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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

NOVEMBER 2024

Stellar Wonders in the Triangulum Galaxy

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THE ESSENTIAL GUIDE TO ASTRONOMY

November 2024 VOL. 148, NO. 5

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ON THE COVER

The spiral galaxy M33 in Triangulum

PHOTO: JOSEF PÖPSEL / VOLKER WENDEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY

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A Paean to the Pleiades

THE SEVEN SISTERS PACK a punch. No other star cluster — indeed, hardly any other deep-sky object — has so captured the imagination throughout human history as the Pleiades.

Partly this is due to proximity. M45, as it's also known, is among the nearest star clusters to Earth, and it's the most obvious one to the naked eye. It's a common sight in Northern Hemisphere winter skies, and it's readily visible in much of the Southern Hemisphere as well.

But it's more than that. The Pleiades have held a special appeal to humans for thousands of years. As Ray Norris notes in his article on page 36, the earliest known possible image of the open cluster dates back roughly 20,000 years. The Pleiades are mentioned in the Bible, in Homer's *Iliad*, and in the ancient Sanskrit epic *Mahabharata*. Practically every culture across our collective past has held traditions about the cluster.

▲ M45, the Pleiades open cluster

NASA / ESA AND AURA / CALTECH

Look at the map on page 40. Starting in Africa, wherever we go along the arrowed routes of our ancestors' migration around the planet, we find evidence that peoples cherished the Pleiades. (Though other scholarly interpretations exist, the following come from "The Mythology of the Lost Pleiad" by Eileen Starr, **https://is.gd/lostPleiad**.)

The ancient Egyptians considered the Seven Sisters the stars of the goddess Hathor. The Mesopotamians knew the cluster as Sevenfold One (or simply Star), the Phoenicians as Seven Stars. One Arabic name for it was a Herd of Camels.

Moving into Europe, we find views of Seven Little Nanny Goats (Spain) and Seven Pigeons or Dovelets (Sicily). In Asia, General of Celestial Armies (India), Six Idle Girls (Japan), and Mother Hen and Six Chicks (Borneo). Still farther from Africa, 13 Women in a Grass Shelter in Their Camp (Australia) and Seven Left Eyes of Seven Maori Chiefs (New Zealand). Lastly, American peoples who have held the Pleiades dear include the Quechua (Storehouse), the Maya (Rattles of the Rattlesnake), and the Wyandot of Ontario (Seven Singing Maidens).

As these references indicate, beliefs about what the Pleiades represent differ widely. (For yet more examples, see Steve O'Meara's "Tales of the Pleiades" on page 45.) They even vary on the number of Pleiads visible to the naked eye.

But one thing is for certain: Just about everybody who has ever lived has known the Pleiades. Along with our common ancestry in Africa and the night sky overhead, it's something we all share. Next time you gaze at the cluster, how about coming up with your own designation?

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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Shadow Alignment

I saw Rich Tansey's "Sun Scout" (*S&T:* July 2024, p. 6) and had to send a picture of my Sun-Spotter. It's a flat board with a bolt screwed through it perpendicularly. The Sun is centered in my telescope by holding the Sun-Spotter flat to the objective end and adjusting the scope until there is no shadow.

John Pember • Beaumont, Texas

Encouraging Beginners

I'm disappointed in the attitude expressed by Gary Seronik in "How Powerful Is Your Telescope?" (*S&T:* July 2024 p. 74) and Jerry Oltion in "Go Looney for Luna!" (*S&T:* July 2024, p. 34) regarding department-store telescopes. I am glad they weren't hosting the new telescope workshop that I attended with my 2-inch Sears telescope more than 50 years ago. If they had, my interest would probably have been killed.

Instead of telling the neophyte how poorly mounted it is, or how small the optics are, show them how to use their telescope and what they can see with it. Show them how to align the finder, maybe add some weights to balance the tube, and tighten the axis enough to allow gentle movements to follow an object. Tell them how to see the Sun safely (and to get rid of those dangerous screw-in solar filters). Pass out a Moon map and star charts. Give them a list of online resources and encourage them to keep a notebook and make sketches. I also hand out older copies of *Sky & Telescope* to the ones who seem to have a keen interest and suggest they join a local club if available.

I am often asked by parents and spouses to recommend a telescope to give as a gift. No, I don't endorse department-store telescopes, pointing them instead to online suppliers. But I always recommend that they give a subscription to *S&T*. Let's be sure we're encouraging the joy of astronomy, rather than being the "hobby-killers."

Bob Anderson
Green Bank, West Virginia

Gary Seronik replies: *I'm glad that, like me, you steer newcomers to our hobby to better scopes than the ones you and I started off with — though I suspect your 50-year-old Sears scope was probably of very good quality and not a "trash scope."*

The term "department-store trash scope" (as you probably know) has been around for quite a while and I believe originated in the 1980s. It's meant to describe (and disparage) scopes like the one I saw in Costco not that long ago, which was a 60-mm refractor advertising 675x magnification. We all know that kind of scope, and I think we'd agree that it's likely to do more harm than good when it comes to introducing beginners to the wonders of the night sky. In the case of my Beginner's Space column, I was simply trying to point out that there is such a thing as excessive magnification.

Incidentally, my first scope (which I still have) was a 3-inch Tasco reflector bought at Sears. The maximum magnification listed on the box is 140x — entirely reasonable. Mind you, that was accomplished with a dreadful Huygenian eyepiece, so it wasn't, strictly speaking, practical. But with better eyepieces, that scope performs very well — possibly as well as your 2-inch refractor!

The Pac-Man in the Moon

I loved Jerry Oltion's "Go Loony for Luna!" (*S&T:* July 2024, p. 34), especially the imaginative illustrations. Given the "estimated bazillion craters" on the Moon, my question for Jerry Oltion and readers is the ultimate challenge. Can you help me find a needle (crater) in this enormous (22.3 million-square-km) haystack? I saw it 15 years ago from the southeastern U.S. and haven't seen it since. I don't know what it was or even exactly where it was (except maybe kind of in the middle-ish). But here is a hint: It looked exactly like a Pac-Man with a dark V-shape shadow of a mouth facing more left/right than up/down. Surely someone else in the last 44 years since the release of that game must have seen it too and noted the uncanny resemblance. This has been driving me, well, loony. Any help would be appreciated!

Günther Junker
Toccoa, Georgia

Jerry Oltion replies: *I haven't heard of a Pac-Man on the Moon, but with all those circular craters and triangular shadows at low lighting angles, I'm not surprised that you've see one there. The surprising thing is that there aren't hundreds of them. I've asked around, run the* Moon Globe HD *app through its phases, and looked at the lunarisms listed on several websites, but the only mention I found of a Pac-Man-like feature was Banting Crater in Mare Serenitatis. The Wikipedia photo of it does indeed have that appearance, but the crater is only 4 miles across, so it's unlikely that's what you saw. Perhaps another reader will know of a more likely suspect. And in the meantime, you've given us yet another reason to take a close look at the Moon!*

Kudos, Camille

I just caught up with the July issue and read Camille M. Carlisle's lucid News Note "Strong Magnetic Fields Swirl Near the Milky Way's Black Hole" (*S&T:* July 2024, p. 10). She is outstanding!

When I read about dark energy or dark matter, the words of two people come immediately to mind. First, Camille Carlisle's prose — here, inexactly reproduced — incisively labeling these terms as "convenient placeholders" for poorly understood phenomena. Second, Nobelist R. B. Laughlin's remarks on theory and observation: "I have since discovered that most good theorists think this way. They always want to know the experimental facts, are intolerant of theories substituted for facts, and understand the difference with crystal clarity." Of all science writers, I have found that Ms. Carlisle most consistently and

JOHN PEMBER

rigorously preserves and highlights that distinction. She best describes what researchers actually did and measured, not just how they interpret their work.

Bob Wieting
Simi Valley, California

A Word of Advice

I just wanted to congratulate Sean Walker and Dennis di Cicco on their co-discovered nebula, WD-1 (*S&T:* June 2024, p. 4) and wish them continued success in the future. However, if they do continue on this path, they might want to skip WD-40. Just saying.

Gary Leiker
Lubbock, Texas

From the Hilltops

Allow me to shout from the star party's darkened hilltop that "F-Bombs in the Night" by Jerry Oltion (*S&T:* June 2024, p. 84) was the most *F-bombing* hilarious astronomical story I've read in ages! Indeed, I admit I likely dropped one or more of those bombs while at the eyepiece. Thanks, Jerry!

Pete Zapadka
Palm Harbor, Florida

Working with the Plates

I enjoyed reading "A Century of Sky, Digitized" by Arielle Frommer (*S&T:* Aug. 2024, p. 9). In the late 1960s, I was an undergraduate student at the University of South Florida working for the astronomy department. I measured star positions from some of the plates from the Harvard Observatory described in her article. Heinrich K. Eichhorn-von Wurmb, the department head, was at that time one of the premier astrometric astronomers in the world.

The measuring machine used was a large, dual-axis device that utilized a microscope system with highly accurately machined, hand-operated screw drives that moved the crosshairs of the microscope. When the crosshairs were moved from the starting position to the target star, a foot pedal connected to a computer recorded the position. Three measurements of each star were taken. Some 128 stars were picked for use in the study. The plates were extremely carefully transported from the Harvard Observatory archives, handled and returned. I thoroughly enjoyed my participation in this work. I have been a subscriber of *S&T* and an amateur astronomer since age 8. I am now 80.

David Knowlton
St. Petersburg, Florida

FOR THE RECORD

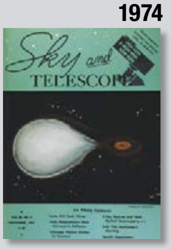
● On page 45 of the August issue in "Hercules and Ophiuchus Head-to-Head," the name of the mortal princess Alcmene was misspelled Alceme.

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

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

1949

1974



1999

◖ November 1949

Gradual Occultation "On June 9th, D. W. Rosebrugh, of Waterbury, Conn., . . . timed the disappearance of Antares behind the moon [as taking] from 0.2 to 0.5 second. When he pondered the matter, he realized that the apparent diameter of Antares, about 0".04, would require an immersion time for this star of about 1/12 second, since the moon moves one second of arc in two seconds of time. The occultation he observed, however, was almost tangential, accounting for [an even more gradual] immersion."

The vast majority of stars, when occulted by the Moon, seem to blink out instantaneously.

◖ November 1974

Mercury Flyby "On September 21st, Mariner 10 swept past Mercury [in its] second visit to the planet's vicinity. [One image mosaic] shows the 'weird terrain,' characterized by a rough, scabby surface and greatly degraded crater rims, often with downslope gouges like landslides. This appearance is also found on the moon in the areas antipodal (directly opposite) to the large impact basins Mare Imbrium and Mare Orientale.

"Since Mercury's 'weird terrain' lies at the antipodal point of the 1,300-kilometer impact area known as Caloris Basin . . . there is a possible connection between the two features. It has been suggested that the Caloris impact produced a shock wave intense enough to propagate all the way through the planet and, being concentrated at the antipodal point, caused a violent upheaval that produced the scabby surface."

In his first major piece as a staff member, Kelly Beatty authored an eight-page special supplement of newly released Mariner 10 images.

◖ November 1999

Bygone Cataclysm "I am sitting on top of an ancient lava flow, amid a mile-high forest of ponderosa pine. It is dark, and the star-studded autumn sky is brilliant from my perch in the arid Southwest. While it looks incredibly peaceful now, 50,000 years ago an iron asteroid tens of meters in diameter . . . slammed into the plateau sediments below [and] excavated 175 million tons of rock in a flash . . . What remained were a 1-km-wide crater and the scattered remnants of the asteroid. . . .

"We cannot know if it was day or night when the iron asteroid came hurtling through the sky 30 to 40 times faster than the speed of sound, but the mammoths and mastodons surely turned with wide eyes to see the brilliant meteor as it fell to Earth. Depending on its velocity, a meteorite this size would have [appeared] up to 10,000 times brighter than the Sun . . ."

David A. Kring (Lunar and Planetary Laboratory) noted that Arizona's famed Meteor Crater has much to teach us about the ecological consequences of asteroid impacts.

TELESCOPES

Meade and Orion Cease Operations — Maybe

RUMORS ARE SWIRLING after two former giants in the astronomy industry closed their doors earlier this week.

Optronic Technologies, Inc., better known to backyard astronomers as the parent company of both Orion Telescopes & Binoculars and Meade Instruments, has shut its offices and storefront in Watsonville, California. Sources have told *Sky & Telescope* that all of the staff were let go at the end of the business day on July 9th, but as of press time, the company has not yet filed for bankruptcy.

For much of its five decades in business, Meade Instruments was one of the world's largest designers and manufacturers of telescopes and accessories for amateur astronomers, particularly with its line of Schmidt-Cassegrain telescopes as well as its Coronado line of solar telescopes. Meade manufactured most of its telescopes and electronics in a plant in Tijuana, Mexico, and had worked closely with independently owned and operated retailers to serve amateur astronomers.

Orion Telescopes & Binoculars, owned by Optronic, made a name for itself in the late 1990s as a source of quality gear for the budget-minded amateur astronomer. Some of its popular scopes include the ShortTube 80 and the StarBlast 4.5 Astro Reflector Telescope.

Shortly after Optronic Technologies won a 2019 antitrust lawsuit against Sunny Electronics, Meade's parent company at the time, Meade filed for Chapter 11 bankruptcy protection (*S&T:* Apr. 2020, p. 11). The company was subsequently purchased by Optronic Technologies in 2021. But Optronic was encountering supply-chain challenges and had difficulty maintaining stock.

As of press time, **telescope.com** and **meade.com** — the primary websites for Meade and Orion products — are still accepting orders.

Neither Meade nor Orion has responded to multiple inquiries or issued an official announcement. Visit **https://is.gd/MeadeOrion** for updates on this developing story.

■ **SEAN WALKER**

SPACE

NASA Cancels VIPER Lunar Rover

THE VIPER LUNAR ROVER, short for the Volatiles Investigating Polar Exploration Rover, was originally designed to search for ice and other potential resources in the cold, dark, and rugged conditions at the south pole of the Moon. It would have touched down on the surface aboard the Griffin lander, developed by the aerospace company Astrobotic as part of NASA's Commercial Lunar Payload Services program. The team was aiming to drive VIPER some 20 kilometers (12 miles) on the lunar surface over 100 days, going in and out of permanently shadowed regions.

But now, it won't be doing any of those things. In a July 17th press conference, NASA announced it was canceling the rover; Astrobotic's Griffin lander, on the other hand, is still moving forward.

While praising VIPER team members for their persistence and ingenuity, Joel Kearns (NASA HQ) notes that the rover, originally scheduled for launch in 2023, was haunted by supply-chain issues. "The delays occurred over and over for several key components," he adds. Those delays pushed back the assembly, integration, and testing of the golf cart–size vehicle. While the assembly was completed, the rover is only now beginning environmental testing.

When VIPER was due to land on the Moon in 2023, its cost had been budgeted at $433.5 million. NASA delayed launch until no earlier than November 2024 so that Astrobotic could conduct propulsion tests on its lander. That upped VIPER's budget to $505.4 million — and $450 million of that has already been spent to assemble the rover. However, the delays related to supply-chain issues were about to necessitate another push back, to September 2025. (That timing is in part constrained by the solar-powered rover, which needs to operate during "summer" at the lunar south pole, when the Moon's slight tilt makes more sunlight available.) The delay to 2025 would have entailed another budget increase to $609.6 million as well as unknown future costs such as those that can crop up during testing. In addition to the cost increase, the change could have set off a chain reaction for subsequent commercial missions, says Nicola Fox, associate administrator of the Science Mission Directorate.

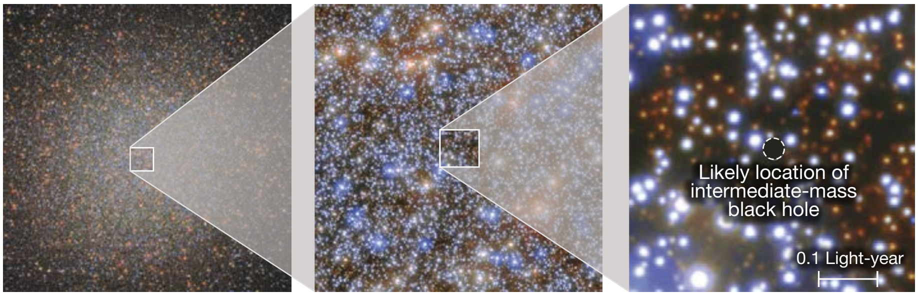
◀ NASA's VIPER rover sits assembled inside the cleanroom at the agency's Johnson Space Center.

NASA

"We are in a highly constrained science budget environment at NASA," Kearns says. "Science at NASA was $1 billion less in the current fiscal year than what was requested from Congress . . . and we're getting indications that the environment will also be constrained in the next fiscal year."

Yet VIPER may see a second life: NASA has called for proposals for the use of its scientific instruments and/or the vehicle itself. Meanwhile, the Griffin lander is still due to launch in late 2025. Also, companies Firefly Aerospace and Intuitive Machines are intending to launch missions carrying NASA payloads to the Moon no earlier than late 2024.

■ **MONICA YOUNG**



◀ Three panels zoom into the core of Omega Centauri, which could hold an intermediate-mass black hole (within the dashed circle).

BLACK HOLES

Intermediate-mass Black Hole in Omega Centauri

A GIANT BLACK HOLE might lurk at the center of a southern-sky jewel, the globular cluster Omega Centauri. In the July 11th *Nature*, Maximilian Häberle (Max Planck Institute for Astronomy, Germany) and colleagues show that seven stars in the cluster core move so fast that they would have escaped if not for the additional gravity of a massive central object.

Previous spectroscopic measurements had already hinted at the presence of giant black holes in Omega Centauri, 47 Tucanae, M15, and other globular clusters. "What's spectacular here is that they have measured velocities of [so many] individual stars," says Simon Portegies Zwart (Leiden University, The Netherlands), who was not involved in the study.

Häberle and colleagues examined 1.4 million stars belonging to Omega Centauri in more than 500 Hubble Space Telescope observations taken over the past 20 years. Close to the cluster's center, they found seven stars moving across the sky faster than 2.41 milliarcseconds per year, which corresponds to the cluster's escape speed. The fastest among them has a *proper motion* of 4.41 milliarcseconds per year, corresponding to a projected velocity of 113 meters per second (250,000 mph).

These unexpectedly speedy stars require the presence of an object with at least 8,200 solar masses to hold them in the core. Since the team only measured proper motions, and the stars' 3D velocities are probably greater than that, the black hole could be even more massive.

Portegies Zwart says Häberle and colleagues are "absolute experts" in this field; however, he remains cautious about the team's conclusions. "We don't know the cluster's escape velocity very precisely," he says. If it's higher, the case for the giant black hole weakens.

However, if confirmed, Omega Centauri's black hole would be one of the most convincing examples of an *intermediate-mass black hole*, sought-after objects that bridge the gap between the stellar variety left behind by supernova explosions and their supermassive siblings in galaxy centers.

Next, the team will use the James Webb Space Telescope to measure the fast-moving stars' *radial velocities* (their speeds toward or away from us rather than across the sky). Additional Gaia data could also reveal curvature due to orbital motions.

■ GOVERT SCHILLING

NEUTRON STARS

Neutron Star Trio Reveals Inside Secrets

ASTRONOMERS SURVEYING dozens of neutron stars have homed in on three that are unexpectedly cool, narrowing down what makes up their interiors.

We still don't know the exact nature of neutron stars, which may contain quarks or even more exotic particles in their cores. The key to finding out what's really inside neutron stars is identifying the *equation of state* that describes the relationship between temperature and pressure in their interiors. There are hundreds of possibilities.

Now, a team led by Alessio Marino (Institute of Space Sciences, Spain) has narrowed the field, publishing findings on June 20th in *Nature Astronomy*.

Studying a collection of 70 isolated neutron stars with known ages, the team used X-ray measurements from the European Space Agency's XMM-Newton and NASA's Chandra missions to estimate their temperatures.

"Three of these neutron stars are much cooler than the others at similar ages," Marino explains.

All three of them are associated with a supernova remnant, which dates their ages to between 800 and 8,000 years old. In other words, they are astronomical infants. The team used machine learning to churn through the multitude of possible equations of state to narrow down which ones would permit such rapid cooling. This process resulted in the team discarding three-quarters of all models.

What's left? One possibility is that radioactive decay in neutron star cores produces neutrinos, which help carry away heat. Alternatively, the stars may be so massive that some of the central neutrons have broken down into their constituent quarks, either individually or bound together in exotic particles such as *mesons*.

▲ The 800-year-old supernova remnant 3C 58 contains an unexpectedly cool neutron star at its center. (X-ray data is colored red, green, and blue; visible light appears yellow.)

"The young ages and cold temperatures of these three have been known for 20 years," says Craig Heinke (University of Alberta, Canada), who was not involved in the research. "But this study is the first to systematically explore a large group of neutron star theories and delineate which theories are ruled out."

■ COLIN STUART

OMEGA CENTAURI CORE: ESA / HUBBLE & NASA / M. HÄBERLE (MPIA); SUPERNOVA REMNANT: X-RAY: NASA / CXC / ICE-CSIC / A. MARINO ET AL.; OPTICAL: SDSS; IMAGE PROCESSING: NASA / CXC / SAO / J. MAJOR

GALAXIES

Early Galaxies Test Ideas About Cosmic Evolution

LITTLE RED DOTS: That's how astronomers describe compact early galaxies that appear as ruby-colored smudges in James Webb Space Telescope (JWST) images (*S&T:* May 2024, p. 20). A new study, published in the July 1st *Astrophysical Journal Letters*, weighs three options that could explain these galaxies' red light.

Initial analyses found that such galaxies must host vast quantities of old stars, which appear redder than younger stellar populations. But that conclusion implies surprisingly massive bursts of star formation. Alternatively, dust might enshroud feeding black holes at the galaxies' centers, leading to the rose-tinted light.

Bingjie Wang (Penn State) and collaborators took a look at these options while exploring thousands of "little red dots" seen in early JWST images. Going back for near-infrared spectra, also from JWST, the team found three galaxies that emit a strong emission feature called the *Balmer break*, which indicates the presence of stars already more than 100 million years old.

However, the feature doesn't tell astronomers *how many* old stars there are, and Wang's team also finds that two of the three galaxies show signs of gas whirling around supermassive black holes. The astronomers thus construct three scenarios to explain the spectra, in which the light comes from old stars, from gas associated with the central black hole, or both.

◀ These three "little red dots" are compact galaxies hailing from the early universe.

"This paper . . . takes a considered and careful look at the data to test a range of possibilities, rather than pushing just one version of the narrative," says Adam Carnall (Royal Observatory Edinburgh, UK), who wasn't involved in the study.

The first of the options — only stars — suggests unexpectedly massive bursts of starbirth took place 500 million years after the Big Bang, or possibly even earlier. The second and third options, both of which include a black hole–related contribution, instead require the dark behemoth to be unexpectedly massive for such small galaxies.

In their summary, the team notes that "none of these models fully align with our current understanding of galaxy formation and evolution." Carnall cautions that cosmological conclusions await more data. Wang and colleagues agree, making the case for "deeper and redder" observations using JWST's mid-infrared capabilities.

■ MONICA YOUNG

OBITUARY

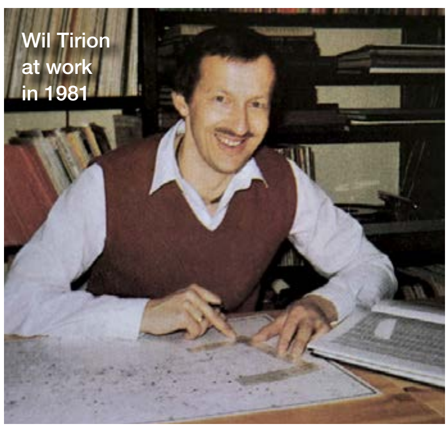
Wil Tirion, 1943–2024

WORLD-FAMOUS DUTCH astrocartographer Wil Tirion passed away on July 5, 2024. He will be remembered by his legacy of beautiful star atlases.

At 12 years old, Tirion had already become fascinated by star maps and even started to draw his own. But it wasn't until 1979 that his work was first published, in the form of five maps that appeared in *Encyclopedia of Astronomy* and later as the Britsh Astronomical Association's *B.A.A. Star Charts 1950.0*. Still as a hobby, Tirion began working on *Sky Atlas 2000.0*, published in 1981 by *Sky & Telescope*'s then-publisher, Sky Publishing Corporation, and Cambridge University Press. The atlas's 26 maps show 86,000 stars down to 8th magnitude, all drawn by hand.

At the time, Tirion had a full-time job as a graphic designer and illustrator at a printing office in Rotterdam. However, the success of *Sky Atlas 2000.0* led him to quit his job in 1983 to become a full-time *uranographer*, or mapper of the stars. Around that time, he began work on a new atlas that would become his biggest project.

The two volumes of *Uranometria 2000.0*, first published by Willmann-Bell in 1987 and 1988, showed more than 280,000 stars (down to magnitude 9.75) as well as many thousands of deep-sky objects. Although the maps were based on computer plots, most of the work was still done by hand. The same was true for his *Bright Star Atlas 2000.0* (coauthored with Brian Skiff) and *The Cambridge Star Atlas*, published in 1990 and 1991, respectively. By the mid-1990s, Tirion had replaced his drawing board with a computer, creating his maps with Project Pluto's *Guide* software, Adobe Illustrator, and an artistic feel.



Wil Tirion at work in 1981

Since then, Tirion's star maps have been published in numerous magazines, books, and websites. Tens of thousands of copies of his star atlases have found their way to public observatories and amateur astronomers. Asteroid 4648 Tirion was named after him in 1993.

Described as endearing, Wil Tirion died just weeks after finishing his latest star maps for numerous publications. He is survived by his wife Cokkie and his children Martin and Naära.

■ GOVERT SCHILLING

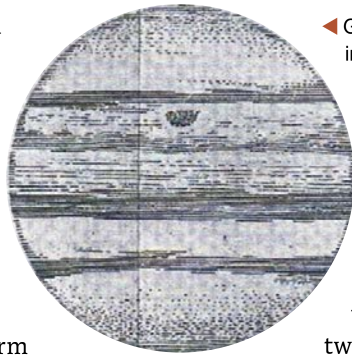
THREE "RUBIES IN THE ROUGH": BINGJIE WANG / PENN STATE; TIRION: MARTIN TIRION

SOLAR SYSTEM

How Long Has the Great Red Spot Really Been Around?

A NEW STUDY suggests that Jupiter's current Great Red Spot has been around less than 200 years. While Giovanni Cassini first drew his observations of a "permanent spot" on Jupiter in 1665, there's no evidence for a spot in records between 1713 and 1831. That has led some to suggest that the feature Cassini and contemporaries saw vanished; the one we know today formed more than 100 years later.

In the June 28th *Geophysical Research Letters*, a team led by Agustín Sánchez-Lavega (University of the Basque Country, Spain) explores this history by first quantifying the historical records, for example, by mapping past spots onto a globe and measuring their width and aspect ratio, while accounting for various filters through which observations were taken. The drawings from Cassini's time show a small, round spot, like today's, while 19th-century astronomers observed a wider spot.



◀ Giovanni Cassini drew many images of Jupiter's "permanent spot," this one in July 1677.

The researchers then turned to computer simulations based on storm growth observed on Jupiter and Saturn. As the researchers simulated events similar to the Great White Spot that formed on Saturn in 2010, they failed to produce a Jovian storm either large enough or with the right wind speeds. A second scenario — a merger of the sort that created Jupiter's Oval BA (*S&T:* Dec. 2000, p. 130) — seems likewise improbable, since the merging storms would have been large enough to be noticed by contemporary observers.

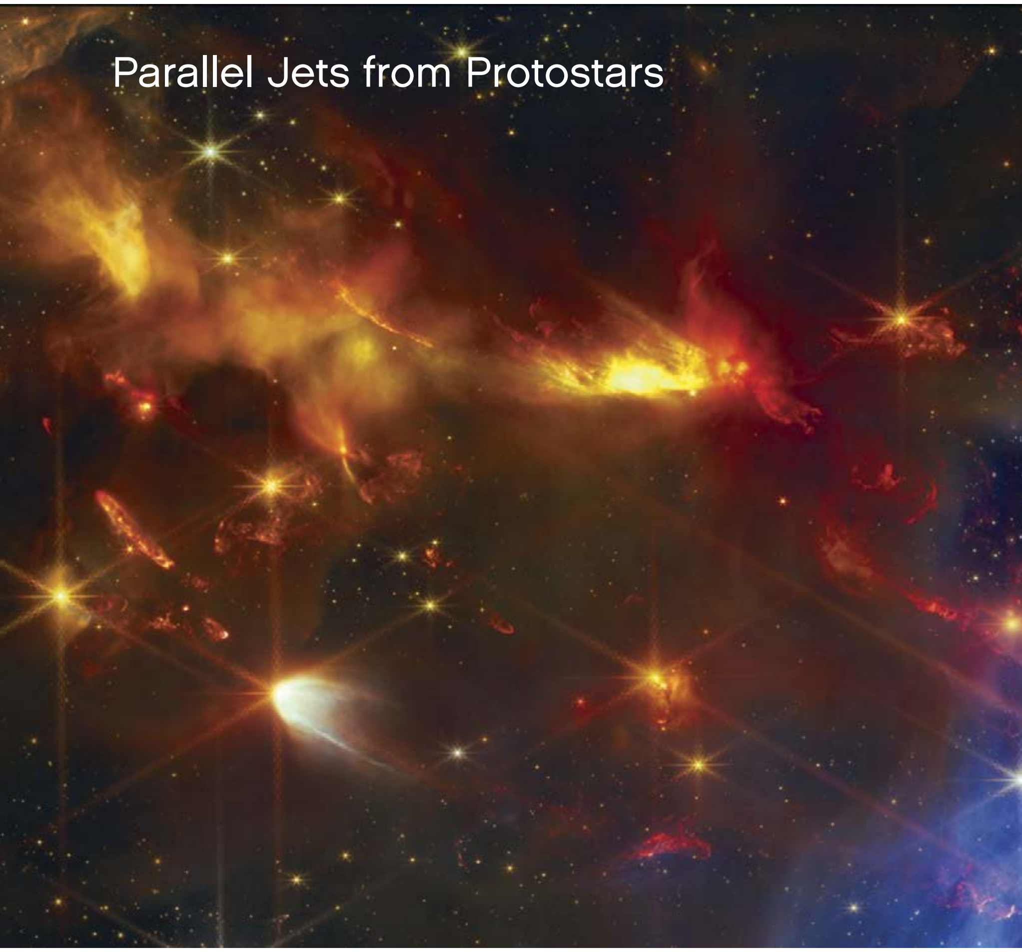
So the researchers turned to a third scenario, based on a phenomenon known as a *south tropical disturbance*: The dark-colored belt bulges, obstructing the flow of the lighter-toned one next to it. If two such disturbances form, they can pinch off a wide, rotating region that gradually pulls tighter, spinning faster and more coherently as it shrinks — all properties that have been observed in the modern Great Red Spot (*S&T:* Apr. 2002, p. 24).

Simulations alone never constitute proof, but these produce testable predictions: This study posits that the current Great Red Spot really is disappearing and that a third, giant spot will someday emerge.

