas blue 9 Geminorum is 5,600 light-years from Earth and 350 light-years above the galactic plane. A supernova remnant in the same association named IC 443 presages the violent ends of most of these luminous stars.

Stars from the Cepheus Spur also twinkle in Taurus and Orion. *B*-type 139 Tauri is 4,600 light-years from Earth. At a similar distance is Chi^2 Orionis, a blue supergiant in northeastern Orion, far north of Betelgeuse. Both 139 Tauri and Chi^2 Orionis are around 5th magnitude.

That we barely see even the most powerful stars in such a nearby section of our own galaxy demonstrates how vast and mighty the Milky Way is. Indeed, even under the darkest skies, you discern only a modicum of our galaxy's enormous extent. Mapping its full domain will surely take decades if not centuries — unless some kind astronomer in the Whirlpool Galaxy beams a picture our way.

■ **KEN CROSWELL** is the author of several books, including one on the Milky Way called *The Alchemy of the Heavens*.

 by Govert Schilling

THE GAIA REV

The precise observations of Europe's prolific surveyor have enabled astronomers to map the universe and unravel the history of our Milky Way Galaxy.

Ask someone to name a revolutionary space telescope right now, and they will probably answer "James Webb." Ever since its launch on Christmas Day 2021, this versatile successor to the Hubble Space Telescope has been stealing the astronomical limelight. But operating from the same part of the solar system, some 1.5 million kilometers behind Earth's nightside, is a lesser-known instrument that is one of the most successful space science missions ever built: the European Space Agency's Gaia spacecraft.

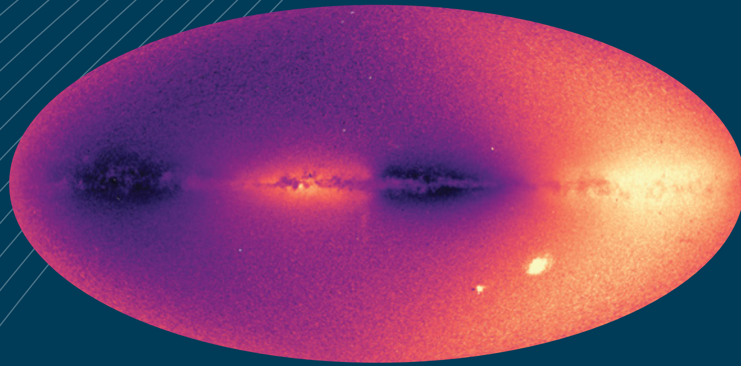
Gaia and Webb are very different. Whereas Webb is the instrument of choice to study selected astronomical objects in detail, Gaia is an all-sky surveyor. Its main mission: to collect precise data on positions, distances, motions, and compositions for almost 2 billion stars and extragalactic objects. It is the ultimate astronomical measuring machine.

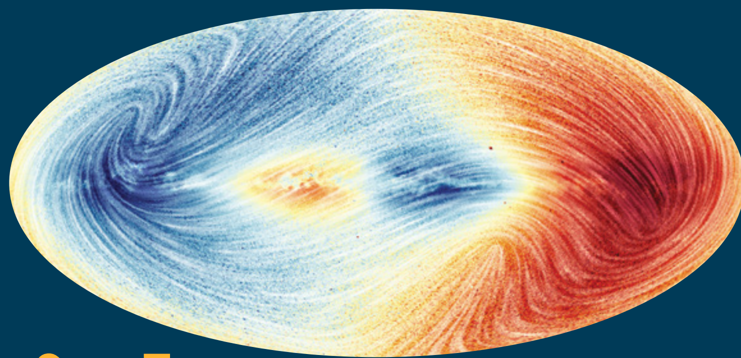
On June 13, 2022, ESA released the third batch of Gaia results (Data Release 3, or DR3), based on the first 34 months of observations. DR3 contains 10 terabytes of information, covering a whopping 1,811,709,771 distinct sources: Milky Way stars (including huge numbers of binaries and variable stars), galaxies and quasars, and small bodies in our solar system. It's the latest in a series of mission catalogs that are providing a tsunami of new results — as evidenced by the steady stream of a few scientific papers per day (on average) that are based on Gaia data.

"There is probably no area where Gaia has not had an impact," says Richard Smart (Italian National Institute of Astrophysics). "It's totally awesome."

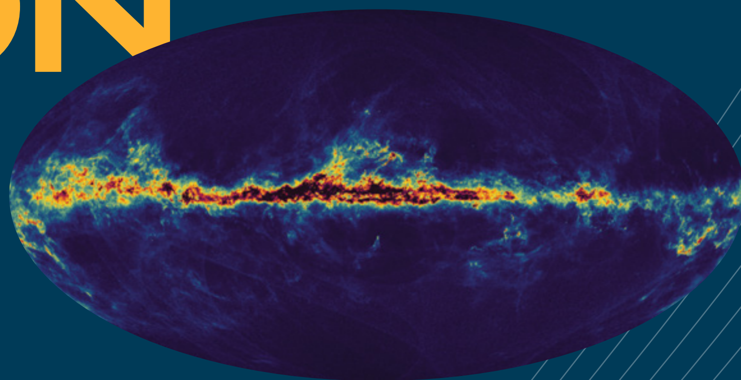
▲ **GAIA'S SKY** This all-sky map uses data from more than 1.8 billion stars observed by Gaia. Brighter regions represent denser concentrations of bright stars, and the colors are a combination of the total amount of light with the amount of blue and red light the spacecraft recorded in each patch of sky.

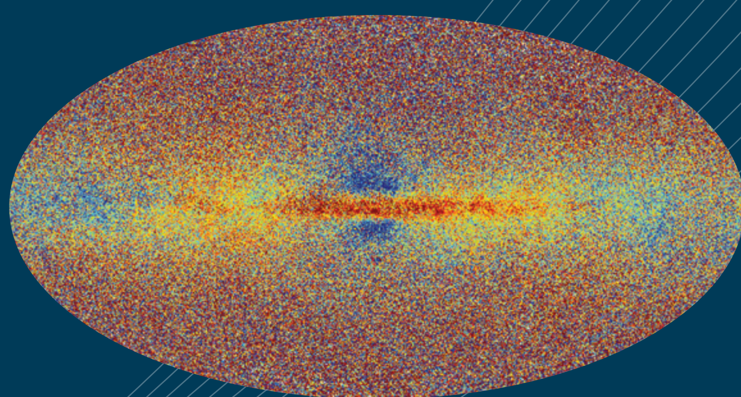
ESA / GAIA / DPAC / CC BY-SA 3.0 IGO, ACKNOWLEDGEMENT: A. MOITINHO





OLUTION





▶ **RADIAL VELOCITY** *First:* Our galaxy's rotation reveals itself in this map, which shows the speeds at which more than 30 million objects (mostly stars) are moving toward or away from us. Bright areas are moving away from us, dark areas toward. (Remember that we're in a rotating disk, and this map curves 360° around us.)

▶ **RADIAL VELOCITY PLUS PROPER MOTION** *Second:* Based on the movements of about 26 million stars, this map shows the parts of the sky where stars' average motion is toward us (blue) or away from us (red). The lines trace the stars' motions projected on the sky, which vary by galactic latitude and longitude.

▶ **INTERSTELLAR DUST** *Third:* Gaia's measurements also reveal the intervening dust that absorbs starlight. Dust concentrates along the galactic plane, with very little in the halo (dark blue regions).

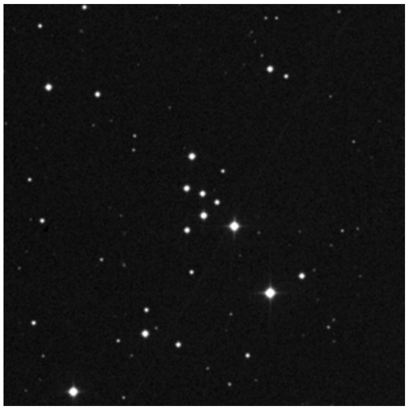
▶ **CHEMISTRY** *Fourth:* Stars richer in elements heavier than helium (redder colors) lie in the galaxy's disk. These stars are relatively close, because interstellar dust blocks our view of farther stars. We have a clearer sightline to the old, metal-poor stars in the bulge and halo concentrated around the galactic center (blue). The high galactic latitudes show a rainbow because we see a mixture of nearby young, metal-rich stars and far-off old, metal-poor stars in the halo.

Mapping the Stars

Astrometry — finding out where the stars are and how they move — is the oldest and conceptually simplest part of astronomy. It all started with the first known star catalog by Greek astronomer Hipparchus of Nicaea (2nd century B.C.), which we think contained sky positions for just 850 stars. Later generations improved on this work. For instance, the three-volume monumental German *Bonner Durchmusterung*, published between 1859 and 1862 and based on many years of visual observations, listed 324,188 stars in the Northern Hemisphere sky down to magnitude 10, with a positional accuracy of a few arcseconds (one arcsecond is 1⁄3600 of a degree).

The field of astrometry changed dramatically with the 1989 launch of ESA's first star mapper, Hipparcos (High Precision Parallax Collecting Satellite). In 1997, the mission team produced a catalog of positions for more than 1 million stars, based on the full 3.5 years of observations. In a separate catalog, the brightest 118,218 stars had their sky positions measured to within the nearest 0.7 milliarcsecond, and astronomers precisely determined their distances on the basis of the stars' *annual parallax* (*S&T:* Oct. 2022, p. 12).

Gaia is Hipparcos's successor. Launched in 2013 from Europe's Spaceport in French Guiana, Gaia arrived in its halo orbit around the Lagrangian point L_2 soon after. It started observations in July 2014.

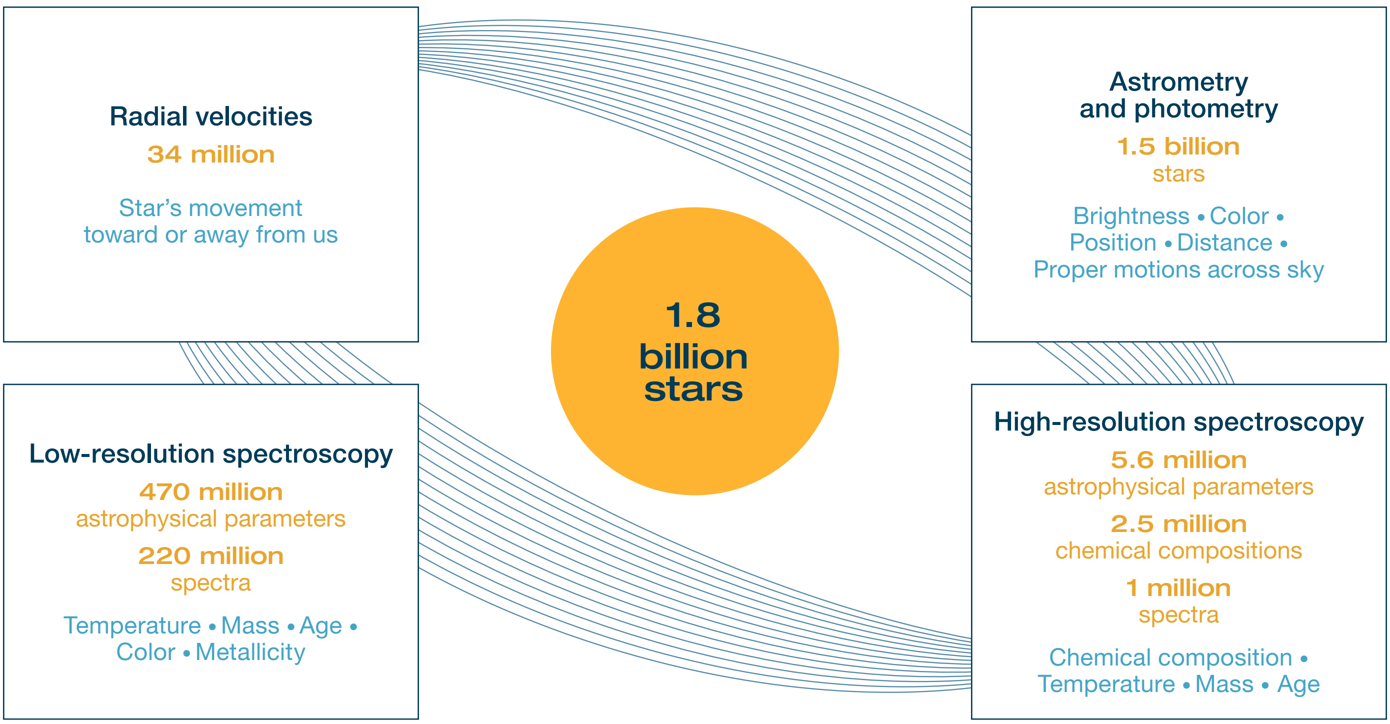


◀ **LOOKS CAN BE DECEIVING** Gaia's data show that several sparse groups of stars are not actually traveling together through space, including NGC 7772, shown here. Astronomers already thought at least one of the putative clusters was masquerading, but Gaia data cinched it.

Gaia doesn't produce spectacular images of the night sky. Instead, its two rectangular concave mirrors, each measuring 1.45 by 0.5 meters, continually scan the celestial sphere as the spacecraft slowly rotates once every six hours (*S&T:* Mar. 2019, p. 20). By design, the two mirrors always look at parts of the sky that are 106.5° apart. They each focus light on a single CCD detector array (the largest ever flown in space, with almost 940 million pixels), which is mounted on the same ultra-stiff, silicon-carbide frame.

As stars from both patches of sky simultaneously drift across the detector, precise measurements of their crossing times yield the angular separation between pairs of stars. Zillions of such angular measurements constitute an elaborate all-sky trigonometric network, from which astronomers will eventually be able to derive sky positions with an accuracy of less than 10 *micro*arcseconds for those stars brighter than magnitude 14 — much more precise than Hipparcos could manage.

▼ **IN A NUTSHELL** Gaia's third data release includes information on some 1.8 billion Milky Way stars. For subsets of those stars, astronomers have different kinds of information (boxes).



NGC 7772: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; MEASUREMENTS GRAPHIC: TERRI DUBÉ / S&T, SOURCE: ESA

Since Gaia returns to each part of the sky many dozens of times over its extended 12-year mission, the ever-growing data archive not only contains full 3D information on the *locations* but also on the *motions* of some 1.5 billion stars. Parallax-based distance measurements reach out to many thousands of light-years, although the accuracy is lower for larger distances.

In addition to parallax and proper motion, Gaia registers brightness variations, using its sensitive dual (blue/red) photometric instruments, which even produce a crude spectrum. Meanwhile, the high-resolution Radial Velocity Spectrometer (RVS), used to measure an object's velocity along the line of sight, also provides detailed information on the chemical composition of many stars and galaxies. Data Release 3 includes low-resolution spectra for 220 million objects, 34 million radial-velocity measurements, and high-resolution spectra for 1 million targets.

All in all, Gaia is nothing less than an astronomer's dream. "Gaia is now providing the reference catalog of celestial sources," says Johannes Sahlmann (ESA). "The first question of an astronomer studying a particular star is now, 'What can Gaia tell me about it?'"

An Embarrassment of Stellar Riches

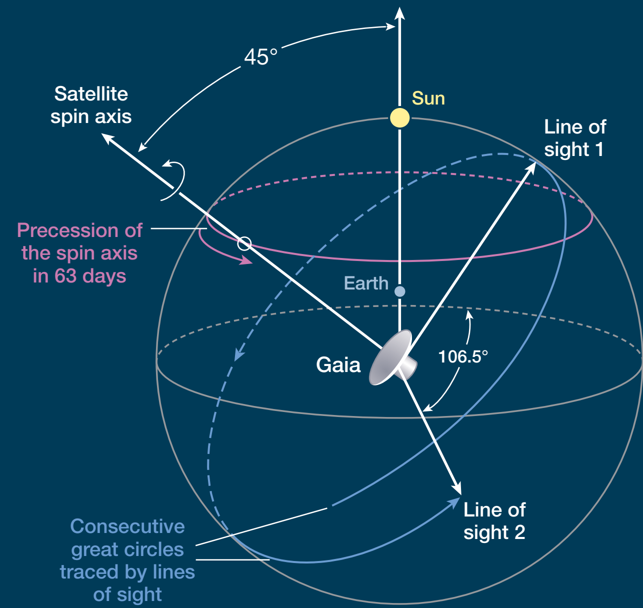
One important topic that Gaia can shed new light on is stellar characterization and evolution. Its spectroscopic observations not only reveal stars' compositions, but also their surface temperatures. If the distance to the star is known (from its parallax), the observed apparent brightness tells you the true luminosity, and it is relatively straightforward to derive the star's mass and age.

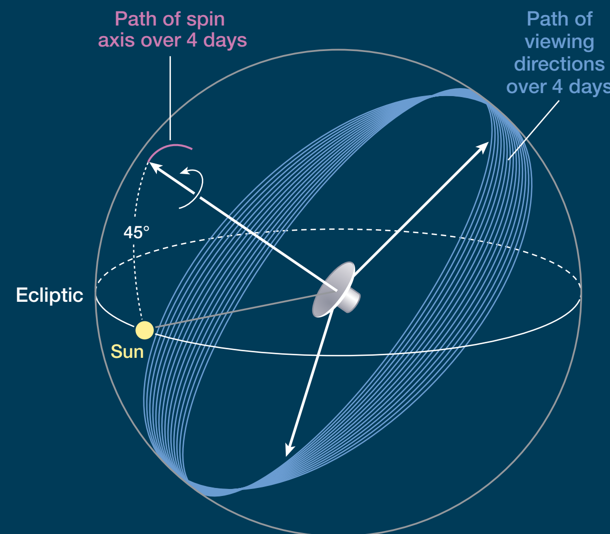
Plotting hundreds of millions of Gaia stars in a temperature-luminosity diagram (also known as a Hertzsprung-Russell diagram) reveals many evolutionary subtleties, as stars of a certain mass move erratically through the diagram as they age. As an example, Anthony Brown (Leiden University, The Netherlands) points to the roughly 500,000 white dwarfs that the telescope has observed. The HR diagram reveals a weak concentration of white dwarfs at a certain luminosity, as if their evolution is slowing down for a while. According to Brown, this is most likely due to the crystallization of their slowly cooling cores, which temporarily slows their cooling rate — a key process that is almost impossible to study otherwise.

Gaia's spectroscopic observations constitute a "wealth of information on Milky Way stars," according to Alejandra Recio-Blanco (Côte d'Azur Observatory, France). The spacecraft's RVS instrument is collecting about 100 high-resolution spectra per second. "For 5.5 million stars, we now have detailed information on their chemical composition," Recio-Blanco said during the presentation of DR3 in June.

Since every star-forming region has a slightly different chemical makeup, Gaia can discern stars that share a common origin. For instance, studying both the chemical compositions and the spatial motions of stars makes it possible to identify members of open star clusters, even if they have started to disperse. Such work with Gaia's previous data release revealed distant members pulled from the well-known, nearby Hyades star cluster in the constellation Taurus, the Bull. Its two S-shaped *tidal tails* together stretch almost 800 light-years and across most of the sky.

So far, Gaia has observed more than 2,000 other open star clusters, many hundreds of which astronomers didn't know about before. These collections include a number of small, dispersed groups in the solar neighborhood, and one relatively old cluster that had never been recognized before because its





GAIA'S DANCE The spacecraft turns around its axis 1° per minute, scanning the sky simultaneously along two lines of sight that trace great circles on the celestial sphere. The rotation axis also precesses as the craft orbits the Sun, enabling Gaia to observe long, overlapping strips of sky.

S&T ILLUSTRATION, SOURCE: ESA

sky location is very close to the bright star Sirius. Then again, Gaia also confirmed that four sparse "clusters" (NGC 1252, 6994, 7772, and 7826) are actually chance projections of unrelated stars on the sky.

By returning to the same part of the sky every month, Gaia also registers brightness variations and transient phenomena. The space observatory has harvested data on countless Cepheids, RR Lyrae stars, and other types of variables. It discovered a number of unusual supernovae as well, including Gaia17biu, one of the nearest *superluminous supernovae* known to date. In 2021, no less than 17 galactic novae were discovered, and Gaia astronomers are compiling the largest ever catalog of cataclysmic variables, which are probable progenitors of Type Ia supernovae. Precise data on Cepheids and Ia's help to improve astronomers' cosmic distance ladder (*S&T:* Oct. 2022, p. 12).

As soon as a new unexpected event is discovered in the Gaia data (usually by automated software), the mission's Data Processing and Analysis Consortium (DPAC) issues a science alert to other astronomers who can carry out follow-up observations. "Since we started the science-alert program, transient astronomy has become ever more exciting," says Simon Hodgkin (University of Cambridge, UK), who is a DPAC member. "Because of Gaia's scanning mode, we are not always the first to detect new events, but even if we are late, we still provide extremely accurate positions."

Exoplanets and Asteroids

Gaia serves an an exoplanet finder, too. After all, a tiny, slow, periodic wobbling of a star's position could reveal the existence of a massive planet or brown dwarf in a wide orbit. Gaia should eventually discover and characterize thousands of giant exoplanets, says ESA's Sahlmann, but it takes time and patience — astronomers really need many years of data.

Nevertheless, the third data release already contains

▲ **GAIA 1** Hidden in Sirius's glare lies the cluster Gaia 1, its stars essentially invisible to the eye (astronomers found it thanks to a computer algorithm). In this image it sits at center, around where the orange, loop-shaped artifact appears left of Sirius. The cluster spans roughly 15 arcminutes — half the size of the full Moon — but its stars are at least 13 magnitudes fainter than the Dog Star at its western edge.

169,000 *astrometric binaries*, in which a companion reveals its existence by tugging on the primary star. Most of those consist of an invisible white dwarf orbiting a main-sequence star. But so far, Gaia has also found some 1,800 brown dwarf companion candidates and tens of new exoplanet candidates, making DR3 "substellar science candy," Sahlmann says.

And there's much more to come. "The real avalanche will come with the fourth and fifth data releases," says Smart.

Another major contribution to exoplanet science is Gaia's ability to better characterize the planets' host stars. Estimates of an extrasolar planet's mass and diameter (and thus its density and composition) rely on knowledge about the mass

Total number of sources	Binary star systems	Variable stars	White dwarfs	Star clusters	Solar system objects	Quasar candidates	Galaxy candidates
1.8 billion (mostly stars)	813,000	10 million	500,000	2,500	158,000	6.6 million	4.8 million

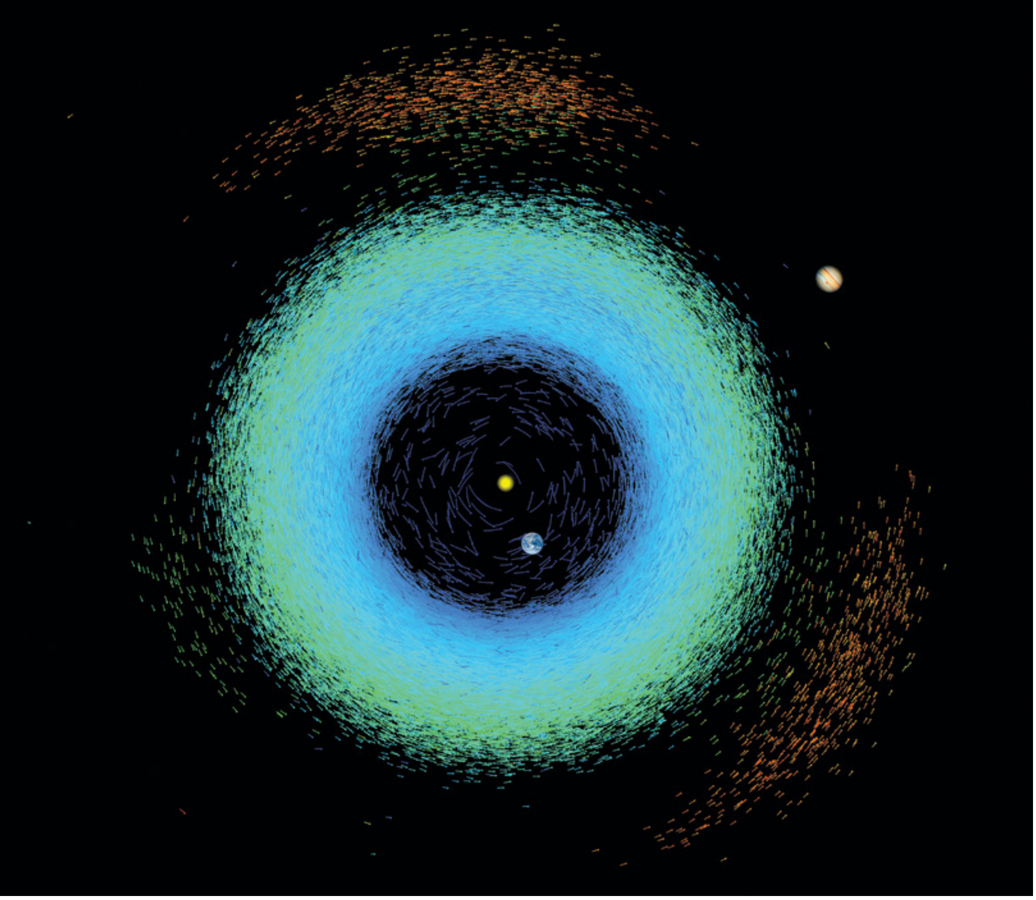
OUTSIDE THE MILKY WAY

When you're surveying between 1 and 2 billion stars, you can't help bagging numerous galaxies and quasars, too. Quasars are the luminous cores of remote galaxies, powered by supermassive black holes. They are found all over the sky, and since they don't exhibit parallax or proper motion, Gaia uses a selection of 1.6 million quasars as a reference frame — a coordinate system against which it measures stellar positions.

But of course, quasars are interesting by themselves, just like the many galaxies studied by Gaia. DR3 includes two separate catalogs of extragalactic sources, containing 6.6 million quasar candidates and 4.8 million galaxy candidates, respectively. For millions of those objects, astronomers have also determined redshifts, providing the distances. "The quality and homogeneity of the data are exceptional," says Christine Ducourant (University of Bordeaux, France).

One particularly interesting part of DR3 is the Gaia Andromeda Photometric Survey (GAPS) — a 34-month photometric data set on 1.2 million sources within a 5.5-degree radius centered on the Andromeda galaxy. Among other things, this survey will enable astronomers to study the variability of the brightest stars in our galactic neighbor, including Cepheids.

GAIA 1 CLUSTER NEAR SIRIUS: IPAC / NASA / D. LANG / S. KOPOSOV; ICONS: TERRI DUBÉ / *S&T*, SOURCE: ESA



ASTEROIDS GALORE
The position of each asteroid Gaia has detected within Jupiter's orbit, plotted for the date of Data Release 3 (June 13, 2022). Each segment represents the asteroid's motion over 10 days. Blue represents the inner solar system, green the main asteroid belt, and orange the Trojans that accompany Jupiter. Earth, Jupiter, and the Sun are shown for orientation and are not to scale.

and diameter of the parent star. Thanks to Gaia, it has been possible to derive much more precise data on the physical properties of many known exoplanets.

Much closer to home, Gaia is revolutionizing asteroid research. DR3 contains data on 158,152 asteroids, Kuiper Belt objects, and planetary satellites, including spectra of 60,518 of these small solar system bodies. "This is simply the largest spectroscopic survey ever published," says Paolo Tanga (Côte d'Azur Observatory). "I am sure that many discoveries will come from this: on the composition of ancient planetesimals fragmented by collisions into asteroid families, on the formation of the asteroid belt, and maybe on asteroid satellites that can be found through astrometry." According to Federica Spoto (Center for Astrophysics, Harvard & Smithsonian), Gaia's "ultra-accurate asteroid positions" are about 100 times more precise than earlier ground- or space-based measurements. "It's really a new way to see the solar system," she said at the presentation of DR3.

Galactic Archaeology

Some of the most exciting Gaia results to date are related to the evolution of our Milky Way Galaxy. Over time, the Milky Way has grown to its present bulk by "consuming" smaller satellite galaxies and globular clusters. But even after hundreds of millions or even billions of years, stars that share a common origin have similar orbital energies and angular momenta, both of which are so-called *conserved quantities*, explains Amina Helmi (University of Groningen, the Netherlands). So astronomers can reconstruct the Milky Way's complicated formation history by precisely mapping the motions and compositions of its constituent stars (*S&T:* Mar. 2020, p. 34).

In April 2018, within hours of Gaia's second data release, Helmi and her collaborators discovered the telltale dynamical fingerprint of a massive galaxy merger that occurred some 10 billion years ago. They nicknamed this galaxy Gaia-Enceladus, after the mythological giant (and son of the Earth goddess Gaia) who was buried under Sicily's Mount Etna, driving its volcanic activity. Likewise, the merger with Gaia-Enceladus produced an eruption of star formation in the Milky Way.

The stars from Gaia-Enceladus (sometimes now called Gaia-Sausage-Enceladus, or GSE) are found throughout our galaxy and in its halo. But more recent mergers have left elongated streams of stars with similar dynamical properties and compositions. More than 20 years ago, Helmi had already found such *stellar streams* in data from the earlier Hipparcos mission. While these so-called Helmi streams were recognized on the basis of just 13 individual stars, Gaia's much greater sensitivity has revealed similar streams of many hundreds of stars, some of which extend over tens of degrees of sky.

"We are now able to find the remains of much smaller and more recent mergers," says Helmi. "Dwarf galaxy streams have typical widths of hundreds of light-years, but we've also discovered streams that are less than 10 light-years wide — the tidally disrupted remains of globular clusters." Eventually, Helmi hopes to use these streams to fully reconstruct the Milky Way's formation history.

Studying stellar streams — which usually extend well into the Milky Way's halo — may also shed light on the mystery of dark matter. According to computer simulations, the galactic halo should be home to countless invisible *subhalos* of dark matter. If they incidentally passed through a stellar stream, they could leave telltale "holes" and other gravitational disturbances. No such signatures have been confirmed so far. Moreover, studying the dynamics of stellar streams could provide information on the overall mass distribution in the Milky Way, which is thought to be dominated by dark matter.

Quiet Revolution

Over the next few years, many new results on a wide variety of astronomical topics will be published on the basis of Gaia DR3 data. But this release is only one third of Gaia's eventual astrometric harvest. "Around 2025, we plan to release the fourth batch of data, based not on 34 but on 66 months of observations," says Brown, who is the chair of the Data Processing and Analysis Consortium. "With DR4, for the first time, we will also publish all individual observations. Five years later, the final data release of 126 months is expected."

The spacecraft's micro-propulsion fuel is expected to run out in early 2025. But scientists and engineers are already drawing up plans for a successor to Gaia that operates at near-infrared wavelengths. GaiaNIR, proposed as part of ESA's Voyage 2050 scientific program, would be able to peer through most of the absorbing dust in the plane of our Milky Way and map stars in the galactic center and dusty spiral arms. By revisiting stars from the Gaia catalog, the new mission would also vastly improve on proper motion measurements. The development of a Gaia-like drift scan detector for infrared wavelengths is still a technological challenge, says Brown, but once that's been solved, GaiaNIR could launch in the 2040s.

For now, astronomers are just wallowing in the wealth of ultra-precise data from Europe's indefatigable star mapper. As Frédéric Arenou (Paris Observatory) says: "Gaia is an all-in-one instrument. There are no fancy images, but Gaia is providing material for an important fraction of the astrophysical field for several years, if not decades. The most profound revolutions are sometimes quiet."

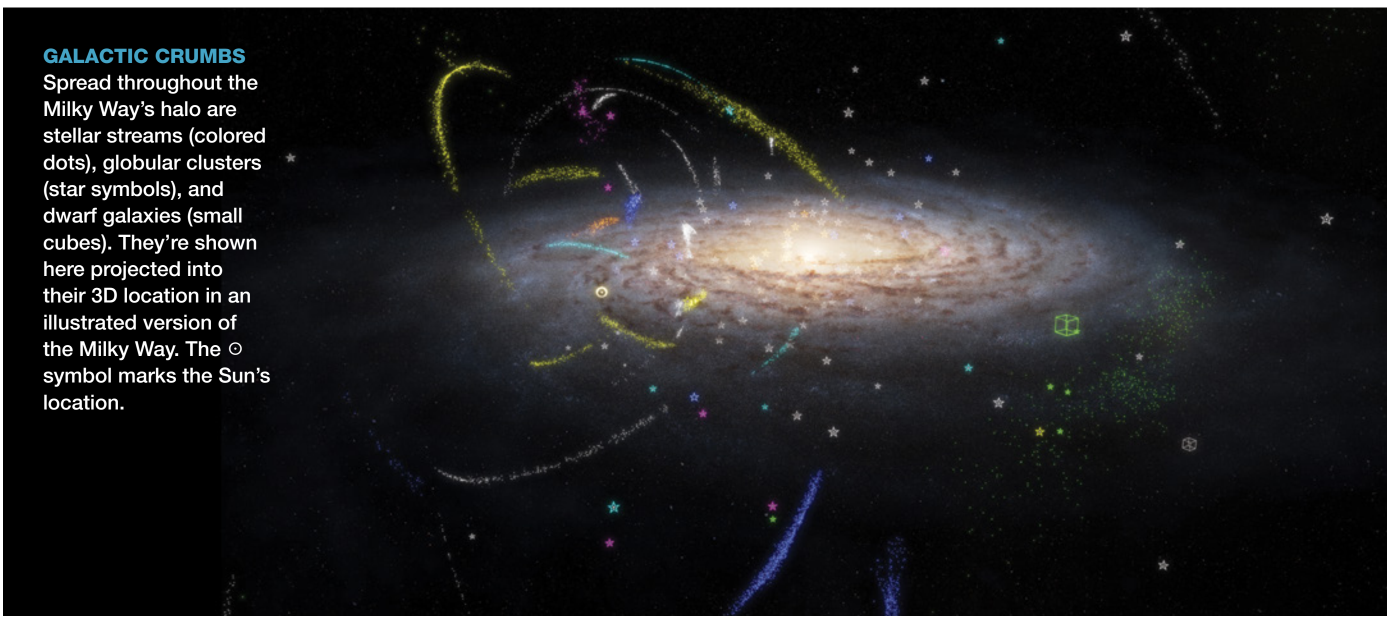
■ Contributing Editor **GOVERT SCHILLING**'s coordinates put him in the Netherlands, and his proper motion is restricted to the surface of a rocky planet orbiting a *G*2V star.

MINE THE ARCHIVE

The 1,548 charts of the 1997 *Millennium Star Atlas* (produced by *Sky & Telescope* in close collaboration with the European Space Agency) were based on data from ESA's Hipparcos mission. There are currently no plans to turn the Gaia measurements into a hardcopy atlas, given that there would be no notable differences in the positions of stars bright enough for observers' use. "But all data are freely available, so everyone can do it," says Anthony Brown, the chair of Gaia's Data Processing and Analysis Consortium (DPAC).

For individual stars and other objects, you can access the latest information through the Gaia Archive (**https://gea.esac.esa.int/archive**) or through the SIMBAD astronomical database (**https://simbad.u-strasbg.fr/simbad**). Moreover, Gaia scientists produced an open-source software package, *Gaia Sky*, advertised as a "3D universe simulator with support for more than a billion objects." You can download Gaia Sky from **https://zah.uni-heidelberg.de/gaia/outreach/gaiasky**.

▲ **MSA** The three-volume *Millennium Star Atlas* used Hipparcos data as well as nebula outlines hand-traced from sky images. It's now a collector's item.



GALACTIC CRUMBS
Spread throughout the Milky Way's halo are stellar streams (colored dots), globular clusters (star symbols), and dwarf galaxies (small cubes). They're shown here projected into their 3D location in an illustrated version of the Milky Way. The ⊙ symbol marks the Sun's location.

MSA: S&T; STELLAR STREAMS IN THE HALO: S. PAYNE-WARDENAAR / K. MALHAN, MPIA

Winter brings a delightful set of constellations and objects to keep you and your stargazing friends busy (see page 18). An auroral display might even dazzle while you're sharing your knowledge of the night sky with your guests. ALAN DYER

OBSERVING
February 2023

3 EVENING: Look toward the east to see the waxing gibbous Moon and Gemini's bright lights Castor and Pollux forming a neat line.

6 EVENING: The Moon, one day past full, trails Regulus in Leo by about 4½° as the pair climbs in the east.

10 EVENING: The waning gibbous Moon rises in tandem with Virgo's lucida, Spica, with some 2½° between them. Turn toward the east-southeast to catch this sight. (Go to page 46 for more on this and other events listed here.)

10 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:12 p.m. PST (see page 50).

13 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:02 p.m. EST (8:02 p.m. PST).

14 MORNING: The Moon clears the southeastern horizon in the wee hours, followed shortly thereafter by Antares. About 4½° separates the waning lunar crescent from the Scorpion's heart.

16 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:51 p.m. EST.

21 DUSK: Face west after sunset to see the thin, waxing lunar crescent hanging around 6° below Venus, while Jupiter gleams upper left of the pair. Make sure you catch all three before they set.

22 DUSK: A slightly fatter crescent Moon sits about 1° left of Jupiter. Follow the duo as they sink toward the western horizon.

26 EVENING: High in the west-southwest the first-quarter Moon poses between the Pleiades and the Hyades in Taurus. If you're out early enough, you'll also see Jupiter and Venus less than 3° apart, low in the west.

27 EVENING: The Moon, just past first quarter, is 1° (or less) from Mars. Look high in the southwest.

28 DUSK: Jupiter and Venus are only 1° apart in the west-southwest. The sight will become more impressive as twilight deepens, but make sure you see it before the planets drop out of view.
— DIANA HANNIKAINEN

FEBRUARY 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				

FULL MOON
February 5
18:29 UT

LAST QUARTER
February 13
16:01 UT

NEW MOON
February 20
07:06 UT

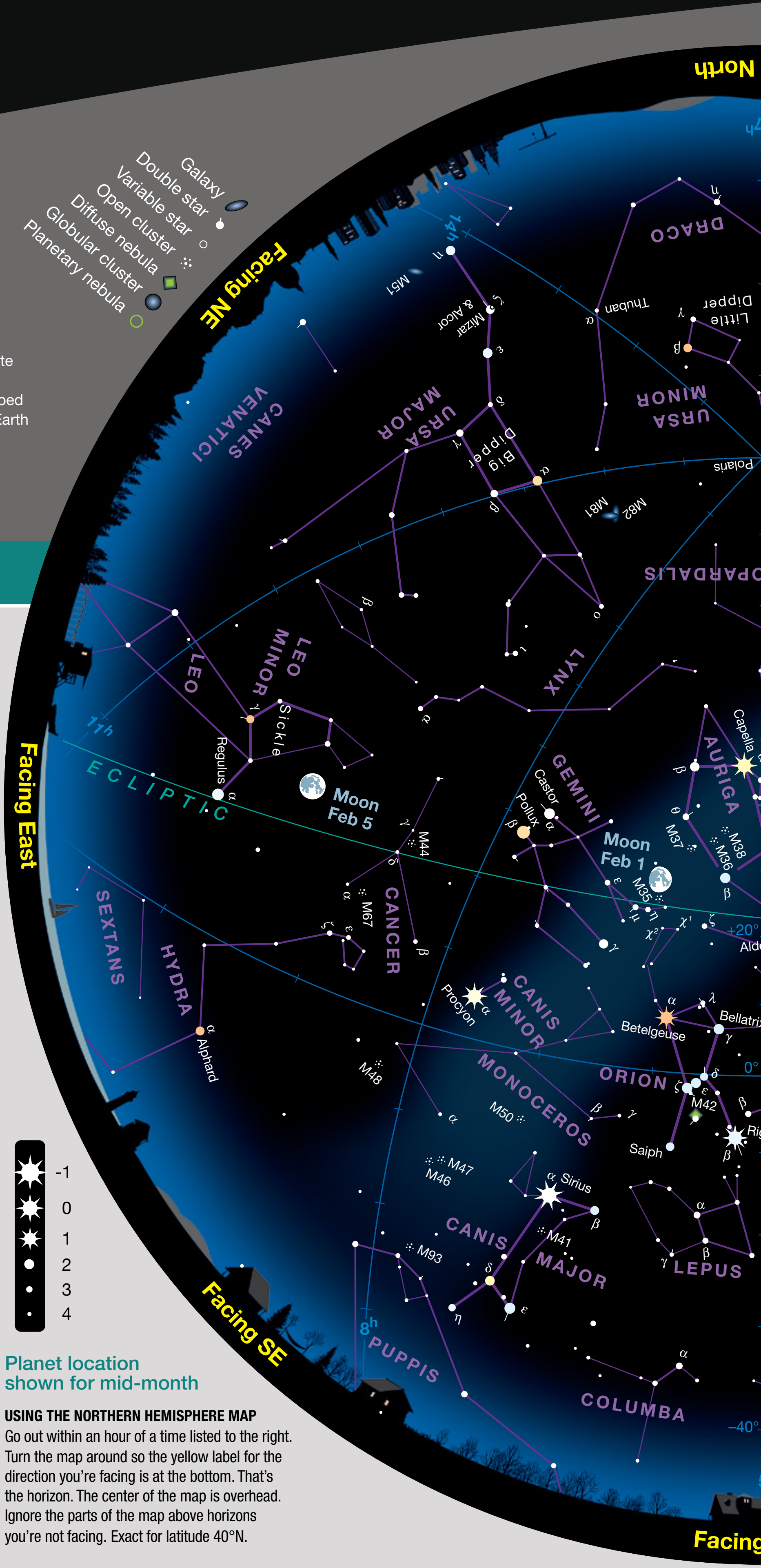
FIRST QUARTER
February 27
08:06 UT

DISTANCES

Apogee	February 04, 9^h UT
406,476 km	Diameter 29′ 24″
Perigee	February 19, 9^h UT
358,267 km	Diameter 33′ 21″

FAVORABLE LIBRATIONS

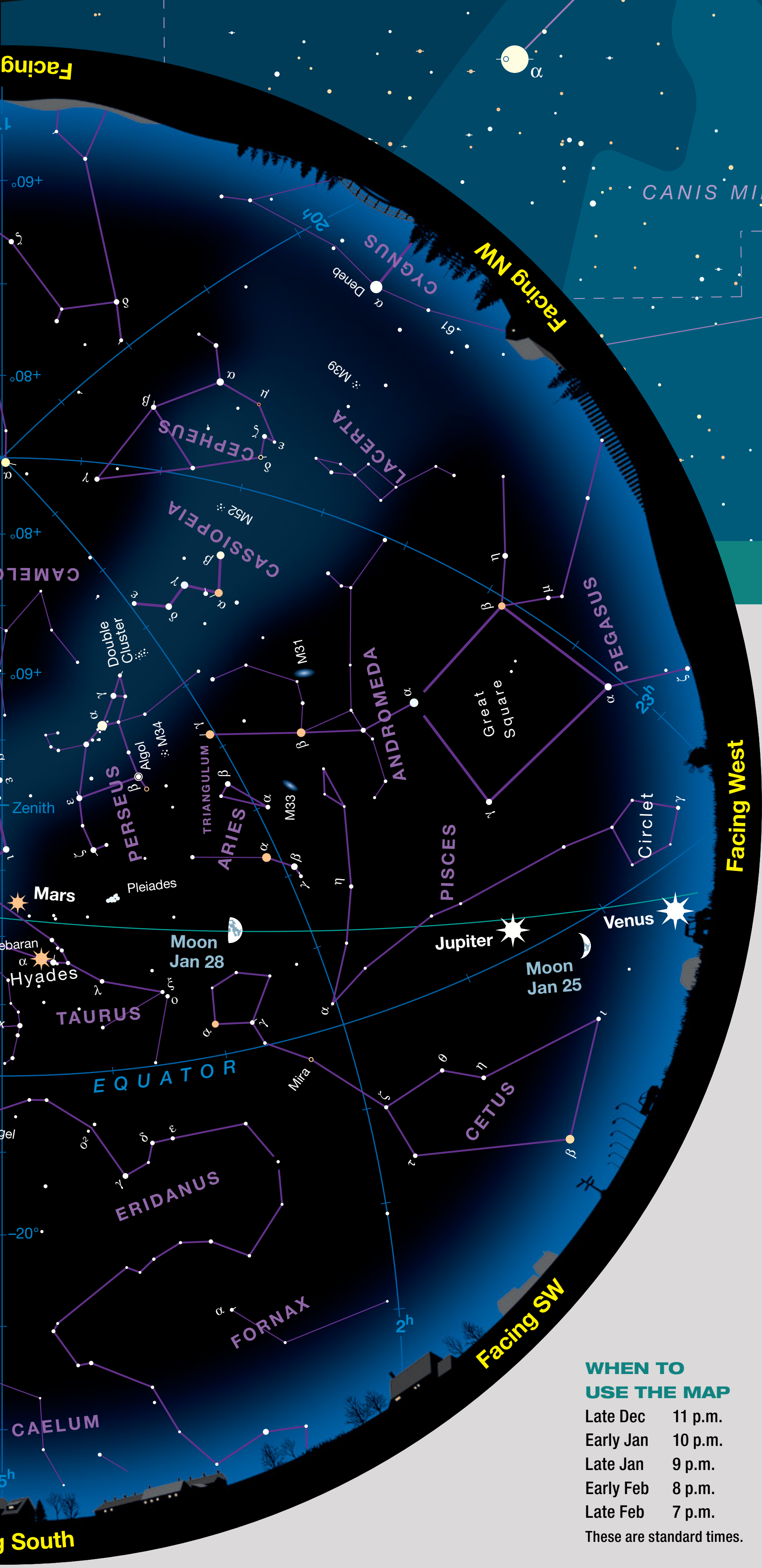
• Mare Australe	February 1
• Malapert Crater	February 5
• Von Braun Crater	February 16
• Neper Crater	February 24