■ EMILY LAKDAWALLA

NASA / ESA / CSA / STSCI / KLAUS PONTOPPIDAN (NASA-JPL) / JOEL GREEN (STSCI)

Parallel Jets from Protostars

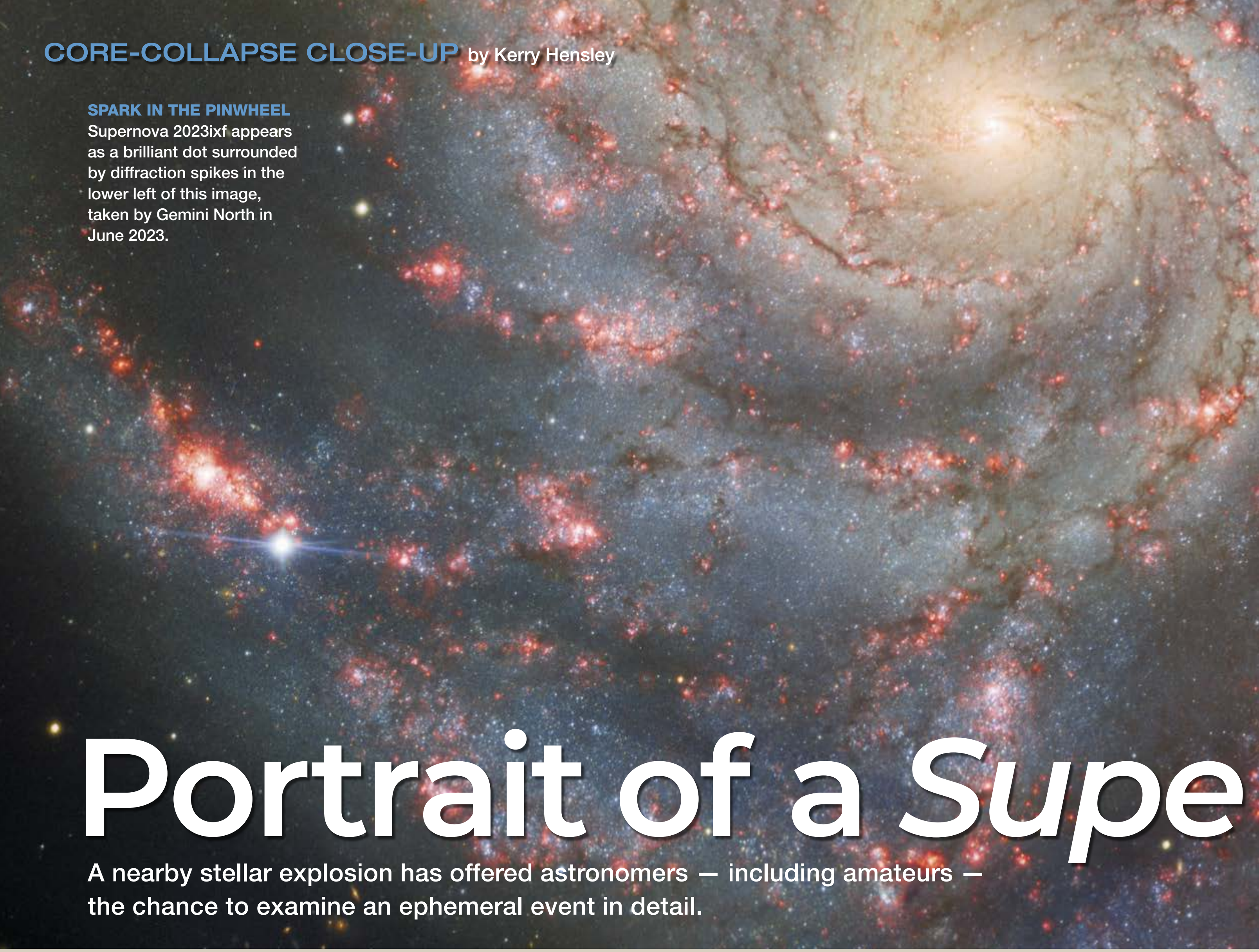


A near-infrared image taken by the James Webb Space Telescope (JWST) reveals unprecedented detail among the jets of material fleeing infant stars in the Serpens Nebula, 1,300 light-years from Earth. The nebula is about 1 to 2 million years old and contains some 100,000 newborn stars in a span of tens of light-years. This image zooms in on a torrent of neatly aligned streaks, revealing molecular hydrogen (red and orange) and carbon monoxide (red only). The latter is a molecule common to protostellar outflows. The streaks are gaseous outflows that formed between 200 and 1,400 years ago, as the newborn stars they come from started gathering material around themselves. The jets became visible as their gas collided with ambient material. "Almost all outflows are pointed in the same direction, to within plus or minus 10 degrees, which is extremely unlikely to happen by chance," says Joel Green (Space Telescope Science Institute), who led the study to appear in the *Astrophysical Journal*. "This means that stars are forming together as they fragment out of a larger collapsing cloud, like a litter of kittens."

■ ARIELLE FROMMER

Read more at **https://is.gd/JWSTjets.**

 by Kerry Hensley



SPARK IN THE PINWHEEL Supernova 2023ixf appears as a brilliant dot surrounded by diffraction spikes in the lower left of this image, taken by Gemini North in June 2023.

Portrait of a *Supe*

A nearby stellar explosion has offered astronomers — including amateurs — the chance to examine an ephemeral event in detail.

Some 22 million years ago, a massive star lost its lifelong battle against gravity. Its outer layers collapsed and rebounded against its shrunken core, creating an explosion seen galaxies away.

In May 2023, the light from this cosmic spectacle reached Earth, treating stargazers to observations of the nearest core-collapse supernova in more than a decade. Cataloged as SN 2023ixf, the event appeared as a bright dot in an outer spiral arm of the nearby galaxy Messier 101 (M101), also known as the Pinwheel Galaxy.

Within a few days of discovery, the explosion had brightened to be visible in 4- to 6-inch telescopes. Observers scurried to study it. A sprawling campaign united professional and amateur astronomers in a quest to soak up all the photons that this fantastic explosion had to offer, beginning mere hours after SN 2023ixf's discovery and stretching on into the present.

More than a year later, astronomers are still picking through the celestial rubble, piecing together the story of the exploded star's life.

The Investigation Begins

Amateur Koichi Itagaki, a prolific supernova hunter whose previous discoveries number well over 100, discovered SN 2023ixf on May 19, 2023, from his home observatory in Japan. Less than two hours later, a team led by Daniel Perley (Liverpool John Moores University, UK) recorded the first spectrum of the event. The spectrum indicated that SN 2023ixf was a kind of core-collapse supernova called Type II and confirmed that it lay in M101.

The time between discovery and the first follow-up was notably brief. Even more impressive, a look through observations from the vast network of amateur and professional astronomers showed that while Itagaki discovered the supernova less than a day after its light first reached Earth, another observer unwittingly caught the explosion even earlier: Chinese amateur Yiming Mao spotted the onset by chance, capturing an abrupt change in brightness in stacked five-minute exposures of M101 taken late on May 18th.

The quick discovery and follow-up gave researchers a rare glimpse into the earliest evolution of a supernova. In those

first days, the supernova's light changed rapidly, morphing from unexpectedly faint and red to brighter and bluer as the shock from the explosion clawed its way through dense, dusty gas surrounding the star. Early spectra showed a series of narrow emission lines — signposts that disclosed the chemical makeup and density of the gas that the supernova had expanded into. These telltale emission lines only lasted a few days, suggesting that the dusty gas was fairly confined. Rather than being arranged in a smooth shell around the star, this material appeared clumpy and asymmetric.

Early observations from infrared to X-ray wavelengths reinforced this picture. (The first detection of the supernova at radio wavelengths didn't come until about a month after discovery, and, curiously, the supernova wasn't detected in gamma rays at all, despite expectations to the contrary.) The space-based Nuclear Spectroscopic Telescope Array (NUSTAR) achieved one of its fastest-ever transitions from being notified of an event to viewing it, locking onto the supernova's X-rays just a few days after the explosion was discovered. The data revealed the fast-moving shock as it expanded into the surrounding gas.

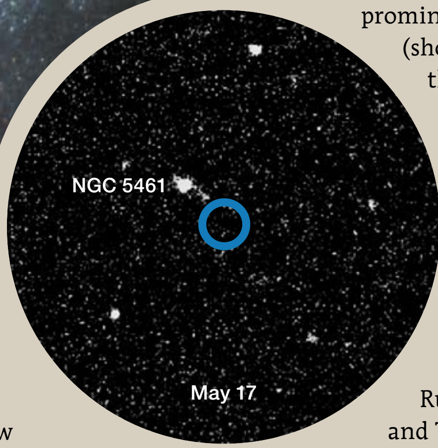
Together, the initial observations confirmed that SN 2023ixf marked the calamitous end of a star far more massive than the Sun.

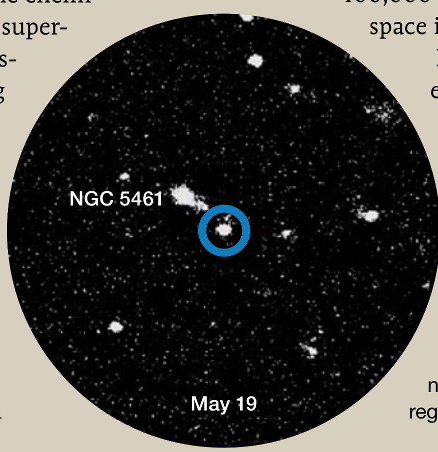
In the days after discovery, the supernova brightened from its discovery magnitude — 14.9 — to magnitude 10.8, becoming accessible to many backyard telescopes and attracting the attention of amateur astronomers across the globe. More than 200 observers reported their measurements of the event to the American Association of Variable Star Observers.

Amateur astronomer and college student Lauren Herrington was among the observers who turned their telescopes toward M101. Since entering college, Herrington has mostly traded all-night observing marathons for all-night homework sessions, but she makes time every couple of months to wrangle her 12-inch Dobsonian out of the garden shed on clear nights. SN 2023ixf was worth the effort.

"This is the first and possibly the last supernova that I will ever see where I could see color in it," Herrington says. "It was blue!" Later, when she looked up a spectrum of the blast, she was gratified to see both more light and more prominent spikes of emission toward the bluer (shorter-wavelength) end. "One other thing that made observing it special for me was that I observed it twice, two and a half hours apart, and I could see it had brightened in that time."

It's hardly a surprise that SN 2023ixf inspired so much excitement among astronomers. While uncommon cosmic phenomena often happen somewhere in the vastness of the universe — upcoming searches for fleeting events by the Vera C. Rubin Observatory's Legacy Survey of Space and Time are expected to discover 300,000 to 400,000 supernovae a year — our little corner of space is tiny and rarely visited by such explosions. But SN 2023ixf is more than just the nearest core-collapse supernova in more than a decade. It also might help astronomers make progress on one of the most stubborn problems in stellar evolution.





◀ **DISCOVERY** These two images of M101's southeastern spiral arm, from Itagaki's observatory, show the last nondetection *(top)* and the discovery *(bottom)*, respectively. The position of the supernova, circled in blue on both images, is next to — but not associated with — the star-forming region NGC 5461.

▲ **BLUE LIGHT** With a 5.5-inch Newtonian, John Chumack captured this shot on May 22nd. The supernova's color is clearly quite blue.

The Problem with Red Supergiants

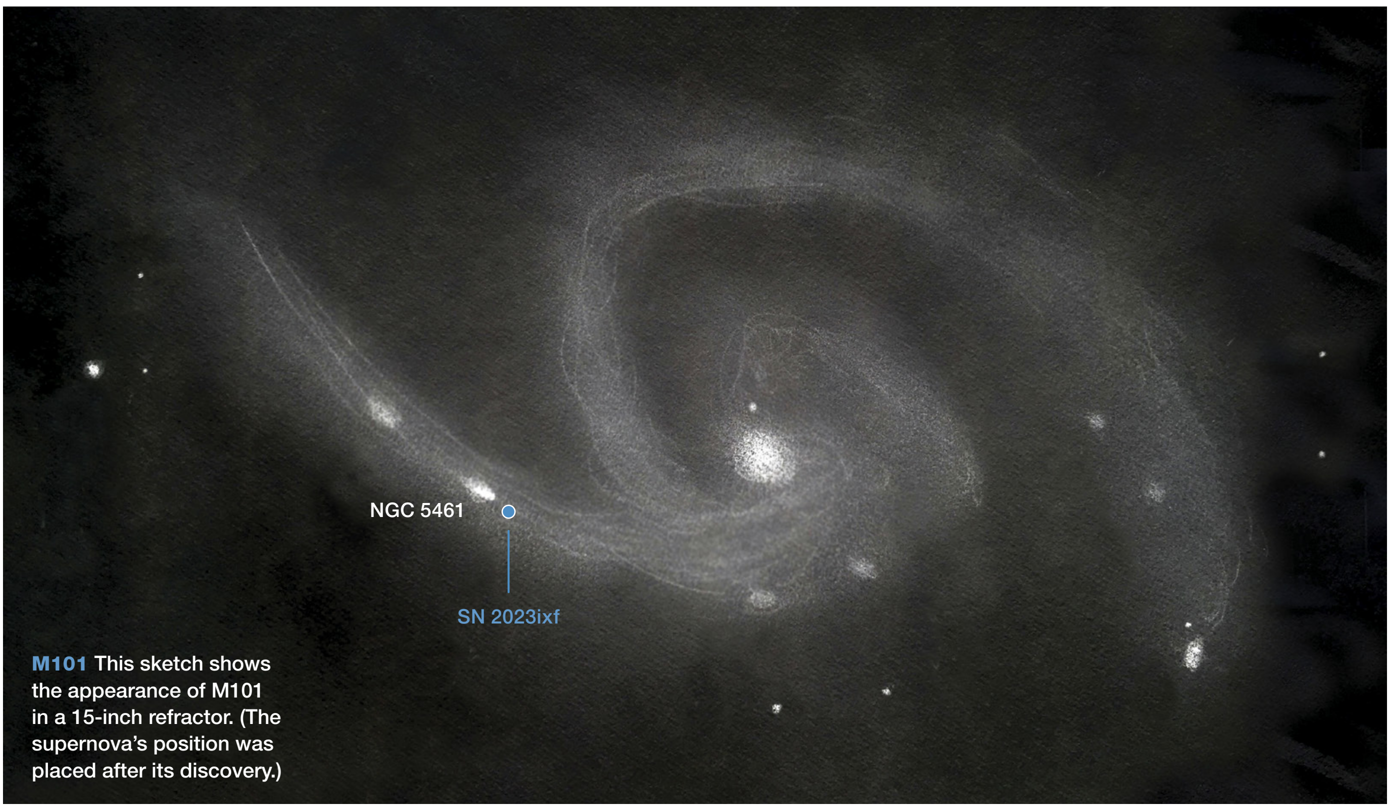
A core-collapse supernova marks the end of a massive star, but not all stars will experience this explosive curtain call. The dividing line between those that will explode as core-collapse supernovae — less than 5% of the stars in our galaxy — and those that do not is somewhere in the range of 8 to 10 times the mass of the Sun.

The most common pathway to core collapse begins with a massive star that exhausts the hydrogen in its core after a few million to a few tens of millions of years. This transition kicks off a series of evolutionary steps that alter the star's interior structure as well as its outward properties. With its core fused into inert helium, the star momentarily halts production of the radiation necessary to hold off the crushing pressure of gravity. As the star begins to collapse, the helium core compresses and heats up, and a shell of hydrogen around the core ignites. This new wave of energy balloons the star outward. The expansion cools the star's outer atmosphere, and the star becomes a red supergiant.

At this point, the clock is ticking. A series of transformations follows, as fusion starts and stops in the core and shells layered around it, creating heavier and heavier elements in a bid to ward off gravity's pull. Each successive fuel source sustains the star for a shorter amount of time.

"They're undergoing these weird changes in their cores, just because they're trying to burn other elements to be able to support themselves against gravity," says Charlie Kilpatrick (Northwestern University), who studies fleeting astronomical phenomena such as supernovae, gamma-ray bursts, and gravitational-wave events. "So the star, it's almost like it's getting more and more desperate."

Once the core transmutes into iron, it's game over: It takes more energy to fuse iron than those reactions would produce, so nuclear burning permanently stalls. The core can no longer hold off gravity's advance, and the star collapses in on itself. A shock wave punches through the layers, the outer



M101 This sketch shows the appearance of M101 in a 15-inch refractor. (The supernova's position was placed after its discovery.)

SKETCH: BOB KING

layers recoiling in an explosion that can briefly outshine the star's entire home galaxy.

Astronomers see red supergiants with masses estimated to be somewhere between 8 and 40 times the Sun's mass. However, the largest star that researchers know has given rise to a supernova weighs in around 18 solar masses. This mismatch between the masses of the largest red supergiants and the masses of the largest supernova progenitors is called the *red supergiant problem*.

It's unclear where the solution might lie. It could be "our fault," meaning that supernovae made by stars more massive than 18 Suns are out there and astronomers just haven't seen them yet. "We don't actually need that many more high-mass red supergiants to sort of ease the problem, because those are also much rarer stars," Kilpatrick says.

Another possibility is that astronomers have already seen supernovae arising from these elusive stars but have assigned the wrong masses to them. Kilpatrick notes that it's no easy feat to figure out the mass of an isolated red supergiant, particularly when it's cloaked in a layer of dust and gas — as many bloated stars are, because dust condenses in the gas that they release from their atmospheres as they age.

But if our observations or models aren't to blame, then this mystery might be telling us something about stellar evolution. Perhaps stars above a certain mass tend to lose their sheaths of atmospheric hydrogen and explode as other types of supernovae. Or perhaps they end their lives in a whimper, collapsing into black holes with no accompanying supernova.

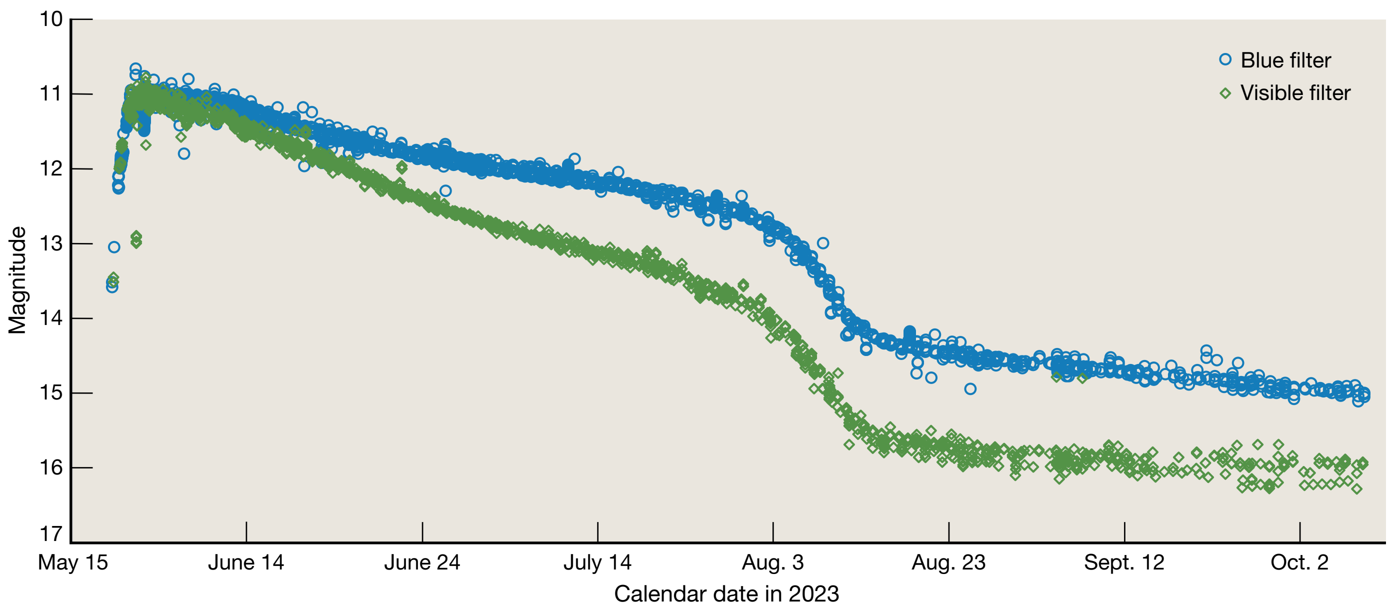
Search for the Supernova's Source

The key to disentangling the intricacies of stellar evolution is connecting the properties and behavior of a star in its pre-supernova days to the properties and behavior of the explosion. Thanks to the growing archive of telescopic data, astronomers have been increasingly successful in their attempts to track down the stars that give rise to supernovae. The identification of dozens of supernova progenitors has confirmed that nearly all core-collapse supernovae come from red supergiants. (A rare few, like the famous supernova SN 1987A, come from blue supergiants instead.)

In the wake of SN 2023ixf's discovery, several teams pored over archival data to hunt for a star at the supernova's location. Monika Soraisam (National Science Foundation's National Optical-Infrared Astronomy Research Laboratory) led one of the first teams to go after SN 2023ixf's progenitor star. "This is not something I typically do for each new supernova discovered," Soraisam says. "But for 2023ixf, given how close it was and with its host galaxy M101 being frequently imaged by several astronomical facilities, finding its progenitor was very likely."

Working from archival Hubble and Spitzer space telescope data, Soraisam's team picked out a star at the supernova's location in a near-infrared Hubble image of the region taken in 2002. The star was absent in images taken at shorter, bluer wavelengths, suggesting a very red star, and its brightness fell into the expected range for a red supergiant. Several research teams pinpointed the same red supergiant as the supernova's likely stellar ancestor.

Because M101 is such a well-photographed galaxy, Soraisam's team had the luxury of exploring 20 years of pre-explosion data to study the star's final years in detail. At visible and infrared wavelengths, the star varied semi-regularly in the years leading up to its collapse, brightening and fading with a period of about three years. This kind of variability is common for red supergiants — the famous red supergiant at the shoulder of Orion, Betelgeuse, also shows this kind of



▲ **AMATEUR CONTRIBUTIONS** As news of the discovery spread, thousands of observations from members of the American Association of Variable Star Observers outlined the shape of the supernova's initial spike and gradual decline in brightness as well as its changing color.

BEATRIZ INGLESSIS / *S&T*; SOURCE: AAVSO variability, though its changes are much smaller in amplitude than those of SN 2023ixf's progenitor. These variations are likely due to changes in the opacity of the star's atmosphere as it expands and shrinks.

Although this behavior is normal for red supergiants in general, SN 2023ixf marks the first time that astronomers have witnessed semi-regular variability in the years leading up to a star's collapse. Intriguingly, researchers found no evidence of outbursts in that time period, so it's unclear exactly where the dense, dusty shell that surrounded the star came from. Theories range from a gentle stellar wind that carried away just one-thousandth of a solar mass of material per decade to a massive outburst that expelled an entire solar mass of gas in one go.

To Weigh a Star

A significant challenge for SN 2023ixf was figuring out the mass of the star it came from. Kilpatrick's team modeled the star's observed *spectral energy distribution* — how its energy output is distributed across different wavelengths of light — to estimate the mass. They found that the progenitor star was likely an 11-solar-mass red supergiant surrounded by a shell of gas and dust at a distance of 8,600 solar radii, or roughly the average distance between Pluto and the Sun.

Soraisam's team instead examined how quickly the star's infrared brightness varied, using that variability as a measure of the star's intrinsic brightness and thus its mass, finding the latter to be between 16 and 24 solar masses. This finding would make 2023ixf's progenitor one of the most massive found to date.

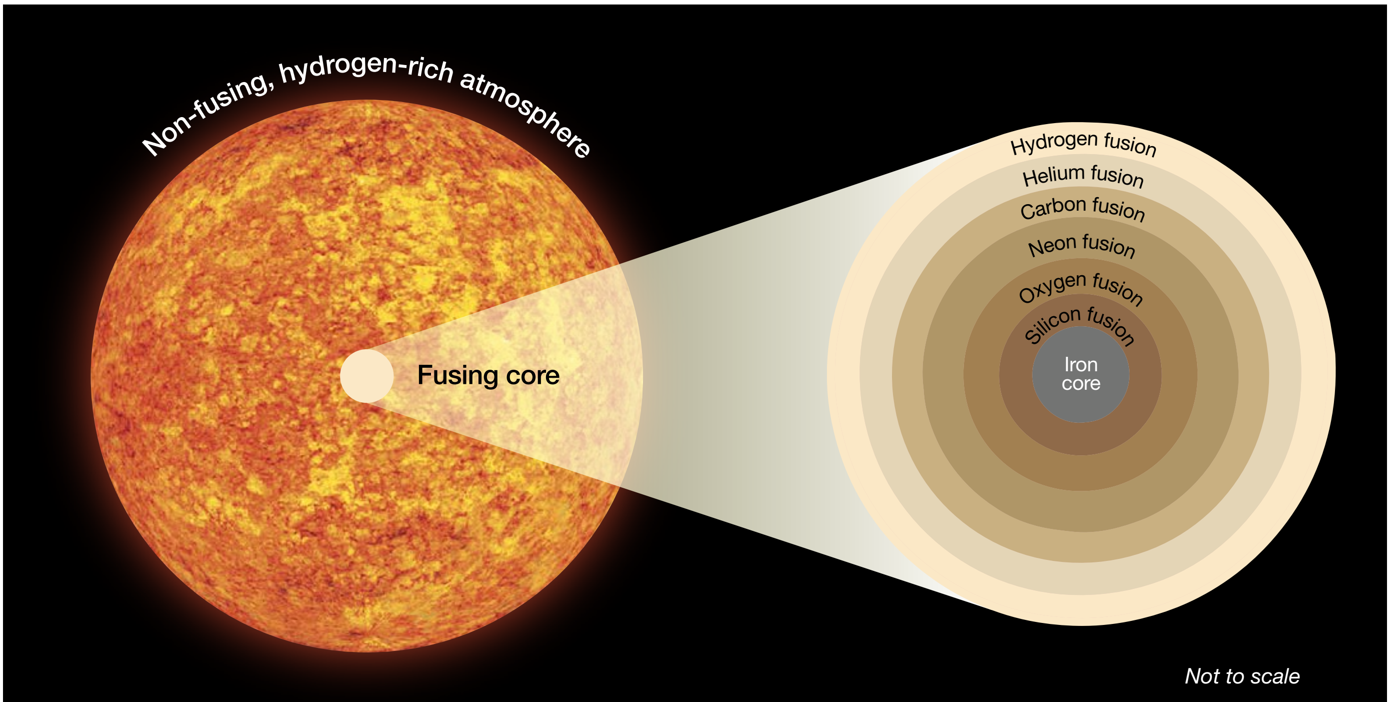
"If we find other progenitors in the future for which such large masses can be confirmed, that would mean that the red supergiant problem is not in fact a problem and rather a consequence of our limited sample of progenitors," she says.

Other methods of "weighing" the star yielded wide-ranging estimates from 8 to 22 solar masses. "The modeling is very hard, so it's not really that surprising to me that there is such a wide range of masses," Kilpatrick says. Much of the difficulty comes about because massive stars tend to wrap themselves in a dusty shroud before they die, which obscures their properties.

Bringing the estimates into agreement may depend on advances in modeling. "I think in the future, we're going to rely on theorists to create more detailed, more 'correct' — or at least consistent with stellar evolution — models for red supergiants enshrouded by dense circumstellar material," Kilpatrick adds.

The Future of the Red Supergiant Problem

While SN 2023ixf has dimmed greatly from its original brilliance, its story is far from over. Even a year after it first appeared, it was shining just shy of magnitude 17 — still accessible to large amateur scopes. Not until the glare of the supernova fades further will researchers be able to confirm that the star they've tagged as SN 2023ixf's progenitor has in fact disappeared.



LAYERS OF A GIANT Inside a red giant star, fusion occurs both in the core itself as well as in surrounding shells, creating heavier and heavier elements arranged in onion-like layers. Only iron cannot produce energy via fusion to support the star against gravity. Around the central region, an extensive, cooler atmosphere of mostly hydrogen extends dozens of solar radii outward.

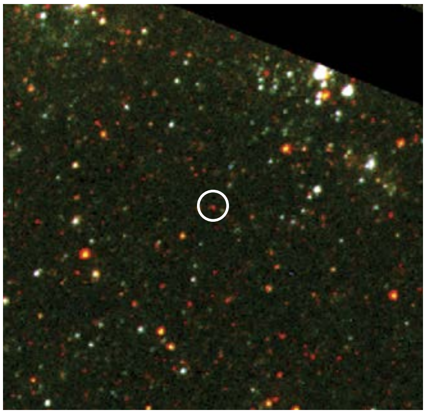
LEAH TISCIONE & BEATRIZ INGLESSIS / *S&T*; SOURCE: EMILY LEVESQUE

The fading light of the supernova will allow researchers to resolve another lingering mystery: whether or not SN 2023ixf's progenitor had a binary companion. The existence of a stellar partner wouldn't change how researchers interpret the core properties of the progenitor star — its luminosity, rate of variability, and the like — but it would throw a wrench into our understanding of its evolution.

Indirectly, the possibility of a stellar companion hints at another solution to the red supergiant problem: Massive stars that interact with such companions might not evolve into red supergiants at all, instead becoming an entirely different kind of star.

For the next year or so, the supernova will likely remain too bright for these questions to be answered. But there's plenty left to puzzle over in the meantime. The myriad observations and modeling efforts have made one thing clear: Despite the broad range of exquisite data for this supernova — far better than is collected for most supernovae — there's still much that we don't know about it.

Luckily, the future is bright for supernova hunters and characterizers everywhere: The James Webb Space Telescope can take excellent measurements of the composition, mass, temperature, and dust surrounding other supernova progenitors. In addition, the upcoming Rubin Observatory and the Nancy Grace Roman Space Telescope will churn out impeccable light curves of massive stars once they're operational, expected in 2025 and 2027, respectively. Hand in hand with these professional facilities, well-equipped amateur astronomers around the world are as poised as ever to capture supernovae from their earliest, brightest days until their light fades.



◀ **PINWHEEL PROGENITOR** Hubble imaging taken in 2002 shows a star where the later explosion occurred. (The white circle, centered on the 2023 supernova, is 1 arcsecond wide.)

Since SN 2023ixf, the universe has conspired to provide us with another nearby supernova: SN 2024ggi has graced the outskirts of the spiral galaxy NGC 3621, which lies about the same distance from Earth as M101 does. It topped magnitude 12 in mid-April before beginning its fade. Here's hoping that others will follow, giving astronomers everywhere more exploding stars to investigate.

■ **KERRY HENSLEY** is a planetary-scientist-turned-writer and serves as the AAS deputy press officer and editor of AAS Nova. (This article is editorially independent from her AAS work and does not indicate AAS endorsement of the research presented.) She eagerly awaits the next Milky Way supernova.

PRE-BLAST BURST? If the progenitor of SN 2023ixf shed a huge amount of mass up to a year before exploding, then it might have looked something like this artist's concept. But while some researchers think such an outburst occurred, others think the star blew material away far more gently, divesting itself of only one-thousandth of a Sun's worth per decade.

PROGENITOR: KILPATRICK ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2023; RED GIANT STAR: MELISSA WEISS / CENTER FOR ASTROPHYSICS / CC BY-SA

Jupiter

A group of amateurs gathered last year to measure the gas giant's gravitational effect on starlight.

Deflection Project

MAHA EL-SAYED; LAURA DIXON; DON BRUNS; JULIE AMATO; KENNETH CARRELL; RICHARD SENEGOR & ANNA NUNES; PAMELA DUNCAN; STEPHANIE LAWTON; GEORGE SILVIS; STAN MOORE

Since 1919, astronomers have measured deflections of starlight due to general relativity near the Sun. Einstein had already calculated the deflection coefficient in 1916 (which is 1.75″ for stars located near the Sun's limb), but scientists of the time were understandably frustrated as they couldn't test this immediately — they had to observe this effect during a total solar eclipse. Eclipses aren't very common — nor are they convenient as the observations had to be completed during the few minutes of totality. Einstein also noted that this solar deflection coefficient could be measured during daytime without an eclipse; so far this has proven unsuccessful.

Einstein's third proposal was to use Jupiter as the gravitational source. General relativity predicts that starlight passing close to Jupiter's limb will be deflected by about 0.016″. However, technology just wasn't up to the task during his lifetime, so he never saw this experiment realized. In 1988, astronomers had measured the deflection at radio frequen-

The Group *(from left to right)*

Bill Fisher

Terry and Gabbi Dixon

Don Bruns's dual telescope

Francesco Meschia

Kenneth Carrell

Richard Senegor

Greg Duncan

Jonathan Lawton

George Silvis

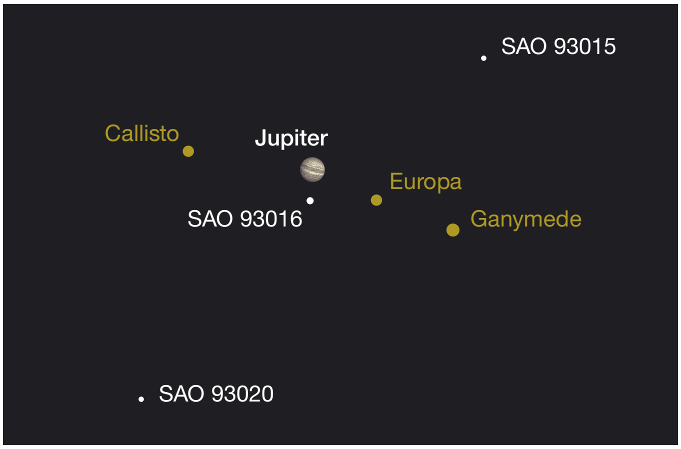
Stan Moore's telescope





A Group Effort

A few years ago, Don Bruns identified a rare conjunction that promised the opportunity to measure Jupiter's gravitational deflection of starlight. Bruns brought this to the attention of Stan Moore. Moore initially thought it impossible but was intrigued. The pair embarked on extensive theoretical investigations and simulations and determined that the experiment actually might work — under good conditions and with the right equipment. In addition, preliminary nighttime tests were encouraging. After they published a short note in *Sky & Telescope* calling on volunteers, more observers joined the effort. Special thanks go to Bill Fisher (especially for automating the Python programming for the data analysis), Francesco Meschia, Greg Duncan, Jonathan Lawton, Richard Senegor, Robert Minor, Joe Izen, George Silvis, Nikola Nikolov, Terry Dixon, and Kenneth Carrell. Hundreds of email exchanges among the participants showed the strong social component of this collaboration, which was a delight to witness.



▲ **FORTUITOUS NIGHT** The conjunction of a bright star with Jupiter on the night of October 27–28, 2023, provided astronomers with an opportunity to test Einstein's general theory of relativity. On that night, SAO 93016 passed within 25″ of the gas giant's limb (in the diagram, Io is behind the planet). Two other stars were used as references to calibrate the data.

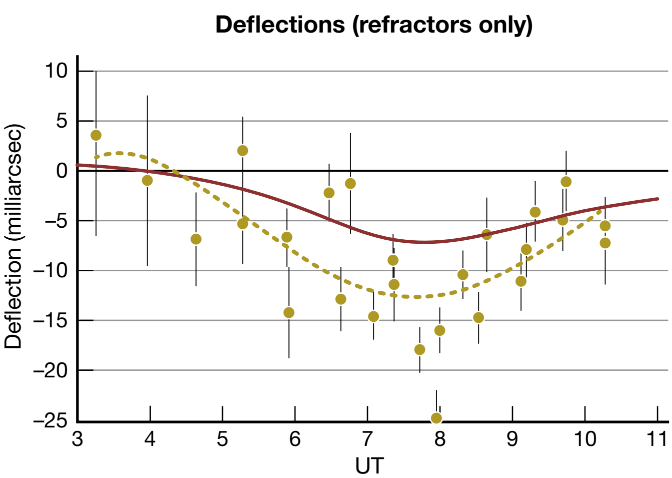
cies, but to our knowledge no one has yet done so at visible wavelengths. (In 1995, scientists using the Hubble Space Telescope were unsuccessful; also, analyses for the European Space Agency's Gaia mission included Jovian deflections when calculating the positions of stars for the catalog, but direct visual measurements have never been achieved.)

A Serendipitous Night

Using Jupiter to measure deflection of starlight is convenient in that an observer can use a telescope almost anywhere in the world, as long as a bright star passes within 100″ of the planet when it's at high altitude in a clear sky. The Jovian passage takes several hours, so timing isn't critical, and the measurement noise can be reduced by analyzing thousands of images. Another prerequisite is that the target star be located near two bright reference stars so that an accurate scale can be calculated. As temperature affects instrument performance, the ideal reference stars should be in a line with the target star, thus minimizing changes in the relative plate scale. We also expected that combining results from several observers would yield very good agreement with theory, as long as we could eliminate the effect of Jupiter's glare.

A conjunction of Jupiter and a trio of stars in October 2023 provided a unique opportunity to test Einstein's third idea for measuring the gravitational deflection of starlight. The diagram at left shows the positions of the target star, 7.3-magnitude SAO 93016, and the two reference stars near Jupiter. The last time a conjunction this close occurred in 1928 and will not repeat until 2106 — we *had* to take this opportunity to do this measurement. A few of us got together and realized that — using modern equipment — we might be successful.

After more than a year of planning and preparation, the participants listed in the sidebar on page 19 were poised on the night of October 27–28 to acquire data. A few observers were completely clouded out and many had partial clouds or hazy skies. There were also equipment malfunctions and calibration issues. But some of us eventually succeeded in getting data, which we proceeded to analyze.



▲ **SUCCESS! . . . OR NOT** The results of the deflection experiment (from refractors only) show that the averaged data — the yellow dotted line – follow the theoretical prediction — the solid red line — but with a greater effect.

Snafus and Challenges

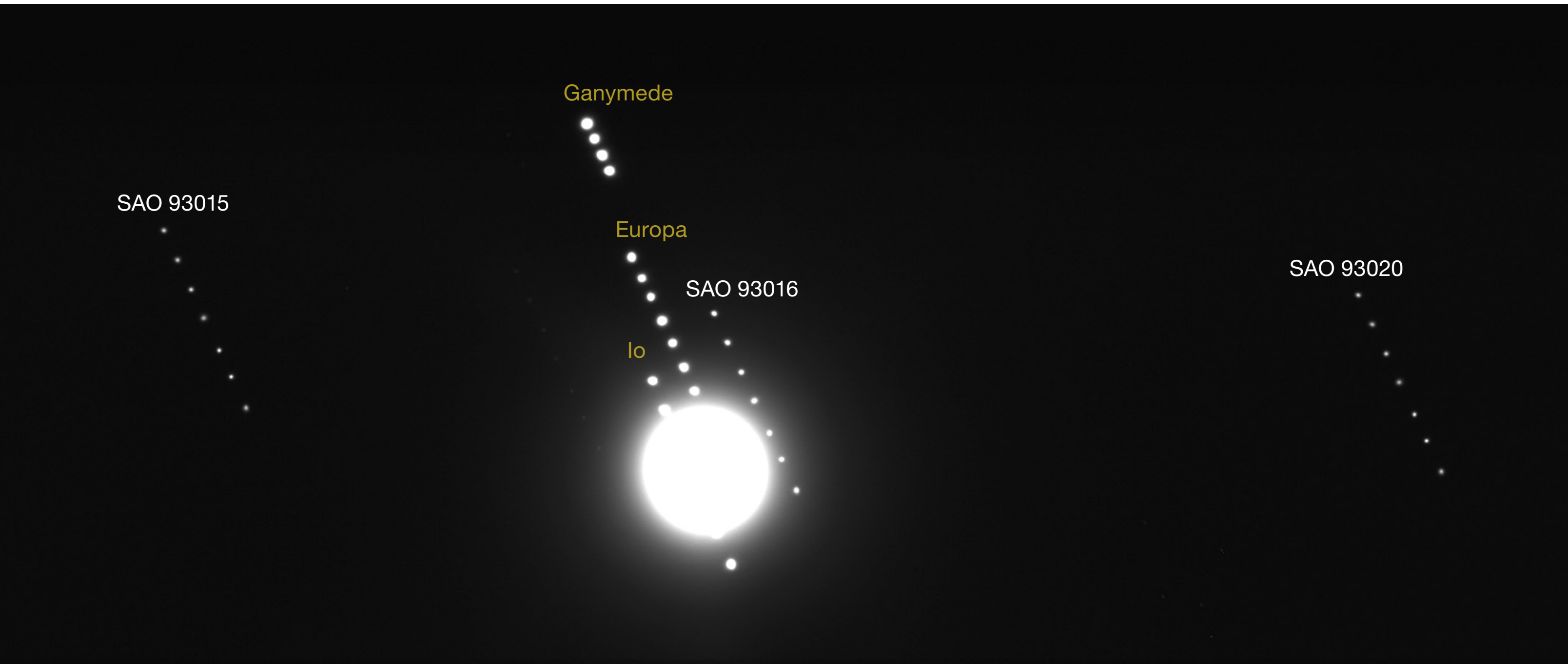
The first step in the analysis was to assess datasets for internal consistency and sufficiently low noise. A simple way to go about this was to compute the typical measurement noise between the outer two stars, which had to be significantly less than the predicted gravitational deflection. While this initially showed promise, the real difficulty lay hidden ahead.

A composite of images taken every hour from 3 UT to 9 UT on the night of the conjunction is shown in the image on page 21. The locations of Io and Europa are irrelevant; the target star is a little dimmer than Jupiter's moons but still had a high signal-to-noise ratio in each image.

Unfortunately, Jupiter is *much* brighter than 7.3-magnitude SAO 93016. In fact, on that night it was more than 12,000 times brighter. In our lead-up to the event, we simulated subtracting the bright background glare generated by Jupiter — which worked well. However, the devil was in the details! It turned out that the data obtained with reflectors that had secondary mirror supports were all very poor, and we couldn't use them in our analyses. Even a slight miscollimation of the secondary mirror in a Schmidt-Cassegrain telescope skewed the glare enough to ruin the results.

In the end, we succeeded in processing the data from three refractors — the graph at left shows these results. The greatest deflection of SAO 93016's light was on October 28th at 7:45 UT, when it was only 25″ from Jupiter's limb. The planet's gravity generated an apparent outward deflection of 0.0072″, measured with respect to 8.3-magnitude SAO 93020. Tests using these two stars as well as 8.1-magnitude SAO 93015, while still far from Jupiter, resulted in measurement errors typically of 0.002″.

JUPITER, MOONS, AND STARS: LEAH TISCIONE / S&T; SOURCE: STELLARIUM; GRAPH: LEAH TISCIONE / S&T; SOURCE: DON BRUNS & STAN MOORE



GLARING PLANET This composite, obtained with Don's 5-inch f/7.5 refractor, shows well that one of the biggest challenges in the data analysis ended up being subtracting Jupiter's strong glare before measuring the star's position.

DON BRUNS

The dotted line represents the best-fit curve to the data points, while the red line represents the theoretical curve. It's obvious that even these data are far from the predicted value. We noted that the largest error bars occurred when Jupiter was low in the sky, where atmospheric turbulence was greatest.

The averaged data curve (the dotted line) is similar to the theoretical curve — but it's about 70% larger than the expected value. Even though we used several Jupiter-background-subtraction techniques, they all resulted in deflections of about the same magnitude. No theory of gravity could explain the difference. We can only conclude that subtracting Jupiter's background glow must simply be more difficult than expected. Atmospheric turbulence across Jupiter's disk, which varied from image to image, destroyed the uniformity needed for an accurate subtraction.

One thing we learned: This experiment was much harder than we expected! Even if our results proved inconclusive, we hope everyone enjoyed the experience — we all met new people, learned about high-precision measurements, and crossed our fingers that the data would show Einstein was right!

Looking Ahead

But we haven't given up. We decided that for our next experiment we're going to use the Jovian moons instead of distant stars. The moons are on average about eight times brighter than our target star, so subtracting Jupiter's glare should be much less of a problem. Starting in late 2024 and through 2025, Jupiter will be positioned even farther north on the ecliptic, which will favor Northern Hemisphere observers — hopefully getting good Jovian moon data will be easier. The best arrangement will be when the moons are in a line, with two moons far from Jupiter's glow. We'll perform tests with the target moon in front of Jupiter as well as with the target moon moving behind the planet. Since theorists disagree about the deflections in these cases, this could be more than just a historical completion of Einstein's wishes!

Interested?

If you'd like to participate in the next attempt to measure the deflection of starlight, please contact Don at **dbruns@stellarproducts.com**.

■ **DON BRUNS** got his first department-store refractor at age 12 and was blown away by Saturn and the Moon. He has been interested in astronomy ever since. He got a PhD in physics in 1978 and worked in various industrial labs for 35 years, mainly in optics and lasers. After retiring, he focused on astronomy projects. **STAN MOORE** developed an interest in astronomy in grade school, encouraged by the Astronomical Society of Las Cruces (New Mexico) and inspired by members such as Brad Smith and Clyde Tombaugh. A professional software engineer, Stan was an early participant in the CCD revolution.

FURTHER READING: To read more on Don's work, see his article in the August 2018 issue of *Sky & Telescope* on stellar deflection measurements during the 2017 total solar eclipse.

TRIANGULUM TREASURES by Scott Harrington

Observe M33's Bright

GLORIOUS SPIRAL Brimming with H II regions and clusters — open, globular, and in between — M33 is a fascinating galaxy with an interesting history of discoveries.

BERNHARD HUBL

est Stars and Clusters

Grab your largest telescope and explore some of the Triangulum Galaxy's best-kept secrets.

Once commonly known as the "spiral nebula in Triangulum," the nearly face-on galaxy M33 has played a key role in our understanding of galaxies beyond our own. Not only was it one of the first for which astronomers discerned a spiral pattern, but in it they also discovered one of the very first, extragalactic star-forming regions, NGC 604. M33 was also one of the first galaxies in which astronomers identified individual member stars and star clusters.

However, while many amateur astronomers are aware of M33's emission nebulae and OB associations (*S&T:* Nov. 2023, p. 58), few know about its brightest individual stars and star clusters. I hope this article helps change that since, to my own surprise, I've seen more than 20 member stars and clusters using my late grandfather's now 40-year-old 10-inch Meade Schmidt-Cassegrain. To have the best shot at seeing these features, you'll need the galaxy high overhead under the darkest skies you can get to. It also helps to have steady enough seeing to use a magnification of at least 20× per inch of aperture, detailed charts, and some determination!

Journey to the Center

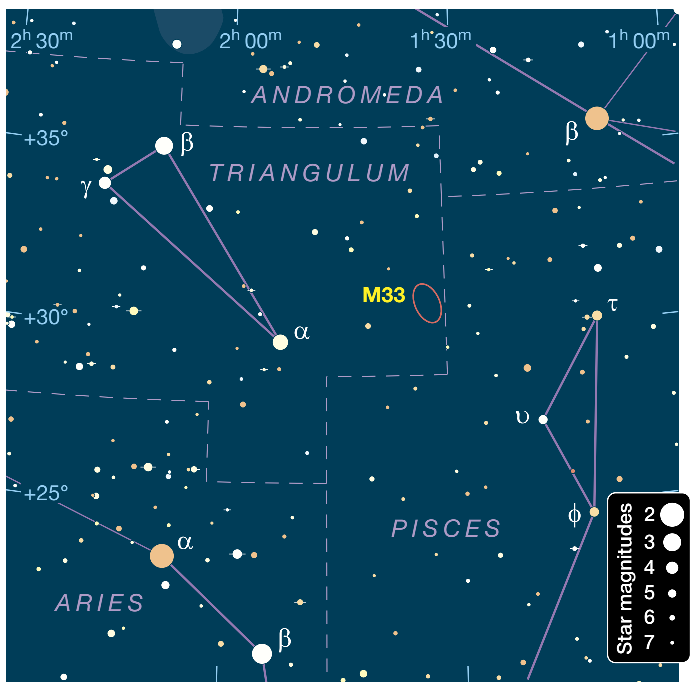
Let's start at the galaxy's center, where one can find the nucleus that Edwin Hubble once described in his 1936 book *Realm of the Nebulae* as "semistellar" and "resembles in appearance a giant globular cluster, although no evidence of resolution is found." With a listed magnitude of 14.0, I tried for it one night with my 6-inch reflector. At first, using 164× I could only see the broad central region punctuated by a 12.9-magnitude star on the northeastern edge. But with patience, the core not only flashed into view, but I could hold it with averted vision. In my 10-inch at 400×, it appears stellar, seemingly offset to the northwest of a broad central region with a 14.5-magnitude star 0.8′ west-southwest. Only in my 16-inch Dobsonian at 440× does the core seem soft. How do you see it?

Professional astronomers continue to be puzzled by a smaller-than-anticipated estimate for the mass of M33's expected central black hole (just 1,500 solar masses). In fact, one has yet to be detected!

Aided by the Largest

Hubble's pioneering work in the 1920s on the Andromeda Galaxy, M31, yielded around 140 "nebulous objects" that he identified as globular clusters. While examining photographic plates taken with the largest telescope of the day — the 100-inch Hooker telescope on Mount Wilson — Hubble was also the first to find some of M33's star clusters. However, he wasn't sure what to make of them since they were noticeably fainter and bluer than the objects that he'd already identified in M31. Within a few years, though, he isolated three that somewhat resembled those in M31.

To find more star clusters and understand why M33's appeared different to M31's, Hubble would need a bigger telescope at a darker site. Luckily for him, funding had already been secured for what would become the 200-inch Hale Telescope on Palomar Mountain. Sadly, observations with the 200-inch were in such high demand after its first light in 1949 that Hubble died before he had a chance to point it at M33. It would be one of his graduate-student assistants, Allan Sandage, who would do so in 1955 — less than two years after Hubble's death.



▲ **IN THE TRIANGLE** Look for the pretty spiral galaxy M33 in the western reaches of Triangulum. At magnitude 5.7, it might be visible to the naked eye under dark skies. However, to snag the stars and clusters described here, you'll need a telescope.

▲ **LARGEST IN THE WORLD** When it saw first light in 1949, the 200-inch Hale Telescope on Palomar Mountain was the largest in the world, a title it held until 1975. Astronomers made many discoveries with this telescope, including several of the objects discussed in this article.

The plates Sandage took were of such high quality that he identified more than 100 cluster candidates. Following this, William Hiltner (based at Yerkes and McDonald observatories) published his pioneering photometry of 23 of Sandage's clusters in 1960. His results led him to surmise that for the majority "it appears more reasonable to consider these objects as rich open clusters . . ." His finding was significant for it revealed that there are different types of stars clusters in different types of galaxies. A 1978 survey by European Southern Observatory astronomers Jorge Melnick and Sandro D'Odorico more than doubled the number of known clusters. From their study, they concluded that the majority of clusters in M33 were "not 'genuine' globular clusters but rather blue, intermediate type clusters much like the ones found in the Magellanic Clouds."

Identifying and classifying nonstellar objects in M33 didn't stop there. In 1982, American astronomers Carol Christian and Robert Schommer published the most comprehensive catalog of nonstellar objects in M33 of the time, *The Cluster System of M33*. By comparing the cluster population of M33 to those of other galaxies, three distinct groups emerged: a number of bright, blue, presumably young clusters; a somewhat fainter, small population of red clusters — most of which may be true globulars; and a sizeable population of intermediate color, which also may be of intermediate age. Going forward, I'll refer to their catalog's designations (a letter followed by a number) since they are still commonly used today.

Cluster, Cluster, on the Wall . . .

Many additional cluster surveys were made in the past 40 years, but let's pause and visit a few of the early discoveries. It's a little-known fact that Hubble found what is now considered the brightest of the true globular clusters in M33. Known as **U49**, it lies off M33's northern arm and is some 10′ due west of NGC 604 and 1.3′ north of an 11.2-magnitude star. In my 10-inch at 400×, U49 is not as bright as its magnitude of 16.3 would imply and has a dull, softer look than nearby stars.

To an observer on a planet in M33, at around 100 light-years across U49 would look like M22 in Sagittarius looks to us. Despite being the brightest of M33's globulars, U49 — and its companions — all have significantly lower luminosity (and are thus fainter) than those in M31.

C39 lies far, far from the galaxy's glow to the southeast (21.7′, in fact) and can take a minute to find 15.7′ east of the 8.1-magnitude star HD 9483 and 1.2′ southeast of a 12.0-magnitude star. It, too, has a distinctly soft, dull appearance that stands out even more in my 16-inch at 440×. At magnitude 16.1, this is the brightest of the so-called "intermediate-age" clusters and was discovered presumably in the 1940s by Nicholas Mayall of Lick Observatory.

The brightest cluster Hiltner listed languished until 2007 — when suddenly no less than three different research groups cataloged it. **SM 395**, as it came to be known, lies 8.7′ east-southeast of the galaxy's center and 10.8′ south of NGC 604. In my 10-inch at 400×, the 15.9-magnitude object appears to lie beyond M33's disk, almost midway between two 15.3-magnitude stars that are aligned northeast-southwest 3′ apart. It's not terribly hard to see, and despite its youth its mass is greater than most of the Milky Way Galaxy's open clusters!

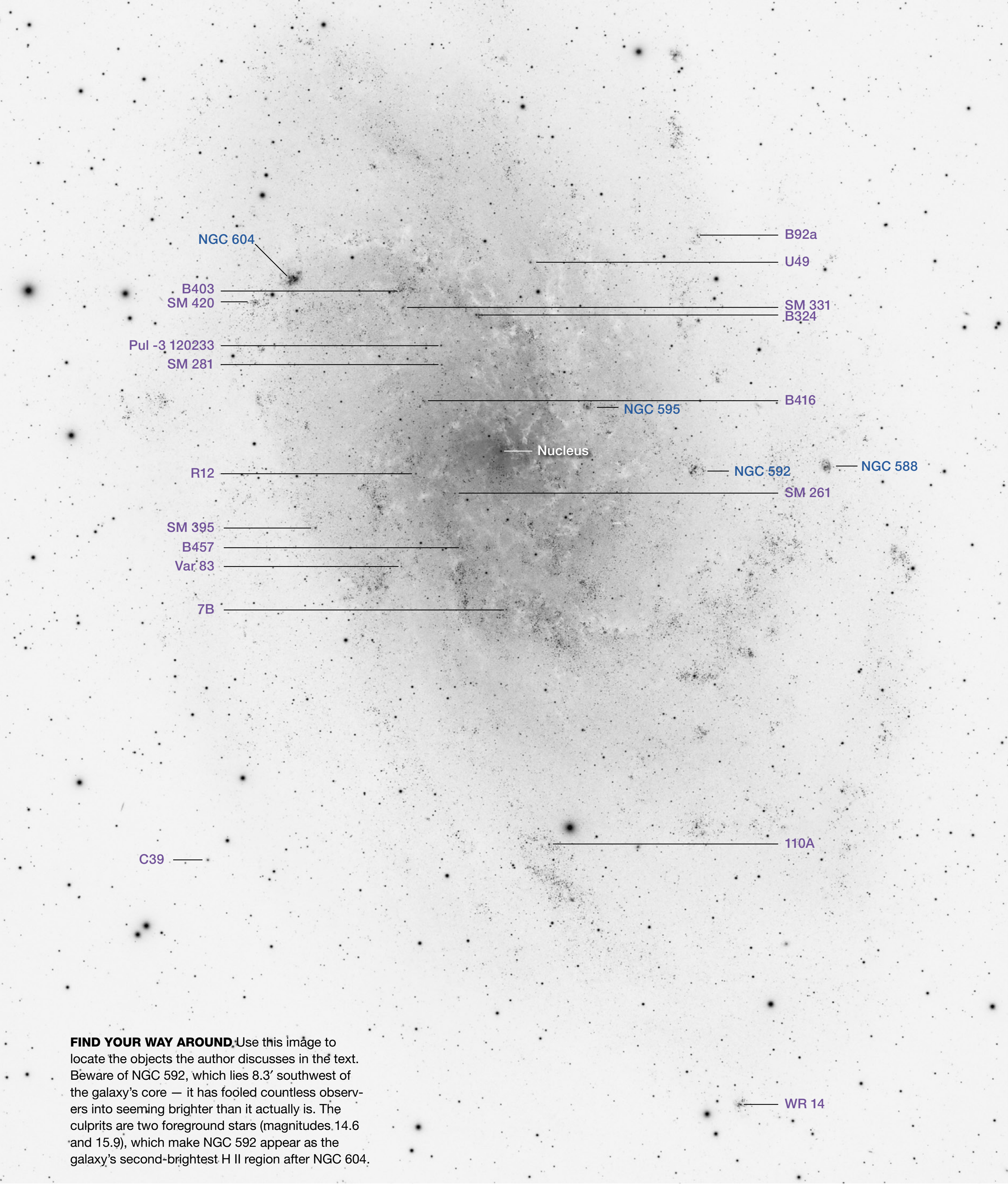
Christian and Schommer discovered many clusters, but the only one I've seen in my 10-inch is 16.4-magnitude **R12**, which is one of the few true globular clusters in M33. It's a challenging target to spot, however, due to its location 3.8′

Where Are M33's Globular Clusters?

Globular cluster systems are important tracers of galaxy formation and evolution due to their age. For example, the substructure within a galactic halo reveals its merger history, and globulars can be used as one tracer of such substructure. Astronomers consider that those farthest from the galactic center — known as *outer-halo* globular clusters — are important not least because they may be the last that were accreted to the host galaxy.

Compared to M31 and the Milky Way, each of which boasts dozens of outer-halo globulars, so far only a handful have been found around M33. Of the six known, M33-B is the brightest one and lies 0.8° southeast of M33 — at a distance similar to M79's from our galaxy's center. At magnitude 17.8, M33-B is visible in telescopes with 20 to 25 inches of aperture.

HALE TELESCOPE: DETLEV VAN RAVENSWAAY / SCIENCE PHOTO; M33: BERNHARD HUBL

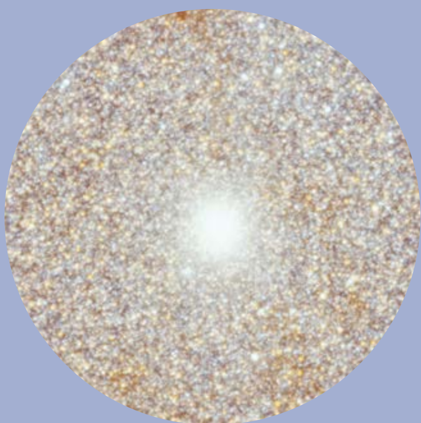


FIND YOUR WAY AROUND Use this image to locate the objects the author discusses in the text. Beware of NGC 592, which lies 8.3′ southwest of the galaxy's core — it has fooled countless observers into seeming brighter than it actually is. The culprits are two foreground stars (magnitudes 14.6 and 15.9), which make NGC 592 appear as the galaxy's second-brightest H II region after NGC 604.


U49


B403


SM 331


Nucleus


Pul -3 120233


SM 281

NASA / ESA / M. DURBIN / J. DALCANTON / B. F. WILLIAMS (12)

east of the nucleus. The best advice I can give you is to first look about 3′ south of the galaxy's center for an eye-catching row of three 13th- and 14th-magnitude stars about 2′ long. Now, continue that line to the northwest for another 2.5′ and you might just see R12 as a very faint "star" that also happens to lie 3′ north of a 13.8-magnitude star.

In 1998 Barbara Mochejska (then at Warsaw University Observatory) and her colleagues compiled one of the last catalogs of new star clusters prior to the availability of Hubble Space Telescope data. And of the 35 new candidates they found, I've seen three in my 10-inch that are confirmed clusters. The easiest to find and brightest to my eyes is 16.0-magnitude **SM 261**, which lies a mere 2.7′ southeast of the galaxy's core and in the same path I use to find R12 (it's 0.5′ off the northeastern star of the trio). Interestingly, a 2009 study showed that the cluster would be several magnitudes fainter if not for two bright red supergiants!

The next brightest is the 16.1-magnitude blue cluster **SM 331**, which lies 4.8′ west-southwest of NGC 604. In my 10-inch at 400×, it's not too hard to catch sight of it 0.9′ southwest of a 13.7-magnitude foreground star and 0.7′ south of 16.0-magnitude B403. The final cluster I saw is more challenging as it lies closer to the core of the galaxy, 3′ southwest of SM 331. Known as **SM 281**, at magnitude 16.4 it's the faintest true globular I've seen in my 10-inch — seek it about 0.9′ south of two 15th-magnitude stars aligned east-west and separated by nearly 0.7′.

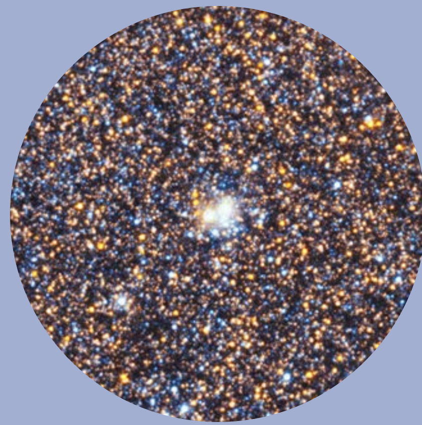
At magnitude 15.9, **SM 420** is possibly the brightest and easiest star cluster to locate since it lies just 2′ southeast of NGC 604. However, it was first cataloged as a blue supergiant at the heart of the small OB association A85 in 1980 — its true nature was accidentally revealed by spectroscopy only in 1994! It's one of the youngest clusters in the galaxy at less than 10 million years old. In my 10-inch at 400×, averted vision reveals the small, soft glow of an OB association. SM 420 sits at its heart, and direct vision makes the cluster pop.

A Century of Discovery

In a typical galaxy, many of the very brightest stars are extreme in nature — they have high masses and strong stellar winds — and are thus highly variable. So, it's no surprise that several variable stars were discovered in M33 *before* Hubble started studying the galaxy. American astronomer John Duncan found the first two while looking for novae a little more


B416


R12


SM 261


B457


Var 83


7B

than a century ago. The variables stood out because unlike novae, their brightness changed irregularly, and they were present on photographic plates stretching back more than two decades. The brightest one, which was independently discovered by German astrophotographer Max Wolf in the same year, peaked around magnitude 15.5 in late 1924.

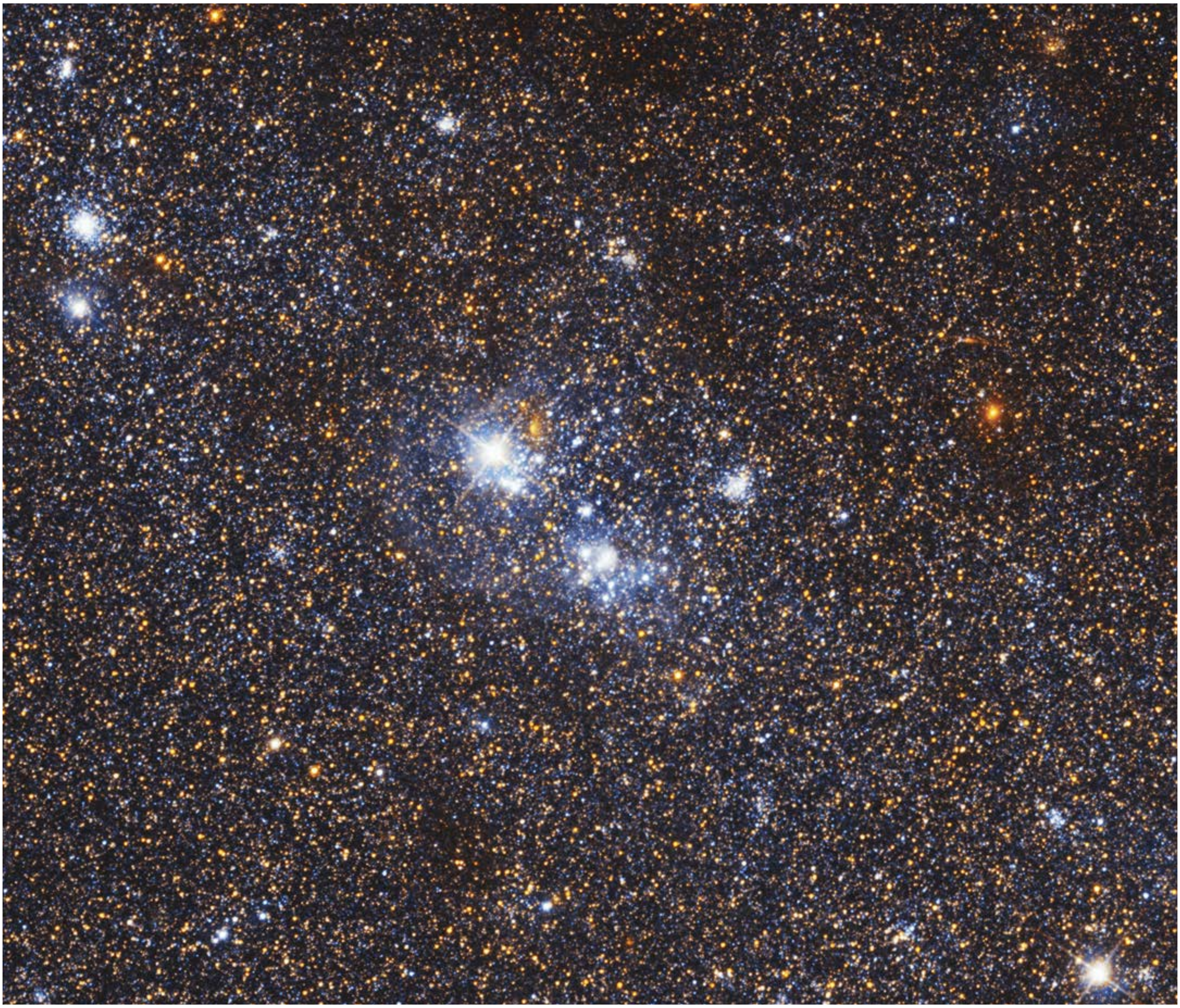
In the ensuing three decades, astronomers found four more irregular variables. By studying the light curves of all six stars, in 1953 Hubble and Sandage concluded that four of them were unique — yet they shared similar properties. The pair had identified a new class of variable stars, writing, "The members of this class are exceedingly luminous and have quite blue color indices. This type of luminous, blue, irregular variable is rather rare in extragalactic nebulae, since only one is known in M31 and five in M33 . . ." Now known as *luminous blue variables*, they represent a phase lasting less than 30,000 years that only the most massive stars go through. The two brightest and best-known in our galaxy are P Cygni and Eta Carinae.