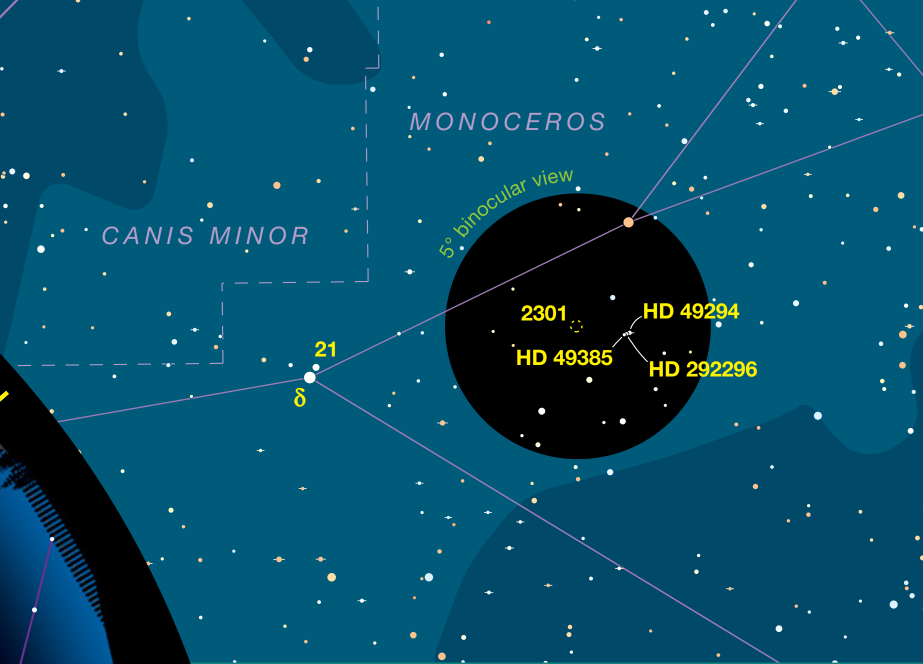


Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing. Exact for latitude 40°N.





WHEN TO USE THE MAP

Late Dec	11 p.m.
Early Jan	10 p.m.
Late Jan	9 p.m.
Early Feb	8 p.m.
Late Feb	7 p.m.

These are standard times.

Binocular Highlight by Mathew Wedel

Stalking the Unicorn

I never tire of exploring Monoceros — the celestial Unicorn is also a unicorn in the metaphorical sense of something rare and valuable. The constellation may not have any bright stars, but it is spangled from one end to the other with open clusters, nebulae, double stars, and asterisms. For this month's unicorn hunt, we'll check in on a few of my favorite objects.

Start at 4.1-magnitude **Delta (δ) Monocerotis**, and enjoy the wide optical double star formed by Delta and 5.4-magnitude **21 Monocerotis**. Both are white, main-sequence stars, so there's no color difference to appreciate, but with a separation of 13′ they make a pretty, easy double that you should be able to split both with any binos and with the naked eye.

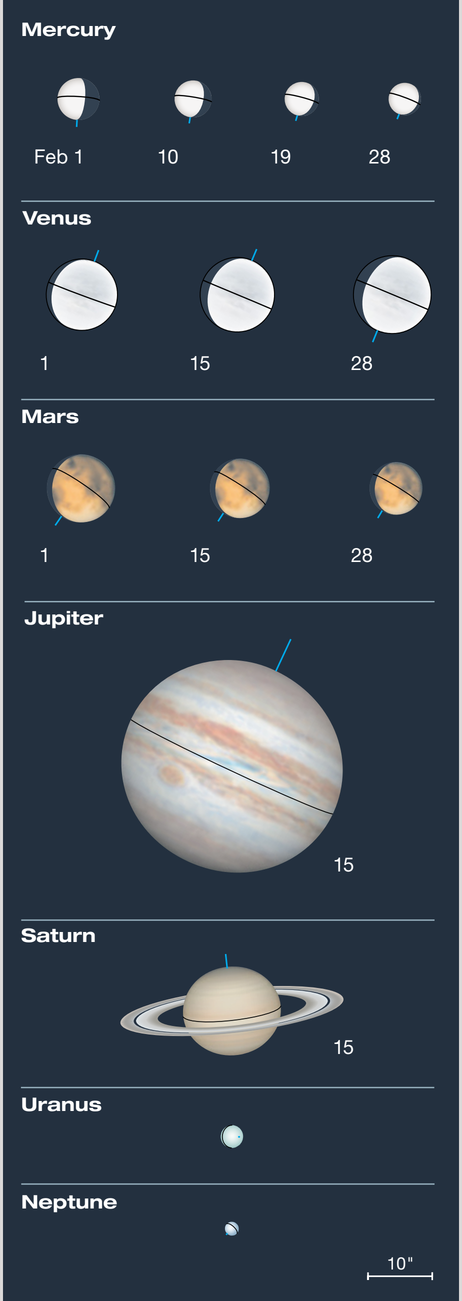
Scan 5° west-northwest of Delta Monocerotis to find the 6th-magnitude open cluster **NGC 2301**. With keen eyes and 10× or higher magnification, you may spot a ragged line of stars trending roughly north-south across the center of the cluster. More magnification, like 15× or 20×, will reveal dense swarms of dimmer stars unfurled on either side like wings. Many informal nicknames for NGC 2301 compare it to a starship or a dragon, but I myself fancy it to be an angel. NGC 2301 formed at least 160 million years ago, when some feathered dinosaurs were launching themselves in the air to become the first birds.

We have one more stop: A shade less than 1° west-southwest of NGC 2301 look for **three** 7th- to 8th-magnitude stars in a straight line, running east-southeast to west-northwest. This micro-asterism is just a chance alignment, but it adds even more charm to an already rich field.

Settle back and enjoy exploring this cosmic wonderland — we've barely scratched the surface.

■ An inveterate classifier, **MATT WEDEL** secretly wonders if Monoceros is his favorite constellation.

Planetary Almanac



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

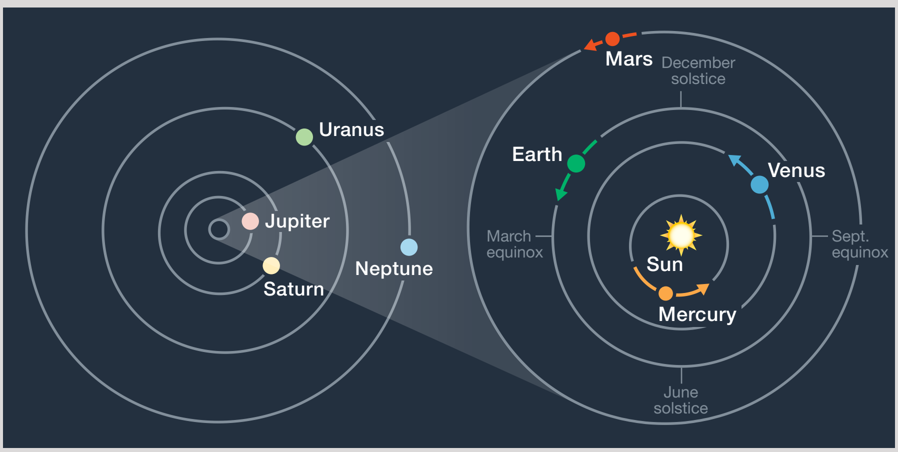
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during February. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn to the 13th • **Venus** visible at dusk all month • **Mars** transits the meridian in the evening and sets before dawn • **Jupiter** visible at dusk and sets in the early evening • **Saturn** lost in the Sun's glare all month.

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	20^h 55.9^m	–17° 19′	—	–26.8	32′ 28″	—	0.985
	28	22^h 41.7^m	–8° 16′	—	–26.8	32′ 18″	—	0.990
Mercury	1	19^h 11.8^m	–21° 43′	25° Mo	–0.2	6.5″	66%	1.030
	10	19^h 59.6^m	–21° 14′	23° Mo	–0.1	5.8″	78%	1.164
	19	20^h 53.7^m	–19° 07′	19° Mo	–0.2	5.3″	86%	1.265
	28	21^h 51.0^m	–15° 15′	14° Mo	–0.5	5.0″	92%	1.334
Venus	1	22^h 32.5^m	–10° 48′	24° Ev	–3.9	11.1″	91%	1.500
	10	23^h 14.0^m	–6° 23′	26° Ev	–3.9	11.4″	90%	1.462
	19	23^h 54.5^m	–1° 45′	28° Ev	–3.9	11.7″	88%	1.421
	28	0^h 34.6^m	+2° 57′	30° Ev	–3.9	12.1″	86%	1.377
Mars	1	4^h 31.5^m	+24° 37′	118° Ev	–0.3	10.7″	92%	0.876
	15	4^h 48.0^m	+24° 59′	108° Ev	+0.1	9.3″	91%	1.007
	28	5^h 08.6^m	+25° 20′	100° Ev	+0.4	8.3″	90%	1.134
Jupiter	1	0^h 22.9^m	+1° 12′	54° Ev	–2.2	36.1″	99%	5.462
	28	0^h 43.4^m	+3° 27′	33° Ev	–2.1	34.2″	100%	5.758
Saturn	1	21^h 52.9^m	–14° 11′	14° Ev	+0.8	15.4″	100%	10.781
	28	22^h 05.5^m	–13° 05′	10° Mo	+0.9	15.4″	100%	10.794
Uranus	15	2^h 50.0^m	+15° 58′	79° Ev	+5.8	3.6″	100%	19.825
Neptune	15	23^h 38.9^m	–3° 34′	28° Ev	+8.0	2.2″	100%	30.779

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**.



A Naked-Eye Cluster Quest

These celestial treasures are yours for the taking if your skies are dark enough.

As you peruse our February center star map (pages 42 and 43), notice the numerous open star clusters plotted along the softly glowing band of the winter Milky Way. Remarkably, many of these stellar agglomerations can be glimpsed without optical aid under sufficiently dark skies. Why not try the Great Naked-Eye Cluster Quest and see how many you can find?

All the open clusters appearing on our chart reside within our home galaxy, but some are closer to Earth than others. Indeed, the ones displaced the most from the band of the Milky Way tend to be the closest, thanks to a perspective effect arising from their proximity. Consider a row of telephone poles along a straight highway stretching into the distance. The poles nearest to us appear farther to our left and right than the more distant ones. Indeed, one of the most striking naked-eye clusters is the Hyades in Taurus. This clutch of stars is just 150 light-years from Earth and appears noticeably offset from the galactic equator.

Hyades aside, you might wonder whether or not there really are enough naked-eye clusters to create much of a list. Certainly, any such tally would include the lovely Pleiades (also in Taurus) and Cancer's M44, known as the Beehive Cluster. And for those stuck under suburban skies, your selection more or less ends there. But if you have better conditions, you can add several more winter wonders plucked from the span of sky that runs from Puppis in the south to Perseus in the north, where we'll begin our quest.

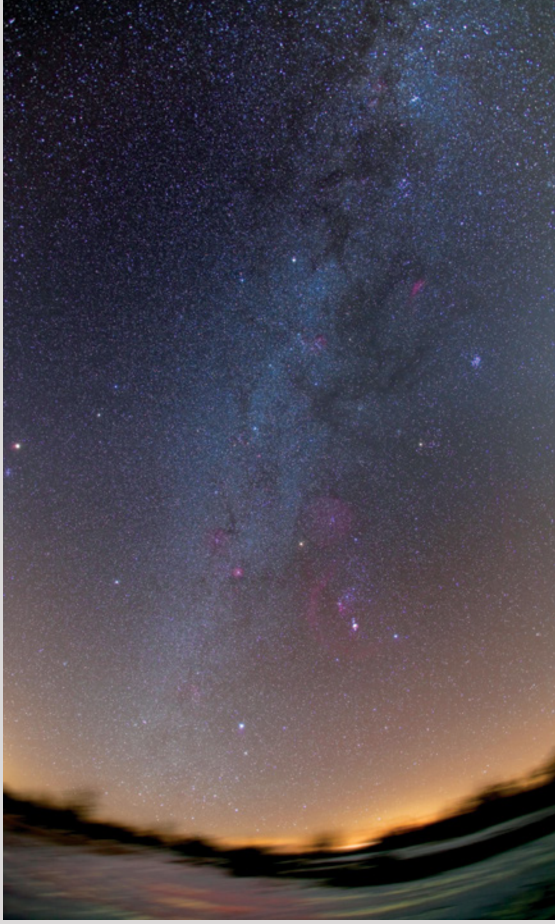
As Perseus, the Hero, descends toward the northwestern horizon on February evenings, we can aim for three naked-eye clusters within the constellation. Or perhaps *four* if we count the Double Cluster as two! The Double Cluster (cataloged as NGC 869 and NGC 884) lies midway between the eastern end of Cassiopeia's distinctive W pattern and the top of Perseus. It's quite noticeable even if a little light pollution is present. Under better conditions (and with sharp vision) you should make out two separate blobs with a smear of starlight surrounding them.

The other two Perseus clusters are very different from each other. The first (and easiest) is a collection of stars huddled around 2nd-magnitude Alpha (α) Persei, also known as Mirfak. The Alpha Persei Cluster includes roughly a dozen stars of naked-eye brightness. Our final Perseus cluster is M34, which lies northwest of the famed variable star Algol. M34 has always been a favorite of mine because it's seldom considered a naked-eye object, even though it shines as brightly as a 5th-magnitude star. Can you spot it?

Farther down the Milky Way, and approaching the zenith, are a trio of Messier clusters in Auriga, the Charioteer. Of the three, M37 is the brightest but perhaps the trickiest to locate since it lies just outside the constellation's prominent pentagon pattern — look for it roughly midway along the pentagon's southeastern side. M36 and M38 are within the pentagon but somewhat fainter and therefore harder to see.

Our next cluster is one I find to be easy in a good, dark sky. Gemini's M35 is big and bright and passes high overhead for observers at mid-northern latitudes. But there's another factor that helps us find M35: It's positioned next to a compact set of stars that marks one of the feet of the more northerly of the mythical twins. Thankfully, M35 is just far enough from the stars in this asterism to not be overwhelmed by their light.

Let's end with another easy object, M41 in Canis Major, the Great Dog. Like M34 in Perseus, we don't usually think of M41 as a naked-eye target. The bright (magnitude-4.5) cluster is often overlooked because it's located only 4° south of Sirius, the brightest star in the night sky. On the other hand, that same proximity is why the cluster's location is a snap to pinpoint. The fact that M41 is at a rather low altitude for those at mid-northern latitudes makes it appear slightly dimmer, but I've always found this lovely spot of glow fairly conspicuous on clear, dark nights.



ALAN DYER

▲ **WINTER WONDER** If your skies are nice and dark, you'll not only see the subtle expanse of the winter Milky Way, but you'll also delight in several of the open clusters that dot its length.

■ **FRED SCHAAF** once viewed numerous naked-eye clusters on a February night from the darkened interior of an observatory.

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

Jupiter Sinks as Venus Climbs

The waxing Moon visits the three brightest planets in the evening sky.

WEDNESDAY, FEBRUARY 1

You have a chance to spot all five naked-eye planets tonight, but it won't be easy. Normally it's the horizon-hugging innermost planet, Mercury, that's the difficult one. However, at the moment, Mercury is a reasonably easy catch at dawn — your greatest challenge is actually **Saturn**. That's because the Ringed Planet is heading for its conjunction with the Sun on February 16th and is hovering low in the west-southwest at dusk. This evening presents your last, best chance to sight it, but only a little more than one hour separates sunset from Saturnset. The longer you wait, the darker the sky, but the lower the planet will be. I'd suggest starting your hunt roughly half an hour after sundown and using binoculars. At that time the planet will be only 5° up, so you'll need very clear conditions and an unobstructed horizon. If you succeed, try spotting Saturn with your eyes alone. On the plus side, the remaining four planets are a piece of cake by comparison!

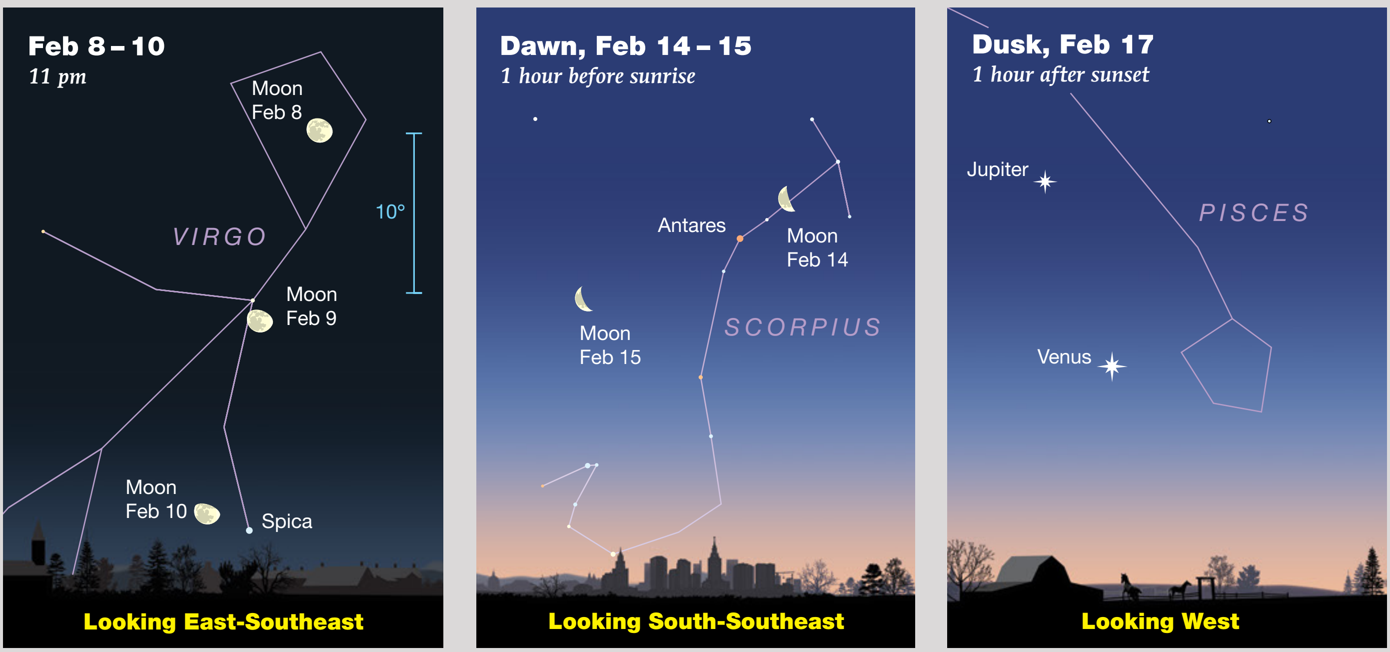
FRIDAY, FEBRUARY 10

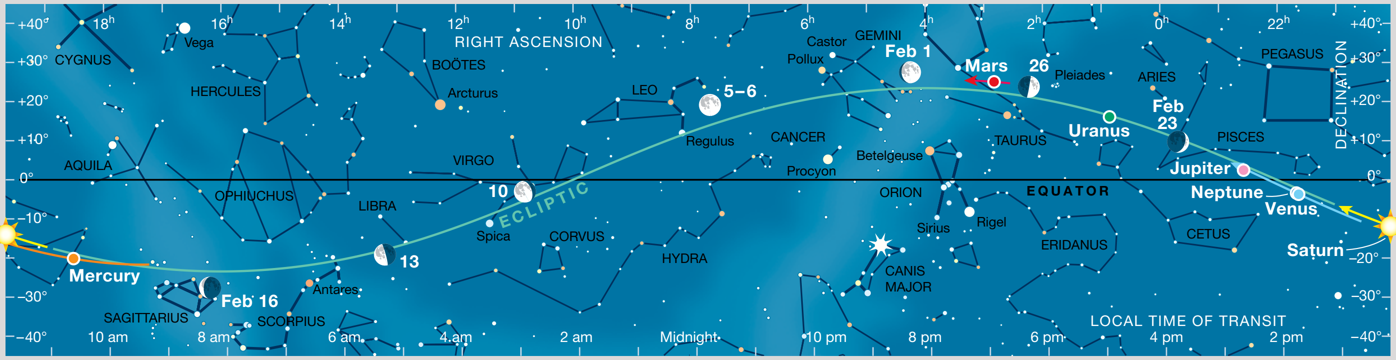
Late this evening, look toward the east-southeast to catch the waning gibbous **Moon** rising above left of **Spica**, the brightest star in the constellation Virgo. The two will be less than 3° apart, which means they'll be an attractive naked-eye sight and close enough to view together in the same binocular field. Spica holds the distinction of being the second-brightest of the ecliptic stars — only Aldebaran, in Taurus, is fractionally brighter. Both are first-magnitude suns, which means they stand up to moonlight well. This evening's encounter is the closest one the Moon has with a bright star all month, though it does get to within 4° of **Antares** (the third-brightest ecliptic star) before dawn on the 14th. The Moon also visits **Aldebaran** on the evening of the 26th, but it keeps its distance, positioned nearly 9° to the right of the star.