In 1975, Canadian astronomer Sidney van den Bergh and his colleagues published their survey of variable stars in M33. They found that one star, number 83 in their list, had got as bright as magnitude 15.8. Three years later, Roberta Humphreys (University of Minnesota) added Var 83 to the list of known luminous blue variables.

In 1980, Sandage teamed up with Humphreys and, using Sandage's plates taken with the 200-inch starting in 1955, the pair compiled a comprehensive list of the brightest stars. Of all their finds that have since been confirmed as bona-fide members, I've managed to see seven in my 10-inch at 400×. Let's now take a look at those, plus three other interesting stars.

Stars of the Show

On average, the brightest star in M33 is 14.9-magnitude **B324**, a warm *hypergiant* (a very large star with an extremely high mass and luminosity) that usually outshines all the others by half a magnitude or more! It lies in M33's northern arm, 8′ west-southwest of NGC 604, and is the main attraction in IC 142, a small nebula astronomers first noticed around 1850. In fact, the star is so bright that with a bit of work, it's an averted-vision object in my 6-inch at 164×! At moderate magnification in my 10-inch, IC 142 is visible as a small, soft glow. Jumping up to 440× in my 16-inch, I can see



▲ **STELLAR ASSOCIATION** This Hubble image of IC 142 spans just 1.2′ across. The space telescope was able to pierce the nebula, revealing the loose conglomeration of hot, young stars inside. Fifteenth-magnitude B324 (left of center) is the brightest member star (on average) in the entire galaxy!

NASA / ESA / M. DURBIN / J. DALCANTON / B. F. WILLIAMS

a faint "star" just southwest of B324 that is a bright knot in the surrounding nebula. Incredible!!

Another star I've seen a bit farther along in the northern arm is 16.0-magnitude **B403** (which I mentioned in my description of SM 331). It resides in the OB association IC 143, about 0.5′ west of a 13.7-magnitude star. Compared to some of the stars to come, it's hard not to call this one bright and an easy find in my 10-inch at 400×.

B416, lying 7.7′ southwest of NGC 604 toward the galaxy's core, was the second member star I ever saw in M33. Possibly a luminous blue variable or even a binary system, at magnitude 16.1 it's not really fainter than B403, and with my 10-inch at 400× I think I can detect the faint glow around it known as Shajn 81. Unsurprisingly, I can see the nebula better in my 16-inch.

Remember my route to SM 281? The westernmost of the two 15th-magnitude stars I mentioned is 15.4-magnitude **PuI -3 120233**, a blue supergiant that was only first cataloged in the 2000s. I snagged it with my 10-inch at 260×.

Before dropping south of the galaxy's core, we'll quickly visit the inseparable pairing of a Wolf-Rayet and blue supergiant star known as **B92a**. It lies in the OB association A135, which is 17.5′ west of NGC 604 and 2′ north-northeast of an 11.2-magnitude star. The puzzle for me is that every time I've looked, it was noticeably easier than its listed magnitude of 16.5 implies.

One of the brightest stars in M33 that eluded me for a long time was the 16.0-magnitude yellow supergiant **7B** in the OB association A7. The problem is that it lies deep in the southern arm with few bright foreground stars to aid in locating it. It's visible almost 7′ south of the core and with averted vision in my 10-inch at 400× has a small clump of stars 0.5′ to its southeast.

Lying 4.5′ south-southeast of the core and 0.8′ west of a close stellar pair is **B457**, a star that Humphreys and Sandage suspected of being a double. It was later cataloged as a double comprising a blue supergiant and a Wolf-Rayet star, but in a 2007 study using Hubble data astronomers erroneously reclassified it as a 16.2-magnitude cluster. Better-quality Hubble data confirmed its earlier stellar designation in 2017. In my 10-inch at 400×, it's about as bright as 7B, and in my 16-inch at 440× it's involved with the small nebula Shajn 69.

Let's backtrack to **Var 83**. While it takes work to hunt down since it's 6.5′ southeast of the galaxy's core and 1.3′ from a 13.8-magnitude star, it's well worth it. In fact, in my 16-inch at 440× both it and the cluster SM 337, which is 0.3′ north-northeast, are visible. That's a single star outshining a cluster, which is 240,000 times more massive than our Sun! And, recently, I was the first to discover that Var 83 was in outburst in the 1850s since it was included in several drawings made using the 72-inch Leviathan of William Parsons, the Third Earl of Rosse!

The penultimate star we'll visit appeared, at magnitude 16.3, a little brighter than Var 83 when I observed it last December and was even easier to find. Simply identify the binocular-bright star HD 9483, which sits 16′ south of the galaxy's center, and look 1.1′ southeast. Known as **110A** for being the brightest star in the OB association A110, it's a candidate luminous blue variable that has a nice 15.2-magnitude guide star just 0.7′ south.

At more than 500 light-years across and nearly 24,000 light-years from M33's center, the massive emission nebula MA 1 is isolated at the very southern edge of the galaxy. And at its heart is a pair of Wolf-Rayet stars, with the brighter of them, 16.1-magnitude **WR 14**, embedded in and yet dominating a compact, young cluster. In my 10-inch at 400×, I detect a small glow with a faint brightening at its center that my 16-inch 440× shows as not quite stellar.

For those of us who live at mid-northern latitudes and dream of observing the Magellanic Clouds (such as yours truly), M33 is as close as you can get with its brighter member stars, HII/star-forming regions, and luminous, young clusters. So, savor everything the Triangulum Spiral has, and it might just become your favorite galaxy, too!

■ Contributing Editor **SCOTT HARRINGTON** might be considered a M33 fanatic since he has a 6-foot tall poster of the galaxy on his wall. He welcomes your comments and questions at **sn4ark@gmail.com**.

ONGOING RESEARCH: While writing this article, Scott made a discovery about Var 83 and is planning to publish a journal paper.

The Glitters of M33

Object	Type	Mag(v)	RA	Dec.
U49	Old cluster	16.3	$01^h 33.8^m$	+30° 48′
C39	Intermediate-age cluster	16.1	$01^h 34.8^m$	+30° 22′
SM 395	Young cluster	15.9	$01^h 34.5^m$	+30° 36′
R12	Old cluster	16.4	$01^h 34.1^m$	+30° 39′
SM 261	Young cluster	16.0	$01^h 34.0^m$	+30° 38′
SM 331	Young cluster	16.1	$01^h 34.2^m$	+30° 46′
SM 281	Old cluster	16.4	$01^h 34.0^m$	+30° 43′
SM 420	Young cluster	15.9	$01^h 34.7^m$	+30° 46′
B324	*A*-type star in HII region	14.9	$01^h 33.9^m$	+30° 46′
B403	Star in HII region	16.0	$01^h 34.2^m$	+30° 47′
B416	*O*-type star	16.1	$01^h 34.1^m$	+30° 42′
Pul -3 120233	Blue supergiant candidate	15.4	$01^h 34.0^m$	+30° 44′
B92a	Double star	16.5	$01^h 33.2^m$	+30° 49′
7B	*F*-type star	16.0	$01^h 33.8^m$	+30° 33′
B457	Double star in HII region	16.2	$01^h 34.0^m$	+30° 35′
Var 83	Luminous blue variable	15.8 – 16.8	$01^h 34.2^m$	+30° 35′
110A	*B*-type star	16.3	$01^h 33.7^m$	+30° 23′
WR 14	Wolf-Rayet star in cluster	16.1	$01^h 33.0^m$	+30° 11′

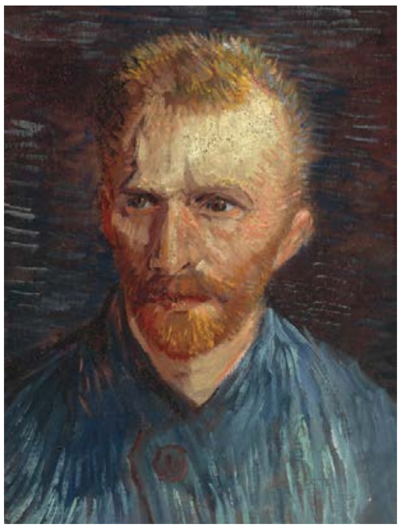
Stars' listed magnitudes indicate an average, as they're all variable by a few tenths of a magnitude. Right ascension and declination are for equinox 2000.0.

Vincent van Gogh and the Setting Sun

When and where did the great Dutch artist create a pair of beautiful paintings?

Twice each year, crowds gather at locations in and around New York City to witness and photograph a dramatic event as the direction to the setting Sun aligns with Manhattan's numbered streets. The orientation of the street grid, tilted 29° clockwise from true north, determines the dates of this phenomenon, known as Manhattanhenge and popularized since 2001 by Neil deGrasse Tyson, director of New York's Hayden Planetarium. These alignments take place not at equinoxes or solstices but rather near May 29th and July 12th, when the disk of the setting Sun is near 29° north of due west. The steel, glass, and concrete towers lining the Manhattan streets make this phenomenon especially spectacular, as the Sun's last rays shine directly along the numbered streets.

But these modern photographers are not the first to capture an event like this. One hundred and forty years ago, the great Dutch artist Vincent van Gogh (1853–1890) used oil paint and canvas to record just such a scene in a work known as *Lane of Poplars at Sunset*. In this early work, he depicted the orange disk of the low Sun aligning with a long, straight stretch of road bordered on both sides, not by modern skyscrapers, but by the black trunks of tall poplars from which the leaves had recently fallen.



▲ **A SELF-PORTRAIT** During his stay in the Dutch town of Nuenen from 1883 to 1885, Vincent van Gogh created many portraits of local peasants — but no self-portraits. This example dates from his residence in Paris, France, in 1887.

VINCENT VAN GOGH / VAN GOGH MUSEUM / WIKIMEDIA COMMONS / PUBLIC DOMAIN

The goal of our research team was to discover the location and the exact date in 1884 for this painting, when van Gogh was working in or near the town of Nuenen in his home country of the Netherlands.

Vincent's Starry Skies

Astronomers have a special interest in several works from the last few years of van Gogh's life, when he created some of the most spectacular paintings of the heavens. *Café Terrace at Night* and *Starry Night Over the Rhône*, both from 1888, portray the sky above Arles, a town in Provence in the south of France. In nearby Saint-Rémy-de-Provence in 1889, he painted the iconic *Starry Night* and *Moonrise (Wheat Stacks)* as well as *Road with Cypress and Star* in 1890. Later that year, after a return to the north of France, he created *White House at Night* in Auvers-sur-Oise, a short distance northwest of Paris.

As detailed in previous *Sky & Telescope* articles (see the sidebar on pages 34 and 35), our Texas State University group determined dates and times for three of these later works. Buoyed by our past successes, we set out to employ the same astronomical methods and research techniques to discover when and where van Gogh painted two earlier works.

Lane of Poplars

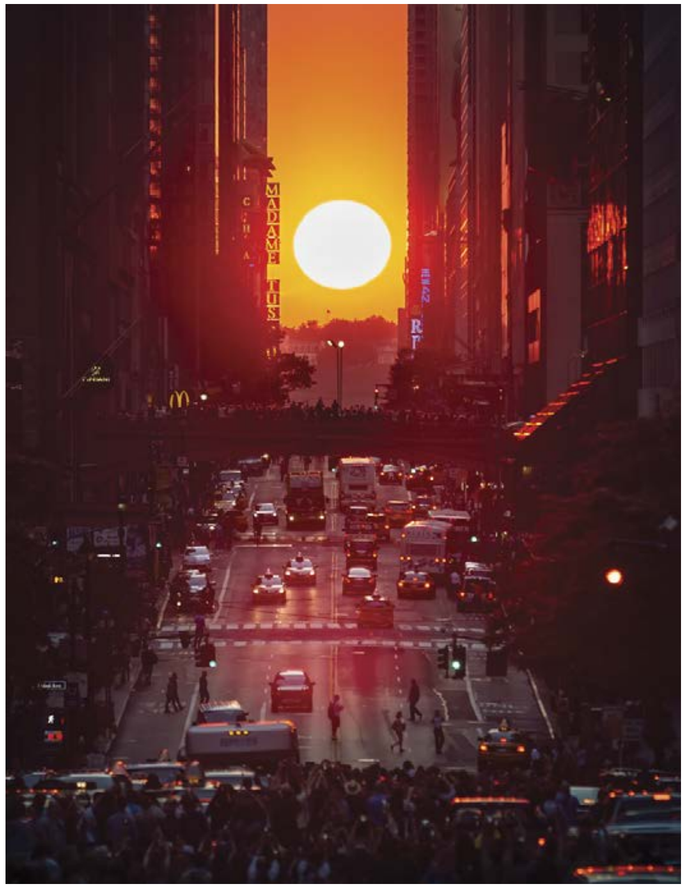
The 1884 painting known as *Lane of Poplars at Sunset* appeared to be another excellent candidate for astronomical analysis, under the assumption that van Gogh actually observed the scene he depicted. If we could identify the lane on 19th-century maps, then we'd be able to establish the compass direction of the road appearing in the artworks. Next, we can use astronomical calculations to determine the date when the disk of the setting Sun aligned as van Gogh portrayed it.

Because the modern titles now used for van Gogh's paintings often differ from the titles (if any) the artist himself used, researchers usually employ the catalog numbers assigned by Dutch art historian Jacob Baart de la Faille in his pioneering and monumental 1928 compilation of the artist's complete works, *L'Oeuvre de Vincent van Gogh: Catalogue Raisonné*. For example, F467 identifies *Café Terrace at Night*, the iconic painting now known as *Starry Night* bears the number F612, while *White House at Night* is recognized as F766.

Lane of Poplars at Sunset (F123, Nuenen, 1884)

VINCENT VAN GOGH / KRÖLLER-MÜLLER MUSEUM / WIKIMEDIA COMMONS / PUBLIC DOMAIN

▶ **SHOWTIME ON 42ND STREET** At sunset on July 11, 2014, a crowd gathered on 42nd Street in New York City to witness the alignment known as Manhattanhenge. The event occurs when the azimuth of the rising or setting Sun aligns with the city's street grid.



Lane of Poplars at Sunset was assigned the number F123. As our study of this canvas proceeded, some relevant chronological clues came from evidence regarding another work: *Lane of Poplars in the Autumn*, numbered F122. Compared to F123, F122 must depict a scene earlier in the autumn season. The trees in *Lane of Poplars in the Autumn* have abundant leaves with vivid fall colors, while the leaves are almost completely gone from the trees in the sunset depiction.

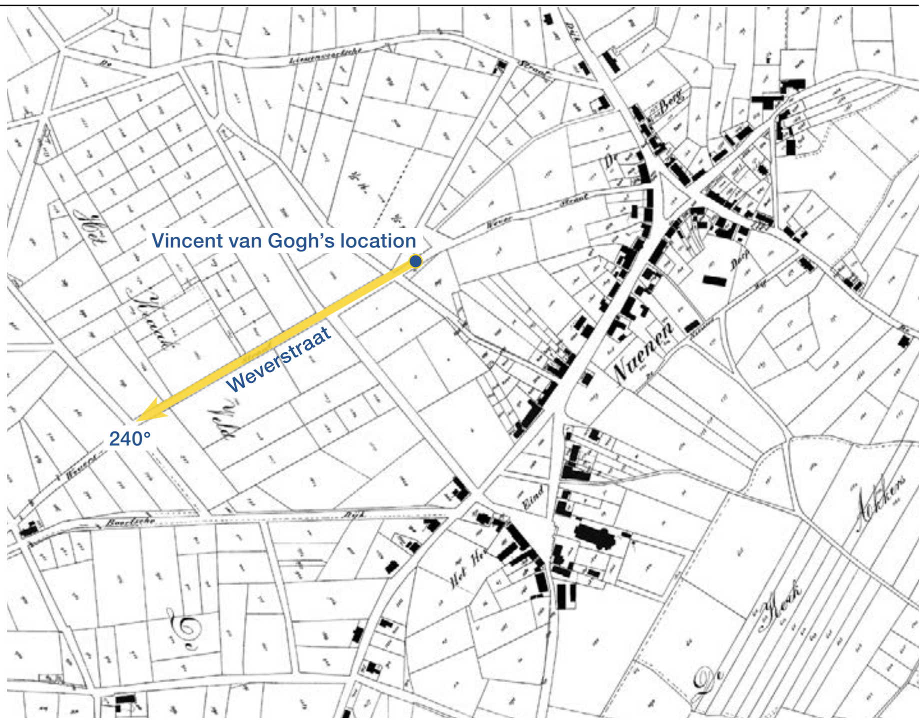
Letters to Theo

By examining Vincent van Gogh's correspondence, we can narrow down the range of possible dates for his works. A complete set of all the surviving letters that van Gogh wrote or received appears on an authoritative website compiled by leading scholars (**vangoghletters.org**). Three letters, all written by Vincent to his brother Theo during the autumn of 1884, include important evidence related to the two poplar paintings.

In letter 466, dated October 22, 1884, the artist offers chronological clues regarding the leaves:

> *It is extraordinarily beautiful here at the moment with the autumnal effects. In 14 days, we will have the real fall of the leaves — when everything that is on the trees falls in a few days.*

▶ **NUENEN ROADS** This 1883 official "cadastral map," created as part of the appraisal and collection of property taxes, shows the road system in and around the Dutch town of Nuenen exactly as it was during van Gogh's time. The proposed location for the painting *Lane of Poplars at Sunset* is marked on the straight stretch of Weverstraat, where the road is directed toward azimuth 240° — that is, 30° south of due west.



▲ **VAN GOGH'S PATH** Poplars lining both sides of Weverstraat can be identified in this photograph, taken around 1900–1911 with a view that looks slightly north of east toward the road called De Berg, visible in the distance. Vincent van Gogh would have been more than 200 meters (660 feet) behind this photographer's position and facing in the opposite direction, toward the southwest, to observe the November setting Sun.

MANHATTANHENGE: EDUARD MOLDOVEANU PHOTOGRAPHY; VIEW OF WEVERSTRAAT: COURTESY DE DRIJEHORNICK LOCAL HISTORY SOCIETY, NUENEN, GERWEN, AND NEDERWETTEN, PHOTOARCHIVE MUNICIPALITY, FOTOSGARDENIERS, ALBUM01, IMAGE NUMBER 63); MAP: BRABANT HISTORICAL INFORMATION CENTER

Letter 467, dated on or about October 25, 1884, includes a detailed description that matches the scene shown in *Lane of Poplars in the Autumn*:

> *The last thing that I made is a rather large study of a lane of poplars with the yellow autumn leaves, where the Sun makes glittering patches here and there on the fallen leaves on the ground, alternating with the long shadows cast by the trunks.*
>
> *At the end of the road is a peasant cottage, and above it the blue sky between the autumn leaves.*

Letter 469, dated on or about November 14, 1884, places an upper limit on the date for *Lane of Poplars at Sunset*:

> *These days, although it is freezing quite hard here, I am still working outdoors on a rather large study (more than 1 meter) of an old water mill in Gennep, on the other side of Eindhoven. I want to finish the whole thing outdoors – but it will definitely be the last that I paint outdoors this year.*

According to letter 466, the "real fall of the leaves" would occur about two weeks after October 22nd — that is, on approximately November 5th. The leaves appear to be almost completely gone from the trees in *Lane of Poplars at Sunset*. Freezing weather forced the last outdoor painting to be that of the Gennep water mill, in progress on or about November 14th. The information in van Gogh's letters therefore indicates that the date of the sunset painting falls approximately between November 5th and 14th in 1884.

Proposed Dates and Location for *Lane of Poplars in the Autumn*

Analysis of the painting F122 is relatively straightforward. The date of letter 467 shows that van Gogh must have completed it on or shortly before October 25, 1884.

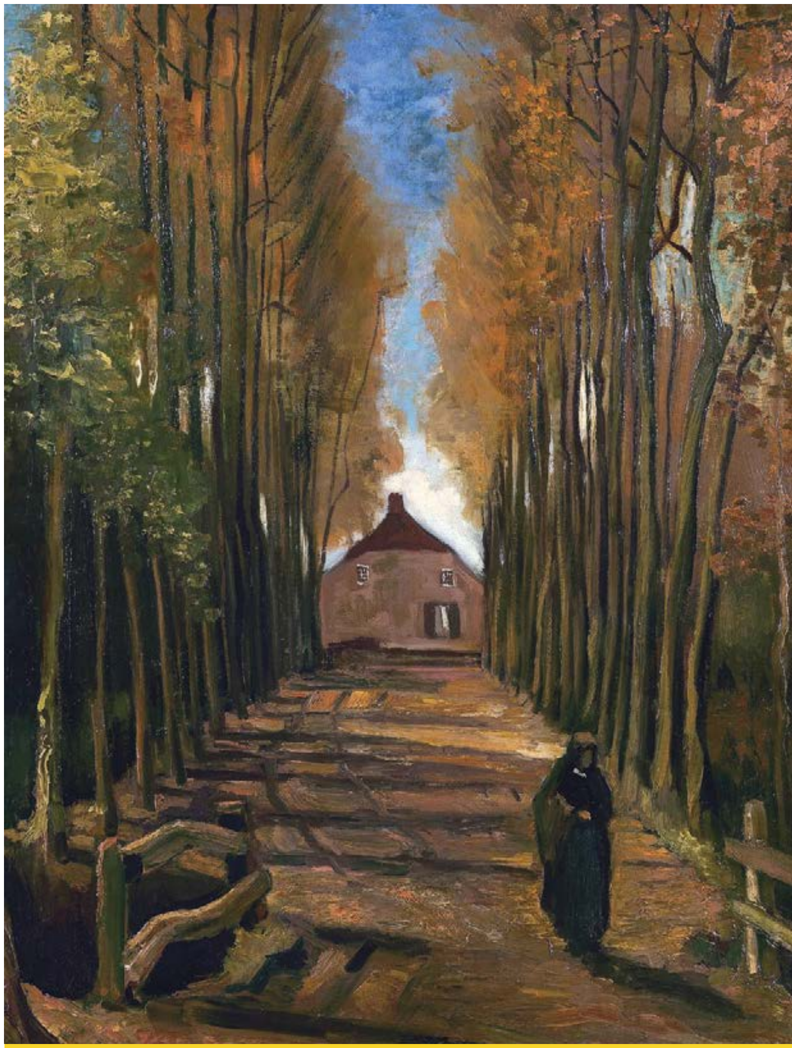
In the 1880s, the Royal Dutch Meteorological Institute (in Dutch it's the Koninklijk Nederlands Meteorologisch Instituut, or KNMI) collected weather observations and published them annually in a volume titled the *Nederlandsch Meteorologisch Jaarboek*. The yearbooks listed detailed weather data three times per day for primary stations such as Utrecht (north of Nuenen) and Maastricht (south of Nuenen), and once per day for secondary stations such as 's-Hertogenbosch and Horst (both closer to Nuenen). Although overcast skies and rain prevailed for much of October 1884, a brief period of clear weather (no rain and cloud cover ranging between 0% to 20%) occurred at all four weather stations during October 23rd and 24th — dates matching the depiction of blue skies above the trees in *Lane of Poplars in the Autumn*. This narrows down the range of dates to just these two days in October 1884. Either could be correct, though it isn't possible to determine which.

Local history expert Roland van Pareren has identified the cottage in this work as the home called Schoteldonkse Hoeve in the village of Nederwetten, immediately northwest of Nuenen. The Van Gogh Village Museum in Nuenen encourages tourists to visit the scene in Nederwetten and has placed an informative panel with an image of the painting at the spot.

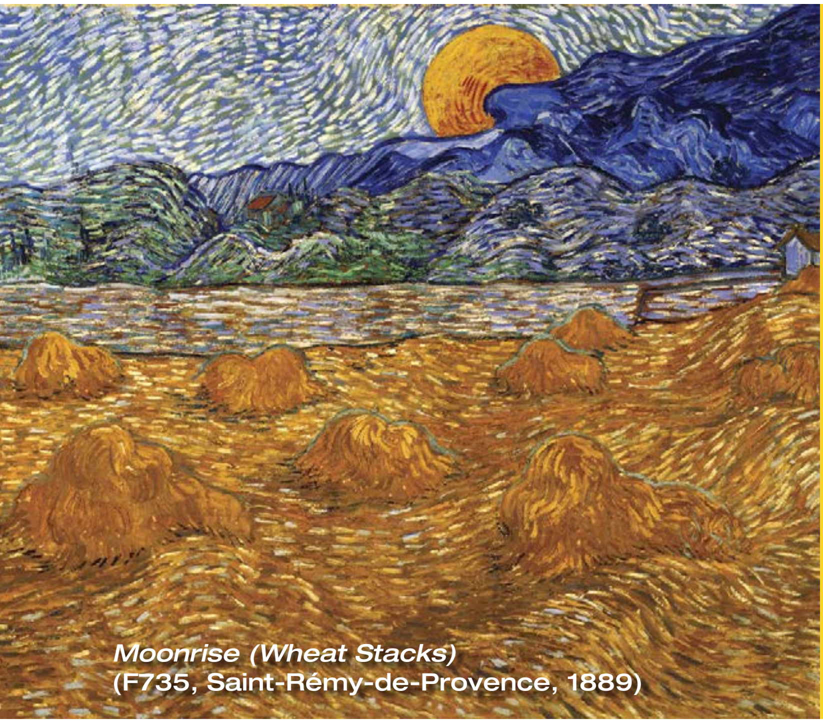
Because van Gogh's direction of view along the road looked almost directly to the west, the dramatic shadows he depicts establish that the time of day is generally in the afternoon. Unfortunately, because the shadows of the trees, the bridge railings, and the walking woman appear to point in somewhat inconsistent directions, it's not possible to determine a more precise clock time.

Determining the Date and Location of *Lane of Poplars at Sunset*

Compared to the analysis of *Lane of Poplars in the Autumn*, the study of *Lane of Poplars at Sunset* poses significantly more difficult and interesting problems. In part this is because



Lane of Poplars in the Autumn (F122, Nuenen, 1884)



Moonrise (Wheat Stacks)
(F735, Saint-Rémy-de-Provence, 1889)

VINCENT VAN GOGH / WIKIMEDIA COMMONS / PUBLIC DOMAIN

Previous Datings

With various colleagues, I determined dates and times for three later van Gogh works by using astronomical calculations, clues in the artist's letters, observations preserved in meteorological archives, and research trips to the sites. We described these efforts in previous *Sky & Telescope* articles.

At 9:08 p.m. on July 13, 1889, van Gogh witnessed a dramatic moonrise over a distinctive ridge in the Alpilles mountain range southeast of Saint-Rémy-de-Provence, and this scene inspired his *Moonrise (Wheat Stacks)* (*S&T:* July 2003, pp. 54–58).

On April 20, 1890, a grouping of Venus and Mercury near a thin waxing crescent Moon in the evening twilight is depicted in *Road with Cypress and Star* (*S&T:* Oct. 1988, pp. 406–408; Mar. 1989, p. 237).

On June 16, 1890, the first clear night after a week of cloudy weather and rain, the planet Venus dominated the evening twilight sky, as painted by the artist in *White House at Night* (*S&T:* Apr. 2001, pp. 34–39).

—DON OLSON

van Gogh never described the work in his letters, and also because no building or other landmark is visible.

Astronomers use *azimuth* to specify the compass direction of a celestial object, with 0° indicating due north, 90° due east, 180° due south, and 270° due west. As previously noted, van Gogh's letters indicate that the date of *Lane of Poplars at Sunset* falls approximately between November 5th and 14th in 1884. Within this range of dates, planetarium software shows that the Sun set in the southwest, in the range of azimuths between 240° and 244°. (These figures refer to the azimuth of the Sun calculated just as the lower limb of the solar disk first touches the ideal flat horizon.)

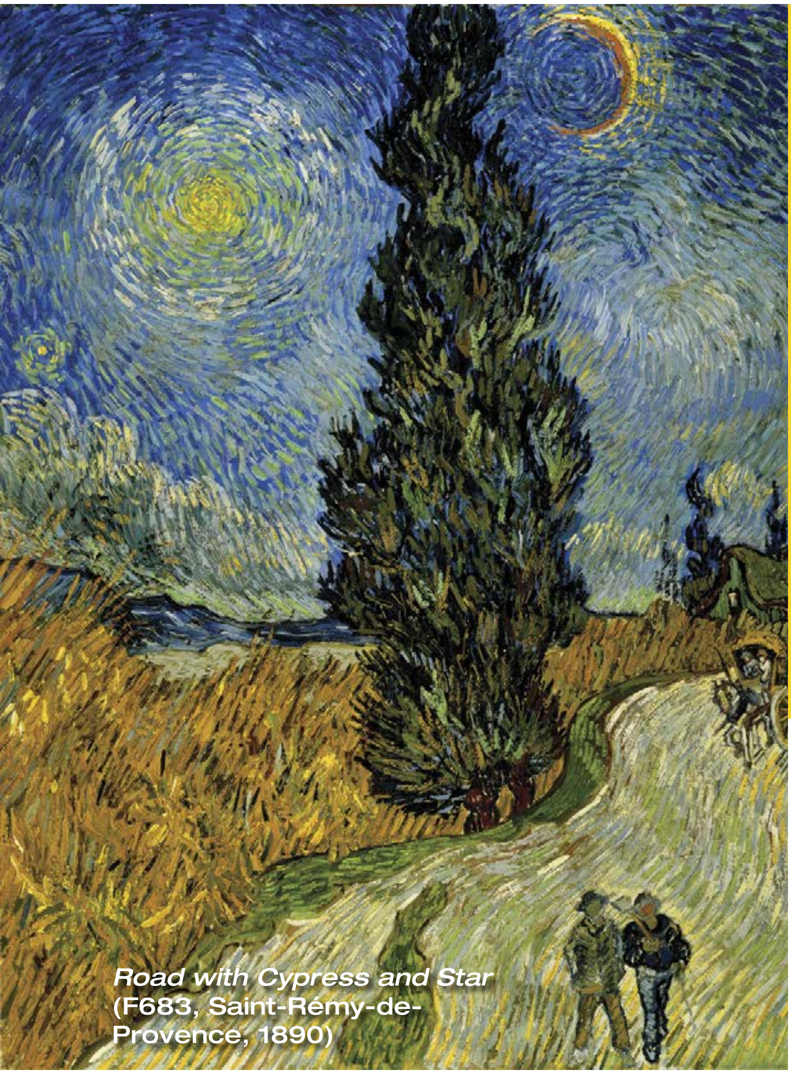
To determine a possible location that matches the calculated position for the setting Sun, we consulted the archived holdings of the Brabant Historical Information Center in 's-Hertogenbosch. There we found a detailed set of maps dating from 1883 that show all the roads in and around Nuenen and the nearby villages of Gerwen and Nederwetten. We searched for roads with straight stretches pointing toward the target azimuth range. Our investigation produced three candidates: Hoekstraat (directed toward azimuth 242°) in Nederwetten, to the northwest of Nuenen; a lane called Braakweg (directed toward 240°) on the west side of Nuenen; and Weverstraat (also directed toward 240°) in Nuenen, running to the southwest from the center of town. But which of these appears in *Lane of Poplars at Sunset?*

Hoekstraat at first seemed an especially promising location for the setting of our painting, because it begins from a spot near the cottage depicted in *Lane of Poplars in the Autumn*. This hypothetical viewpoint along Hoekstraat for *Sunset* would therefore lie only a short distance from the location where van Gogh set up for the earlier painting. However, this attractive possibility can be ruled out. We first note that the evidence of the falling leaves suggests that the paintings are separated in time by two or three weeks. We felt that if they were separated by only one or two days, that would strengthen the case that they were painted at nearly adjacent sites. More importantly, the straight stretch of Hoekstraat appears to be too short to accommodate the number of trees seen in our painting. The Braakweg lane is even shorter, which means it too can be ruled out.

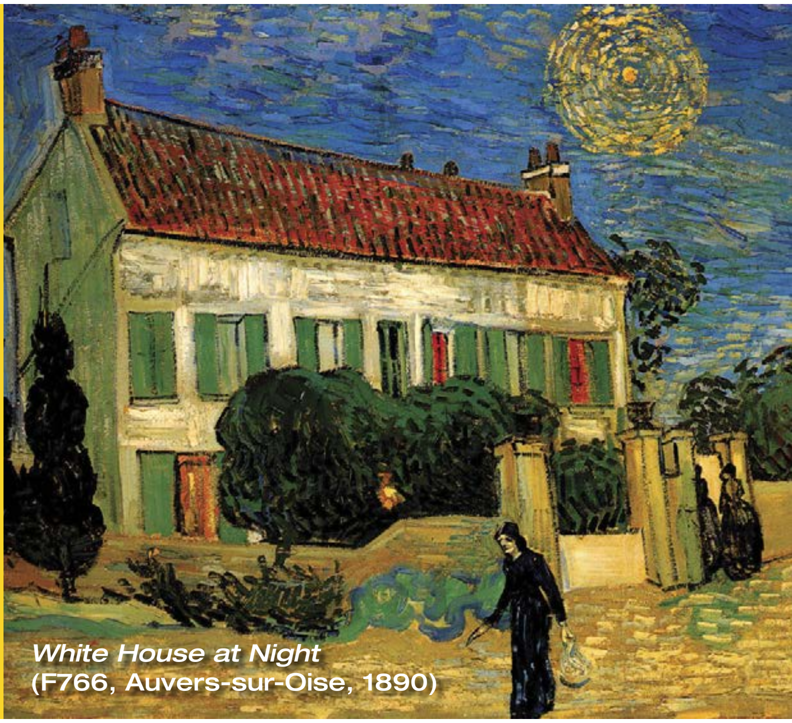
On Weverstraat, the long straight stretch that points toward azimuth 240° extends 365 meters (1,200 feet) — definitely long enough to match the view depicted in *Lane of Poplars at Sunset*, with as many as 15 trees visible on each side of the road. We consulted local botanical expert Rien van de Laar, who identified the trees in both the van Gogh painting and several vintage photographs of Weverstraat as the specific type known as Brabantse Staander poplars — reinforcing the idea that the scene van Gogh painted was real and not imaginary.

To reach Weverstraat, van Gogh would have started his journey from his lodgings at the vicarage in central Nuenen and walked to the southwest, a direction consistent with the artist's known excursions in November 1884 to Eindhoven and Gennep, both of which lie southwest of Nuenen. Users of Google Earth will find this proposed viewpoint near the place where two streets, Jasmijnstraat and Monseigneur Cuytenlaan, meet Weverstraat.

Astronomical calculations show that the full disk of the low Sun, only a few minutes before setting, could have been visible to the southwest over Weverstraat on November 13 or



Road with Cypress and Star
(F683, Saint-Rémy-de-Provence, 1890)



White House at Night
(F766, Auvers-sur-Oise, 1890)

ROAD WITH CYPRESS: VINCENT VAN GOGH / KRÖLLER-MÜLLER MUSEUM / WIKIMEDIA COMMONS / PUBLIC DOMAIN; WHITE HOUSE: VINCENT VAN GOGH / HERMITAGE MUSEUM / WIKIMEDIA COMMONS / PUBLIC DOMAIN

November 14, 1884. These dates, determined by astronomical considerations, are also consistent with observations in the meteorological archives. Although overcast skies, fog, and rain prevailed during much of November 1884, a remarkable five-day period of unusually clear weather (no rain and cloud cover ranging between 0% to 20%) occurred during the interval November 11–15, 1884.

And So It Must Be . . .

Biographical information places van Gogh in Nuenen during the autumn seasons of both 1884 and 1885. We wanted to check the possibility that he might have created *Lane of Poplars at Sunset* in 1885, because the Sun follows nearly the same path through the sky on corresponding calendar dates in any given year. The low Sun's azimuth on November 13 and November 14, 1885, therefore nearly matched the azimuth calculated for the preceding year. However, this period as a possible time for *Sunset* can be ruled out because of poor weather. Meteorological stations in central and southern Netherlands recorded completely overcast skies (100% cloud cover) on the afternoons of November 12–14, 1885.

As with our previous van Gogh projects, a combination of astronomical calculations, the artist's letters, vintage maps, meteorological archives, and multiple site visits provided evidence for determining the locations and dates of his paintings. The artist created two canvases depicting avenues of poplars during the only two periods of good weather in October and November 1884. The work known as *Lane of Poplars in the Autumn* shows a view looking west toward a cottage in Nederwetten, during the afternoon of October 23 or October 24, 1884. The canvas known as *Lane of Poplars at Sunset* matches the scene looking to the southwest down a long straight stretch of Weverstraat, shortly before sunset on November 13 or November 14, 1884.

Today, we can still gaze down the same stretch of road where van Gogh walked on a chilly autumn afternoon and ponder how the artist, in his native Netherlands, was already interested in portraying sky phenomena, four years before he began to create his famous starry nights in the south of France.

■ Contributing Editor **DON OLSON** is professor emeritus of physics at Texas State University. His most recent article, "Ansel Adams and Moons Over the High Sierra," appeared in the June 2023 issue. He is author of the book *Investigating Art, History, and Literature with Astronomy* (2022). **LOUIS VERBRAAK** and **FERRY ZIJP** are members of the Eindhoven Weather and Astronomy Club in the Netherlands. Louis retired from his position as engineer and quality manager at NXP Semiconductors. Ferry works as an optical designer in the research department of ASML, a Dutch optical lithography equipment company.

 by Ray Norris

ANCIENT STORIES The prehistoric site of Teimareh in Iran contains more than 20,000 examples of ancient rock art from various eras, including images that are more than 10,000 years old.

BABAK TAFRESHI

Why Are There Seven Sisters?

Many cultures tell intriguingly similar stories about the Pleiades, including the long-perplexing detail of a Lost Pleiad.

Wherever you are in the world, the evening sky in November is graced by the beautiful cluster of stars known as the Seven Sisters, or the Pleiades. How many stars can you see in the Pleiades without using a telescope or binoculars? Most people can count six, but depending on your eyesight you may see more or fewer. But almost nobody sees seven. So why do we call them the Seven Sisters?

That's the first mystery about these stars. The second mystery is this: While there are many different folk stories about the Pleiades, some have an oddly similar theme. Peoples from all over the world, from the ancient Greeks to Aboriginal groups in Australia, tell stories about these stars that involve seven sisters and one or more villains in Orion, with something happening to explain the "disappearance" of the seventh sister. Why?

The search for an answer will take us on an adventure through both human history and the sky.

The Lost Pleiad

The Pleiades is an open cluster of hot, young, blue stars. They were born about 120 million years ago and are surrounded by a reflection nebula, a cloud of dusty interstellar gas that reflects the stars' blue light. At least 1,000 stars make up the cluster, but of course we see far fewer than that with the naked eye.

Our ancestors naturally took note of such a bright cluster. The earliest evidence we have comes from Lascaux, France, where archaeologists have found an image from about 20,000 BC that might represent the Pleiades. The Chinese *Shujing* annals, said to date from around the 4th century BC, claim the Pleiades were observed in the 24th century BC. Another reputed image is the famous Nebra sky disk from Germany, which some think is from 1600 BC. There is also rock art depicting the Seven Sisters in Walinynga (Cave Hill) in central Australia, which is thought to be at least 3,000 years old.

Many of these ancient records refer to seven stars, even though with the naked eye, normal eyesight, and good skies, most individuals in the past couple of millennia have only seen six. A few people with exceptional eyesight have claimed to see many more. For example, the 16th-century astronomer Michael Maestlin recorded 11 Pleiades stars, 29 years before the invention of the telescope.

Galileo himself saw six. In 1610 he wrote in *Sidereus nuncius* that "I have depicted the six stars of the . . . Pleiades (I say *six* intentionally, since the seventh is scarcely ever visible)."

So why do we call them *seven* sisters? This inconsistency was noted as far back as the third century BC, when the Greek poet Aratus of Soli named the Seven Sisters (according to him: Halcyone, Merope, Celaeno, Electra, Sterope, Taygete, and Maia) but said that "only six are visible to the eyes." Greek mythology explained this inconsistency by saying that one of the sisters, Merope, married a mortal, and her shame caused her to fade from sight.

That story is confusing, because Merope is one of the brighter stars, whereas the stars Asterope and Celaeno are so faint that even people with perfect eyesight can barely see them! I suspect the stars' identifications have somehow been mixed up over the years. This idea is supported by another Greek source, which says that the lost star was Celaeno. The six bright stars Galileo marked in his 1610 chart correspond to Atlas, Alcyone, Merope, Maia, Electra, and Taygeta.

What's odd is that many other cultures around the world also say the cluster really has seven stars, and then have a Lost Pleiad story to explain why we only see six. For example, the Onondaga people from upstate New York say that one of the stars is fainter as a result of singing on its journey to the sky. In Australia, Aboriginal people tell stories explaining how the Lost Pleiad died, was captured, or is in hiding. Other variations appear in lore from different continents. These stories from around the world and across the ages suggest that once upon a time there were seven visible stars, and that one of them has since become invisible.

So what happened to the Lost Pleiad? One possibility is that one of the present faint stars, such as Asterope or Celaeno, used to be much brighter. This is quite possible, as all the visible stars in the Pleiades are young, *B*-type stars known to be variable on short time scales. For example, Pleione has a *decretion disk*, a skirt of hot gas thrown off because the star spins so rapidly. This disk changes its shape and orientation on a time scale of years, resulting in a fluctuating brightness. However, our present astronomical observations cover such a short span of human history that we aren't certain how such stars vary on a time scale of centuries, and so we cannot easily say whether any of them used to be brighter.

◀ **NEBRA DISK** Found in Germany, this dinner-plate-size bronze disk bears celestial symbols in gold inlay, including a cluster of seven stars thought to represent the Pleiades. Archaeologists still debate the Nebra disk's age; it could be either 2,500 or 3,500 years old.

Another suggestion is that there may have been a bright star that exploded in a supernova. If that had happened in the last 4,000 years, it probably would have been recorded by ancient Chinese astronomers, but there is no record of such an event. If there was an explosion before that, even back to 100,000 years ago, we would still detect a supernova remnant with our radio telescopes (*S&T:* May 2024, p. 12). But none has been found close to the Pleiades. So that explanation seems unlikely.

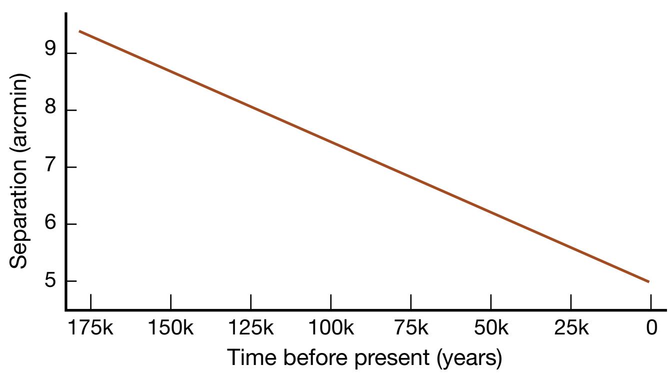
My son, Barnaby, and I realized that there's another possible explanation. The Hipparcos and Gaia space telescopes have shown that the stars of the Pleiades are slowly moving in the sky. The stars Pleione and Atlas are now so close together that most people see them as just one star. But if we rewind 100,000 years, the two stars were sufficiently far apart — more than 7 arcminutes — that most people would see them as two separate stars. So at that time, observers would have seen seven stars in the cluster, even though now we only see six.

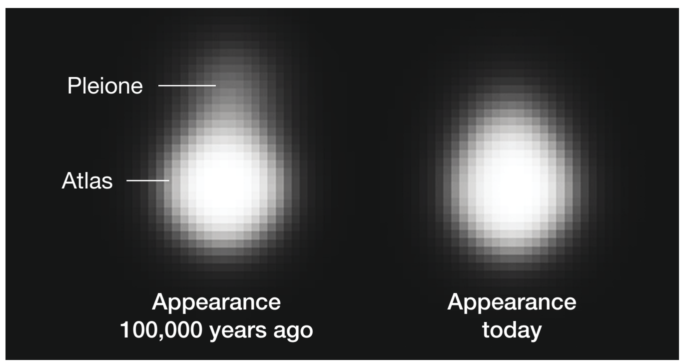
But 100,000 years is a long time. Is there any other evidence that these Seven Sisters stories could really be that old?

Perhaps there is, and it involves Orion.

Orion and the Pleiades

Greek mythology tells us that the Pleiades were the daughters of Atlas and Pleione. Zeus forced Atlas to hold up the sky

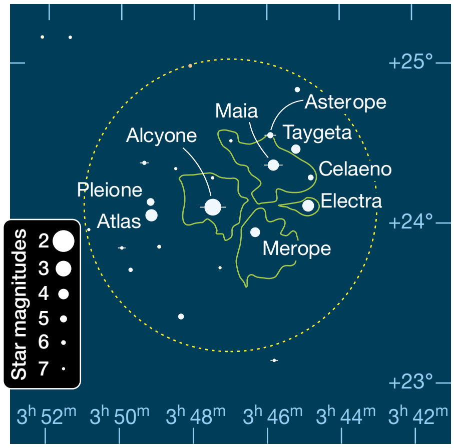




▲ **COMING CLOSER** Based on data from Gaia's third data release, this plot *(left)* tracks the apparent motion of Atlas and Pleione across the plane of the sky over tens of thousands of years. Today, the stars are 5 arcminutes apart; 50,000 years ago, they were 6.2 arcmin apart, and 100,000 years ago they lay 7.4 arcmin apart — a separation more easily discernible to typical human vision *(right)*.

NEBRA DISK: FRANK VINCENTZ / CC BY-SA 4.0; GRAPH: LEAH TISCIONE / S&T, SOURCE: EVAN CRAWFORD; APPEARANCE: THE AUTHOR as punishment for being on the wrong side of a war. Thus occupied, Atlas could no longer protect his daughters, so Zeus transformed them into stars to protect them from Orion the Hunter, who was chasing them.

In the sky, the constellation of Orion lies just to the east of the Pleiades. When we look at them, Earth's rotation makes it appear that Orion continues to chase the Pleiades. But in the Southern Hemisphere, Orion is upside-down, making it look less like a hunter. This may be why many people in Australia and New Zealand call Orion the Saucepan.



◀ **PLEIADES TODAY** At the limits of human vision (magnitude 7), the Pleiades include more than seven stars. But observers often report seeing only six: Pleione/Atlas (merged into one), Alcyone, Merope, Electra, Maia, and Taygeta. The surrounding nebulosity (green outlines) is an independent cloud that's drifting through the cluster, not the dusty wisps of the stars' natal cocoon.

Nevertheless, in many of the 100 or so surviving Aboriginal language groups across Australia, Orion is a hunter, or a lustful young man, or a group of young men.

Just as in the Greek stories, most Aboriginal cultures say that the Pleiades are a group of (usually seven) young girls. They are associated with sacred women's ceremonies and stories, and they are important as an element of Aboriginal calendars and astronomy. For example, many groups interpret the first rising at dawn of the Pleiades as the start of winter.

Some of these stories also connect the Pleiades with Orion. The Anangu people in the center of Australia call Orion Nyiru and say that he is pursuing the Seven Sisters (Kunkarunkara). Specifics change from teller to teller, but the story is that Nyiru chased the sisters from the north and down past Uluru (Ayers Rock), until they hid in Walinynga Cave. Various lurid details follow, in which Nyiru captures and rapes the youngest sister. Eventually the sisters escape from the back of the cave and flee up into the sky, rescuing the seventh sister as they go. This rescued sister is the "missing" star. In other Aboriginal stories, the seventh girl is in hiding or is ashamed.

One extra twist found in some parts of Australia is that the bright red star Aldebaran, between Orion and the Pleiades, is interpreted as a dingo dog belonging to the girls that barks at Orion to try to protect them.

So in both ancient Greece and in Aboriginal Australia, people say there are seven stars, but then have another story to explain why most people see six. In both cases, they say the Pleiades are female and Orion is male. In both cases, they say the man/men of Orion are chasing the Seven Sisters.

Why Are the Stories So Similar?

So how come the Australian Aboriginal stories are so similar to those of the Greeks? Could it be coincidence? After all, we are dealing with only a subset of the world's Pleiades legends — other tales portray the Pleiades as a hen with chicks, for example, or a single woman, or a star broken into six pieces (see page 45 for more examples). But the most common tale seems to be that of a group of girls, appearing in more cultures' lore than the other versions do.

Could it be that these tales have a common origin?

It's possible. We now know from DNA evidence that all modern humans are descended from people who lived in Africa about 100,000 years ago. Over the following millennia, these groups began their long migrations to the far corners of the globe. In the case of Aboriginal Australians, they left Africa at the same time that the ancestors of Europeans, Asians, and everyone else did and arrived in Australia at least 50,000 years ago. After that time, there were no further waves of migration into Australia, leaving the Aboriginal people almost untouched by other cultures until the arrival of the British in 1788.

We also know the Aboriginal Seven Sisters stories are very old, both from their distribution across Australia, including regional variations, and from rock art at Walinynga and elsewhere that is thousands of years old.

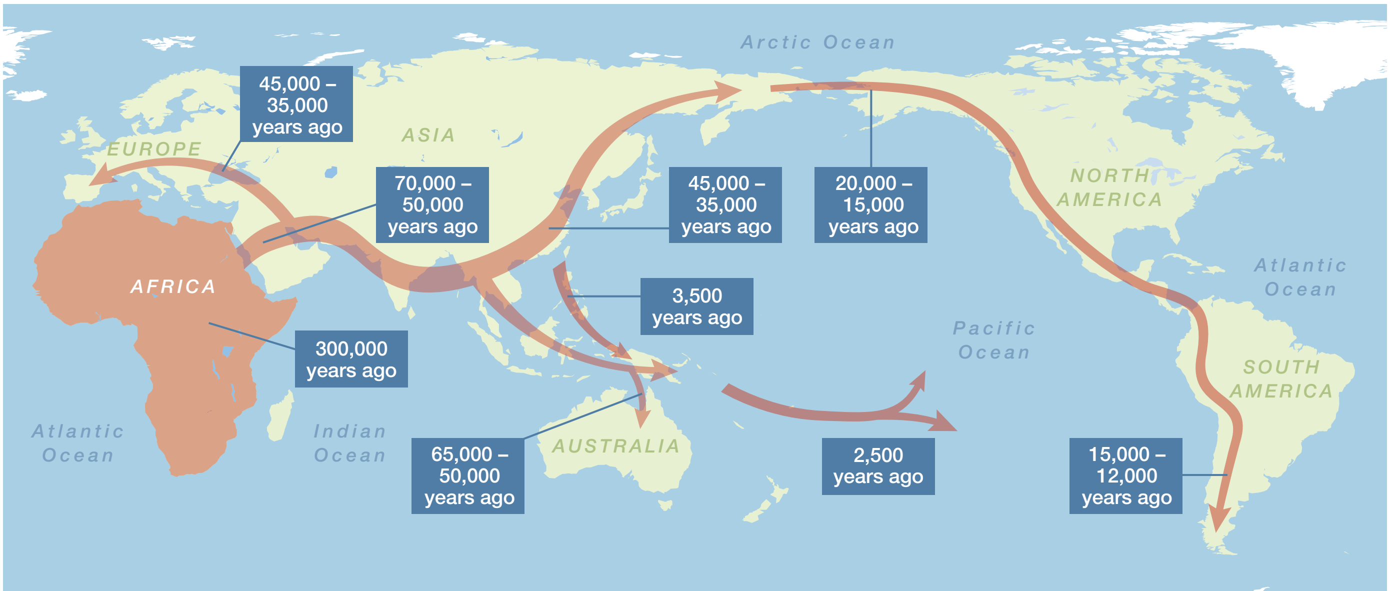
Given that the stories are old and that there was little to no contact with other parts of the world, it may be that the Aboriginal people brought these stories with them. Since the tales are similar to the stories from the Greeks (and other peoples around the world), it seems possible that these stories came from where we all did — Africa. If that is true, then roughly 100,000 years ago, our ancestors were sitting around their campfires in Africa, telling one another stories of Orion and the Seven Sisters — stories that are still with us today.

At that time, the Pleiades really did have seven easily visible stars. This explains why these different cultures called them the Seven Sisters: that's how they appeared in 100,000 BC. But when the seventh star gradually disappeared, each culture had to invent a story to explain why we only see six of them now.

The Oldest Story?

After I published an article describing these ideas, I learned of work by French researcher Julien d'Huy (Laboratory of Social Anthropology, France) who, unknown to me, had been studying the world's Pleiades stories from a completely different angle. He uses a technique called *phylogenetic analysis*, which evolutionary biologists employ to track the extent of genetic relationship between species. For several decades, anthropologists have also applied this technique to different versions of myths from around the world, constructing family trees that trace the transmission of stories or their motifs from culture to culture.

LEAH TISCIONE / S&T



▲ **HUMAN MIGRATION** Based on archaeological and genetic evidence, *Homo sapiens* originated in Africa a few hundred thousand years ago. We then spread across Africa and to other continents, sometimes intermixing with other hominin species such as Neanderthals. Humans left Africa multiple times, but the key dispersal occurred roughly 60,000 years ago when, over many thousands of years, we spread worldwide (some possible routes and dates shown). Scientists debate the exact timeline of this migration; estimates for arrivals in Australia and North America vary by several thousand years. Every living non-African today is descended from that wave of migrants.

Using this analysis, d'Huy and Yuri Berezkin (Museum of Anthropology and Ethnography, Russia) explored possible connections between different Pleiades myths. Pulling from a database of roughly 55,000 narratives gathered from some 1,500 ethnic groups from all the inhabited continents, they selected the narratives that involved the Pleiades. From these, they identified 21 different motifs that appear in the stories — thematic elements like the Pleiades being a sieve, or a flock of birds, or a group of girls or women. Stories often contain multiple motifs.

The researchers built phylogenetic trees and networks to determine which traditions might share a common heritage, and how far back those connections went. In this way, they were able to trace the spread and evolution of the mythological traditions linked to the Pleiades.

This analysis showed that some story elements probably did originate in Africa and had spread across the world through humans' various migrations. In fact, of only four motifs that they could trace back to those earliest migrations out of Africa, three often appear in the Seven Sisters stories: (1) The Pleiades are a group of girls or women, (2) Orion appears in the same tale, and (3) Orion and the Pleiades are opposed as one or more men versus one or more women (usually, Orion is male).

They had reached a similar conclusion to the one I had, using a totally different approach.

D'Huy and Berezkin also identified a fourth ancient motif, which doesn't fit in this picture: The Pleiades are one person, usually paired with a warrior or hunter. D'Huy suggests this alternate motif indicates that different tales existed even before we left Africa.

While other myths, such as those involving Ursa Major/the Big Dipper, are also found in different cultures, the Pleiades-Orion myth seems to be the most widespread and the most consistent. I suspect that this may be because constellations such as Ursa Major are barely visible from most of the Southern Hemisphere. Similarly, the most obvious constellations and asterisms in the south, such as the Southern Cross, are not visible from most of the Northern Hemisphere.

On the other hand, Orion straddles the celestial equator, and the Pleiades are only 24° north of it. They are therefore easily visible from both hemispheres and the most prominent celestial patterns that can be seen from nearly every point on Earth. These stars would have been visible to any migrating group of people as they travelled from continent to continent.

So it is possible that these stories are so old that our ancestors were sharing versions of them in Africa approximately 100,000 years ago, before Europeans and Aboriginal Australians went their separate ways.

That would make the Seven Sisters story the oldest story in the world.

■ **RAY NORRIS** (Commonwealth Scientific and Industrial Research Organisation, Australia) studies radio galaxies at the edge of the observable universe and admires the intellectual achievements of Aboriginal astronomers. He acknowledges and pays his respects to the traditional owners and elders, both past and present, of all the Indigenous groups mentioned. All Indigenous material was found in the public domain.

Explore the rock art of Walinynga and the Seven Sisters story: https://is.gd/walinynga_tour.

LEAH TISCIONE / *S&T*, SOURCES: ENCYCLOPEDIA BRITANNICA, ELEANOR SCERRI / MAX PLANCK INSTITUTE OF GEOANTHROPOLOGY

SKY AT A GLANCE
November 2024

2 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:42 p.m. EDT (7:42 p.m. PDT; see page 50).

3 DAYLIGHT-SAVING TIME ENDS at 2 a.m. for much of the U.S and Canada.

4 DUSK: Face southwest to see the delicate crescent of the waxing Moon hanging about 3½° lower left of Venus — catch this sight before the pair sets. Turn to page 46 to read more on this and other events listed here.

10 EVENING: The waxing gibbous Moon and Saturn are less than 30′ apart in the south-southwest. Some locations in the southeastern U.S. will see the Moon eclipse the planet.

16 MORNING: High in the west, the just-past-full Moon gleams in the Pleiades. You'll need binoculars or a telescope to glimpse the cluster stars (go to page 48).

17 MORNING: The sight of the waning gibbous Moon about 5° right of Jupiter greets early risers. The gas giant gleams between the horns of Taurus, the Bull, in the west.

17 MORNING: The Leonid meteor shower is predicted to peak. However, the bright Moon will hamper viewing.

19 EVENING: The waning gibbous Moon is some 2½° below Pollux as the pair rises above the east-northeastern horizon.

19 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:36 p.m. PST.

20 EVENING: Face east to see the Moon, two days shy of last quarter, around 4½° lower left of Mars.

22 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:25 p.m. EST (8:25 p.m. PST).

23 MORNING: The last-quarter Moon follows Regulus, Leo's brightest star, by a bit more than 4° as they climb in the east.

25 EVENING: Algol shines at minimum brightness for roughly two hours centered at 8:14 p.m. EST.

27 MORNING: The waning crescent Moon occults Spica for viewers in central and eastern North America as the duo rises in the east-southeast. Turn to page 48 for details on how to see this event.

—DIANA HANNIKAINEN

▲ NGC 604 is a huge H II region in the Triangulum Galaxy (M33). The newly formed stars emit ultraviolet light that makes the surrounding cloud of gas glow, as seen in this Hubble Space Telescope image. Turn to page 22 for more on targets in the Triangulum Galaxy.

NASA / ESA / M. DURBIN / B. F. WILLIAMS (UNIVERSITY OF WASHINGTON)

NOVEMBER 2024 OBSERVING

Lunar Almanac
Northern Hemisphere Sky Chart

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

MOON PHASES

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

NEW MOON
November 1
12:47 UT

FIRST QUARTER
November 9
05:55 UT

FULL MOON
November 15
21:29 UT

LAST QUARTER
November 23
01:28 UT

DISTANCES

Perigee	November 14, 11^h UT
360,109 km	Diameter 33′ 11″
Apogee	November 26, 12^h UT
405,314 km	Diameter 29′ 29″

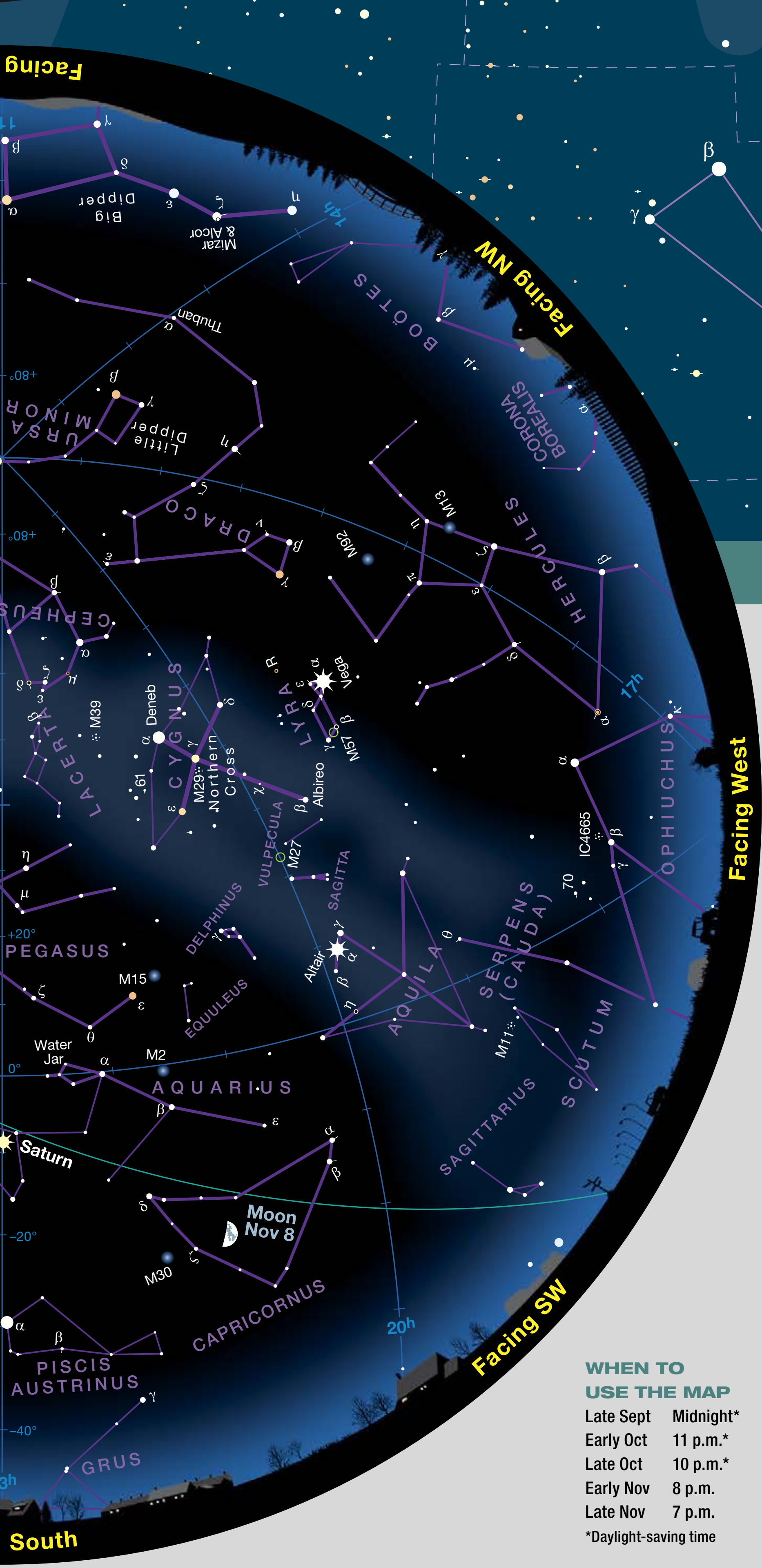
FAVORABLE LIBRATIONS

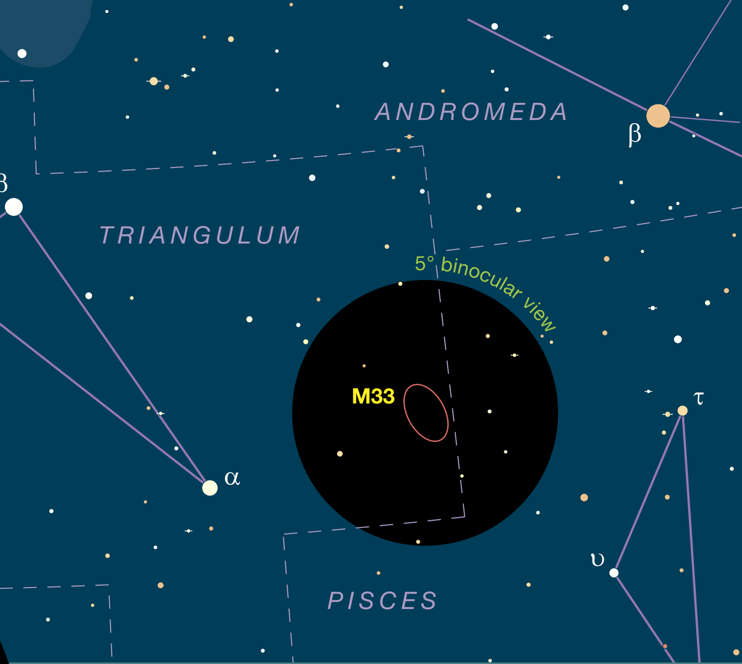
• Casatus Crater	November 14
• Boussingault Crater	November 15
• Pontécoulant Crater	November 16
• Peirescius D Crater	November 17

Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

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 Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Unresolved Matter

Our target this month is **M33**, the Triangulum Galaxy (see also the article on page 22). As the third-largest galaxy in the Local Group, along with the Andromeda Galaxy (M31) and our own Milky Way, the Triangulum spiral is reasonably famous among observers. Or perhaps I should say infamous — thanks to M33's nearly face-on orientation, its 6th-magnitude light is spread across a full degree of sky. The galaxy's faint surface brightness is easily wiped out by light pollution or thin clouds, and it can be a challenging and frustrating target.