TUESDAY, FEBRUARY 21

One of the celestial highlights of most months occurs when the crescent **Moon** is near **Venus**. That's when the two brightest objects in the night sky are close together. But some encounters are better than others, and this evening's rates as only "good" — much better

▼▶ 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.





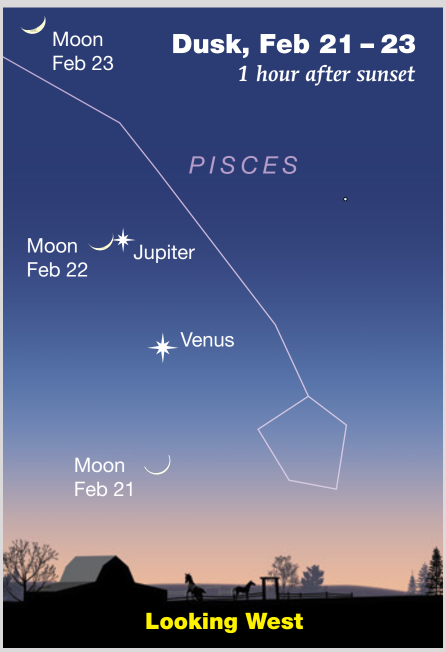
▲ The Sun and planets are positioned for mid-February; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" 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.

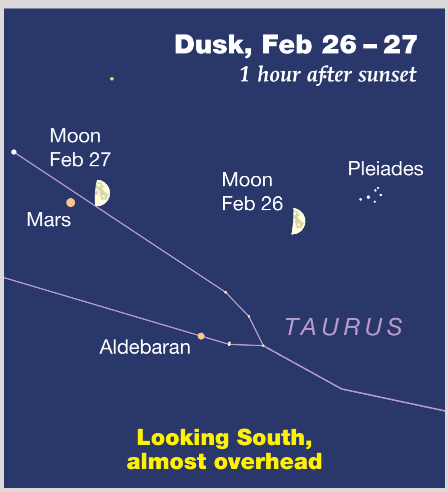
Moon-Venus pairings occur later in the year. Soon after sunset you should be able to spot a thin, waxing lunar crescent sitting about 6° below the Evening Star. Earthshine (sunlight reflecting off Earth and striking the Moon) will make the "unlit" portion of the lunar disk visible as twilight fades. It's a pretty sight and a reminder not to let "better" be the enemy of "good." But better does arrive tomorrow . . .

WEDNESDAY, FEBRUARY 22

The best conjunction between the **Moon** and a planet occurs this evening when the lunar crescent sits just 1° left of **Jupiter**. Compared with Venus, Jupiter is quite a bit dimmer — magnitude –2.1 versus the Evening Star's –3.9. The "better" part of this event obviously comes from the fact that the Moon is so much closer to its planetary partner. And, it has to be said, magnitude –2.1 is still pretty bright! But what's really going to capture your attention isn't just this tight pairing, it's the three-for-one spectacle that includes **Venus** serving as the apex of a thin, isosceles triangle that's less than 7½° long. That triangle includes all three of the brightest night-sky objects.

The fates of the two planets, however, are quite different. Venus is early into its evening apparition and slowly gaining altitude, while Jupiter is nearing the end of its current showing and will gradually slip into twilight's glare as it marches toward its April 11th conjunction with the Sun. The gap between the two planets will continue to close all month until reaching a climactic peak on the evening of March 1st when they're just ½° apart. More about that next month.





MONDAY, FEBRUARY 27

In both December and January, the **Moon** passed very close to **Mars** and from some locations actually occulted the planet. It performs that trick again tonight, but only for observers in Iceland and northern Scandinavia. For those of us here in the Americas, we simply get a very nice close encounter as the waxing gibbous Moon approaches to within roughly ½° of the +0.4-magnitude Red Planet. They'll be closest around 1 a.m. EST on the morning of the 28th, and the farther north you are, the smaller the gap between the pair will be. From Edmonton, Alberta, the southern limb of the Moon passes just 23′ above Mars, but from Houston, Texas, the gap is more like 37′.

Although the Moon will continue to visit Mars on a monthly basis for much of the rest of the year, tonight's encounter is the final, closest one remaining. It's also an excellent way to celebrate the final phase of the current Mars apparition. The planet reached opposition back in early December and has been fading and shrinking ever since. On the 7th of this month its disk was smaller than 10″, marking the unofficial end of the Mars telescopic observing season.

■ Consulting Editor **GARY SERONIK** has been keenly watching Mars come and go since 1971.

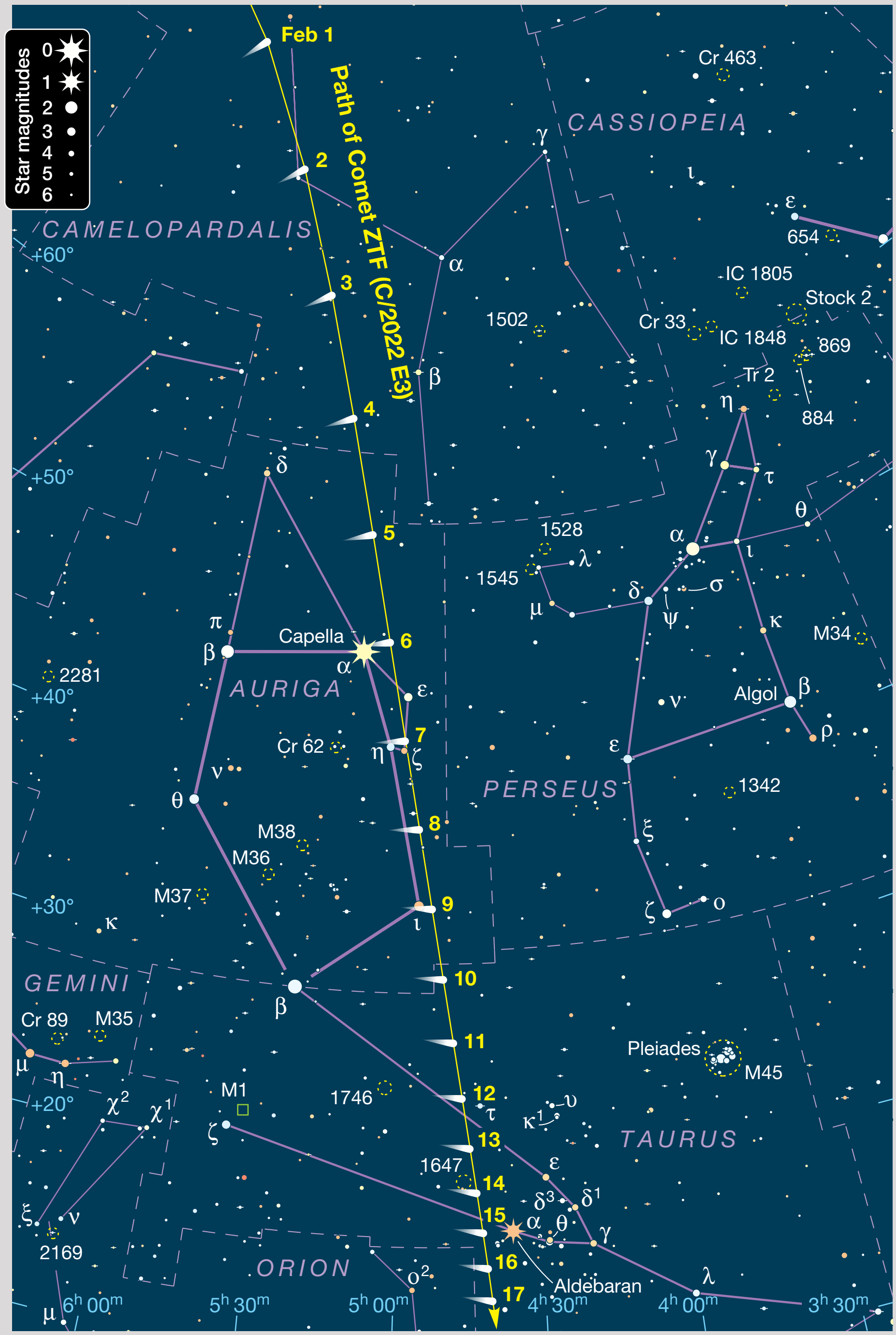
Comet Prospects for 2023

Eight icy visitors are expected to be bright enough for modest backyard scopes.

You should be able to spot Comet ZTF (C/2022 E3) in binoculars this month. On February 1st it reaches its peak magnitude of 5 as it moves rapidly southward from Camelopardalis into Auriga, and on the evening of the 5th it passes 1½° west of zero-magnitude Capella. (I covered the comet's discovery and the first part of its apparition in the January issue.) With luck, it will prove to be just one of several enjoyable telescopic comets to appear in 2023.

A stone's throw from C/2022 E3, another ZTF (Zwicky Transient Facility) comet plies the northern sky: ZTF (C/2020 V2). Discovered in November 2020 when it was only 19th magnitude, ZTF V2 is expected to brighten to magnitude 9.5 this month, placing it within reach of 6- to 8-inch scopes. When I saw the comet in late-October 2022, it was an 11th-magnitude, moderately condensed fuzzy glow about 1′ across with a hint of a tail.

In February, ZTF V2 travels from Cassiopeia, nicks the edge of Perseus, and spends most of the month in eastern Andromeda, where it's well placed for viewing in the northwestern sky at nightfall. You'll have lots of time to get to know this frozen visitor because it's predicted to remain brighter than 10th magnitude through mid-October while drifting southward. Twilight claims it from mid-April to mid-June, when the comet returns at dawn in Aries. Closest approach to Earth occurs on September 17th at a distance of 1.9 a.u. (2.8 million kilometers or 1.8 million miles). From late August through early September, ZTF V2 should be at its peak bright-



▶ Comet positions are shown for 0h UT.

ness of magnitude 9.5.

A few more comets are expected to reach magnitude 10 or brighter this year. If you have a telescope, reasonably dark skies, and good horizons, you should be able to see most of these.

February: 96P/Machholz

Amateur astronomer Don Machholz passed away last August at his home in Arizona (*S&T:* Dec. 2022, p. 10). He was a dedicated and prolific comet hunter, racking up 12 discoveries in more than 9,000 hours of searching. He nabbed Comet 96P/Machholz in May 1986, with his homemade 29×130 binoculars. The comet's perihelion distance is only 17.4 million km, which is one of the closest known for a periodic comet. After reaching that point in its orbit on January 31st, it swiftly departs the solar glare while rapidly fading. Northern Hemisphere observers might glimpse 96P/Machholz glowing at magnitude 8 low in the eastern sky at the start of morning twilight in early February as it scoots from Aquarius into Aquila. Catch it while you can — the comet plunges to around magnitude 13 by month's end.

June – August: Lemmon (C/2021 T4)

The best views of Comet Lemmon will be from tropical and southern latitudes from late June through late August. As it brightens from 10th magnitude to a maximum of 8 in late July, it travels from southern Cetus to Telescopium. Observers south of latitude 40° north should take advantage of a brief window of visibility from late June through early July when the comet pops up in Sculptor low in the southeastern sky before dawn. After dipping farther south it swings north and returns into view at dusk, climbing from Lupus into Libra during August as it fades.

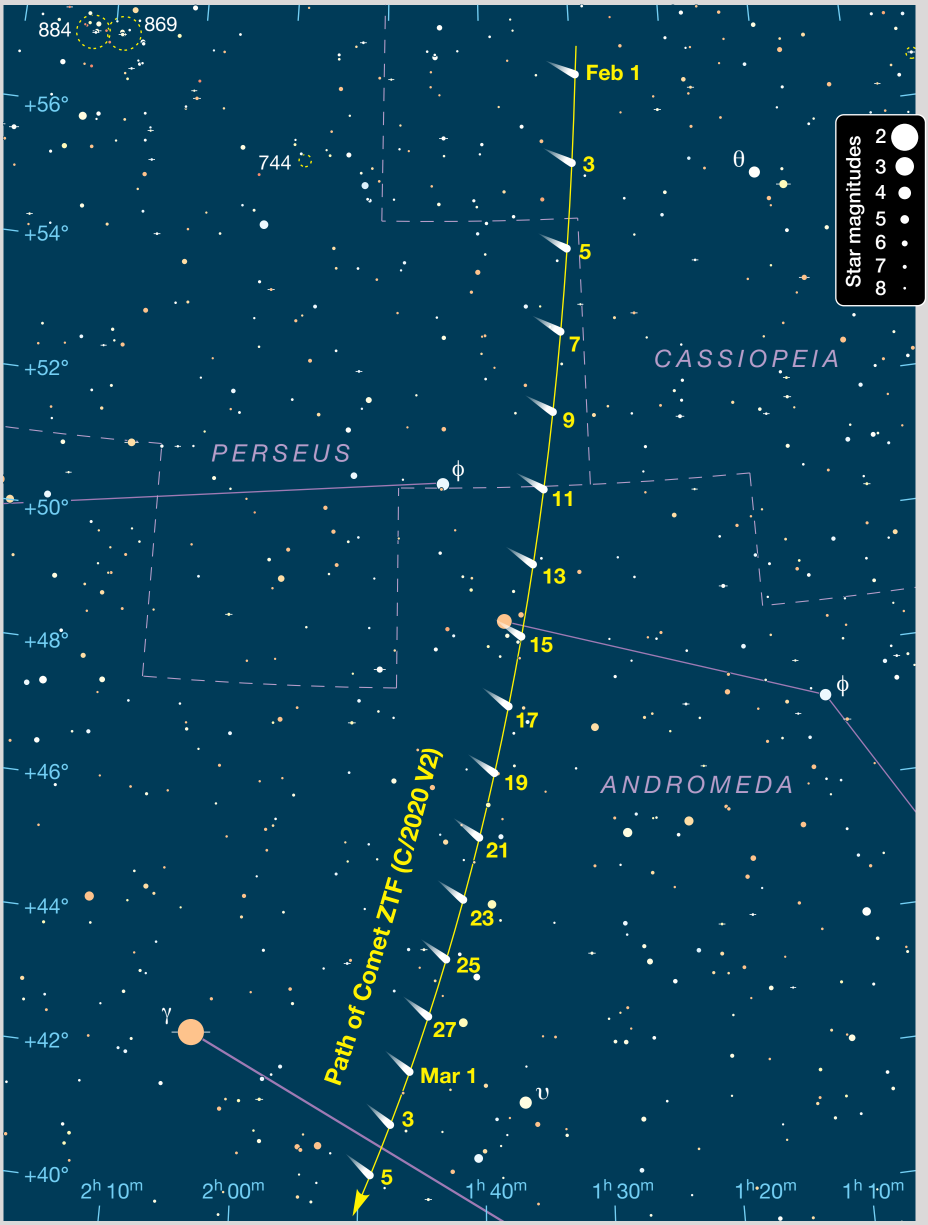
August – December: 103P/Hartley

NASA's Deep Impact space probe made a close flyby of Comet 103P/Hartley back in November 2010. This will be an excellent apparition, with the comet reaching magnitude 10 in mid-August near Beta (β) Andromedae and brightening to around 8th magnitude in late September as it crosses from Perseus through Auriga and into Gemini. While 103P/Hartley will be visible before midnight low in the northeast during the brightest part of its apparition, you'll see it best before dawn as it approaches the zenith. It should remain brighter than magnitude 10 through early December.

Closest approach to Earth (0.4 a.u.) occurs on September 26th, and the comet reaches perihelion on October 12th. Jonathan Shanklin, with the British Astronomical Association Comet Section, writes that due to its relative proximity Hartley will likely appear quite large and diffuse when it swings by Earth.

October: 2P/Encke

This famous and frequent visitor returns this autumn. Watch for Comet 2P/Encke just before dawn in early October low in the eastern sky at around magnitude 10. Although Encke brightens to 8th magnitude by mid-October, it becomes increasingly difficult to see as its altitude decreases and twilight interferes. Closest approach to Earth (0.8 a.u.) happens on Septem-



▶ During a favorable apparition (such as the one in March 2017 when this photo was captured) Comet 2P/Encke displays a bright, strongly condensed coma and a long, wispy tail. Encke returns to view at dawn this fall when it may reach 8th magnitude shortly before its October 22nd perihelion.

ber 24th, with perihelion occurring on October 22nd (0.3 a.u.). Southern Hemisphere observers will catch the fading comet after perihelion as it re-emerges in Libra in early November.

November – December: 62P/Tsuchinshan

Discovered in 1965 at Purple Mountain Observatory in China, this comet returns every 6.6 years. The current apparition will be excellent with the comet brightening to magnitude 8 or 9 in late December in the morning sky. Before that, on the mornings of November 13th and 14th, it glows at magnitude 10.5 while skirting the northern border of the Beehive Cluster (M44) in Cancer. Perihelion occurs on December 25th (1.3 a.u.), and Comet 62P passes closest to Earth (0.5 a.u.) in early 2024. On the mornings of December 25th and 26th, the comet drops by the Leo Triplet (M65, M66, and NGC 3628).

November – December: PanSTARRS (C/2021 S3)

Best placed for Southern Hemisphere observers, this comet should crack magnitude 10 in late November and climb to 8.5 by year's end. It crawls eastward across northern Centaurus in the morning sky and continues to slowly brighten and climb northward in 2024. Dedicated comet-watchers south of latitude 40° north will spot it low in the southeastern sky in the latter half of December 2023. Peak visibility and brightness (magnitude 7) occur in late February 2024, when the comet sails into Serpens to the delight of northern and southern observers alike.

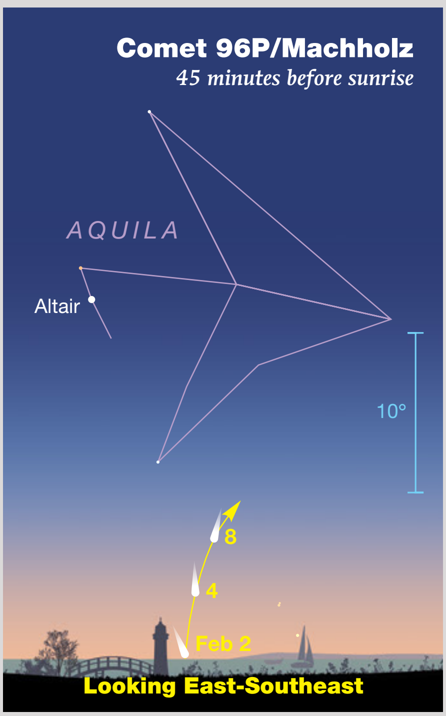
Action at Jupiter

THE CURTAIN IS TRULY starting to come down on the current Jupiter apparition. As the month opens, the planet is positioned well past the meridian in the southwest at dusk.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

January 1: 0:20, 10:16, 20:11; **2**: 6:07, 16:03; **3**: 1:59, 11:55, 21:50; **4**: 7:46, 17:42; **5**: 3:38, 13:34, 23:29; **6**: 9:25, 19:21; **7**: 5:17, 15:13; **8**: 1:09, 11:05, 21:00; **9**: 6:56, 16:52; **10**: 2:48, 12:44, 22:39; **11**: 8:35, 18:31; **12**: 4:27, 14:23; **13**: 0:19, 10:14, 20:10; **14**: 6:06, 16:02; **15**: 1:58, 11:54, 21:49; **16**: 7:45, 17:41; **17**: 3:37, 13:33,



Minima of Algol

Jan.	UT	Feb.	UT
2	3:42	2	16:44
5	0:31	5	13:33
7	21:20	8	10:23
10	18:09	11	7:12
13	14:59	14	4:02
16	11:48	17	0:51
19	8:37	19	21:40
22	5:27	22	18:30
25	2:16	25	15:19
27	23:05	28	12:08
30	19:55		

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

▲ Perseus is conveniently positioned near the zenith during evening hours in February. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

GERALD RHEMANN

23:28; **18**: 9:24, 19:20; **19**: 5:16, 15:12; **20**: 1:08, 11:04, 20:59; **21**: 6:55, 16:51; **22**: 2:47, 12:43, 22:38; **23**: 8:35, 18:30; **24**: 4:26, 14:22; **25**: 0:18, 10:14, 20:09; **26**: 6:05, 16:01; **27**: 1:57, 11:53, 21:49; **28**: 7:45, 17:40; **29**: 3:36, 13:32, 23:28; **30**: 9:24, 19:19; **31**: 5:16, 15:11

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

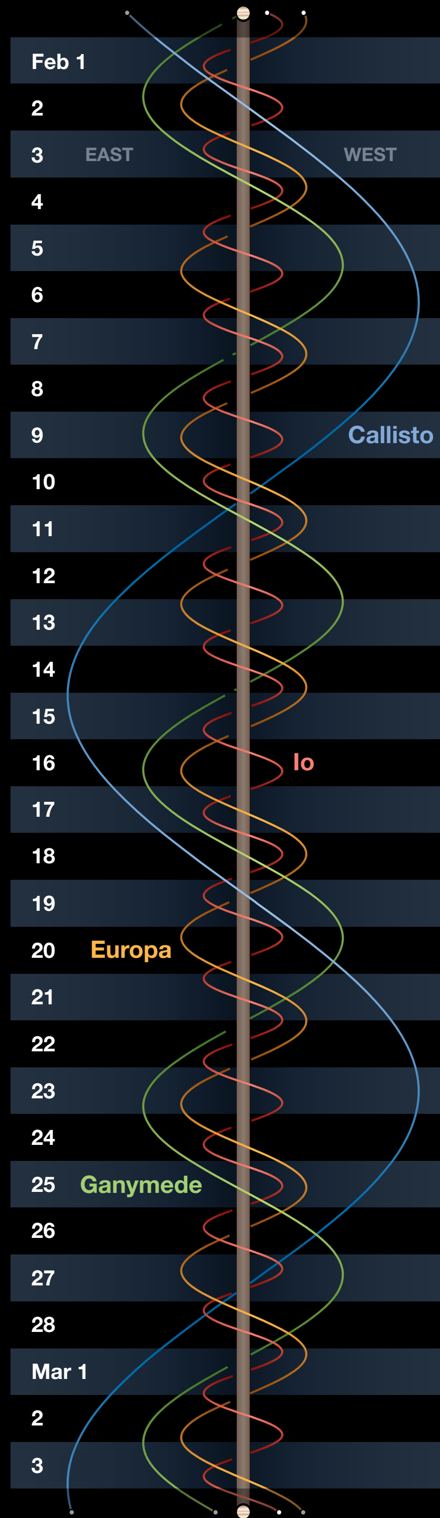
These times assume that the spot will be centered at System II longitude 34° on February 1st. If the Red Spot has moved elsewhere, it will transit $1\frac{2}{3}$ minutes earlier for each degree less than 34° and $1\frac{2}{3}$ minutes later for each degree more than 34°.