My recipe for hunting M33 includes getting to the darkest skies I can and being fanatical about dark adaptation — you might be surprised how effective it can be to pull a hood around your face to block all local light. I prefer to use 7×50 binoculars for their combination of largish aperture and low magnification, enough to enlarge the galaxy to easy visibility. To find M33, look a bit more than 4° west-northwest of 3rd-magnitude Alpha (α) Trianguli.

Like all galaxies, M33 only shows as a fuzzy patch in handheld binos. Some of that glow is ionized gas or light-reflecting dust, but most of it is simply stars, millions of stars. The thought of so many suns — and their attendant worlds — fills me with a numinous yet vertiginous feeling, like bumping shoulders with infinity. That feeling is my prime motivator for observing galaxies with binoculars: to see stars, not as individual objects, but in such numbers and at such distances that even in their myriads they're reduced to a faint fog of light. Considered this way, the lack of resolution is a feature, not a limitation. Have a look and see if you acquire the same taste.

■ **MATT WEDEL** loves binocular observing for the freedom to let go of all the objects that are beyond his reach, to focus on the lifetime's worth he can see.

NOVEMBER 2024 OBSERVING

Southern Hemisphere Sky Chart

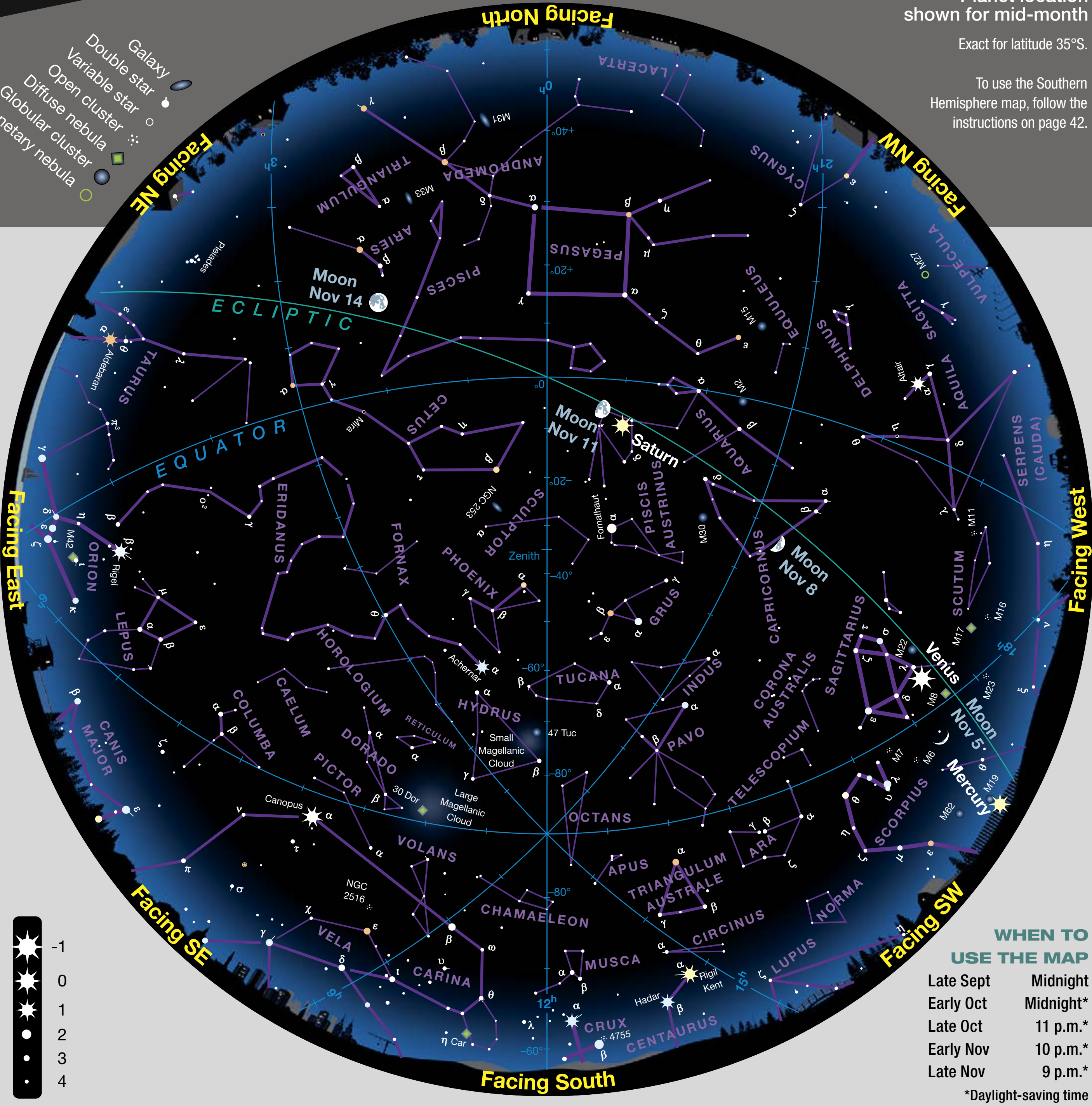
by Jonathan Nally

Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

Planet location shown for mid-month

Exact for latitude 35°S.

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



WHEN TO USE THE MAP

Late Sept	Midnight
Early Oct	Midnight*
Late Oct	11 p.m.*
Early Nov	10 p.m.*
Late Nov	9 p.m.*

*Daylight-saving time

PERCHED JUST TO the west of the Small Magellanic Cloud is the second-brightest globular star cluster in the night sky, **47 Tucanae**. On November evenings you'll find it directly south and about halfway up from the horizon. The cluster is visible as a small, 4.1-magnitude fuzzy patch that looks a bit like the head of a comet. In reality it's a huge ball of tens of thousands of stars, about 14,500 light-years from Earth.

Being so far south and out of sight from Europe, it took until the early 1750s for 47 Tuc to be cataloged by the French astronomer Nicolas-Louis de Lacaille while observing in South Africa. Its home constellation, Tucana, the Toucan, on the other hand, made its debut more than 150 years earlier when it appeared on a celestial globe made by Dutch-Flemish cartographer Petrus Plancius. ■

Tales of the Pleiades

This Taurus cluster is known as the Seven Sisters, but not all cultures saw them that way.

▲ In January 2013 Jupiter visited Taurus and approached the Pleiades (upper right), the Seven Sisters of classical mythology. In the current apparition, the planet returns to the same patch of sky and creeps westward toward the cluster until February, when it reverses course and drifts eastward.

ALAN DYER

The Pleiades is one of the star groups for which the oldest myths exist. In numerous tales they are female in nature. Many western cultures know them as the Seven Sisters — a name that comes from classical mythology and refers to the seven beautiful mountain nymphs pursued by Jupiter and Orion. (See "Why Are There Seven Sisters?" on page 36.)

But other cultures saw them differently. One Māori legend from New Zealand, for example, tells us that the Pleiades are Matariki, a mother and her six daughters who travel across the sky each year to visit their ancestral Earth Mother. Many more examples of the female nature of the Pleiades exist. But let's look at the Pleiades through the lens of indigenous Americans, whose stories embrace elements of their local environment and cultural beliefs.

Winter in the Northern Hemisphere has traditionally been a time to tell tales during long, cold nights. To the Lakota Sioux of South Dakota, life is a sacred circle or hoop in which all things are connected: nature, animals, and people. The region's Black Hills lie within a terrestrial sacred hoop — their Mother Earth's ceremonial home, which mirrors a circle of stars in the sky. Part of that circle includes Tayamni, an enormous celestial animal that stretches from the Pleiades (its head) to Sirius (its tail), with the Belt of Orion and Aldebaran representing the creature's backbone, while Betelgeuse and Rigel form its ribs. According to an article by Native American rock-art researcher Herman Bender, the animal may represent a bison on its haunches in a berthing posture.

In one myth from the Blackfeet people of the northern Great Plains of western North America, the Pleiades were orphaned boys rejected by their tribe yet befriended by a pack of wolves. Although appreciative of the kindness of the wolves, the boys wanted to escape their earthly sadness and play together in the sky as celestial beings. The Great Spirit heard their prayers and lifted the boys into the sky as the Pleiades. Today, we can still hear wolves mournfully howling over the loss of their friends.

A popular Cherokee legend interprets the Pleiades as seven boys who once spent their days rolling a stone wheel along the ground with a stick instead of helping their mothers in the cornfields. To teach them a lesson, the mothers boiled some stones and told their hungry sons that if they liked playing with them so much, they could eat stones instead of corn. Angered, the boys ran away to their playground. There, they danced around in circles, praying to the spirits to help them escape to a place where their mothers would no longer trouble them. With each round, the boys rose higher and higher off the ground. By the time their mothers found them, they were so high that only one could be pulled back to Earth. The other six made it into the heavens where they became the Pleiades.

Of course, the Pleiades have a story to tell scientists, too. Lying about 445 light-years distant, the cluster is one of the nearest to our Sun. It's a true family of youthful stars, around 100 million years old. We view the stars through an interstellar dust cloud through which the cluster members are currently passing.

As plotted on this month's Northern Hemisphere star chart (pages 42 to 43), Jupiter and the Pleiades are well on the rise. As the weeks pass, you'll see Jupiter's retrograde (westward) motion carry it ever closer to the Pleiades. As some legends have it, three of the Seven Sisters succumbed to the loving embrace of Jupiter, who was enamored with their beauty. During this particular apparition, however, Jupiter won't embrace any of them. In early February, the planet briefly stalls before it reverses direction and drifts eastward away from the Pleiades. It's as if Jupiter has a sudden change of heart and decides to save the rendezvous for another time.

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

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

An Evening Planet Parade

Five naked-eye planets are visible before midnight this month.

MONDAY, NOVEMBER 4

November opens with a bang. Sort of. Face southwest at dusk to catch the reliably eye-catching pairing of the crescent **Moon** and **Venus**. On this occasion, the 11%-illuminated Moon is a bit more than 3½° below and left of the brilliant Evening Star, which gleams splendidly at magnitude –4.0.

As twilight begins to fade, you should be able to make out the Moon's "dark" portion dimly lit by *earthshine* — sunlight reflecting off the oceans and clouds of our planet. Because the phase of Earth as seen from the lunar surface is the inverse of the Moon's, fully 89% of our planet is reflecting sunlight moonward. That's why earthshine is so much easier to see when the Moon is a narrow crescent and becomes increasingly difficult to perceive as it waxes toward first quarter.

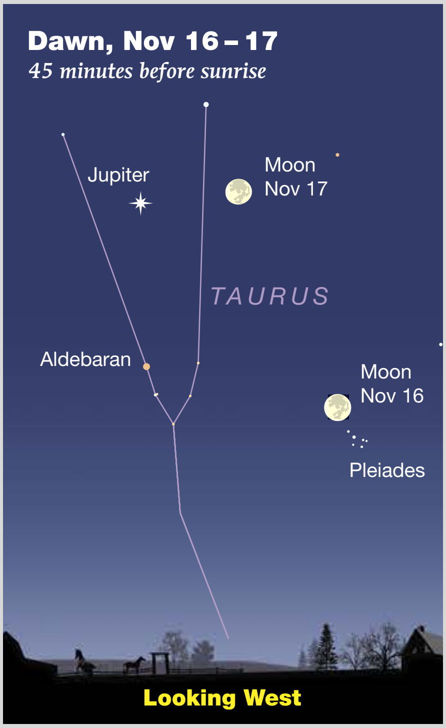
Binocular users might be able to add two celestial players to this dusk scene. Scan about 11° lower right of the Moon and see if you can catch 1st-magnitude **Antares** flickering away near the horizon. Even lower and 7½° to the right you might pick up **Mercury**, shining at magnitude –0.3. Neither object is very high, though, so don't be surprised if they elude you — without absolutely transparent skies and a completely unobstructed horizon, you don't stand a chance. Mercury is presently in the middle of its worst dusk showing for 2024. It's at its highest on the 19th, but even then, it hovers only 5° above the southwestern horizon 30 minutes after sunset.

SUNDAY, NOVEMBER 10

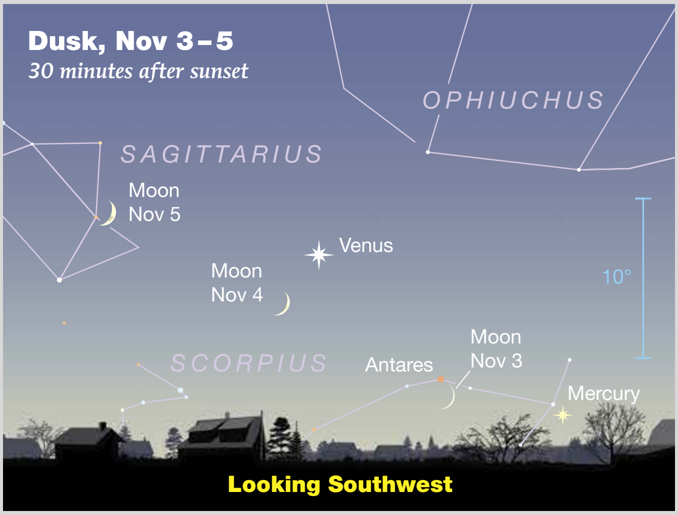
This evening the waxing gibbous **Moon** (70% illuminated) passes just below +0.9-magnitude **Saturn**. This is the closest pairing between the Moon and a planet this month — but how close they get depends on your location. From mid-northern latitudes, less than half a Moon diameter separates them. However, the gap narrows the farther south and east you are. For example, from New Orleans, Louisiana, the gap between them is less than 7′ wide. And if you go to the southernmost part of the continental U.S., instead of a conjunction you'll see an occultation. From Miami, Florida, the northern edge of the lunar disk covers the Ringed Planet from about 9:26 p.m. to 10:06 p.m. EST. (The occultation zone includes Central America, the Caribbean, and the northern portion of South America, too.) Binoculars or a telescope will make the event much more enjoyable to watch.

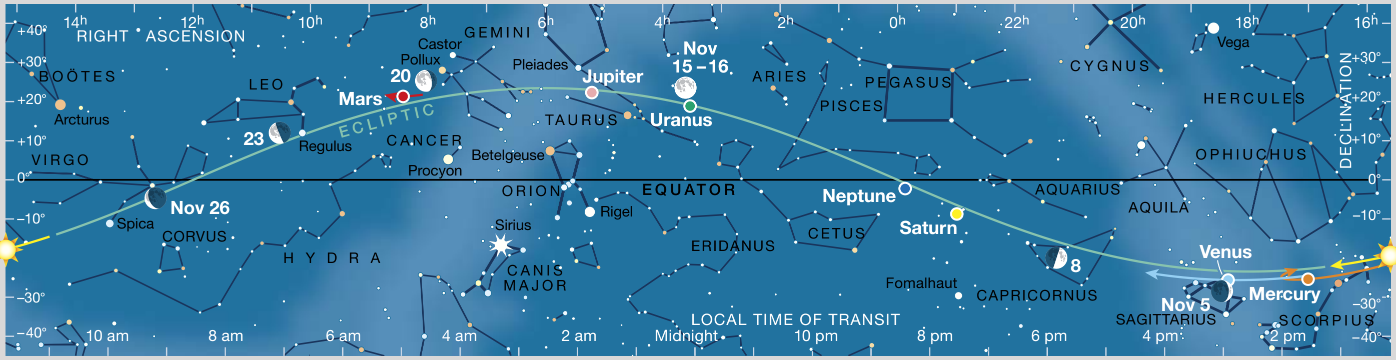
SATURDAY, NOVEMBER 16

This morning the full **Moon** makes its way across the **Pleiades**, in Taurus. On paper, it sounds like a noteworthy event and one you certainly don't



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





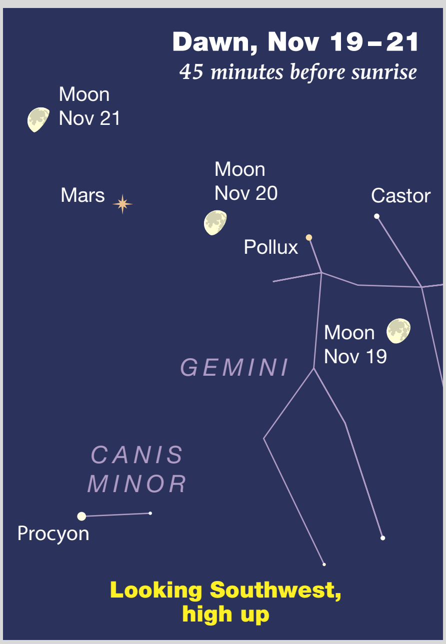
▲ The Sun and planets are positioned for mid-November; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

want to miss. However, thanks to the Moon's overwhelming glare, the cluster gets a bit lost. And so, the result isn't the visual spectacle you might expect. Indeed, you'll need binoculars or a telescope to watch the occultation unfold. The lunar disk covers the first bright Pleiad (3.7-magnitude Electra) at around 2 a.m. EST and takes about three hours to completely cross the tiny dipper shape formed by the lovely cluster's six brightest stars.

SUNDAY, NOVEMBER 17

After a week's worth of eastward drift along the ecliptic, the **Moon** approaches **Jupiter** this morning. The later you look and the farther west you are, the closer the pairing will be. From the West Coast, the waning gibbous Moon (96% illuminated) sits about 5° to the right of the planet as twilight begins to brighten the sky.

What makes this dawn sight even more splendid is a tall pyramid of bright stars and planets above the western horizon during morning twilight. The peak of the pyramid is occupied by peach-hued Mars, now shining brightly at magnitude –0.2. The left-hand side of the figure is defined by Mars along with +0.4-magnitude Procyon and Sirius — at magnitude –1.5, the night sky's brightest star. The right-hand edge includes Mars, Pollux (magnitude 1.1), Castor (1.6), Capella (+0.1), and Mirfak (1.8), a star perhaps better known as Alpha (α) Persei. The pyramid's base is raggedly marked by — from left to right — Sirius, Rigel (magnitude +0.1), Betelgeuse (+0.4), Aldebaran (+0.9), and Mirfak. The Moon and Jupiter are tucked inside the pyramid, near its bottom right. Altogether, it's a lovely scene and one that's definitely worth sacrificing a little sleep for.



WEDNESDAY, NOVEMBER 20

The graceful dance between the **Moon** and planets resumes tonight as the 68%-illuminated waning gibbous rises soon after **Mars** in the late evening. As the twosome clears the east-northeastern horizon, they're separated by less than 4°. Once the pair has climbed higher, you'll notice that the Moon has now effectively exited the pyramid described previously.

Binocular users can once again try for an additional treat. If you aim your binos at the Moon-and-Mars pairing, you might also catch a glimpse of the brightest stars in the Beehive Cluster (M44) to the right of the Moon. Unfortunately, lunar glare is going to conceal the majority of the hive's stellar bees.

■ Consulting Editor **GARY SERONIK** watches the planets parade from his home in the southern interior of British Columbia, Canada.

A Trio of Lunar Occultations

This month the Moon passes in front of Neptune, the Pleiades, and Spica.

Spica shines just to the east (left) of the first-quarter Moon shortly before being occulted on July 13, 2024. From Duluth, Minnesota, the event occurred during twilight, but the star was easily visible in binoculars before sunset. The crescent Moon will hide Spica again on November 27th during the early morning hours.

BOB KING

You probably don't read this magazine for the latest astrology news. Still, you might be interested to know that aficionados of the subject and other related spiritual beliefs celebrate Occult Day in November. Amateur astronomers can "join in" by watching the Moon occult Neptune on November 11th, the Pleiades on November 15–16, and Spica on November 27th.

The fun begins the evening of the 11th when the dark limb of the 10-day-old gibbous Moon eclipses 7.8-magnitude Neptune for most of the U.S. (except the northwest), eastern Canada, Central America, and Greenland. From many locations it will take the Moon about 6 to 8 seconds to cover the distant planet's tiny, 2.3″-diameter disk. Observers in the eastern third of North America, Central America, and northern South America also get an appetizer: Roughly 90 minutes before the Neptune occultation, the Moon eclipses 5.5-magnitude 20 Piscium.

Despite the brilliance of the 80%-illuminated Moon, a small scope should suffice to extract Neptune from the lunar glare — at least at disappearance. The ice giant's reappearance on the bright limb will be considerably more challenging! Use magnification upwards of 200× to contrast Neptune's bluish disk next to the bone-white lunar landscape. For an extensive list of cities and times for the planet's disappearance and reappearance, visit the International Occultation Timing Association's dedicated web page **https://is.gd/IOTA_Neptune**.

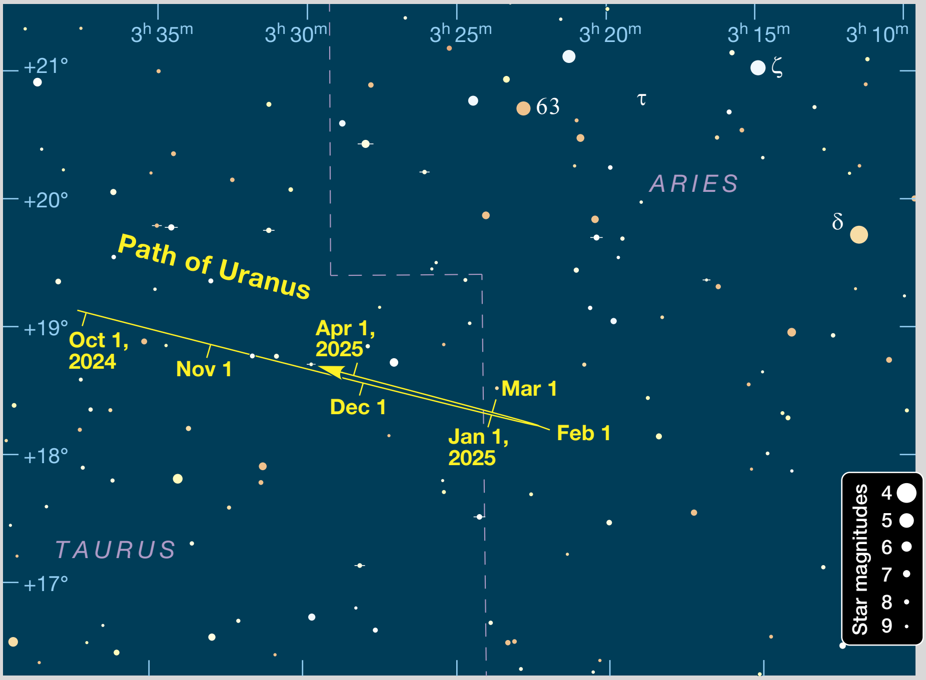
When the full Beaver Moon gleams over frosty forests on November 15–16, it'll be concealing a secret. Nearly hidden within its light is one of the sky's most beloved star clusters, the Pleiades. But instead of glittering — in the words of Alfred, Lord Tennyson — "like a swarm of fireflies tangled in a silver braid," the dipper-shaped group is awash in moonlight and struggling to be seen. While binoculars may reveal the main stars, a telescope will provide the best view of the event.

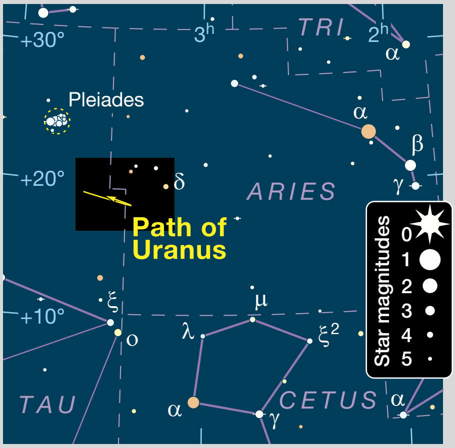
From many locations across North and Central America, the Moon will occult several of the cluster's brightest stars, including Merope, Alcyone, Electra, and Atlas. Observers in the eastern half of the U.S. witness this multi-star occultation in the early morning hours, while in the Pacific Time Zone it begins around 10 p.m. local time on the 15th and concludes after 1 a.m. on the 16th.

Due to the Moon's proximity to Earth, it exhibits significant parallax, which causes its path across the cluster to vary depending on your location. To find out which stars you can see occulted, simulate the event using a stargazing app such as *Stellarium* to step through the event with the software set to your specific location.

For me, the peak occultation experience is witnessing a bright star or planet disappearing or reappearing along the smoky, earthlit side of a crescent Moon. Lunar glare is minimal and the ability to clearly see the approaching (or departing) limb adds a three-dimensional quality to the scene. Observers across more than half of both the U.S. and Canada will have this sight delivered on a silver platter on the morning of the 27th when the 13%-illuminated waning lunar crescent blots out 1st-magnitude Spica. Both the bright-limb disappearance and dramatic reappearance at the dark limb are visible from the Midwest and the Eastern U.S., but even observers as far west as Denver, Colorado, can watch the star reemerge shortly after moonrise.

For full details, go to IOTA's website, **https://is.gd/Spica_Nov27**.





Uranus Reaches Opposition, and Mars Grows

URANUS WILL BE at opposition on November 16th (November 17th, UT) just 6½° southwest of the Pleiades star cluster — a convenient reference point. The planet moves westward in retrograde motion, crossing into Aries on December 29th. Direct (eastward) motion resumes on January 30, 2025. Uranus shines at magnitude 5.6 at opposition and has an apparent diameter of 3.8″ with its north pole facing Earth. Even a small telescope will resolve Uranus's bluish-green disk. Observers using 8-inch or larger instruments can look for the planet's two brightest moons, Titania (magnitude 13.8) and Oberon (14.0). To find out where to look, visit the Tools page of **skyandtelescope.org** for our "Moons of Uranus" interactive observing aid.

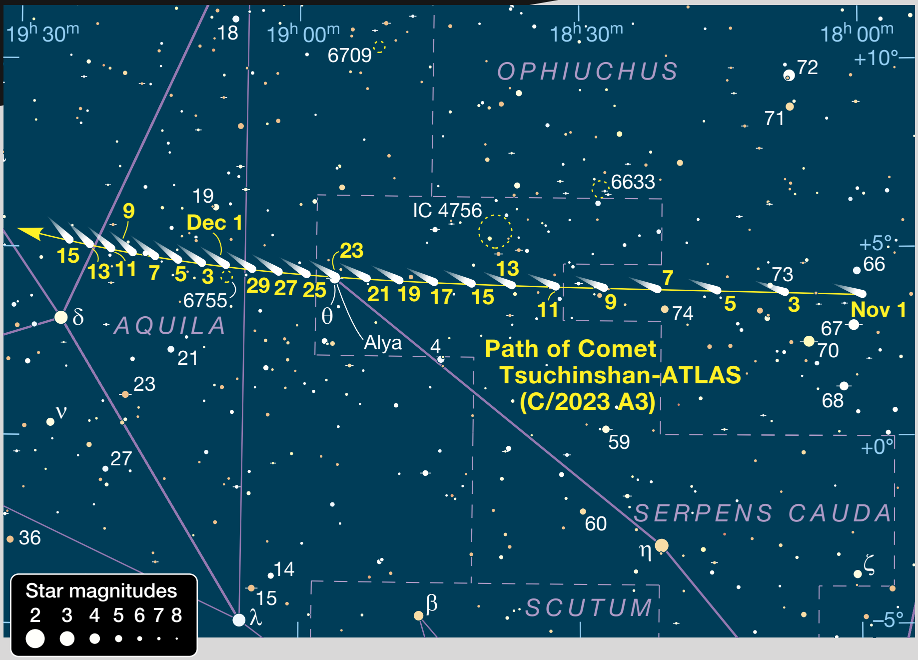
Meanwhile, Mars continues to brighten as it approaches its January 16, 2025, opposition. It begins November at magnitude +0.1 and with an apparent diameter of 9.2″. It crosses the 10″ threshold on the 11th and finishes the month at magnitude –0.5 and 11.5″ across. Mars motors eastward across Cancer, ending the month 2° northwest of the Beehive Cluster (M44).

From local midnight until dawn, Mars's altitude is sufficient for high-magnification telescopic views. Its current gibbous phase is obvious even at 75×, while at magnifications of 150× and greater the largest dark albedo features come into view. Syrtis Major, Mare Cimmerium, and Mare Acidalium are among the most prominent. To identify them and others, visit the Tools page of our website and use the online "Mars Profiler."

November Fireballs

Nightfall comes early this month and with it the opportunity to see slow fireballs from a reliable pair of sparse meteor showers, the Southern and Northern Taurids. The first of these peaks on November 5th with a *zenithal hourly rate* (ZHR) of 5–10 meteors per hour. The ZHR is an idealized number based on what an experienced observer would see under pristine, moonless skies with the shower radiant overhead. The Northern Taurids climax a week later with a broad maximum centered on the 12th and a rate of 5 meteors per hour. Both showers stream from oval regions approximately 20° long by 10° wide near the Pleiades, and their radiants culminate around midnight local time.

During the Southern Taurids the Moon will be a waxing crescent that sets early. Although it grows to gibbous phase by the time the Northern Taurids peak, moonlight will inflict only modest damage. Moonset occurs around 2:30 a.m. local time with the radiant still high in the southwest. The shower has a broad maximum with a steady output the first two weeks of the month, so you have some play in selecting the best viewing date. Both streams are related to Comet 2P/Encke, which next returns to Earth's vicinity in late 2026.



▲ The comet's position is shown for 0h UT on the dates indicated.

Tsuchinshan-ATLAS Update

IT'S HARD TO let go of a good comet. Maybe that's because it's so easy to get wrapped up in their beautiful tails. While October saw Comet Tsuchinshan-ATLAS (C/2023 A3) at its peak, the show isn't over yet. As November opens, the comet should still be a dim, naked-eye object with a 5th-magnitude coma and northeastward-pointing tail. The comet is expected to fade to 8th magnitude by month's end.

You still have lots of time to see the fuzzy ball of "snirt" (snow and dirt). The best opportunities occur when the Moon interferes least, from November 1st to 8th and from the 19th to the 30th.

Minima of Algol

Oct.	UT	Nov.	UT
2	13:45	3	2:42
5	10:34	5	23:31
8	7:23	8	20:20
11	4:12	11	17:09
14	1:00	14	13:58
16	21:49	17	10:47
19	18:38	20	7:36
22	15:27	23	4:25
25	12:16	26	1:14
28	9:04	28	22:03
31	5:53		

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 approaches the zenith after midnight in November. Every 2.87 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).

Action at Jupiter

AS NOVEMBER BEGINS, Jupiter is only a month away from opposition and rises in the early evening. That means you can productively observe the planet most of the night if you wish. By mid-month, it transits the meridian around 1:30 a.m. local time, though it's favorably placed from around 10 p.m. through to dawn. On the 15th Jupiter gleams at magnitude –2.8 and presents a disk spanning a generous 47.4″. With the planet located in Taurus and near the northernmost portion of the ecliptic, these are happy times for northern Jupiter observers.

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

Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Daylight Time is UT minus 4 hours.)

October 1: 6:08, 16:04; **2**: 2:00, 11:55, 21:51; **3**: 7:47, 17:42; **4**: 3:38, 13:34, 23:29; **5**: 9:25, 19:20; **6**: 5:16, 15:12; **7**: 1:07, 11:03, 20:59; **8**: 6:54, 16:50; **9**: 2:45, 12:41, 22:37; **10**: 8:32, 18:28; **11**: 4:24, 14:19; **12**: 0:15, 10:11, 20:06; **13**: 6:02, 15:57; **14**: 1:53, 11:49, 21:44; **15**: 7:40, 17:35; **16**: 3:31, 13:27, 23:22; **17**: 9:18, 19:14; **18**: 5:09, 15:05; **19**: 1:00, 10:56, 20:52; **20**: 6:47, 16:43; **21**: 2:38, 12:34, 22:30; **22**: 8:25, 18:21; **23**: 4:17, 14:12; **24**: 0:08, 10:03, 19:59; **25**: 5:55, 15:50; **26**: 1:46, 11:41, 21:37; **27**: 7:33, 17:28; **28**: 3:24, 13:19, 23:15; **29**: 9:11, 19:06; **30**: 5:02, 14:57; **31**: 0:53, 10:48, 20:44

November 1: 6:43, 16:39; **2:** 2:34, 12:30, 22:25; **3:** 8:21, 18:17; **4:** 4:12, 14:08; **5:** 0:03, 9:59, 19:55; **6:** 5:50, 15:46; **7:** 1:41, 11:37, 21:33; **8:** 7:28, 17:24; **9:** 3:19, 13:15, 23:10; **10:** 9:06, 19:02; **11:** 4:57, 14:53; **12:** 0:48, 10:44, 20:40; **13:** 6:35, 16:31; **14:** 2:26, 12:22, 22:17; **15:** 8:13, 18:09; **16:** 4:04, 14:00, 23:55; **17:** 9:51, 19:46; **18:** 5:42, 15:38; **19:** 1:33, 11:29, 21:24; **20:** 7:20, 17:15; **21:** 3:11, 13:07, 23:02; **22:** 8:58, 18:53; **23:** 4:49, 14:45; **24:** 0:40, 10:36, 20:31; **25:** 6:27, 16:22; **26:** 2:18, 12:14, 22:09; **27:** 8:05, 18:00; **28:** 3:56, 13:51, 23:47; **29:** 9:43, 19:38; **30:** 5:34, 15:29

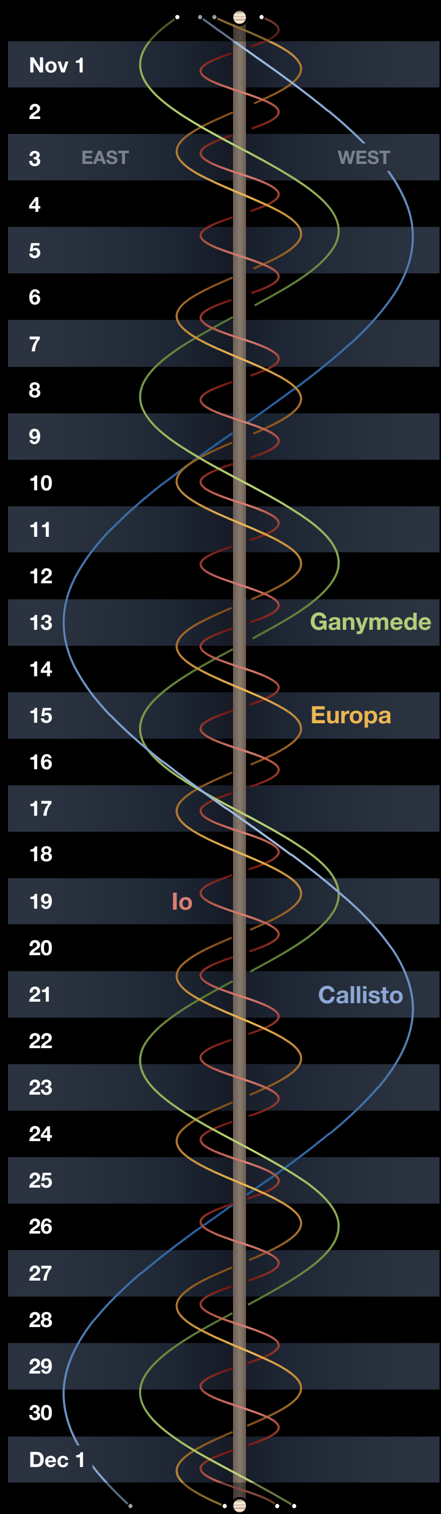
These times assume that the spot will be centered at System II longitude 68° on November 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 68° and 1²/₃ minutes later for each degree more than 68°.

Phenomena of Jupiter's Moons, November 2024

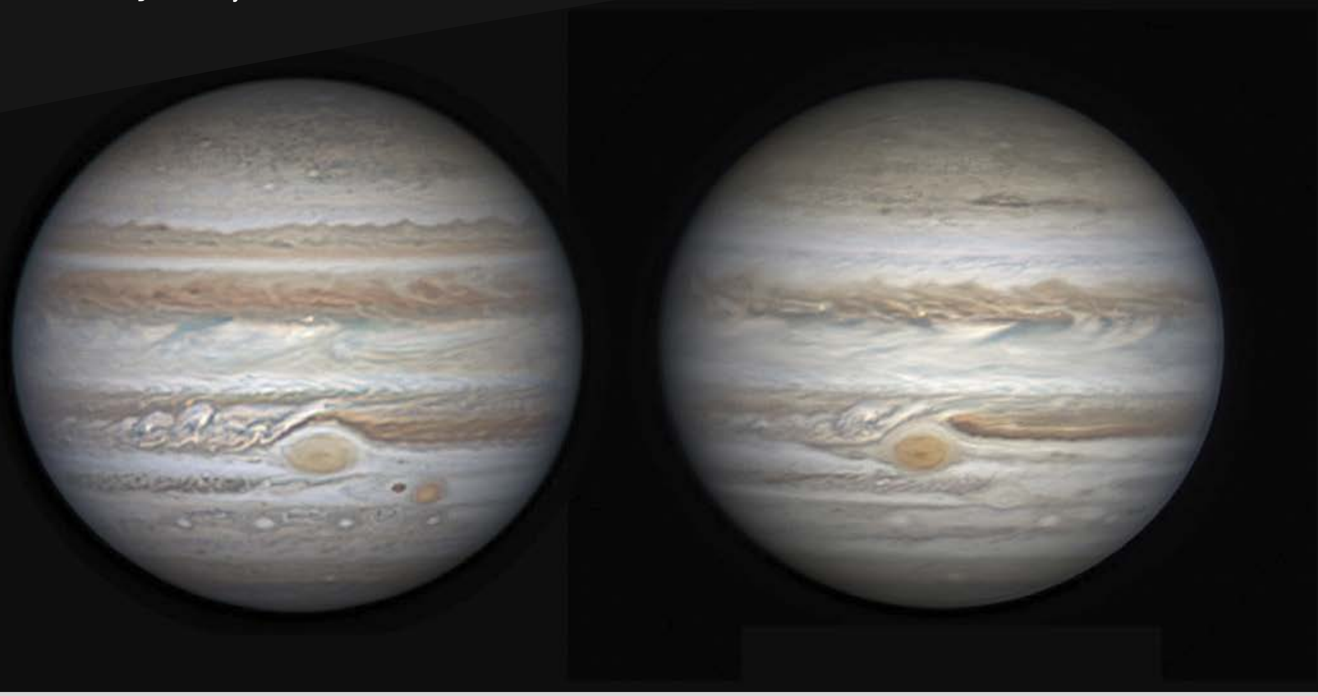
Nov. 1	2:49	I.Ec.D
	5:53	I.Oc.R
	23:58	I.Sh.I
Nov. 2	0:49	I.Tr.I
	2:08	I.Sh.E
	2:59	I.Tr.E
	8:21	II.Ec.D
	12:35	II.Oc.R
	21:18	I.Ec.D
Nov. 3	0:20	I.Oc.R
	2:39	III.Sh.I
	4:44	III.Sh.E
	6:06	III.Tr.I
	8:03	III.Tr.E
	18:26	I.Sh.I
	19:15	I.Tr.I
	20:37	I.Sh.E
	21:26	I.Tr.E
Nov. 4	3:30	II.Sh.I
	5:08	II.Tr.I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

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.



Observing Jupiter's "Blue Holes"

Look for these enigmatic features along the edge of the planet's North Equatorial Belt.

Jupiter's turbulent cloudscape is divided into alternating bright zones and dusky belts running parallel to its equator, giving the planet its characteristic striped appearance. The contrasts arise from differences in vertical motions and temperatures in Jupiter's upper atmosphere.

Zones are sites where upwelling causes the planet's ammonia-rich atmosphere to expand and cool, forming brilliant, white crystals of ammonia ice. This high cloud canopy is located where pressures range from 0.6 to 0.9 atmospheres (60% to 90% of the density at sea level on Earth).

In the belts, the atmosphere warms as it descends, causing the ammonia ice to evaporate and form a colorless gas. This exposes denser, deeper layers of clouds. Located where atmospheric pressures of 1 to 1.5 prevail, these deeper layers comprise primarily frozen ammonium sulfide and ammonium hydrosulfide. These compounds normally have a very pale-yellow hue, but exposing them to solar ultraviolet radiation drives photochemical reactions that impart a rich palette of warm colors often described using adjectives like sepia, cocoa, ocher, hazel, tawny, amber, and beige.

There's another class of prominent Jovian markings with contrasting colors from the cool end of the spectrum. Known as the North Equatorial Dark Formations (NEDFs), they are located along the southern edge of the North Equatorial Belt (NEB) where it meets the broad Equatorial Zone (EZ), at a latitude of 6° to 7°N. This region is where a very powerful atmospheric current known as the NEB jet stream blows eastward at a whopping 100 to 150 meters per second (224 to 336 miles per hour).

Usually, NEDFs are arrayed in a planet-encircling procession of discrete spots spaced at intervals of about 30°, which gives the southern edge of the NEB a serrated appearance. The life expectancy of individual NEDFs ranges from weeks to years. Many develop narrow, curved wisps and filaments that project into the EZ and are sometimes called *festoons*. The sizes and shapes of these features are so prone to rapid change that it's often difficult to reliably identify them from one week to the next.

▲This pair of Jupiter images taken in 2012 (left) and 2023 (right) captures the delicate blue hue of the North Equatorial Dark Formations (NEDFs) and their trailing, wispy festoons. A pronounced narrowing of the North Equatorial Belt and the shrinkage of the Great Red Spot are also evident.

SEAN WALKER

Bertrand Peek's classic 1958 guidebook *The Planet Jupiter* contains this evocative description:

> *The dark projections are generally features that catch the eye immediately. They take many forms, from tiny humps or short spikes to large elongated masses or streaks. The humps and spikes are often the points of departure of grey wisps or festoons, some of them most delicate and some quite*

conspicuous, that seem to issue from the S. edge of the belt and look as if they were dispersing like smoke in the Equatorial Zone. Frequently, however, they do not simply vanish but curve round . . . and return to the belt, almost certainly reaching it at a point where another projection appears.

NEDFs and their associated festoons usually appear gray through telescopes of less than 5 inches of aperture, but larger instruments often reveal vivid turquoise or azure-blue colors. For many years, American planetary observers have referred to these markings as "Olivarez Blue Features" in honor of José Olivarez, the Association of Lunar and Planetary Observers' Jupiter Section Recorder who monitored them intently for several decades. Yellow (Wratten 8 or 12) or orange (Wratten 21) filters that selectively block blue light make NEDFs stand out boldly against the surrounding white ammonia cirrus clouds of the EZ.

The pattern of bright zones and dusky belts seen in visible light appears reversed at infrared wavelengths of 4 to 8 microns. At these wavelengths, the EZ appears dark because its frigid canopy of ammonia ice clouds blocks the wan glow of Jupiter's internal heat. In infrared, the NEDFs are transformed into bright "hot spots." Clearings swept free of clouds and aerosols by powerful downdrafts that penetrate both the high ammonia cirrus and low ammonium hydrosulfide cloud decks provide a pathway for internal heat to escape from deeper levels in Jupiter's atmosphere. Unlike the warm colors of Jupiter's belts that are imparted by chemical composition, the bluish color of the NEDFs is caused by the same Raleigh scattering of sunlight by molecules of colorless gases that gives a clear daytime sky on Earth its characteristic blue color.

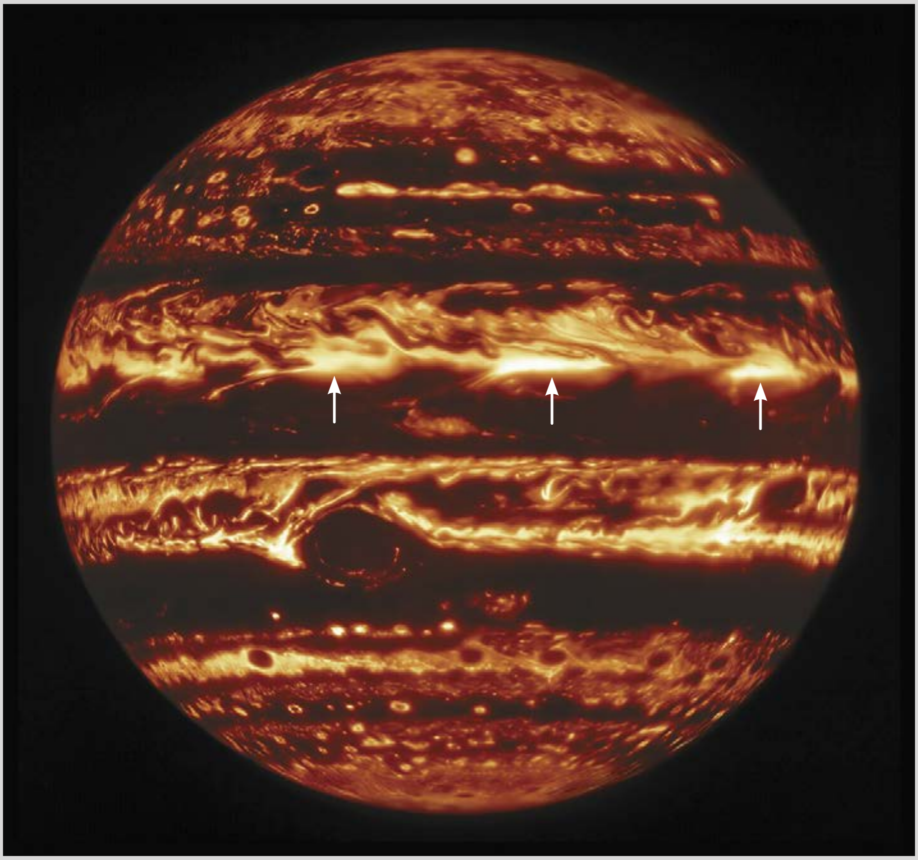
When the British Astronomical Association's Jupiter Section director John Rogers reviewed a century of observations, he uncovered a rather stunning fact. Throughout the late 19th century and during the first decade of the 20th century, the southern edge of the NEB was almost devoid of its familiar array of prominent dark spots and projecting festoons. Instead, these features were seen along the northern edge of the South Equatorial Belt (SEBn). Rogers discovered that "the only notable difference from today's NEBs features was the spacing":

Numerous nineteenth-century drawings and maps show a typical spacing of 17 – 25° for the SEBn spots, in contrast to the typical spacing of 30 - 35° for the modern NEBs features. When NEBs features were present then, they were much smaller and sparser.

The dramatic reversal in atmospheric circulation patterns occurred between 1908 and 1913. Why it happened — and why it has persisted for over a century — remain among Jupiter's many lingering mysteries.

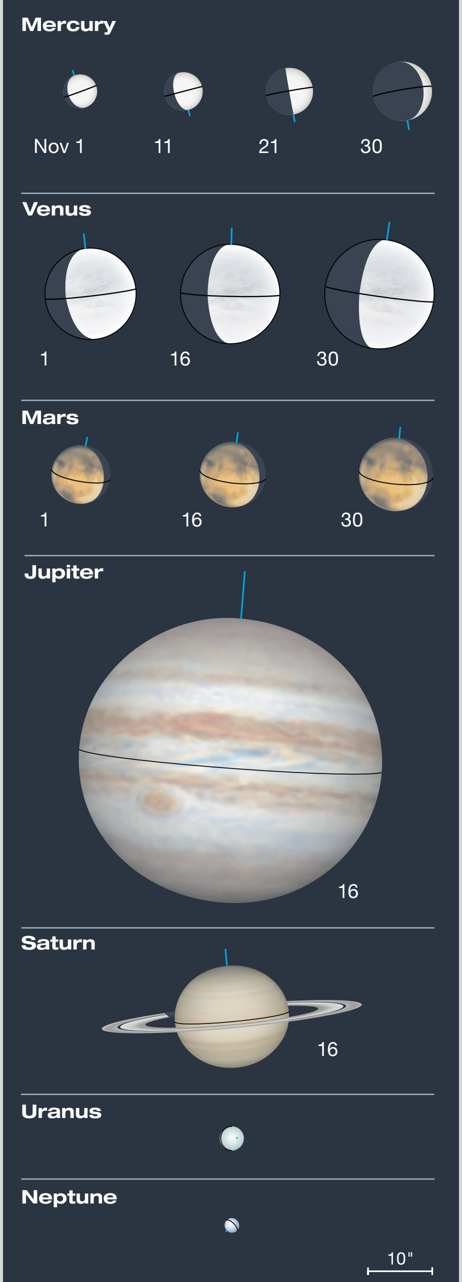
■ Contributing Editor **TOM DOBBINS** co-authored *Epic Moon: A History of Lunar Exploration in the Age of the Telescope*, available at **shopatsky.com**.

▲This sketch by veteran planetary observer Carlos Hernandez depicts a pair of blue festoons projecting from prominent NEDFs that merged to form a narrow Equatorial Band on November 11, 2001.



▶The NEDFs (arrowed) glow brightly in the thermal infrared region of the spectrum. This 2017 image of Jupiter at the deep-infrared wavelength of 5 microns was taken with the 8.1-meter Gemini North Telescope in Hawai'i using the Near-Infrared Imager. Bright features indicate thermal radiation emerging from the atmosphere below the clouds, while darker regions correspond to opaque clouds silhouetted by the underlying thermal emission.

INTERNATIONAL GEMINI OBSERVATORY / NOIRLAB / NSF / AURA, M. H. WONG (UC BERKELEY) / M. ZAMANI



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

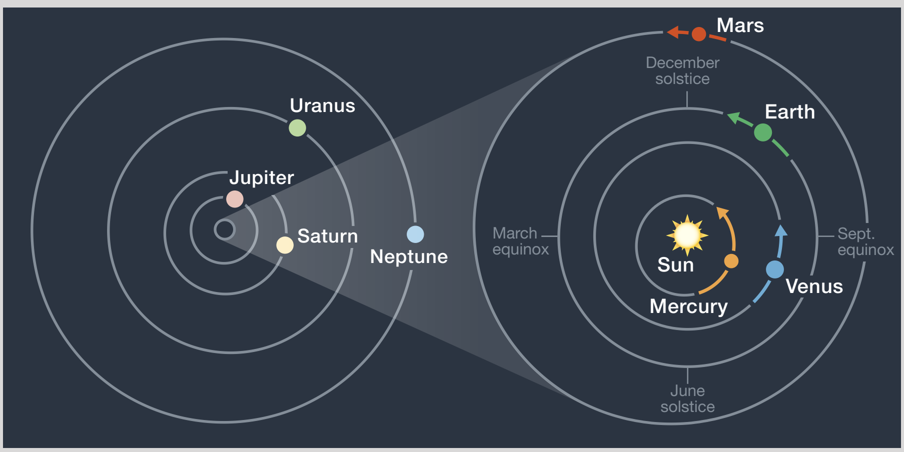
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during November. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dusk from the 12th to the 24th • **Venus** visible at dusk all month • **Mars** rises in the late evening and visible to dawn • **Jupiter** rises in the early evening and transits in the predawn • **Saturn** transits in the early evening.

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	14^h 25.3^m	–14° 24′	—	–26.8	32′ 14″	—	0.993
	30	16^h 24.6^m	–21° 38′	—	–26.8	32′ 26″	—	0.986
Mercury	1	15^h 37.4^m	–21° 27′	19° Ev	–0.3	5.3″	86%	1.272
	11	16^h 33.9^m	–24° 36′	22° Ev	–0.3	6.0″	74%	1.122
	21	17^h 17.9^m	–25° 27′	22° Ev	–0.2	7.3″	50%	0.918
	30	17^h 20.7^m	–23° 45′	13° Ev	+1.6	9.2″	14%	0.731
Venus	1	17^h 01.7^m	–24° 33′	38° Ev	–4.0	14.2″	77%	1.175
	11	17^h 54.4^m	–25° 34′	40° Ev	–4.1	15.0″	74%	1.110
	21	18^h 47.0^m	–25° 22′	42° Ev	–4.1	16.0″	71%	1.043
	30	19^h 33.4^m	–24° 11′	43° Ev	–4.2	17.0″	68%	0.981
Mars	1	8^h 03.8^m	+21° 49′	100° Mo	+0.1	9.2″	89%	1.019
	16	8^h 23.6^m	+21° 20′	111° Mo	–0.2	10.3″	90%	0.910
	30	8^h 34.1^m	+21° 19′	122° Mo	–0.5	11.5″	92%	0.813
Jupiter	1	5^h 17.3^m	+22° 21′	139° Mo	–2.7	46.1″	100%	4.276
	30	5^h 03.7^m	+22° 07′	171° Mo	–2.8	48.1″	100%	4.096
Saturn	1	22^h 58.9^m	–8° 50′	124° Ev	+0.8	18.3″	100%	9.061
	30	22^h 58.7^m	–8° 46′	95° Ev	+1.0	17.5″	100%	9.511
Uranus	16	3^h 30.6^m	+18° 45′	179° Mo	+5.6	3.8″	100%	18.572
Neptune	16	23^h 50.8^m	–2° 26′	123° Ev	+7.8	2.3″	100%	29.344

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 Sprinkle of Stars

Rambling through eastern Andromeda is easy and fun.

If someone says "Andromeda," I don't think of the well-known constellation, nor the Princess Andromeda of Greek mythology. Instead, I picture in my mind the Andromeda Galaxy, M31. Too bad for me that the famous spiral galaxy, which looks spectacular in color astrophotos, registers in my suburban-based telescopes as little more than a pale, grey, diffuse nebulosity. Light pollution is galaxy kryptonite.

Thankfully, there is more to Andromeda than M31. Last fall, I encountered a few modest deep-sky treasures well away from M31 as I star-hopped through slightly more than 5° of sky in the easternmost part of the constellation. I conducted my leisurely exploration with two very different telescopes: an 8-inch (20-cm) f/6 Newtonian reflector and a 4.7-inch (120-mm) f/7.5 apochromatic refractor. Both instruments aced their assignments.

Join me on my recreational ramble into a part of Andromeda that's too often overlooked.

Almach Is Alright

My star-hop starting point last fall was **Gamma (γ) Andromedae**, or Almach. Shining at 2nd magnitude, Almach was an obvious choice because it's a relatively bright star. But there's an additional reason: It's one of the most beautiful double stars in the northern heavens. The Almach system consists of a 2.3-magnitude yellow sun and a 5.0-magnitude blue sun 9.5″ apart. Together, they're a compact combo of contrasting colors you won't want to miss.

Almach was striking in my Newtonian reflector — provided I applied sufficient power. The blue secondary was visible at 38× (with a 32-mm eyepiece), though not really impressive. At 76× (a 16-mm eyepiece), the components were nicely separated and the vivid hues clearly evident. Ditto for the apo refractor: it could resolve Almach tightly at 56× (the same 16-mm eyepiece), but the split was much more pleasing at 100× (a 9-mm eyepiece). Beautiful!

After admiring Almach, I used my 8×50 finder to shift southward on a zigzag star-hop. First, I dropped 2½° to the southwest to 5.4-magnitude 55 Andromedae. Then I turned southeast-

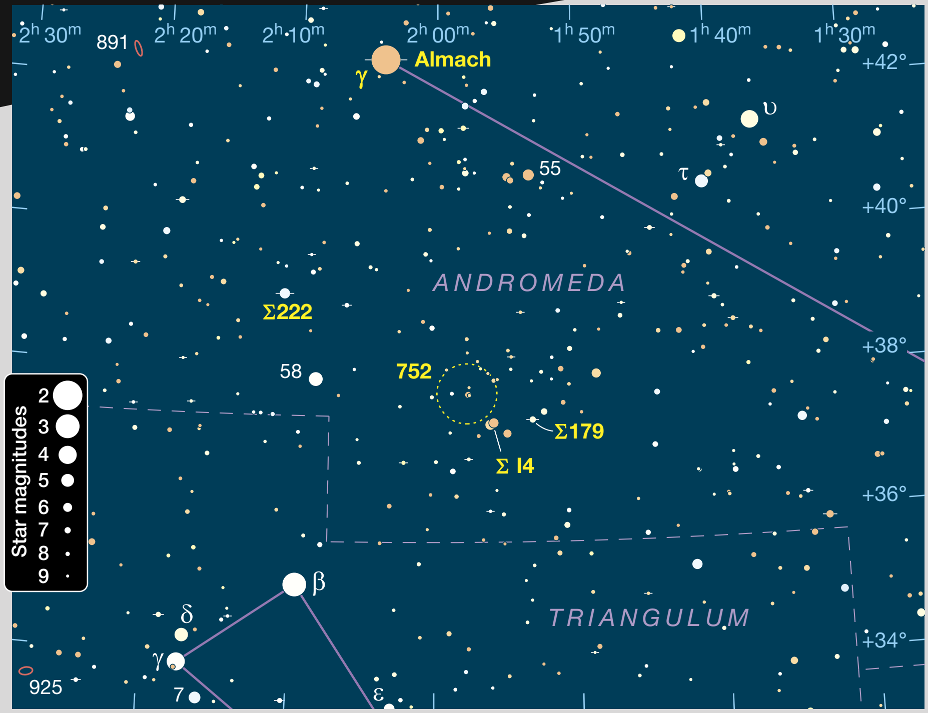
▲ **SPRAWLING OPEN CLUSTER** Andromeda's NGC 752, more than a degree in diameter, is nicely framed in this 2½°-wide field of view. The cluster is almost 1,200 light-years from Earth. Although it contains only faint stars, it's ably signposted by the beaming pair of 56 Andromedae and HD 11727. The duo helps form the blade of the celestial hockey-stick asterism clearly visible below and right of NGC 752.

BERNHARD HUBL

Alternative Andromeda

Object	Type	Mag(v)	Size/Sep	RA	Dec.
γ And	Double star	2.3, 5.0	9.5″	$2^h\ 03.9^m$	+42° 20′
Σ222	Double star	6.1, 6.7	16.6″	$2^h\ 10.9^m$	+39° 02′
NGC 752	Open cluster	5.7	75.0′	$1^h\ 57.6^m$	+37° 50′
Σ I4	Double star	5.8, 6.1	202.5″	$1^h\ 56.2^m$	+37° 15′
Σ179	Double star	7.6, 8.1	3.5″	$1^h\ 53.2^m$	+37° 19′

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.



▲ **ANDROMEDA EAST** The easternmost part of the constellation Andromeda contains modest targets for small backyard telescopes under badly light-polluted skies. The author's tour sets off from the lovely binary star Almach, then zigzags southward to the very large open star cluster NGC 752.

ward and headed almost 4° to locate fainter 59 Andromedae. The star is an easy double known as **Struve 222**, or Σ222. Separated by 16.6″, the 6.1- and 6.7-magnitude suns of Σ222 resolved instantly in both scopes.

Next, I swung south-southwest 1¼° degrees to 4.8-magnitude 58 Andromedae, then shifted two degrees directly west to my prime target — the large open cluster **NGC 752**. But buyer beware: The stated visual magnitude of 5.7 is a tad misleading since the cluster's light is sprinkled across an expansive area roughly 75′ across. Within that circle of sky is a loose population of some six dozen faint stars. The brightest is only magnitude 7.1, and none of the other cluster members exceeds magnitude 8.1.

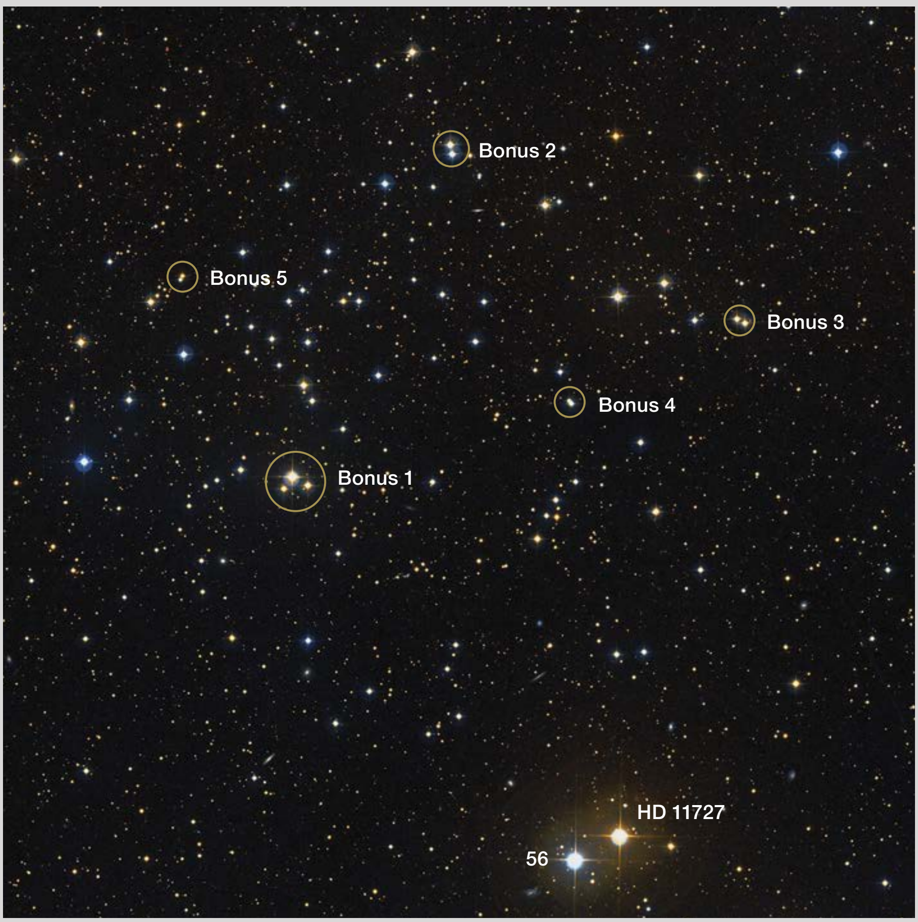
Harrumph. In my decent-quality finderscope, NGC 752 was an extremely pale, slightly mottled mist, its dim stars essentially swamped by my badly light-polluted suburban sky. Definitely not a finder-friendly situation.

Sparse Sparkle

Despite the finderscope difficulties, NGC 752 is a target worth inspecting in a telescope. The total number of stars you'll see in the cluster will depend on your sky conditions, your scope's aperture, and how big the grouping appears in your field of view.

I found the ragged limits of NGC 752 difficult to define in my backyard equipment. The refractor working at 30× revealed a thin scatter of approximately 60 stars. The same wide-angle, 30-mm eyepiece on the reflector delivered a similar number but in a smaller field of view. It was actually a very attractive sight.

And happily, that "attractive sight" came with bonuses. The bonus bits have no official names, so I decided to number them. The most notable feature is a triangular triple system illuminat-



◀ **TAKE FIVE** A close look at the thinly populated cluster NGC 752 reveals at least five bonus sets of tightly spaced stars. Four of the five are pairs; the other set (Bonus 1) is a triple system forming a tight triangle. The brightest point on the triangle is HD 11885, the most luminous star in NGC 752.

DSS2

ing the heart of the cluster. (It's labelled Bonus 1 on the photo on page 56.) The three-star triangle spans 95″ along its widest (southern) side. That baseline is dimly lit by stars of 9.0- and 9.7-magnitude; however, the vertex fairly gleams with 7.1-magnitude HD 11885, the cluster's leading light.

A ragged row of stars slants prominently northeast-southwest across the northwest portion of the cluster. Near the northeast end of that jagged chain is where I found Bonus 2, a double comprising 8.9- and 9.1-magnitude stars 37″ apart. I noticed another slam-dunk duo, Bonus 3, at the southwest terminus of the chain. That one offers nearly identical 9.4- and 9.5-magnitude stars separated by 36″. Both scopes resolved all three cluster bonuses at low power — yet I didn't notice them until I scanned the cluster carefully.

If you like tougher tandems, NGC 752 has them. A binary labelled Bonus 4 is located two-thirds of the way from Bonus 1 to 3. The components of Bonus 4 are dim — magnitudes 10.0 and 11.2 — but they're a reasonably generous 15″ apart. Another optical double of similar separation, yet even dimmer, is Bonus 5, which possesses 11.0- and 11.4-magnitude elements separated by 16″. I ferreted out Bonus 5 in the eastern part of the cluster, helpfully located right beside a box of four stars.

Those Bonus 4 and 5 binaries resolved in both scopes at around 100×. I hadn't planned on scrutinizing this coarse cluster at high power, but I'm glad I did!

▲ **WITH SPRINKLES** This simulated low-power telescopic view of open cluster NGC 752 and its adjacent hockey-stick asterism emphasizes the attractive nature of this small piece of the constellation Andromeda. The region is well placed for viewing on autumn evenings.

ALAN DYER

Hockey Anyone?