Phenomena of Jupiter's Moons, February 2023

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

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



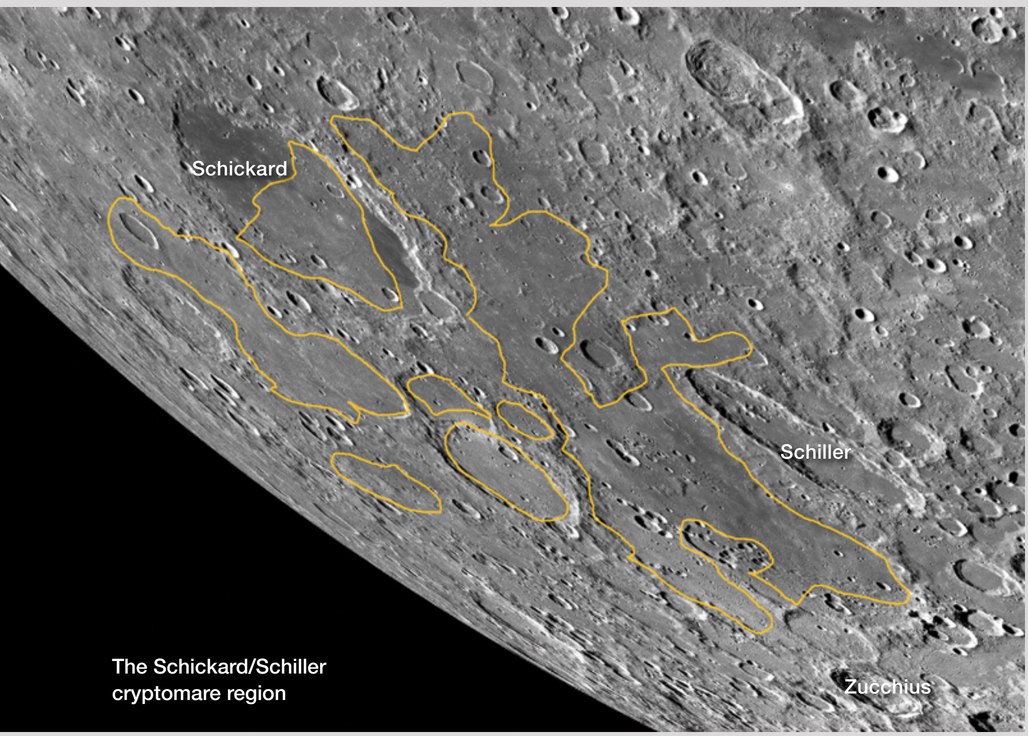
The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

Hidden Maria

Tiny clues that reveal the true nature of some *light plains*.

A quick look at the full Moon reveals two main types of lunar terrain: expansive, light-hued regions and large patches of dark material. Closer study shows the bright material to be ancient highlands dominated by impact craters, while the dark regions consist of younger basaltic lava flows (maria) at lower elevations. Maria have far fewer impact craters than do the highlands, implying that by the time maria formed (mostly after 3.8 billion years ago), the rate of crater formation had greatly subsided. By coincidence, the Moon's cratering rate declined to a very low level at about the same time as the start of lunar volcanism, which is caused by internal heating from radioactive decay of thorium, potassium, and uranium.Cratering continues today at a low level, while volcanism peaked around 3.8 to 3.5 billion years ago, with the last gasps apparently occurring about a billion years ago.

Roughly 10% of the lunar surface shares the same relatively smooth surface of the maria but lacks the characteristic dark colors of basaltic lava. Known as *light plains* (*S&T:* Dec. 2022, p. 52), these regions were originally interpreted as volcanic material with a different composition than basalts to account for their lighter hue. But when Apollo 16 landed on the light plains near the crater **Descartes**, the astronauts immediately noticed the lack of volcanic rocks. Instead, they saw pulverized ejecta from the formation of the Imbrium and other giant impact basins.



The Schickard/Schiller cryptomare region

In 1971, lunar scientist William K. Hartmann and I proposed ejecta deposits as an explanation of why older impact basins were sometimes filled with light material while younger basins contained mare lavas. Every crater-forming event produces massive amounts of pulverized rock that blankets the surrounding terrain with layers of light-hued debris. Some of this ejecta falls across maria, masking the true nature of the underlying rock.

Surefire indicators of buried mare lavas are small dark-halo craters (DHCs), including **Copernicus H**, a 4-km-wide (2.4-mi-wide) crater just southeast of Copernicus. In telescopes it's easy to see at full Moon because of its broad, dark halo. Copernicus itself formed on dark maria but sprayed a thin deposit of bright ejecta all around it. The subsequent impact that formed Copernicus H excavated beneath this coating, exposing the dark mare material below.

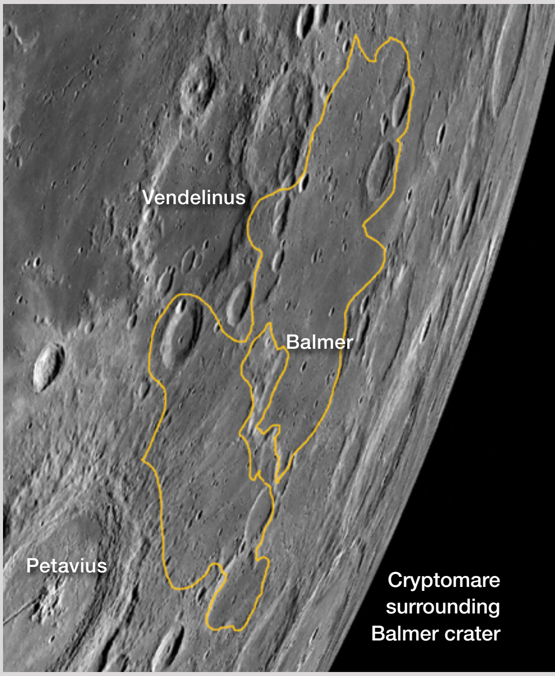
Ejecta-covered dark basalt is called *cryptomaria*, or *hidden maria*. Many hidden mare lavas were identified thanks to DHCs. The other effective way to categorize them is with spectral studies that reveal mafic minerals (those containing abundant magnesium and iron), which give mare basalts their characteristic dark tone. Impacts into cryptomare create a regolith mixture comprising small, fragmented ejecta particles and underlying lava material.

In 2015, Jennifer Whitten, now at Tulane University in New Orleans, and James W. Head of Brown University, produced a list of 20 cryptomaria sites, 12 of which are visible on the lunar nearside. These are challenging targets for telescopic observers because cryptomaria have no visible features except for DHCs, which typically are small and hard to see.

By far the largest nearside cryptomare is the expanse coating a portion of **Schickard** and beyond. Like many cryptomaria, this one partly resides within an impact basin, the 360-km-diameter Schiller-Zucchius Basin, whose light-hued, mare-lava floor is coated with ejecta mostly from the nearby Orientale Basin. Schickard is famous

Nearside Cryptomaria

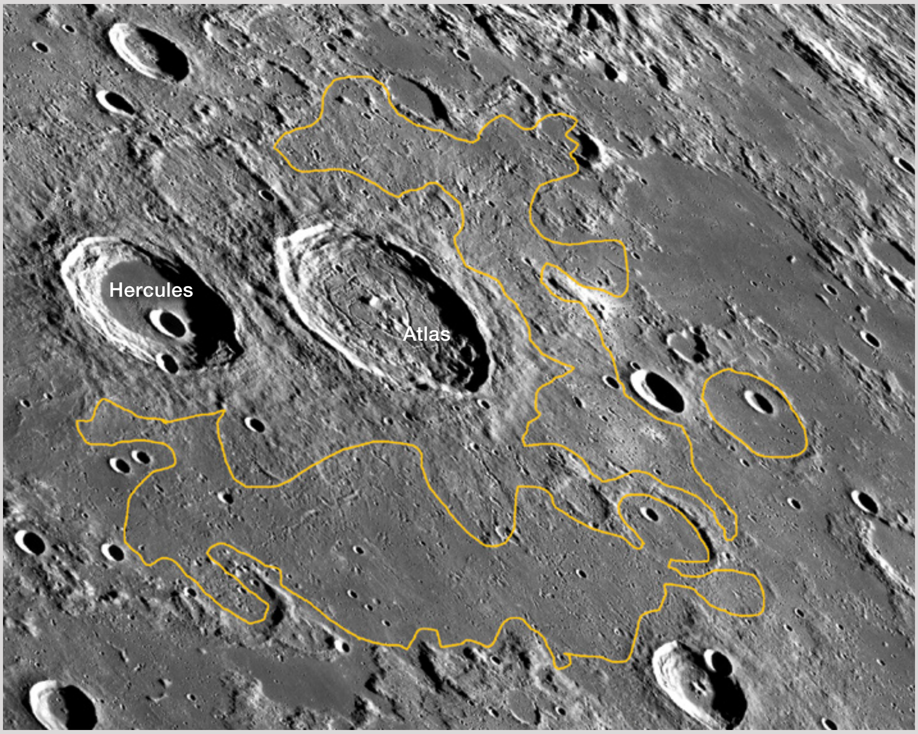
Name	Area (km^2)	Sources of Ejecta Coating
Schickard/Schiller	132,000	Orientale, Mendel-Rydberg, Humorum, and Nubium Basins
Balmer-Kapteyn Basin	61,000	Smythii, Serenitatis, and Nectaris Basins
Smythii Basin	39,000	Serenitatis and Crisium Basins
Mare Australe	27,000	Planck and Smythii Basins
Mare Marginis	25,000	Smythii and Crisium Basins
West Procellarum	16,700	Orientale and Imbrium Basins
Hercules/Atlas	12,000	Hercules/Atlas craters
Humboldtianum Basin	9,100	Imbrium Basin
Mare Frigoris	7,600	Aristoteles and other smaller craters
Cleomedes	5,700	Geminus and Tralles craters
West Humorum	3,200	Orientale, Imbrium, and Humorum Basins
Taruntius	2,300	Taruntius crater



Cryptomare surrounding Balmer crater

for a zebra stripe of bright material that crosses the middle of its floor, with dark maria patches at both ends. The existence of a DHC and spectrally identified mafic regolith demonstrate that, unsurprisingly, the bright streak covers mare material. Schickard is a mare-filled crater dusted with Orientale ejecta.

The hidden maria situation at the Balmer-Kapteyn Basin is similar to Schiller-Zucchius because both are ancient impact basins. The Balmer-Kapteyn feature is a little-known, two-ring basin about 265 km in diameter. Located east of **Mare Fecunditatis**, its outer rim touches the younger craters **Langrenus**, **Petavius**, **Humboldt**, and **La Pérouse**. Ejecta from each of these craters contributed to brightening the floor of Balmer-Kapteyn, as did the nearby Serenitatis, Smythii, and Nectaris basins earlier. The more than 25 tiny DHCs show that the 130-km-wide inner ring of Balmer-Kapteyn is filled with mare lava, as is the terrain between the southwest portion of its inner and outer rings.



Ejecta that creates small cryptomare deposits typically comes from the formation of nearby craters. For example, DHCs in the cryptomare curving around **Hercules** and **Atlas** craters (seen at left) show it was their ejecta that covered nearby dark maria.

Cryptomaria indicate that the Moon erupted more mare basalts than lunar geologists previously recognized, and that all such maria must be older than about 3.7 billion years — the formation of the youngest big basins, Orientale and Imbrium. Each cryptomare may even be more extensive than we can detect, particularly if the overlying ejecta is so thick that later impacts didn't penetrate deeply enough to create DHCs or spread spectrally detectable regolith. Can you find these hidden maria listed in the table?

■ Contributing Editor **CHUCK WOOD** continually marvels at the complex story told by the lunar surface.

The Simplest Astrophotography

Great night-sky shots can be made with just a camera, lens, and tripod.

Go To mounts, autoguiders, and narrowband filters are all wonderful inventions — but a minimalist approach has its advantages. And taking astrophotos with just a camera mounted on a tripod is about as minimalist as it gets.

If you're travelling, this may be the only option available given airline baggage restrictions, and it might represent the limit of what you can carry in a backpack on a hike to a remote location. It's coincidentally the most budget-friendly approach. But there's also real joy in capturing compelling images using the absolute minimum amount of equipment.

Gearing Down

A basic setup actually requires careful pre-planning and employing a few "best practices" to ensure you can wring out every drop out of your gear's potential. To begin, let's consider your camera and lens settings. First, make sure your camera is set to shoot in RAW mode (not JPEG) for maximum flexibility during post-processing. Second, put your camera in Manual mode so you can individually adjust the three key exposure-triangle settings: shutter speed, lens aperture, and ISO.

The duration of your exposures is always limited when shooting the night sky with a fixed tripod. Due to Earth's

▲ **STARLIGHT AND FIRELIGHT** Despite the smoke and light pollution from nearby wildfires, the sky was dark enough to allow photographs of the Milky Way (and Mars, the bright object to the left of the tree) at the Mount Kobau Star Party in 2018. The scene was captured in a single, 30-second, tripod-mounted exposure made with a Canon EOS 6D camera set to ISO 3200 and a Canon EF 15mm f/2.8 fisheye lens, used wide open.

rotation, the stars will appear to trail if you leave the shutter open too long. But how long is *too* long? Well, that depends on the focal length of your lens and which part of the sky you're photographing. Telephoto lenses will show trailing very quickly, while wide-angle lenses allow longer exposures.

Stars near the celestial equator trail the most, and those near the poles trail the least.

For a camera with a full-frame sensor, you can estimate the approximate maximum exposure time (in seconds) by dividing 500 by the focal length of your lens. This is known as "the 500 rule." For example, a 50-mm lens will allow about a 10-second exposure (500 ÷ 50) before trailing becomes noticeable. For crop-sensor cameras, which usually have smaller pixels, or for tighter star images with any camera, use a value of around 300 instead. In such scenarios, that same 50-mm lens will be good for roughly a 6-second exposure. Reviewing your images at 100% magnification will reveal the maximum time you can use before the stars start to trail objectionably.

To gather as much light as possible you'll need to shoot with your lens wide open at its lowest f/stop setting. Each decrease in f/stop (for example, going from f/4 to f/2.8) doubles the amount of light gathered during each exposure. If your budget permits, consider upgrading to the fastest ultra-wide-angle lens you can afford. This will maximize the total amount of light you can collect during a single shot.

The optimum ISO setting is very camera-specific. Increasing the ISO won't capture more light, but it will produce brighter-looking images. Modern sensors display less noise at high-ISO settings than older cameras, so as a starting point try ISO 1600.

Once you've dialed in your initial settings, take a series of test exposures, ideally on a clear, moonless night. Experimenting with different combinations of ISO settings and shutter speeds will allow you to find the best compromise between image brightness and noise for your particular setup. You may also find that using your lens fully open results in unacceptably poor star images, especially near the edges of the field. If so, closing the aperture by a stop or more might be preferable even if it means sacrificing some light.

Getting all your settings dialed in correctly is important, but a fixed-tripod setup always has limitations arising from the necessarily short exposure times. But there are a couple of things you can do to improve your astrophotos without investing in additional equipment.

◀ **TAKING IT EASY** Aside from a camera and lens, a basic astrophoto setup consists of a sturdy tripod and (optionally) a remote shutter-release. Remote releases from camera manufacturers can be expensive, but third-party versions (such as the one shown here) function well at a fraction of the cost.

Getting More with Less

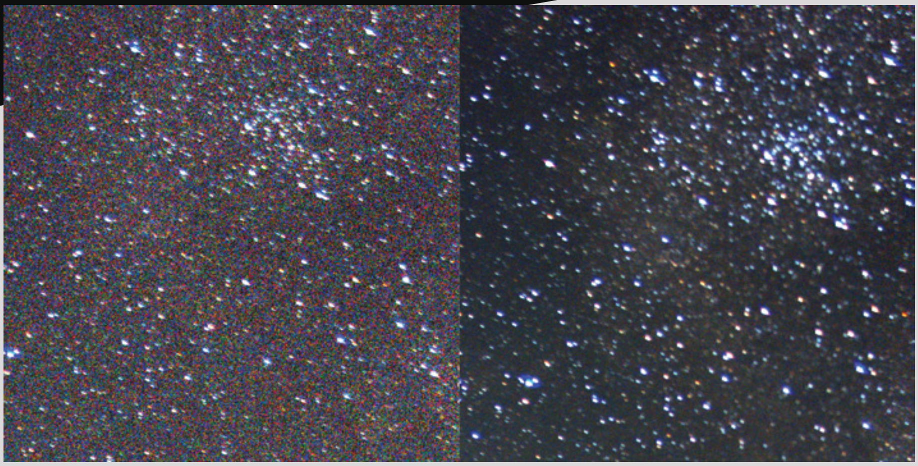
If you live in or near a big city, the first thing to try is a trip out of town around the time of new Moon — darker skies always produce better astrophotos. By shooting from a dark location, you can eliminate interference from light pollution, revealing fainter stars and the grandeur of the Milky Way. Check **lightpollutionmap.info** and seek locations far from populated areas. National parks and dark-sky preserves are the best options.

Another benefit to remote locations is that they often offer compelling landscapes that add visual interest to your images. Here's where ultra-wide lenses shine. They allow you to include a foreground scene while still capturing wide swaths of the night sky.

Stacking the Astro Deck in Your Favor

Every astronomical image requires some post processing to reveal all it has

▲ **BIG DIPPER TRAILS** As this 8-minute exposure shot with a 35-mm lens shows, even stars near the celestial pole show considerable trailing. The closer you aim your camera at the celestial equator, the more the apparent motion of the stars increases, leading to even longer trails.



▲ **NOISE POLLUTION** This 100% crop illustrates the benefits of digitally stacking multiple shots of the same scene. Compare the amount of sensor noise in the single, 10-second exposure (left) to that of a stack of 32 images (right). Low-noise photos are more attractive and allow much more extensive post-processing.

to offer. But the problem with short exposures is that they don't tolerate the amount of aggressive image editing that's usually required to produce a good image. One way around this is to shoot multiple exposures and add (or, "stack") them together before you begin your final edits.

For example, let's say you're using a full-frame camera with a 16-mm lens that allows 30-second exposures before the star trails become noticeable. Rather than taking just one image, shoot several 30-second exposures, one right after the other. And while the stars will shift slightly from frame to frame, you can align and merge the images later with software such as *Adobe Photoshop*, *Affinity Photo*, or *DeepSkyStacker*. Specialty programs like *Sequator* (*S&T:* Aug. 2022, p. 66) and *Starry Landscape Stacker* will even automatically align the foreground and sky separately.

Averaging the light value for each pixel across a large number of separate shots smooths out the randomly distributed digital noise. The final image these programs produce will have much less noise than any individual frame, allowing far greater latitude in post-processing.

Worth Repeating

How many shots is enough? Each incremental improvement in noise reduction requires a doubling of the number of shots. So, going from 4 to 8 exposures will give you a distinctly better image, but you'll need to double that again — for a total of 16 frames — to get an equivalent bump in quality. Use your own judgement to decide how many shots you need to take with your equipment to achieve results you like.

▲ **CONJUNCTION COMPOSITION** Tripod-mounted cameras using telephoto lenses are limited to very short exposures, but that's not a problem when shooting bright targets. This ¼–second twilight portrait captured with a Canon 70D DSLR (at ISO 3200) and 300-mm f/4 telephoto lens shows a conjunction of the Moon, Mars, and Venus.

If you plan on taking dozens of images, a remote cable release or intervalometer can make the process easier. Note that several modern digital cameras have built-in interval timers (check your manual to see if yours has this handy feature).

You'll need to adjust the position of your camera periodically to prevent Earth's rotation from carrying your target area off of the edge of the frame. Longer focal-length lenses will require repositioning frequently due to their narrow field of view, while ultra-wide lenses are much more forgiving.

You might wonder if you can avoid this entire process by taking only one image and then stacking multiple copies of it on your computer. Sadly, this won't work. As noted earlier, the stacking process relies on the fact that image noise is randomly distributed across each frame. Stacking a bunch of identical values won't get you anywhere — the noise will add up just as much as the light from the stars does. (Turn to page 54 of the April 2022 issue for additional details on how and why image stacking works.)

After you've loaded a set of frames into your computer, don't be surprised if the alignment and stacking process takes a while to complete. These are processor-intensive tasks that can require many minutes (or even hours), depending on the age of your computer and the size and number of individual shots. At the end of the wait you should have a single, well-aligned photo with very little visible noise.

As a final step, you'll want to apply some additional processing to bring out subtle details hidden in your stacked image. Unlike typical daytime photos, night-sky shots tax the limits of even modern digital cameras. The details are there, but they are subtle and will require some processing to reveal. But the results are certainly worth the extra time and effort involved.

■ **TONY PUERZER** is a retired professional photographer who loves the freedom of traveling to dark-sky locations with just a camera and a lightweight tripod.

The Lure of Extragalactic Supernovae

By knowing where and how to look, you can spot an exploding star in your scope.

Why sit around waiting for a galactic supernova when you can observe an *extragalactic* one almost any time? And not just one. A half dozen or more become bright enough to view in a 10-inch scope most years.

French astronomer Ludovic Gully discovered the first supernova ever seen outside the Milky Way by accident during a public observing event on August 17, 1885. He dismissed it as scattered moonlight and didn't follow up. Three nights later, German astronomer Ernst Hartwig was showing some friends the Andromeda Nebula (as the galaxy was then called) through the 9-inch refractor at Dorpat Observatory in Estonia, when he noticed a "new" star near the galaxy's nucleus. Hartwig wanted to alert other astronomers of his discovery, but observatory director Ludwig Schwarz insisted he wait to re-observe it without interference from moonlight to verify the object wasn't an artifact.

No doubt chomping at the bit, Hartwig nevertheless sent a letter reporting the discovery, but it went missing. He finally broke the news by telegram on August 31st and was credited with the supernova's discovery.

Supernova SN 1885A was just 16″ from the galaxy's nucleus and peaked at magnitude 5.9 on August 21st. Many described the star as yellow or gold in color. It faded to magnitude 16 by February 1886 and to this day remains the only supernova observed in the Andromeda Galaxy.

Extragalactic supernova discoveries slowly trickled in following the 1885 blast, with new finds ranging between one and 15 per year through the 1940s. In the 1950s the pace quickened, and these days astronomers can't haul them in fast enough. In 2021 alone, the catch came to 2,294!

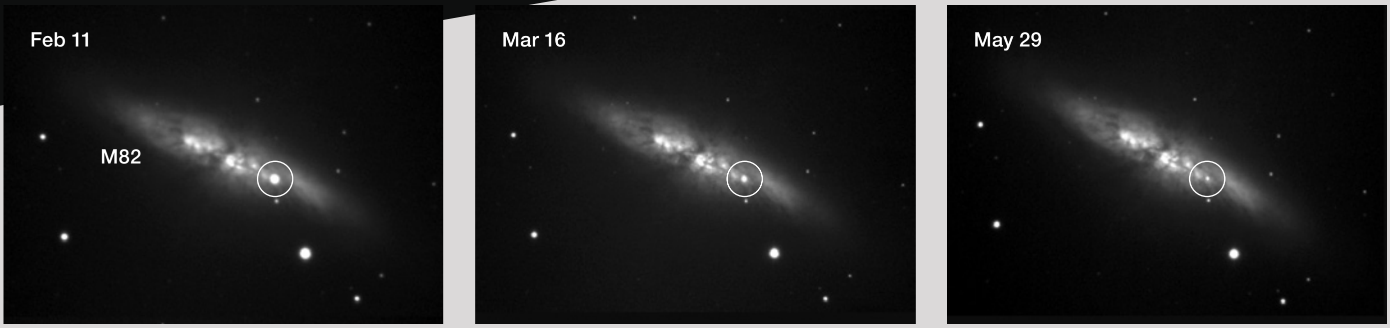
ESA / HUBBLE / NASA / A. RIESS / SHOES TEAM / ACKNOWLEDGEMENT: MAHDI ZAMANI

▲ **LIGHT THE SPARK** Supernovae are among the most powerful events in the universe. Type Ia supernovae, such as SN 2018gv in NGC 2525 (marked with tickmarks above), tend to be the brightest and can appear in all galaxy classes from ellipticals to spirals to irregulars. Type II are primarily found in spiral galaxies and associated with their dusty spiral arms. Although generally fainter, they remain visible longer.

What's in a Name?

To keep track of all these discoveries, each new object is given the prefix "SN" followed by the year of discovery and a one- to four-letter suffix. The first 26 supernovae in a year are designated with a capital letter from A to Z. Pairs of lowercase letters are used for additional discoveries: aa, bb, and so on up to zz. In recent years, the number of supernova discoveries has (ahem) exploded. Now it's common to see lowercase trios: aaa, bbb, and even quads. As of mid-October 2022, we've already reached SN 2022xuq!

David Bishop's *Latest Supernovae* website (**https://is.gd/bishop_sn**), a clearing-house of supernova and extragalactic nova discoveries, reported 21,086 supernovae in 2021. Of them, 2,294 were confirmed and received official designations, with 18,790 stuck in limbo as *possible* supernovae. The torrent of new discoveries in recent years has created a data overflow. The main reason so many remain unconfirmed is



▲ **LONG DECLINE** Members of the public often picture a supernova as a short-duration event like a camera flash. In truth, exploding stars radiate for days, weeks, and even months. If the blast is discovered early, the object will continue to gradually brighten to maximum — in the case of SN 2014J (above), it peaked at magnitude 10.5 on January 31, 2014, some two weeks after its discovery. By the end of May, it had faded to magnitude 14.0.

that "there simply aren't enough people taking spectra," says Bishop.

Meeting the Need

Bishop, an amateur astronomer and firmware designer for an aerospace firm, lives in Rochester, New York, and has maintained the page since 1997.

"Many years ago, I was looking for a niche, a way to contribute to astronomy, and realized that no one was keeping track of supernovae. No one was following them in real time," he said.

He attributes his initial inspiration to SN 1993J in M81. Bishop had just finished building his 8-inch telescope that year and pointed it at the 11th-magnitude supernova. His reaction was immediate: "Hey, that's a single star in another galaxy!"

Bishop's site not only contains current observations but also a rich archive of previous discoveries going back to 1996 and in some cases earlier. Based on his statistics, significantly more Type Ia supernovae are discovered and confirmed compared to the second major variety, Type II. A Type Ia event involves the catastrophic destruction of a white dwarf star in a binary system. In a Type II blast, a supergiant star runs out of fusible elements to sustain the nuclear reactions in its core and keep the crushing force of gravity at bay; defenseless, the star implodes, generating a massive, rebounding shock wave that rips it apart.

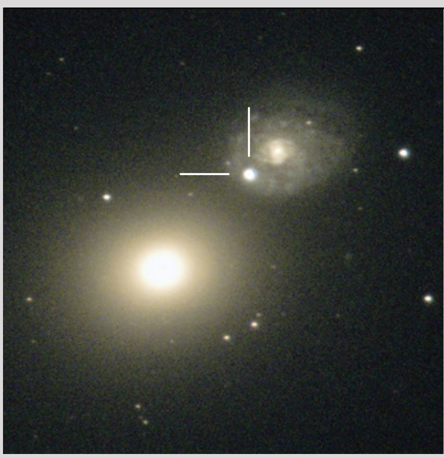
Type Ia supernovae flare with a brilliance five billion times that of the Sun and eject material at speeds up to 20,000 kilometers per second. Although about 2.5 magnitudes fainter, Type II events likewise involve unimaginable destruction and chaos. Most supernovae gradually rise over days or several weeks to a maximum followed by a slow decline to invisibility. The larger your scope, the longer you can hold on for the ride.

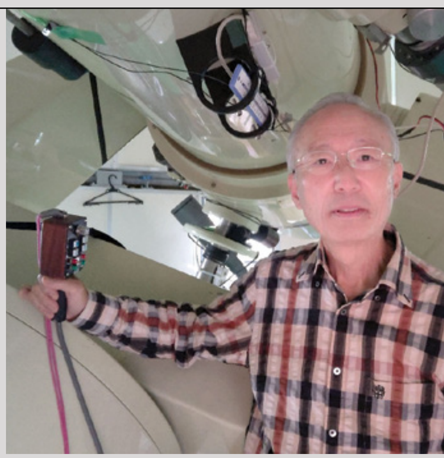
While most supernova discoveries are impossibly faint, it's not uncommon for 10 or more to reach magnitude 14.5 each year, making them accessible with a 10-inch telescope under dark, moonless skies. Of those, several grow even brighter, peaking between 12th and 13th magnitude, within the grasp of a 6-inch. SN 2022hrs in NGC 4647 is a great example. Discovered by prolific supernova- and nova-hunter Koichi Itagaki on April 16, 2022, it rose to 12.2 by that month's end.

Detonation Delight

Do you recall the thrill you felt when you first saw Jupiter or Saturn through a telescope? I felt the same way when I observed my first supernova, SN 1984A in NGC 4419, on February 21, 1984. In my 11-inch Celestron it was a 14th-magnitude stellar speck embedded in the galaxy's soft haze. That was my spark. Now I hunt for and delight in every explosion within reach of my 15-inch.

A supernova's position relative to the host galaxy's nucleus is given in arcseconds. Most supernovae hover close to their home galaxies like moths around a streetlight. Their visibility depends upon how bright the explosion is and





◀ **LOCATION, LOCATION** (*Far left*) One of the easiest supernova catches in recent months was SN 2022hrs in NGC 4647, an 11th-magnitude galaxy paired with M60 in Virgo. A new supernova's location is given in relation to the host galaxy's nucleus. For example, SN 2022hrs was situated 30.0″ east and 18.7″ south of the center of its host galaxy. (*Near left*) Japanese amateur Koichi Itagaki discovered SN 2022hrs as well as SN 2018gv (page 57). To date (mid-October 2022), he has more than 168 supernovae, 67 novae (of which 12 are galactic, the rest extragalactic), three comets, and five asteroids to his name. Professional astronomers frequently use his high-quality observations.

M82 IMAGES: WILLIAM WIETHOFF (3); 2022HRS AND ITAGAKI: ELIOT HERMAN / KOICHI ITAGAKI the distance from the nucleus. Some supernovae even outshine their host galaxies. On more than a few occasions, I've located my target with ease but struggled to see its keeper.

Distinguishing dim supernovae nestled close to a galaxy's densely concentrated, bright core from the "background noise" requires excellent seeing, high magnification, and concentration. Sometimes, a second or third night is needed to make a confirmation. Whatever it takes.

But if the supernova, however faint, appears 30″ or more from the core, and especially if it inhabits the less cluttered space above or below the galaxy's plane, it's *much* easier to see. Some supernovae are displaced so far from the galaxy's nucleus they don't even appear related, yet the data clearly connect the two.

Some galaxies have hosted multiple supernovae, M66 in Leo being a great example with five discovered since 1973. The most prolific supernova mill is the aptly named Fireworks Galaxy, NGC 6946 in Cepheus, with 10 observed supernovae to its credit. Spiral galaxies like it are rich in interstellar dust and gas and are actively giving birth to new suns. No surprise that they also mold the massive stars that later terminate their lives as supernovae.

Let's Start Hunting

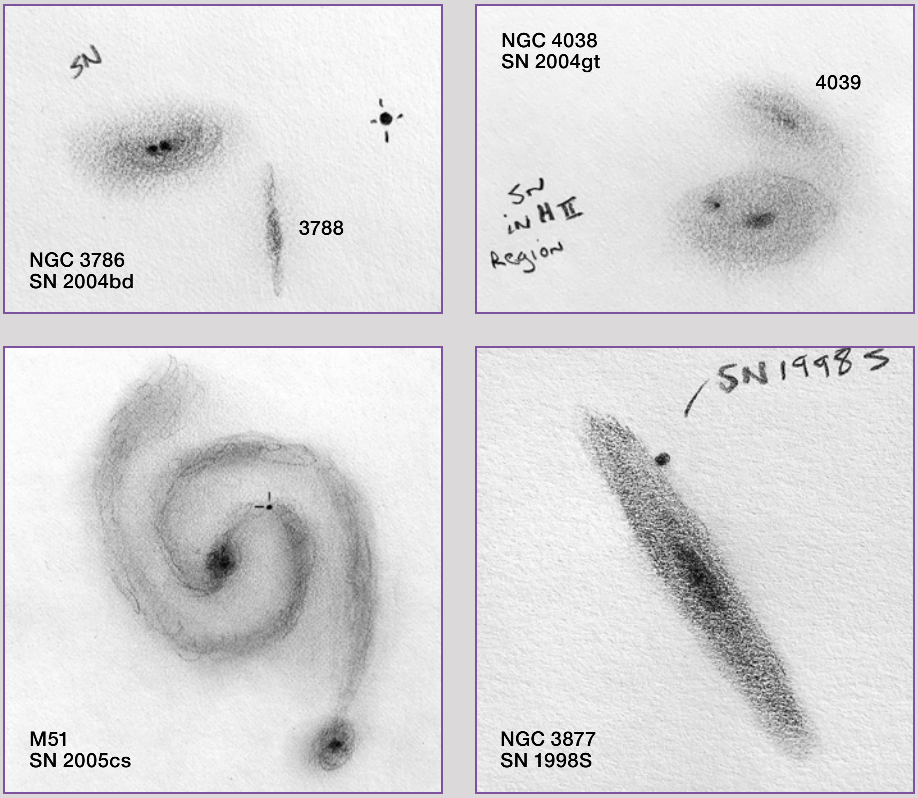
So how do you know when and where to look for supernovae? First, check the left-hand column of Bishop's webpage daily. There he posts relevant info on recent, bright discoveries — scan the column for any supernovae at or brighter than your scope's limiting magnitude. Look for targets that are a half magnitude brighter than the theoretical limit of your scope's aperture.

Once you've identified a candidate, click on the supernova's name, and it will link to a page listing discovery circumstances, current brightness, and, crucially, the object's offset from the nucleus. Knowing how far and in what direction to look from the core is essential. Helpful photos show at a glance how easy or difficult excavating the star will be. A 13th-magnitude supernova 3″ from the nucleus will prove challenging, while the same object offset 80″ is a gimme.

Your next step is to locate the galaxy by consulting, for example, *Sky & Telescope*'s handy *Pocket Star Atlas* or a map generated with your favorite software. Start at low magnification and center the galaxy in the field of view. Bright supernovae jump right out, but typically you'll need magnifications upward of 150× to dig in for the goods. Field stars near or superimposed on the galaxy are your friends. Use them to corral those dimmer blasts.

Check out the Supernova Enthusiasts Group on Facebook or get a free subscription to *The Astronomer's Telegram* (**astronomerstelegram.org**) — you can filter the data so you'll only receive circulars about supernovae. Bishop gets his raw data both from ATEL and circulars from the Transient Name Server (**wis-tns.org**), another rich source of supernova data.

I've enjoyed watching things blow up since I was a child. Now that I'm older I still relish a good explosion, but supernovae have taken my appreciation to an entirely new level. How else might we safely witness the biggest bangs the universe has to offer? While catastrophic, each stellar annihilation recycles freshly minted elements and compounds back into the interstellar medium to build new stars and planets. Importantly, supernovae release the iron that's incorporated in the hemoglobin that carries oxygen from our lungs to all parts of our body. Every breath we take reminds us that our lives depend on these cosmic benefactors.



▲ **SKETCH A SUPERNOVA** Once you spot your quarry, you might find it satisfying to record your observation to test and refine your observing skills. SN 2004bd, at magnitude 14.3, was a tough nut because of its proximity to the galaxy's nucleus compared to SN 1998S, which shone brightly at magnitude 12.6 just beyond the dense galactic disk.

BOB KING

■ Contributing Editor **BOB KING** writes the monthly column Celestial Calendar (see page 48) as well as the Explore the Night blog for **skyandtelescope.org**. He's primed and ready to go for the next Milky Way supernova but happy to travel up to several hundred million light-years to witness an extragalactic one up close.

Sewing Up Nightscapes

Panoramic mosaics can show far more than a single image ever can.

Some of the most popular and dramatic nightscape photographs are not single images but panoramas ("panos" in the lingo), composed of several frames blended together to make one seamless scene.

Shooting and then assembling multiple, overlapping images is certainly more work. But the reward is a picture covering more of the scene and with higher resolution and detail than a single image can provide. If your goal is to produce stunning, wide-angle nightscape images, panoramas are the way to go.

Panorama Subjects

While panoramas of the Milky Way are the most obvious target, they can also be the most difficult, requiring long exposures and high ISO settings. Other sky subjects lend themselves to panoramas that can be easier to shoot, making them suitable for honing your pano skills. For example, aurorae can stretch across a large swath of sky (to the north for the aurora borealis, to the south for the aurora australis). To capture the full display, you simply take an overlapping series of individual frames and stitch them together later using software. In this case, I'll use a fast 20-mm-to-24-mm lens to shoot several segments quickly before the display changes structure enough to make seamless stitching difficult.

Noctilucent clouds, a phenomenon unique to higher latitudes near summer solstice, can, on rare occasions, cover half the sky. More often they hug the horizon. I prefer to shoot these with a short telephoto lens, such as an 85-mm or 105-mm, taking as many frames as needed to cover the display. The resulting panorama better resolves the fine structures that noctilucent clouds often exhibit.

My other favorite use of panorama techniques is for framing the wide arc of Earth's blue shadow and the pink Belt of Venus (the alpenglow visible above the antisolar point) at sunset or sunrise, or a lineup of planets across the twilight sky. The segments of these twilight scenes must be recorded quickly, as sky colors can change enough in a minute to make a smooth blend a challenge.

When shooting any panorama, be sure to use the same manual exposure settings for all frames. Using auto expo-

ALL PHOTOS BY THE AUTHOR

MILKY WAY OVER THE BADLANDS While dark-of-the-Moon nights are usually preferred for Milky Way panoramas, moonlight can bath the landscape with warm, natural illumination. This was shot on a mid-May night illuminated by a waxing crescent Moon at Dinosaur Provincial Park in Alberta, Canada.

sure, say, for twilight scenes, can produce segments that vary too much in brightness to blend seamlessly.

A Good Plan

While aurorae, noctilucent clouds, and twilight panoramas do take some practice at the camera, Milky Way panos also take planning. Framing the arch of the Milky Way can be done only when it's confined to one half of the sky, rather than when the Milky Way is directly overhead. The nightscape community speaks of a "Milky Way arch season" when the galaxy is best placed for such portraits.

In the Northern Hemisphere, this season runs from mornings in February to evenings in June. This is when the

▶ **ESSENTIAL GEAR** The minimum requirement for panorama shooting is a tripod head with an azimuth motion graduated in degrees, typically in 5° increments with every 15° labeled.

▶▶ **RECOMMENDED ADDITIONS** A leveling head helps ensure the camera rotates parallel to the horizon, while an indexing pan head makes it quick to move from segment to segment in the dark.

▲ **WIDE SKY SUBJECTS** The noctilucent clouds panorama (top) is made of six segments with an 85-mm lens, stitched in *Adobe Camera Raw* (within *Photoshop*). The twilight scene above is assembled from nine segments shot with a 28-mm lens and stitched using *Photoshop*'s Photomerge command.

galaxy spans the eastern half of the sky, from Perseus in the north to Sagittarius rising in the southeast. There's a second and less well-known Milky Way arch season: During February and March evenings, the dimmer winter Milky Way and panoply of bright stars in and around Orion set in the west.

From the Southern Hemisphere, the season is similar, but the Milky Way is very different. It arcs high across the south on austral autumn nights, from Orion setting in the west to Scorpius rising in the east. September to November spring evenings bring another opportunity for austral photographers to frame the arch of the Milky Way as it spans the western half of the sky with the galactic core setting.

A planetarium program or app such as *Stellarium* (**stellarium.org**) or *SkySafari* (**skysafariastronomy.com**) is indispensable for previewing when and where the Milky Way will be visible. These apps include the ability to add field-of-view indicators for your gear so you can tell what lens and camera orientation will work best to frame your composition.

Even more useful are specialized apps such as *The Photographer's Ephemeris* (**photoephemeris.com**) or *PhotoPills* (**photopills.com**), which show where the Milky Way and its photogenic galactic core will be in relation to the landscape features at your chosen site.

Choosing the Right Gear

What gear do you need besides your camera and a few lenses? A tripod head with an azimuth scale is essential. This allows moving the camera horizontally by a consistent amount, typically by 15° to 45°, from frame to frame.

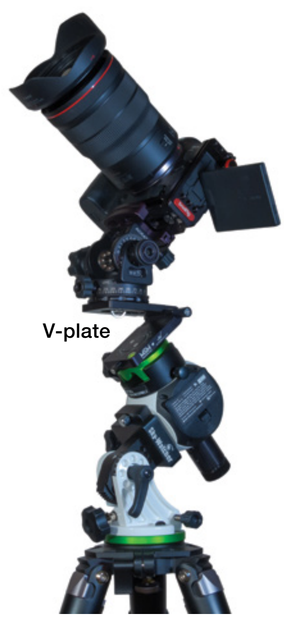
There are two additional items I

◄ **PROGRAMMING PANOS** The MIOPS Capsule360 (since superseded by the newer Capsule Pro) connects to the camera to fire its shutter automatically after every programmed move to a new segment. The mobile app (left) calculates the number of segments needed to cover a given field based on the lens and overlap amount desired.

▲ **TWO OTHER MILKY WAYS** While the Northern Hemisphere's summer Milky Way gets the most attention, the austral autumn Milky Way (top) is even more impressive. This April scene was shot at a star party in New South Wales, Australia. Northerners can catch the arch of the winter Milky Way in February (seen above) when the zodiacal light often adds to the sky scene.

consider invaluable for serious pano photography. A leveling head that goes between the tripod and tripod head makes leveling the camera a quick and easy task, with no need for trial-and-error adjustments to the tripod legs. Level your tripod head first, then use your camera's built-in level to ensure it isn't tilted left or right, so its frame is parallel to the horizon. If either the tripod head or camera is not level, the final panorama will still stitch together but will undulate up and down across the horizon, requiring a lot of warping and cropping to correct.

The second accessory I suggest is an indexing pan head that goes between the leveling head and normal tripod head. These have click stops at preset spacings, typically adjustable from 5° to 90° apart — enough to cover most camera-and-lens combinations. This allows you to quickly move the camera from one click stop to another just by feel.



▶ **TRACKING PANO GEAR** Star trackers like the Star Adventurer Mini shown here are best paired with an angled V-plate so the camera can be turned parallel to the horizon while still tracking the sky. This pan head's altitude axis is also marked in degrees for precise, incremental vertical movements.

Automating and Tracking

Wouldn't it be nice to automate the shooting? I reviewed a unit for doing just that in our September 2016 issue. The iOptron iPano works great, but it's a large piece of gear to heft if you have to hike to your chosen site. However, a motorized pan head does make it easier to shoot complex "gigapans" that might extend horizontally a full 360°. These all-sky panos require 10 to 12 segments and can extend up to the zenith, requiring two to four rows, or tiers, totaling up to 48 segments — a lot to manually move between and shoot!

More affordable and portable options include single-axis controllers designed primarily for time-lapse shooting, such as the Edelkrone HeadONE (**edelkrone.com**), Manfrotto Genie Mini II (**manfrotto.com**), or the MIOPS Capsule Pro (**miops.com**). All offer programmable panorama modes set with a smartphone app that communicates via a Bluetooth LE connection. You can pair two units and program both the horizontal and the vertical movements needed for multi-tier panos. I prefer to keep things simple and sturdy, using just a single-axis controller for the horizontal moves. I perform the vertical changes manually, as only two or three are needed at most.

▲ **PLANNING APPS** *Left:* This *SkySafari* screenshot shows the field of view of a 24-mm lens in landscape orientation framing the rising Milky Way and Lyra. The *Photographer's Ephemeris* app (right) displays the terrain at the shooting site, indicating the setting Moon and the rising Milky Way as an arc of dots. Both apps are set for the location where the badlands panorama on the opening page was captured.

Can you track the sky during a pano shoot to ensure pinpoint stars? Absolutely. I like to use Sky-Watcher's Star Adventurer Mini tracker for its accuracy, compactness, and light weight (*S&T:* Dec. 2017, p. 58). I combine it with an Alyn Wallace V-plate sold by Move-Shoot-Move (**moveshoot-move.com**). The angled plate allows turning the camera parallel to the horizon manually from segment to segment while the tracker follows the sky.

Although trackers allow longer exposures, avoiding star trailing while recording more detail in the sky, I find exposures are best kept to no more than one to two minutes for each segment. Each segment can then be captured within a span of 10 to 20 minutes — before the sky turns too much. This simplifies the blending of the sky images with the ground segments, which are best framed and shot first with the tracker's motor off to prevent the ground from blurring.

Blending the tracked and stationary panoramas takes some deft work in *Photoshop*, usually requiring nudging the masked ground layer up to hide the blurred (and possibly misaligned) horizon in the star-tracked layer.

Tips and Techniques

Next to ensuring that your camera and tripod head are level, the most important secret to success in panorama shooting is to include sufficient overlap

▼▶ **WIDE OR TALL** *Below:* For this panorama, a full-frame camera with a 14-mm lens in landscape orientation covers the 180° scene in three segments with 50% overlap. But using a 20-mm lens and turning the camera 90° (facing page) provides the same vertical coverage with greater resolution, though it requires six segments with a minimum of 30% overlap.

between each panel. While too much overlap might cause problems when stitching, too little certainly will. I aim for about 50% overlap, but a value as low as 30% can work. Keeping overlap low (but above 30%) means fewer individual segments are needed, speeding up the shooting time.

With ultra-wide lenses that typically exhibit a lot of distortion at the corners of the frame, it's better to be generous with the overlap. Even then, programs such as *Adobe Lightroom* and *Photoshop* can have trouble stitching segments shot with 10-mm to 14-mm lenses. It's wise to experiment with test panos taken at home to see what works with your gear and software before heading to a remote location.

Regardless of which lens you choose, you can shoot with the camera either in landscape or portrait orientation. The latter provides more vertical coverage and is often used for Milky Way arch panos. The drawback is it requires more segments to cover the scene horizontally.

For Milky Way arches, shoot with a lens that will provide enough coverage vertically to take in not just the Milky Way but at least 20° of the sky above it. When stitching a panorama for a rectangular final image, the top few degrees of sky will be so badly distorted that you'll need to crop that region out of the final image. Plan your framing accordingly.

For any panorama, especially those captured with very wide lenses, shoot an extra segment on either end of the sequence. The end segments will also get distorted in the final stitch and will need some cropping. In other words, always shoot more of the scene than you'll need for your final photo. I also prefer to shoot from left to right, as it makes viewing the segments easier in an image browser when sorting images in ascending order of capture time or filename, my preferred setting.

Milky Way panos on dark nights are often best shot in two passes. One is with short exposures (30 seconds or less) at a high ISO for the sky (to avoid star trailing in untracked panos). The other is captured with a longer exposure (perhaps a minute or more for each segment) and at a lower ISO with the lens stopped down in order to record more depth of field and detail in the foreground.

Suggested Frame Spacing

Lens Focal Length	Landscape Orientation with 50% Overlap	Portrait Orientation with 50% Overlap
14 mm	60°	45°
20 mm	45°	30°
24 mm	40°	25°
35 mm	30°	20°
50 mm	20°	15°
85 mm	15°	10°
105 mm	10°	5°

Segment spacings are given to the nearest 5°, as most pan heads are marked in 5° increments. Spacings assume a full-frame (36 × 24 mm) camera sensor. For cropped-frame (23 × 15 mm) sensors, multiply segment spacings by 0.6×.

To keep noise in check, I prefer to shoot single, tracked segments for the sky and long, untracked segments for the ground, all at low ISO settings, rather than stacking multiple, short, high-ISO exposures. Stacking complicates the workflow since it requires the extra step of creating stacked intermediate frames before stitching can begin.

I also find today's AI-noise-reduction routines so effective that, for nightscapes at least, stacking is not as essential as it once was. This is especially true for panoramas where any noise speckling will appear tiny in the final image.

Easy Assembly

With your set of panorama images on the computer, the next step is to mosaic them together. I first process each raw file as thoroughly as possible, using identical settings

for each segement. My preferred software is *Adobe Camera Raw* (*ACR*), but *Adobe Lightroom* has identical functions. For simple panoramas I'll first try the ***Merge to Panorama*** command. It can work great, with one click. Or it can fail frustratingly, often on scenes similar to ones it previously worked well on. Scenes over water or with dark end segments often can foil the software. If it fails, my next recourse is to send the processed files into *Photoshop* and try its ***Photomerge*** command. This sometimes works for image sets that *ACR* or *Lightroom* balk at.

The Adobe competitors *Affinity Photo*, *Capture One*, and *ON1 Photo RAW* also have good panorama stitching functions. But I've found that any sets that give Adobe's software trouble usually also fail in the competitor's programs.

Advanced Stitching

For problem pans, and usually for 360° scenes and multi-tier panos, I resort to *PTGui* (which stands for Panorama Tools Graphical User Interface), a $160 program for Linux, MacOS, and Windows (**ptgui.com**). While it can process raw files from most cameras, it will not read any of the settings applied to the frames in other programs. So I export processed raw files as 16-bit TIFFs for each segment, then import the TIFFs into *PTGui*.

Hitting *PTGui*'s ***Align Images*** magically results in a seamlessly stitched and blended panorama . . . usually. Sometimes it also fails. In such cases the software at least indicates which segments have issues and offers the option to manually create alignment "control points." This involves examining adjacent frames and clicking on identical stars or landscape features in each frame. The process can be tedious. And you have to know the sky well enough to identify the same stars on multiple frames.

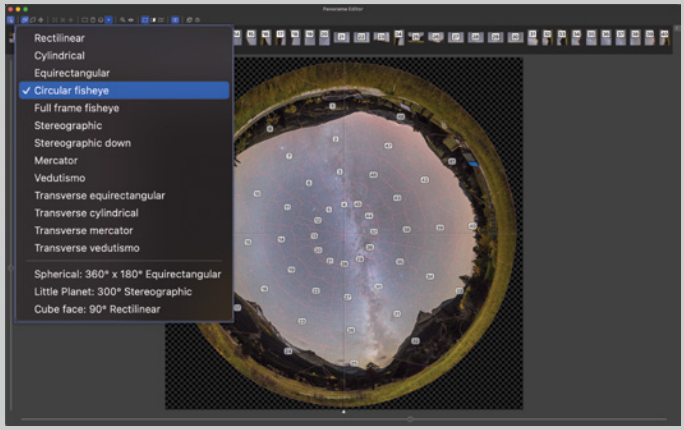
I always export the stitched segments to a layered Photoshop file (PSD). This allows me to manually edit the automatically generated masks to fix minor issues such as horizons with "fault lines" resulting from *PTGui* aligning on the moving stars, rather than on the stationary ground. Be warned: Even single-layer panos can be tens of thousands of pixels wide and many gigabytes in size. This will likely tax the ability of your aging computer to process and save them.

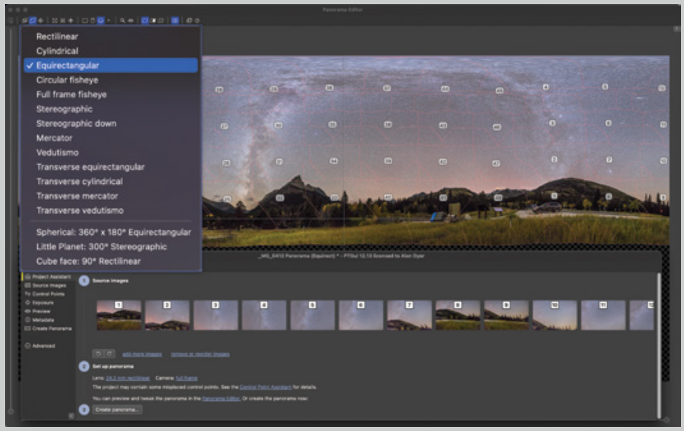
A key feature of *PTGui* is that for 360° scenes you can rotate and move the entire scene around to improve the final composition. Other programs, if they work at all on such scenes, can't do that. What they give you is what you get.

Although all stitching programs can be balky at times, the results can be wonderful, and much easier to create than in the old analog days when we had to cut and paste (literally!) prints together to make panoramas. Try some simple panos to start. I think you'll soon be hooked on the wide-fields and pixel-peeping resolution that panoramas can provide.

■ **ALAN DYER** is coauthor with Terence Dickinson of *The Backyard Astronomer's Guide*. A gallery of his panorama images can be viewed at **https://is.gd/nightpanos**.

▼▶ ***PTGUI* PROJECTIONS** The dedicated stitching program *PTGui* can handle complex panos, like this one consisting of 40 segments (four strips of 10 images each), merging them using a choice of map projections, such as Equirectangular (bottom) or Circular fisheye (right). The latter style of 360° panorama is possible only with sets of images that cover the entire sky from horizon to zenith.





iOptron's Hybrid Equatorial Mount

This lightweight mount adds strain-wave technology to the company's latest Go To offering.

HEM27EC Hybrid Equatorial Mount

U.S. Price: $3,248 mount, $318 optional tripod
ioptron.com

What We Like

High load capacity

Low periodic error

Zero-backlash RA axis

What We Don't Like

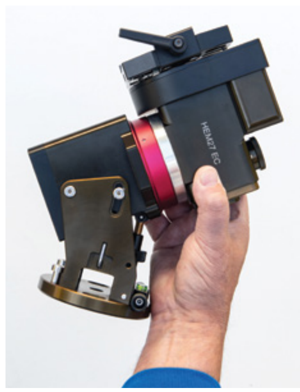
Saddle clamp lever can interfere with declination motion

Potential to tip over with unbalanced loads

CHINESE MANUFACTURER iOptron has long offered innovative equatorial mount designs. Their center-balanced CEM series mounts deviate from the classic German equatorial design by better positioning the center of gravity of the payload to provide greater stability. Recently, the manufacturer announced the HEM27EC, its most compact German equatorial mount to date. This is the company's first design to incorporate an innovative drive that's quickly gaining acceptance throughout the astronomy community.

The 3.7-kilogram (8.1-pound) HEM27EC is rated to carry a 13.5-kg load, which translates to a surprising 3.65-to-1 payload-to-mount-weight ratio. And it does this without a counterweight — a defining feature of German equatorial mounts since Joseph von Fraunhofer built the first one in the 1820s. However, an optional 20-cm (8-in) counterweight bar and a 4.5-kg counterweight are available and still helpful, as I'll explain further on.

The most innovative feature of the HEM27EC is its drive system. The mount incorporates a strain-wave gear in the right-ascension axis that produces extremely high torque with no backlash (also featured in last month's test report). This drive is coupled with a digital encoder to improve its pointing accuracy and periodic error. The declination drive is a more conventional worm/belt drive system, hence the term "hybrid" in the mount's name. A version of the mount without the encoder is also available (the HEM27 for $1,998).



▲ The iOptron HEM27EC with High Precision Encoder is a German equatorial mount that packs a lot of capability into a surprisingly small package.

A 120-volt AC power supply is included with the HEM27EC, supplying 12V DC at 5 amps. Also provided is a zippered case with form-fitting foam cutouts for the mount head, its power supply, cables, and the Go2Nova 8409 hand controller.

For our tests, we also borrowed the optional Carbon Fiber Tripod ($318) to evaluate the portability of the system. The extendable legs provide a height range from 53.5 cm to 83.5 cm. This is fairly short. Even with the legs fully extended, its height could place the eyepiece of long refractor telescopes uncomfortably low to the ground. This is awkward for visual observing but isn't much of an issue for imagers.

Before heading into the night with this mount, you may have to switch its saddle to match your telescope's. The saddle is designed to accommodate both Vixen-style and Losmandy-D-style dovetail bars, but converting the saddle from one design to the other involves removing both saddle clamping jaws and flipping them over. Eight screws connect the parts. However, the four screws for the moveable jaw are on the underside of the saddle and only accessible when the entire saddle is removed from the mount.

Under the Stars

Setting up the HEM27EC takes only

ALL PHOTOS BY THE AUTHOR

slightly more effort than for a basic star tracker. Indeed, the compact mount is about the same size and weight of some star trackers. But while most star trackers can work unguided with focal lengths of around 135 mm or less, the HEM27EC drive is accurate enough for unguided imaging at much larger image scales.

The lightweight equatorial head attaches to the tripod by two hex-head screws, which also lock down the azimuth axis during polar alignment. A hex wrench is provided that stores in a convenient, magnetic slot just above one of the screws. This wrench also fits every screw on the mount and can also be inserted into holes around the mount's altitude adjustment wheel to provide additional torque if needed.

Fully assembled, the mount on the Carbon Fiber Tripod weighs just 10.4 kg. With the tripod legs retracted and folded in, the top-to-bottom distance of the package is only 81 cm — easily fitting in the back seat of most any vehicle.

Missing from the setup sequence is installing a counterweight shaft and weight to balance the load across the RA axis. The mount's manual states flatly, "No RA balance is needed for an HEM27 mount." The RA shaft can only be turned when the mount is powered up and operated by the hand controller or a computer.

Because there's no clutch to release the RA shaft, the telescope load and counterweight can't be precisely balanced even with the optional counterweights and shaft installed. The declination axis, however, includes a small locking knob just below the saddle plate to release its gear and allow balancing the declination axis.

When attaching your telescope, you need to take care after tightening the lever that clamps the saddle dovetail. Its protruding plastic handle is spring-loaded and should be rotated after tightening to place the lever in the "up" position so that it won't interfere with declination movement. This step is important enough to be mentioned in the user manual. My failure to check the lever position one night resulted in it colliding with the declination housing.

Alignment with *iPolar*

Once assembled, the mount needs to be polar aligned to perform at its full potential. Absent on the HEM27EC is a polar finderscope, or at least an eyepiece for one. Instead, alignment is done with the built-in iPolar electronic pole finder. It's a small lens and camera that requires the use of an external computer to run the *iPolar* software. While this wasn't as convenient or straightforward as an optical finder, *iPolar* produces dead-on polar alignment and is worth the extra trouble.

▲ This shot of NGC 7293, the Helix Nebula, demonstrates the capabilities of the HEM27EC. The photo was assembled from 47 out of the 78 unguided 60-second exposures recorded with an 8-inch f/8 Ritchey–Chrétien telescope and ZWO ASI2600MC Pro camera.

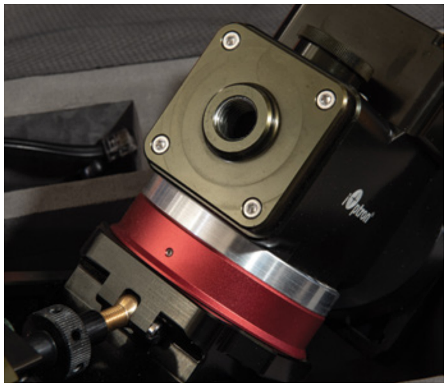
▲ This view of the mount shows at bottom one of the azimuth adjustment screws, which double as the main connection for securing the head to the tripod. An included hex wrench stores conveniently in a magnetic compartment just above the azimuth locking screw.

▲ The polar axis includes the power input and switch, the port to connect the iPolar alignment device, a USB 2.0 connection, an ST-4-compatible autoguiding port, and hand controller (HBX). A 12-volt output and USB passthrough port is seen on the rear of the saddle plate.

▲ This view of the iOptron HEM27EC shows its integrated iPolar's objective lens uncovered. Altitude and azimuth adjustment knobs are at bottom. Small holes around the edge of the altitude adjustment wheel accept an onboard hex wrench to help precisely turn the wheel.

After roughly pointing the mount north, you begin recording short exposures through the iPolar camera with its *iPolar* control software (for PC computers only). The software then matches the star patterns with its internal database of known stellar positions in a process called *plate solving*. It quickly determines the rotational center of the RA axis within the iPolar's camera image (marked with a "+" sign) and the true pole's position designated with a red circle. You then adjust the mount's azimuth and altitude knobs. The onscreen view zooms in as you close in on the celestial pole, permitting finer adjustments until you're within 30 arcseconds of your target. Once you've moved the "+" sign onto the circle, it turns green and you're done.

Once set up and polar aligned, the mount is a joy to use. The Go2Nova hand controller's menu is easy to navigate, and the whir when the mount slews to its destination is barely audible. I controlled the mount with its hand paddle as well as using the *Sky Safari Pro* app on my iPad, connecting with the onboard Wi-Fi. The company also provides its own control app, *iOptron Commander Lite* for both iOS and Android devices and available on their respective marketplaces. There's also a USB port that allows direct computer connection and control of the mount with desktop planetarium programs.



◀ Unlike a typical German equatorial mount, the HEM27EC doesn't come with a counterweight and counterweight shaft. It's capable of carrying a fairly heavy telescope without either, though there is the option to purchase a bar for $45 that threads onto the bottom of the declination axis.

Like other iOptron mounts, the HEM27EC includes passthrough ports for power and USB 2.0 on the saddle plate. I took advantage of both ports to control and power my ZWO cameras.

The excellent Go To accuracy of the system meant I didn't use the finderscopes on any of the scopes I used during my tests. Targets always landed within the field of view after every slew. I only needed to make fine adjustments with the hand control to finesse the final composition of my image.

This photo of IC 1805, the Heart Nebula, consists of 22 unguided 5-minute exposures recorded with the 8-inch Celestron Rowe-Ackermann Schmidt Astrograph telescope and ZWO camera seen on page 68.

The tracking accuracy of the HEM27EC is excellent, even without counterweights or autoguiding. Images with a 71-mm f/4.9 refractor coupled to a full-frame DSLR were effortless for the HEM27EC, tracking 1-minute exposures perfectly. On a different night, I tried a 4-inch refractor operating at a focal length of 700 mm, which also produced round stars in most exposures. Out of 60 two-minute exposures, 41 were perfectly tracked, and the other 19 displayed only slightly elongated stars.

The mount managed with heavier loads, too. My 8-inch Celestron RASA and ZWO ASI2600MC Pro camera together weigh 9.9 kg. This combination on the mount resulted in a total of 48 perfectly tracked 1-minute exposures out of 60, operating at a focal length of 400 mm. A similarly heavy 8-inch f/8 Ritchey-Chrétien scope with the same ZWO camera also produced many acceptable unguided exposures at 1,625 mm, or 0.59 arcseconds per pixel. Of the 78 1-minute test exposures taken with this combination, 49 had round stars.

Unguided imaging is a big test for any mount, and this one passed hand-

▶ The optional Carbon Fiber Tripod includes three steel spikes to help anchor the lightweight tripod. The plastic foot under each leg is unscrewed and replaced with a spike.

ily — a testament to the added precision of the right-ascension encoder combined with permanent periodic correction. Of course, adding autoguiding resulted in perfectly round star images with all three setups even with 5-minute exposures.

Unbalanced Concerns

Eliminating the counterweight bar and weights is a nice convenience, but it adds additional considerations that might not be on a user's radar.

A typical GEM balanced across the RA axis places the weight of the payload over the tripod's center. Lacking a counterweight, the load is unbalanced and offset toward one side of the mount when the scope is pointed near the meridian. This causes flexure in the lightweight carbon-fiber tripod, which degrades the accuracy of the polar alignment, resulting in fewer acceptable exposures.

The iPolar system confirmed this flexure as the load shifted from one side of the mount to the other, seen at right. The heavier the scope, the greater the shift. The best solution, of course, is to add the optional counterweight system to balance the load.

Heavier telescopes on the unbalanced HEM27EC introduced another problem. The off-centered weight made the entire setup unstable enough that I was afraid the mount would tip over if I left it unattended. My 14kg, 11-inch SCT was dangerously out of balance and threatened to topple over when pointed to certain areas in the sky.

The manufacturer provides a partial solution to this danger in the form of three steel spikes that replace the tripod's plastic feet. The spikes are intended to anchor the tripod firmly

▲ *Left:* The declination axis on the HEM27EC utilizes a standard worm-gear drive, which can be disengaged when balancing the telescope, as seen here with a 102-mm refractor attached. *Right:* The HEM27EC is shown with the author's 8-inch Ritchey–Chrétien telescope. When combined with the ZWO AZI2600MC Pro camera, the load on the mount reached just over 10 kg, but the combination tracked very well and produced the image of the Helix Nebula seen on page 69.

▲ Three combined screenshots from *iPolar* reveal some flexure in the tripod under heavier loads. The central green crosshair indicates near perfect polar alignment when the telescope load was oriented on top of the polar axis in the mount's home position. The red circle on the right records when the telescope load was slewed to the mount's extreme west side. The other red circle shows the shift in polar alignment when the scope was on the mount's east side. No shift was detected when the mount was attached to the author's permanently mounted observatory pier.

in the ground and ensure your setup is more stable and secure even when significantly off balance.

One final issue I discovered when imaging with this unbalanced system is that I needed to redo polar alignment each time I swapped OTAs. No such flexure occurred when I attached the mount's head to the permanent pier in my observatory.

The Bottom Line

After testing the HEM27EC for a few months, I am very impressed with its capabilities. Its high-load capacity, accurate pointing, and outstanding tracking accuracy are all coveted features — particularly for travelling astroimagers who want a quick and accurate setup capable of working with a wide range of small telescopes and camera lenses. Accommodating the limitations of an unbalanced load is a small price to pay for the great reduction in equipment and weight necessary to lug out for each session. The mount's accuracy and compact size are particularly attractive for solar-eclipse photographers looking for a robust rig for the 2024 event.

■ Contributing Editor **JOHNNY HORNE** is often spoiled by all the amazing technology in the products he reviews.

In Her Own Words

THE MILKY WAY: *An Autobiography of Our Galaxy*

Moiya McTier
Grand Central Publishing, 2022
256 pages, ISBN 9781538754153
US$27.00, hardcover

MOIYA MCTIER, an astrophysicist and folklorist, explains in the opening pages of this book why she chose the unusual approach of having the Milky Way tell its own story. When she, an only child, was young, her family moved from Pittsburgh into Pennsylvania's coal country, "full of people," as she writes in the Foreword, "who had only seen a Black person on TV . . ." She lived in a log cabin in the woods with no running water and stood out uncomfortably as "the blackest person" at her school.

McTier felt most herself at night, and later, in college, she became captivated by "the logical, data-driven nature of astronomy." She loved folklore as well, and she came to realize that mythology and science aren't as contradictory as they might at first appear. "Both are tools we humans use to understand how we fit in with the rest of the universe," she writes. McTier went on to become the first undergraduate in Harvard's history to study both astronomy and mythology. By the time she finished her PhD in astrophysics at Columbia, she says, her perspective had widened "in the most illuminating way."

McTier writes as herself only in the Foreword and Notes. The rest of the book is written as if by the Milky Way. I was curious to see how well this approach would work. Would I retain information as well as with a more traditional style? Would I gain a new perspective, akin to McTier's own broadening? Would I *like* the Milky Way?

Once I settled into the book's flow, acquiescing to a sort of willing suspension of disbelief, its contents went down refreshingly. McTier is witty, irreverent, and deeply knowledgeable in all matters astrophysical.

After introducing herself, the Milky Way (now's your turn to suspend disbelief) notes that we have given her many names, among them Silver River, Way of Birds, and the Deer Jump. Most, she stresses, derive from myths, which are "tools for understanding the natural world and communicating that knowledge to others."

Through her protagonist, McTier succeeds in communicating heaps of specifics engagingly. We learn that, in the first tiny fraction of a second, the universe during the Big Bang inflated by 100 septillion, or 10^{26}. (The author enjoys toying with big numbers, as when she informs us in the Notes that $10^{10,000}$ is ten tremilliatrecendotrigintillion.) "Every single proton, neutron, and electron in your body was made in the first three minutes after the Big Bang," our galaxy informs us. "That must blow your little human mind!"

As she unfolds the Milky Way's life story, McTier delves into the cosmic background radiation, galaxy evolution, black holes, dark energy, and much more. She explains interferometry and Hawking radiation and the main sequence, all in easy-to-grasp ways. Fittingly, she honors the major contributions to astronomy by women such as Annie Jump Cannon and Henrietta Swan Leavitt (*S&T:* Dec. 2021, p. 12).

McTier always factors in the big picture and deep time, as when the Milky Way mentions that in the next four or five billion years, the Andromeda Galaxy will get so close to her that "the spiral beauty will stretch across half your sky . . ." (What a sight that will be, if any intelligent beings are around to appreciate it.) Or how the Moon, which drifts away from our planet every year by about 3.8 centimeters (1.5 inches), will eventually lie so far that total solar eclipses will no longer occur on Earth.

The author's sense of humor shines throughout. Upon explaining that the Small Magellanic Cloud is called an *irregular dwarf galaxy*, the Milky Way says, "'Irregular,' as far as I can tell, is a human astronomer's way of saying 'misshapen blob' without sounding rude or overly colloquial." After introducing the term *parsec*, our galaxy-cum-author remarks, "In case it makes a difference, and you aren't just reading these values as 'blah blah blah *really big number* blah blah blah,' one parsec is a little more than three light-years."

Humor is subjective, of course, so whether this style — and McTier's approach as a whole — gratifies or grates will be up to each reader. But, while I can't say I gained a new way of contemplating the universe, I did enjoy the read, learned a few things, and felt upon finishing that, if this take appeals to a wider or just different demographic than the usual introductory books on astronomy, excellent. It's all about getting the word out and inspiring people, however you go about it.

Editor in Chief **PETER TYSON** *did* like the Milky Way in the end and looks forward to our next rendezvous.

Finders' Keepers

Prevent catastrophe with these simple modifications.

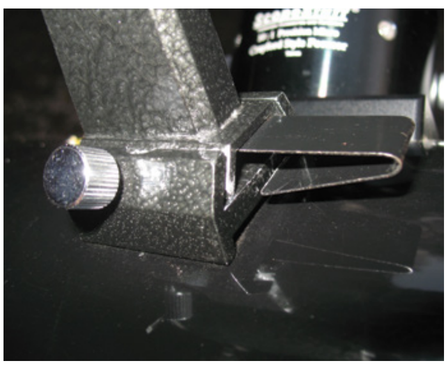
A piece of spring steel can prevent your finder from slipping out of its backward-facing mounting shoe.

IN OUR NOVEMBER 2022 issue I went on a bit of a rant about eyepiece undercuts, entreating manufacturers to end that pointless practice. At the end of the column I also mentioned the backward finderscope brackets that come on so many commercial telescopes, and how they're practically designed to dump your finder onto the pavement some cold night.

The problem is simple: The dovetail foot on many quick-release finder mounts loads into its shoe from below. A clamp screw holds the foot in place, but when that screw loosens and your telescope is pointed upward (where else would it be pointed?), the finder slips right back out of its shoe and falls to the ground. If you have an open-truss telescope, the finder could just as easily fall on your primary mirror. "Darn" wouldn't be the word you use when that happens.

The foot does have a stop on it to prevent sliding all the way through the shoe, so the most obvious fix would be to turn both foot and shoe around, so the finderscope mount loads from the front. Unfortunately, most finders aren't designed to be reversible, and refractors often have the finder mount molded in. The next most obvious fix would be to screw something into the front of the dovetail foot that would prevent it from slipping out when the clamp screw loosens, but there's usually not enough metal there to hold a screw. Besides which, you need something that will let you remove the finder without tools when you want to.

After my finder fell to the ground and busted the eye lens (fortunately not badly enough to render it completely useless), I put my vast intellect to work on the problem and came up with what's probably a laughable kluge, but hey, it works.



When mounted in place, the bent portion of the spring steel drops down below the edge of the dovetail shoe, preventing it from falling out even if the clamp screw loosens.

JERRY OLTION (2)

I cut a piece of steel strapping, bent it into a tight J shape, and screwed it to the bottom of the dovetail foot with the hook of the J protruding forward and down. Now when I slip the dovetail foot into its shoe, the springy metal lets it slide in, then the hook pops down below the floor level of the shoe, preventing the foot from slipping back out. The clamp screw snugs the foot up against the side of the shoe, holding the finder rigidly in place, but if the clamp screw loosens — which it's wont to do as the metal cools — the springy steel hook prevents the finder from falling out.

To release the finder from its mounting bracket, simply loosen the clamp screw, squeeze the springy part to push it up above the floor of the shoe, and slide the whole works out.

You have to drill a hole and tap threads into the underside of the dovetail foot and drill a matching hole in the cargo strap. That's easy, but bending spring steel is tricky. Try bending it around a nail or a bolt so it doesn't kink and break.

New Jersey ATM Vic Palmieri came up with another solution: He made a U-shaped clip that fits over the side of the dovetail shoe, with tabs extending across both the front and the back of the shoe. A hole drilled in the right

▲ Vic Palmieri's fix uses a simple U-shaped clip that wraps around the front and back of the finder bracket.

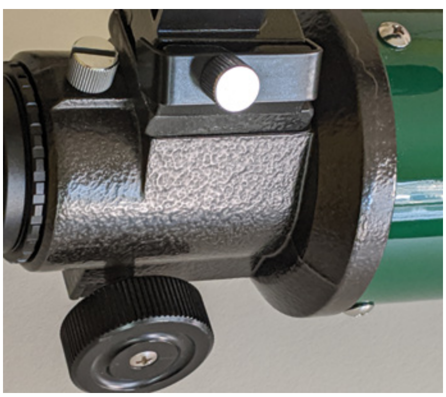
spot allows the clamp screw to reach through the clip into its usual spot in the shoe and press against the foot to hold it in place as always. But now if that clamp screw loosens, the clip keeps the finder from falling out. Vic recommends making a template out of light cardboard (like an index card) before you make the real thing. Also, a longer clamp screw may be required.

You have to remove the clamp screw entirely in order to remove the finder, but that's a small price to pay for security. Plus, Vic's design looks a lot nicer than mine. (He had his powder-coated to get that professional look.)

Either way you go, or if you design something else yourself, it's well worth the effort to lock your backward-mounted finder in place.

■ Contributing Editor **JERRY OLTION** loves solving problems, but he sometimes wishes the designers hadn't created them in the first place.

▼ When the clamp screw is tightened with the clip in place, the clip keeps the finder foot safely in its shoe.



VIC PALMIERI (2)

What Are the Greek Letters on Star Charts?

TAKE A CLOSE LOOK at the central star map featured on pages 42–43 — or at the snippet at right. You'll see that besides the constellation names (in purple) and star names (in white) there are Greek letters accompanying many of the star symbols. (Messier objects are prefixed with the letter "M.") You might very well have been wondering what those curious characters mean and what purpose they serve. Well, we're here to clear that up for you.

Higgledy-Piggledy Heavens

There wasn't much organization to the heavens back in the mists of time, when early stargazers first cast their eyes skyward. We owe much of our knowledge of the ancient skies to the 2nd-century Alexandrian astronomer, Claudius Ptolemaeus, better known as Ptolemy. His legacy is a fascinating compendium entitled the *Almagest*.

The *Almagest* counts 13 books, of which Books VII and VIII are a star catalog, one of the earliest known. Ptolemy expanded on the work of the great Greek astronomer and mathematician Hipparchus — in fact, it's largely thanks to Ptolemy that we know of Hipparchus's efforts. The *Almagest* lists 1,022 stars along with their celestial coordinates and magnitudes. Ptolemy ranked the brightest stars magnitude 1 and the faintest visible to the unaided eye magnitude 6, based on Hipparchus's original system. Each magnitude is twice as bright as the preceding one, making it a logarithmic scale. Ptolemy also arranged the heavens into 48 constellations, 47 of which are still in use today (see page 24). Such was the influence of the *Almagest* that it functioned as a textbook until the Renaissance, right up to when Nicolaus Copernicus placed the Sun at the center of our solar system.

During the ensuing centuries following publication of the *Almagest*, celestial cartographers used the information in Ptolemy's catalog to produce *star atlases*. However, more often than not, they placed stars randomly on constellation lines, dictated by artistic license rather than reality. Also, there was neither order nor method to the types or sizes of symbols used to denote the stars.

Take a look at the depiction of Orion from the *Leiden Aratea* (facing page, bottom left), dated to the Middle Ages. What do you see? Your first impression might be that it portrays Orion as the mythological hunter, holding up an animal skin folded over his left arm and his sword hanging from his belt. You might notice that the stars are all similar in size — and if you're familiar with the constellation, you'll also see that there appear to be extra stars on the Hunter's back and several missing in places where we'd expect to see some. It might be a pretty picture, but it's not terribly useful to the serious astronomer.

Thankfully, a systematic-minded celestial cartographer took the matter into his own hands and tidied up the heavens for us.

Enter the Greeks

German magistrate and amateur astronomer Johann Bayer published a celestial atlas in 1603 that organized the stars into 60 constellations. He largely drew on the meticulous work of Danish astronomer Tycho Brahe for Northern Hemisphere star magnitudes and positions. Bayer's opus, entitled *Uranometria*, was the first star atlas to portray the constellations around the south celestial pole (gathered together in a single plate). In addition, Bayer's constellations reproduce the stars as we see them *looking up* into the night sky — until then, many star atlases and globes showed the constellations as if we were *looking down* onto the celestial sphere.

Most importantly for our discussion, Bayer introduced the letters of the Greek alphabet to label the brightest stars in a constellation. Not only that, he arranged them in order of magnitude. So (for the most part) he assigned Alpha to the brightest star, Beta to the next brightest, Gamma to the third brightest, and so on. (When he ran out of the 24 letters of the Greek alphabet for larger constellations with many stars, he continued with a system using Latin letters.) Auriga, the Charioteer, and Taurus, the Bull, are good examples of Bayer's methodical approach.

But as always there are exceptions. Let's take another look at our friend Orion, the way Bayer portrays him (below right). First, the good news — you'll note that he oriented the figure the way we see the Hunter in the night sky. Also, brighter stars *appear* larger than fainter stars, so Bayer used different-size symbols to illustrate this. You'll note that Bayer drew two stars much larger than the others: Betelgeuse (the shoulder) and Rigel (the foot). See the Greek letters by those two star symbols? Yup, they're Alpha and Beta. The only problem is that the Beta star (Rigel) is, in fact, slightly brighter than the Alpha star (Betelgeuse). The same fate befell nearby Gemini, where Pollux — the brightest star — bears the Beta designation, whereas his dimmer twin Castor carries the Alpha label. One of the more popular explanations is that Bayer may have assigned the letters according to the order in which the stars popped above the horizon as they rose in the east.

To properly denote stars' names using Bayer's system, you'll also need

Greek Alphabet

α Alpha	β Beta	γ Gamma	δ Delta	ε Epsilon	ζ Zeta
η Eta	θ Theta	ι Iota	κ Kappa	λ Lamda	μ Mu
ν Nu	ξ Xi	ο Omicron	π Pi	ρ Rho	σ Sigma
τ Tau	υ Upsilon	φ Phi	χ Chi	ψ Psi	ω Omega

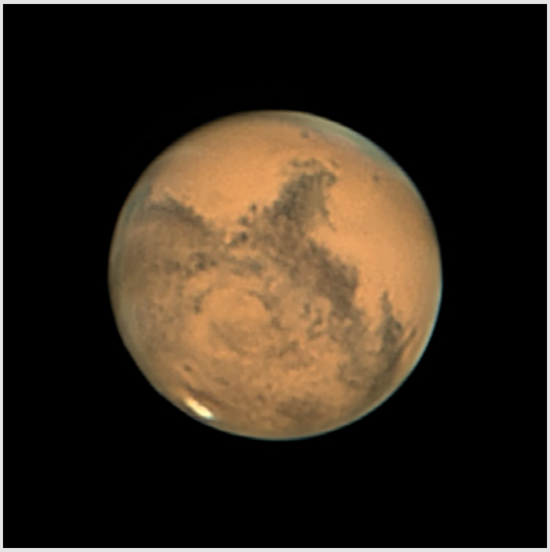
to know Latin grammar — a star's complete designation consists of the Greek letter followed by the constellation's genitive case. Let's look at Betelgeuse, the Alpha star in Orion: Its Bayer name is Alpha Orionis. The good news is you don't need to memorize all this — a useful resource is at **https://is.gd/SandT_constellations**.

Regular readers of this magazine will notice that in our observing articles and columns we include the symbol for the Greek letter in parentheses thus: Alpha (α) Orionis. This helps you easily identify which star we're discussing when you refer to the finder chart in the article (or the central star chart). You can snap a photo of the handy table above so you always have it with you (or you can look for a similar version online).

So when you study the central star chart or peruse our *Pocket Sky Atlas* you can thank a meticulous German celestial cartographer for systematically organizing the night sky for us. ■

▼ **ORION IN THE MIDDLE AGES AND BY BAYER** *Left:* A plate from an astronomical treatise from the 800s shows the mythological hunter Orion, but not as we'd recognize him today. For starters, we're seeing him from the back. And the star symbols are all presented the same size as if they were all the same brightness, which is clearly not the case. *Right:* Johann Bayer introduced the Greek lettering system to label stars, adopted the world over. By introducing this convention, he instilled order and method in star charts and atlases. Today we tend to use larger symbols for the Greek letters, but look closely and you should spot them in the chart below. Refer to the table above to learn the letters' names.

MIDDLE AGES ATLAS: LEIDEN UNIVERSITY CATALOGUE / PUBLIC DOMAIN; BAYER ATLAS: JOHANN BAYER / PUBLIC DOMAIN



▷ RED PLANET RENDEZVOUS

Jeff Phillips

Mars presents an abundance of fine detail in this image recorded on October 10, 2020. Dusky Syrtis Major Planum (top) stands out against the planet's sandy plains, while the white South Polar Cap (bottom) has nearly shrunk out of sight.

DETAILS: *Celestron C11 Schmidt-Cassegrain and ZWO ASI224MC camera. Stack of thousands of video frames.*

▽ CELESTIAL SPECTER

Dan Crowson

LDN 974 in Cygnus is a dark cloud of gas and dust that permeates the star field like a shadow. Open cluster NGC 7062 is the tight knot of stars at bottom left.

DETAILS: *Astro-Tech AT90EDT refractor and SBIG STF-8300M camera. Total exposure: 4 hours 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.

COSMIC QUERY

Chuck Ayoub

The large emission nebula NGC 7822 resides about 3,000 light-years away, overlapping the borders of Cygnus and Cassiopeia. When framed to include Sharpless 2-170 (bottom), the composition leaves the viewer with a big question mark.

DETAILS: *William Optics RedCat 51 II APO refractor with ZWO ASI2600MC Pro camera. Total exposure: 18½ hours through narrowband filters.*

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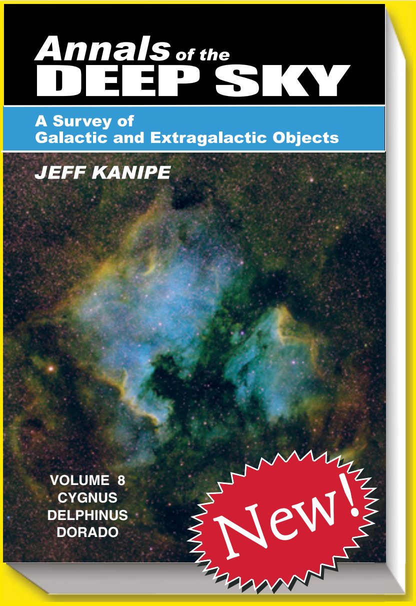

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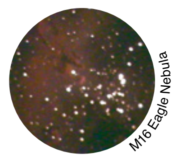

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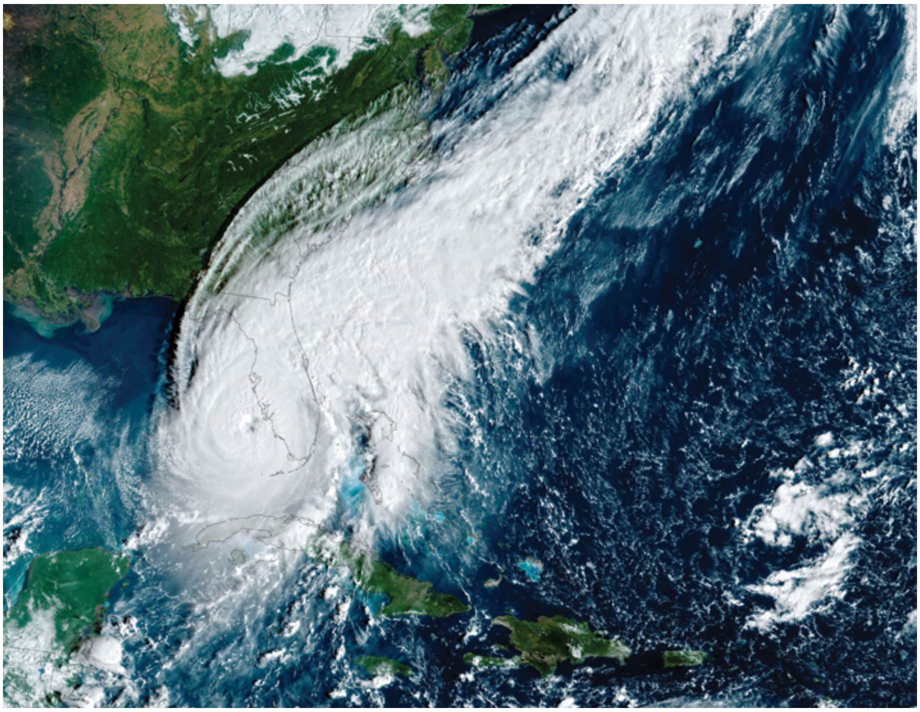
Even the Darkest Clouds

One day after Hurricane Ian devastates his area of coastal Florida, the author finds a silver lining.



◀ Hurricane Ian's eye passes just west of Fort Myers, Florida, on September 28, 2022.

NOAA VIA GETTY IMAGES

I GREW UP in Queens, New York, where the night sky was unremarkable at best. On the clearest evenings, only the brightest stars were visible, and they never really caught my attention.

One day in 1965, when I was 12, my parents decided that for our summer vacation our family would take a road trip out West. It proved to be a grand adventure. We hit many national sites, stopping first at Mount Rushmore and Yellowstone in the north before continuing on to California, where we drove down the coast then headed back east through the southern states.

The day that changed my life occurred in Grand Canyon National Park in Arizona, where we stayed overnight in a park cabin. The cabins were primitive affairs, with shared outhouses and only one dim light outside so you could find your way back in the dark.

That night I ventured out to use the facilities. I informed my parents where I was going, but when I hadn't returned a half hour later, my mother came looking for me. She found me standing just outside the circle of cabins, staring up at the star-filled sky. When she asked what I was doing, I pointed up in amazement and said, "Mom, where did all those come from?"

My mother stood with me for a few minutes, unable to answer my sky questions, and finally said it was time to go in. Embarrassed, I had to admit I hadn't yet used the outhouse. I was hustled off to finish what I came out for.

Back home in New York, I devoured astronomy books and studied the heavens with my dad's World War II binoculars. Although disappointed with the severely limited New York celestial sphere, I did my best with what I had.

Decades later, in 1998, I moved to North Fort Myers, Florida. The sky was better than New York's but still not great, and it has since become far worse. The Milky Way is barely visible on the most transparent of nights and only if you know exactly where to look.

Jump to September 28, 2022, when Hurricane Ian plowed through our part of southwest Florida. It decimated our barrier-island communities, tearing up bridges, buildings, homes, and trees. The storm surge flooded our community and left behind a dreadful death toll. Everyone experienced shock and horror. That first night after the storm I went to bed exhausted and depressed.

The next day Floridians began the long process of recovery. Once again, as evening came, I felt spent from the day's travails and looked forward to an early bedtime, as none of us had power except for the few with generators.

As I took the dog out one last time, I looked up, as I have ever since that night in Arizona. Déjà vu! The Milky Way was clearly visible — I could easily follow its hazy glow from Cassiopeia all the way south to Scorpius. With the widespread power outages, light pollution had become almost non-existent.

Exhaustion be damned. After staring up for a few minutes, I ran to get my Celestron C8. I made sure to tell my wife what I was doing, not wanting a repeat of that situation so many years ago. I set up the scope and observed long into the night, largely forgetting about the storm and its terrible aftermath as I reveled in the sight of an incredible, nearly unrecognizable sky.

Sometimes the darkest of clouds have a silver lining.

■ **BOB KONIOR** lives with his wife in North Fort Myers, Florida.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