There's another value-added aspect to NGC 752 and, with one exception, it can be appreciated using low magnification in any backyard telescope.

The fun begins with a relatively wide headlight pair of stars 202.5″ apart and lying immediately southwest of NGC 752. The headlights are yellowish 56 Andromedae and orangey HD 11727, shining at magnitudes 5.8 and 6.1, respectively. Together, they form a double called **Struve I4**, or Σ I4 (not to be confused with Σ14). The duo isn't physically part of the cluster, nor are they related to each other, but Σ I4 is a helpful marker for NGC 752 — they showed in my city-based finderscope even when the cluster itself didn't.

The Σ I4 set is the brightest part of an eye-catching asterism suggestive of a hockey stick. The 1½°-long shaft of the stick is marked by 5.9-magnitude HD 10975 and 6.3-magnitude HD 11624 (plus a series of fainter stars between them), while Σ I4 forms the tip of the ¼°-wide blade. The combination of asterism and cluster is quite pretty in my refractor at low power. And bumping up to 100× produced one further prize — **Σ179**, partway up the shaft of the hockey stick. The tightest binary in my survey, Σ179 comprises 7.6- and 8.1-magnitude elements with a mere 3.5″ between them.

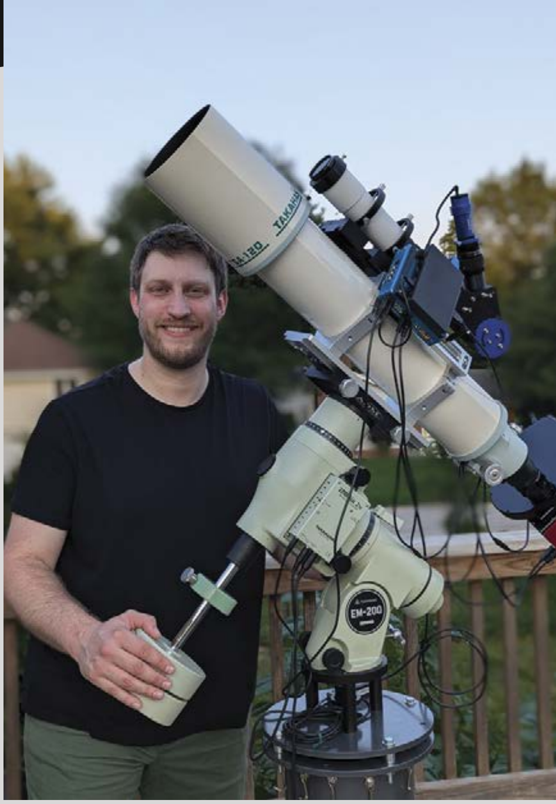
By the way, the hockey-stick asterism was a picturesque pickup in my 10×50 binoculars. Once found, it became a celestial landmark I noticed every time I visited the area. The cluster was a different story. As with my finderscope, the binos barely registered NGC 752 as an almost imperceptible, slightly textured mist. Except for the 7th-magnitude lucida — a solitary point — the cluster was visible only with patient averted vision. The detection was successful because I knew exactly where to look, thanks to the signpost headlights pair Σ I4 in the blade of the hockey stick.

As November opens, the region of Andromeda encompassing Almach and NGC 752 stands well above the eastern horizon at nightfall. I hope you'll get outside with whatever telescope you have and enjoy my casual ramble — even though it bypasses M31!

■ Contributing Editor **KEN HEWITT-WHITE** imagines star clusters and hockey sticks in his sleep.

Backyard Spectroscopist

Amateur astronomers are making big strides in acquiring spectral data. Professional astronomers should take heed.



▲ Austin Kuecher launched himself into the world of astronomical spectroscopy only two years ago and is already churning out spectra by the dozens!

AUSTIN KUECHER

Are you an amateur astronomer interested in reaping more science out of your backyard observing experience? Meet Austin Kuecher, an amateur who entered the hobby a mere two years ago and has already forged ahead to working with spectra.

Lasers and magic. Like so many amateurs and professionals, Austin's interest in astronomy sparked when he was a kid — for him, the moment was seeing Comet Hale-Bopp through an Astroscan reflector. But, as is so often the case, life intervened, and he became busy with other things. However, just two years ago he caught the bug again — this time around he became more deeply involved in astronomy.

Of course, the intriguing and inspiring images that trickle down to us from the Hubble and James Webb space telescopes have fired up many an imagination. But there's another way astronomers learn about the universe, and that is through splitting starlight, creating a *spectrum* (think: Isaac Newton and his prism). Austin remembers first learning about *spectroscopy* — to give the field its technical name — while still an undergraduate student in a physics course. He recalls, "It remained in my mind as an important though vague concept that could determine the chemicals in a sample through lasers and magic."

Austin connected with his local club, the Omaha Astronomical Society, where like-minded individuals encouraged him to explore the night sky — and that's when the "concept" of spectroscopy really took hold in his mind. Austin became more and more interested in the science powering the astronomical objects that he so enjoyed observing, and he was eager to learn more. What better way to do so than by prizing apart the light that these objects emit into its component parts? He read everything he could get his hands on regarding stars' spectral classes and their relation to color, temperature, and chemical makeup. During his multiple forays into the world of stellar physics, Austin learned that spectroscopy was becoming more accessible to amateurs. Intrigued, he began to explore telescope and camera options.

Equipment for all occasions. In his backyard, Austin has a permanent pier that hosts his ever-growing fleet of instrumentation, including refractors, Schmidt-Cassegrains, and Maksutov-Cassegrains, all in a range of apertures, as well as several astronomical cameras. But for spectroscopy, he uses a Star Analyser SA-100 slitless diffraction grating mounted to a small guide camera — and it's beginner-friendly and affordable to boot! Even better, despite his light-polluted backyard (streetlights in direct view being among the peskier elements), he can perform spectroscopy without too many detrimental effects.

To dive more deeply into the field, Austin took part in the Astronomical League Spectroscopy Observing Program. He calls that experience — especially seeing the difference between stellar spectral classes — "truly enriching." As part of the AL program, Austin has acquired spectra of the Sun, eclipsing binaries, and RR Lyrae variables. In addition, members of the American Association of Variable Star Observers Spectroscopy Section have provided him with the support network necessary to further hone his skills.

Now, Austin is ready for the next step: science. And maybe you are, too.

Dip into the pool of backyard talent. If you're a professional astronomer in need of reams of data but beleaguered by too little time at a telescope, why don't you tap into the ever-growing and talented cohorts of amateurs who are successfully splitting starlight in their backyards? As Austin says, "Today, many amateurs equipped with high-quality cameras and telescopes are eager to explore the physical principles behind the objects they observe." You could start by scoping out the AAVSO Spectroscopy Section at **https://is.gd/aavso_spec** to connect with amateur spectroscopists. And if you take part in a successful collaboration, be sure to drop us a line!

■ Observing Editor **DIANA HANNIKAINEN** loves meeting and learning about astronomers who inspire others.

Build Your Own Refractor

Here's how to make a telescope using lenses instead of mirrors.

▲ This 5-inch (127-mm) f/5.5 achromatic refractor was simple to build using a lens and focuser purchased from Surplus Shed (**surplusshed.com**), galvanized metal flashing for the tube, and a commercially available focuser. The total cost was less than $250.

▶ All you need to build a refractor is an objective lens, a focuser, and a tube to hold them the right distance apart. *Near right:* Galvanized flashing works well for making refractor tubes. *Middle:* A 5-inch doublet and a dual-speed Crayford focuser are good finds. *Far right:* An 80-mm doublet and a plastic, 1¼-inch rack-and-pinion focuser are easier to acquire online or at swap meets.

Ever since John Dobson brought large reflecting telescopes to the masses, amateur telescope making has mostly been concerned with mirrors. You can find dozens, maybe even hundreds of books and websites devoted to reflecting telescopes, but refractors get short shrift. There's good information about them out there, but you have to search for it.

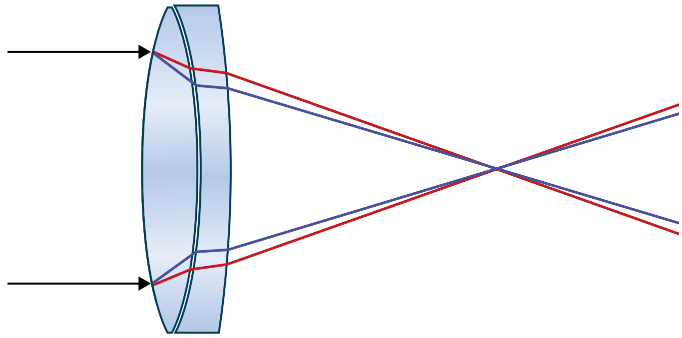
I recently wound up in an email conversation with Wisconsin telescope maker Jim Vatch, who's building a simple refractor with an 80-mm lens he bought online. After a few exchanges in which I answered his questions as best as I could, he suggested that I write an article on the subject — a "cookbook" that beginners could follow to build a refractor of their own.

I've built three refractors, which doesn't make me an expert by any means, but I do know the basics, so I'm going to do just that. By the time you get to the end of this article, you should know enough to build your own refractor, too. Let's dig into it.

The Objective

The heart of any refractor is its objective lens. This does the same work as a reflector's primary mirror, gathering light and focusing it down to an image that you can examine with an eyepiece. Because light goes through the glass rather than reflecting off of it, you don't need a secondary mirror up front to shift the focal point off to the side. Obstructions cause diffraction, which reduces image contrast, so with a refractor you can get the highest contrast possible. That's the good news. The bad news is that glass doesn't focus all wavelengths of light to the same point. That means different colors come to focus at different distances, which leads to color fringing (called *chromatic aberration*) around bright objects. The longer the focal length, the less pronounced the effect, which led to some ridiculously long telescopes back in the early days of astronomy.

Fortunately, in the early 18th century Chester Moore Hall discovered that different types of glass have different *indexes of refraction*, which means they disperse light into its component colors at different angles. By combining two lenses made from different types of glass with different refractive indices (usually crown and flint glass), the focal point of two



▲ An achromatic doublet uses two types of glass elements having different refractive indices as well as convex and concave shapes in order to bring red and blue light to a common focus point.

colors can be manipulated to arrive at the same plane. These types of lenses are called *achromatic doublets*, and they provide images with fairly low chromatic aberration on all but the brightest stars, the planets, or the Moon.

If you add another lens element, you can almost completely eliminate chromatic aberration. Such lenses are called *apochromatic*, and they're relatively expensive compared to achromats. That's because with three lenses there are six surfaces that need to be ground and polished to high precision. And the exotic glass types often used tend to be very costly.

Even with apochromatic lenses, the longer their focal length, the more forgiving they are. *Collimation* (lining up the objective lens with the eyepiece) is also easier. But a longer telescope gives you a narrower field of view, so there's a tradeoff.

People who make reflectors often grind their own mirrors, but very few amateurs grind their own lenses. It's not that much more difficult, and I urge you to try it if you're into making your own optics. Otherwise you can find a decent doublet for a fairly reasonable price these days, as manufacturers are able to make them with automated grinding and polishing equipment. Often you can find suitable lenses for practically nothing at a swap meet.

You're unlikely to find a really large lens. Three inchers (actually 80 mm) are common. Four- or five-inch lenses are also fairly easy to find. Beyond that, the price rises precipitously, and the availability goes down accordingly. My

ALL PHOTOS COURTESY OF THE AUTHOR; ALL ILLUSTRATIONS: BEATRIZ INGLESSIS / S&T; SOURCE: THE AUTHOR

favorite source for lenses is Surplus Shed (**surplusshed.com**), but they're often out of stock. AliExpress (**aliexpress.us**) has a large variety of suppliers, most of them in China, and the quality and prices are pretty good.

The objective needs to be mounted in a holder that ensures its optical axis is aimed straight down the center of the tube. This is called the *lens cell*. The cell also keeps the individual lens elements in position if they aren't cemented together. Ideally, the cell will have fine-adjustment capabilities to tilt the lens a smidgen in case it's not mounted square on the body of the telescope, but if it doesn't, you'll have to make your collimation adjustments when you mount the cell to the tube.

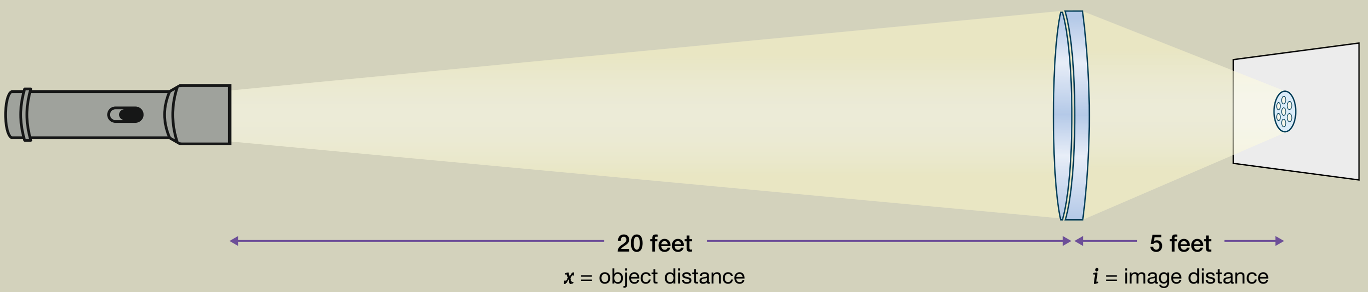
Many lenses come already mounted in a cell, which simplifies construction considerably. If yours doesn't, I highly recommend 3D printing one. Make a ring just big enough to hold the lens a little loosely, with a flange on one end to prevent the glass from falling out. Print a thin ring that will fit snugly inside the first ring and hold the lens in place. Secure it with screws, clips, or whatever you come up with. Just make sure the lens can't fall out, nor fall inward.

The Optical Tube Assembly

A refractor telescope is basically just a tube that holds the objective lens a fixed distance from the focuser. Those three elements — lens, tube, and focuser — make up the *optical tube assembly*, commonly called the OTA. So once you have your objective lens, you'll need a tube for it. How big should the tube be?

You might think that since the light path shrinks downward in a cone from the objective lens to the eyepiece, you could get away with a tube that fits snugly around the lens. Alas, that would be a bad idea for several reasons. For one, air currents from the cooling metal at night would mess up your view. Also, stray light entering the tube from outside the field of view can strike the tube walls and bounce into the eyepiece, reducing contrast. The farther the tube wall is from the light path, the less trouble those factors will create. So you want at least ¼-inch extra radius (½-inch of extra diameter) or even more if you can manage it.

How long should the tube be? That depends on several factors, the first of which is the focal length of the lens. Let's say we're building an 80-mm f/5 scope. That means the lens is 80-mm in diameter and the focal point is five times that distance (400 mm) away. That's only 15¾ inches. That's why Orion named its popular 80-mm f/5 refractor the Short-Tube 80. But that's 15¾ inches from the lens to the eyepiece, and you'll need to install a focuser between them. And unless you want to look straight through the telescope — an awkward position that gets more awkward the higher in the sky you look — you'll also need a *diagonal*, a mirror or prism that



Thin lens formula: $1/x + 1/i = 1/f$

$1/20 + 1/5 = 1/4$

Lens focal length (f) = 4 feet

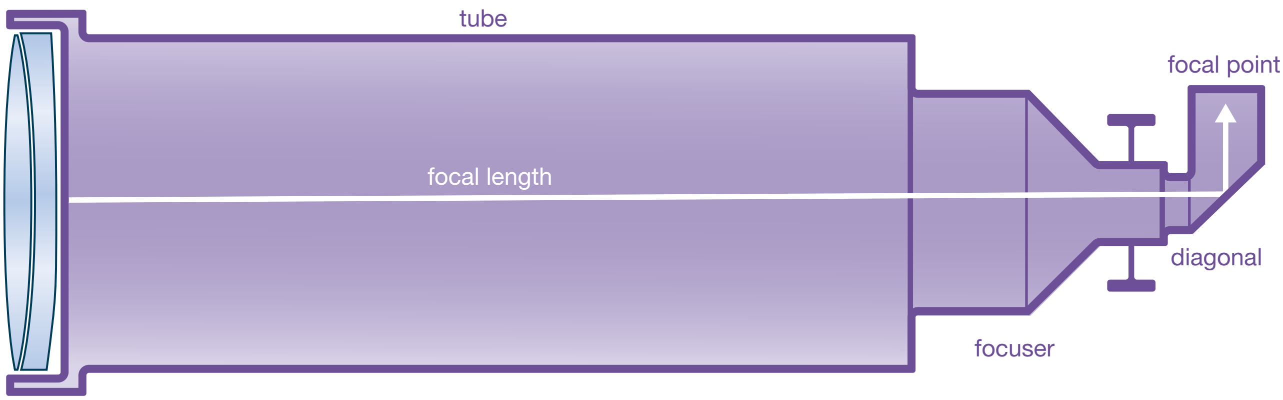
▲ Use the thin lens formula to find the focal length of your telescope objective.

Finding the Lens Focal Length

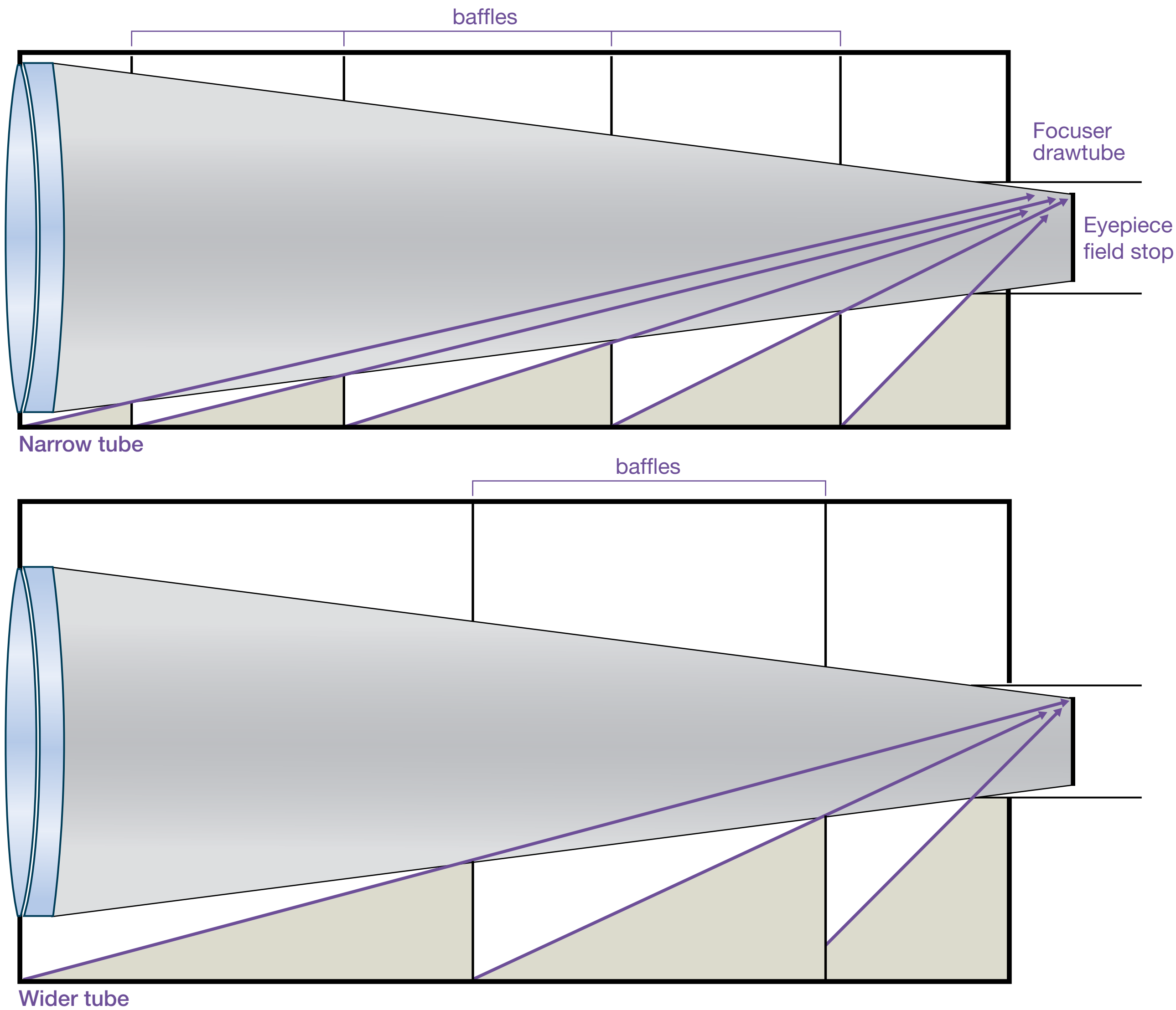
If you don't know the focal length of your lens, it's easy to find it. On a sunny day you can just measure the distance between the lens and a projected, focused image of the Sun, but that image will be dangerously bright and could cause eye damage. Better to wait for a bright Moon and use that. But if you have clouds, or the Moon is in the wrong phase, there's a simple equation to the rescue. Called the "thin lens formula," it's simply $1/x + 1/i = 1/f$, where x is the distance from the lens to an object (in this case a flashlight), i is the distance from the lens to the focused image of the flashlight, and f is the focal length of the lens.

So, if your flashlight is 20 feet away (6 meters) and the focused image is 5 feet from the lens, then the lens formula says $1/20 + 1/5 = 1/f$. Solving for f gives you 4 feet.

Note what happens when the object is an infinite distance away. $1/x$ goes to zero, so you get $1/i = 1/f$, which means $i = f$. That's why measuring the distance to a focused Sun or Moon image works — they're both effectively at infinity.



▲ The tube length will be the lens's focal length minus the distance taken up by the focuser and diagonal. Make sure the focuser is in the middle of its travel range when you make this measurement.



▲ The narrower the tube, the more baffles you'll need. Shaded areas cannot reflect light into the eyepiece. The focuser and diagonal are omitted from these illustrations to simplify the light path.

reflects the light upward so you can look down into the eyepiece while the scope is pointed up into the sky.

The focuser might be only a few inches long for some models, or it can take up a lot of room. I've seen focusers 8 inches long. A 1¼-inch (diameter) diagonal uses about three inches of the light path. A 2-inch diagonal needs closer to five inches. So depending on your lens, focuser, and diagonal, your tube might be only a few inches long.

I've had great luck making telescope tubes using galvanized metal flashing, the sort you can buy off large rolls in a hardware store. Roll it up into a cylinder, rivet or bolt it together, and there you go. The thin metal is surprisingly rigid in tube form.

It's tempting to make your tube taper. After all, the light cone tapers, so why not make the tube do the same? Because it's really hard to make the front end of the tube perfectly perpendicular to the cone's long axis. That means your lens won't be aimed down the tube. You're way better off making your tube cylindrical all the way down.

▲ Make the dew shield at least the length of the tube diameter and wider than the diameter of your lens.

Focuser and Baffling

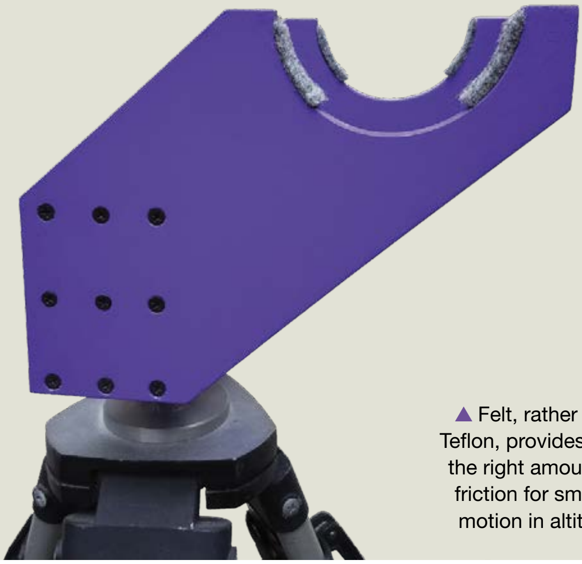
You can make or buy your focuser. One thing to consider is the length of its drawtube. Some commercial focusers have insanely long drawtubes, and with a short-focal-ratio lens, the end of the drawtube closest to the objective lens can cause vignetting, effectively reducing the aperture of your scope. Ideally, you want the drawtube to just allow you to see all of the objective, but if it doesn't — if you can see a lot of the inside side of the tube when you look into the focuser — fear not. Making baffles is, well, not baffling.

Think about using the scope in the daytime. You're looking at a bird on a branch down the street, but light is entering the scope from bright white clouds, from the wall of your house, from the Sun's reflection off the windshield of your car, etc. It's not going straight for the eyepiece, but it's bouncing around inside the tube and eventually winding up there. Your view will be washed out, as if seen through fog.

Painting the inside of the tube flat black helps reduce this problem quite a bit, but at very low angles of reflection, flat-black paint is about as reflective as a mirror. Flocked paper is much better, but best of all are a series of ring baffles, which stop reflected light almost completely. How do they do that? By making it impossible to see the tube wall from the eyepiece, and therefore making it impossible for any light that reflects off that wall to reach your eye.

There are mathematical and graphical ways to calculate the size and placement of ring baffles, but the simplest way is to just look through the focuser (or the diagonal if you're using one) when the outer edge of the focuser or diagonal is at the focal point. Figure out where a ring would need to go inside the tube to prevent you from seeing the end of the tube without the inner edge of the ring getting into the cone-shaped light path of the image you actually want to see. Make that ring (use

▶ The mount's cross-braces fit over the tripod's vertical post. Wax on the post provides smooth motion in azimuth. If you use a camera tripod, it will require a threaded insert rather than holes for a post.



▲ Felt, rather than Teflon, provides just the right amount of friction for smooth motion in altitude.

whatever's handy: cardboard, thin metal, a 3D-printed disk, etc.), paint it flat black, and put it in the tube. Then look again to see where the next ring needs to go in order to prevent you from seeing any tube behind the first ring.

You'll quickly realize that a tube that's much wider than the objective lens will only need a couple of baffles because each baffle obscures a long stretch of tube. A tighter tube will need more baffles.

Are baffles absolutely necessary? No, they're not. At night the only extraneous light you're likely to have will be coming from the sky, and that's not bright enough to cause much trouble. But if you've got a neighbor with a nasty porch light, or you plan to observe under a fat Moon, you should make baffles.

You'll need one more multi-purpose item up front: the lens shield, often called the dew shield. The objective lens is right out there at the front of the telescope, aimed upward toward the cold night sky, which makes it a prime target for dew formation. If you plan to use your scope for more than a few minutes, you'll want a dew shield out front. That's simple: Just make an extension that slides over the front end of the tube and sticks out at least the length of the tube's diameter. One and a half times the diameter is even better. That won't stop dew completely, but it'll slow it down. Make sure the shield's diameter is larger than the lens diameter to prevent vignetting.

Mounting the Scope

That's pretty much the OTA. Now you need to put it on something. A simple alt-azimuth mount is the easiest way to go. There are dozens of designs for these, but the easiest is probably a cradle with two arms angled outward so you can tilt the scope straight up and straight out without banging into the base. Put altitude bearings at the scope's center of gravity and set the scope in the cradle. How you attach the cradle to your tripod depends a lot on your tripod's design. But the cradle needs to be free to swivel left and right and the scope needs to be free to tilt up and down. A little friction here is good, just as with a Dobsonian scope. You want it to be easy to move but stay put when you let go.

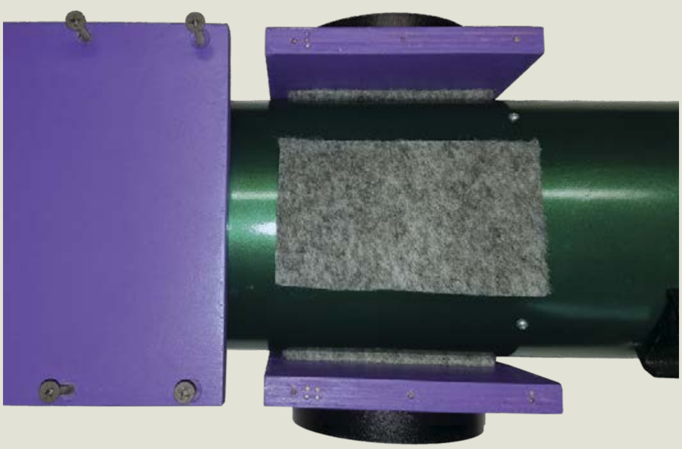
I had a sturdy tripod with a one-inch pipe sticking straight up 4 inches off the top. That made it a perfect fit for the mount shown on page 124 of Jean Texereau's classic *How to Make a Telescope* (2nd edition). I increased the altitude bearing size to Dobsonian proportions to give me better friction control, but otherwise it's pretty much Texereau's design.

I used three horizontal cross-braces, but honestly two would have been fine and given me less of a headache trying to perfectly align the three central holes that the tripod's pipe passes through. I made the angled arms long enough to allow the scope to swing all the way from horizontal to vertical, but not so long that the center of gravity would lie outside the tripod's footprint. Rather than attach altitude bearings to the scope directly, I took another cue from John Dobson and built a tube box around the scope and put the altitude bearings (plywood disks) on that. I glued Formica (909-42 Crystal Finish) on the outer edges of the bearings and I used thick felt rather than Teflon for the pads.

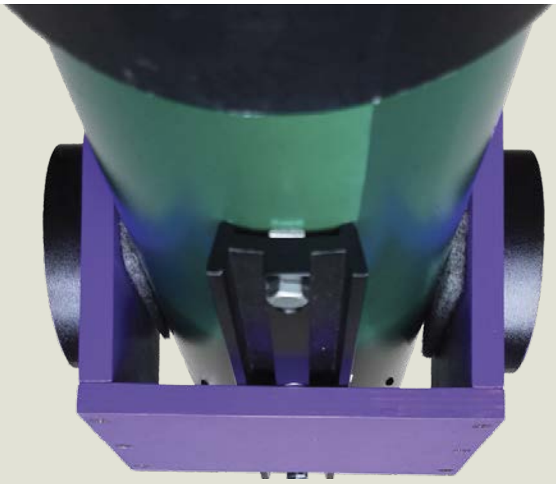
My scope also has a dovetail rail for my equatorial mount when I want tracking. As I was designing the tube box, I realized there was no reason to remove the rail; the box can be built around it so I can I have both options available.

That's all there is to it. Refractors may look a little bit like rockets, but they're not rocket science. They're actually simple devices, and they reward the effort of building them with crisp, high-contrast images. If you're looking for a relatively easy, highly rewarding project, building a refractor might be just what you're after.

■ Contributing Editor **JERRY OLTION** loves splitting tight double stars with his refractors.



▲ Felt pads protect the telescope's paint job and keep the scope snug inside the tube box, yet when they're just the right thickness they allow forward/back adjustment for balance.



▲ A dovetail rail allows for mounting the scope on an equatorial mount. It can be left in place when building the tube box for an alt-azimuth mount.

Sky-Watcher's CQ350-Pro Equatorial Mount

This mid-weight equatorial mount provides a hefty payload capacity for advanced observers and astrophotographers.

Sky-Watcher CQ350-Pro

U.S. Price: $3,500.00 (equatorial head and counterweights)

Skywatcherusa.com

What We Like

Excellent pointing and tracking performance

Solid construction

Lightweight enough for one person to set up in the field

What We Don't Like

Needs better software for computer use and astrophotography automation

▲ With an equatorial head and optional field tripod lightweight enough for one person to set up in the field, and a rated payload capacity of 35 kilograms (77 pounds), the Sky-Watcher CQ350-Pro is an attractive mount for many observers and astrophotographers.

ALL IMAGES ARE BY THE AUTHOR

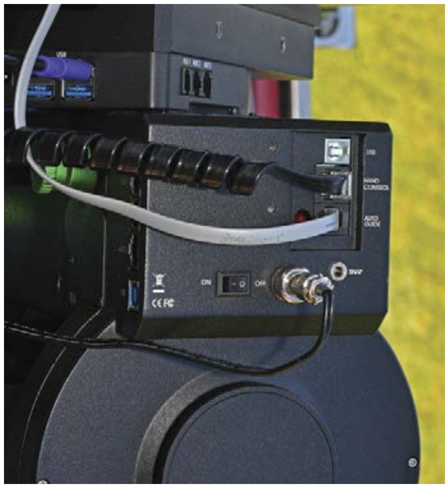
SKY-WATCHER CONTINUES adding to its impressive line of telescope mounts. From new strain-wave models that follow the latest industry trend, to a dedicated mount for solar telescopes, to compact star trackers for cameras, to a full line of equatorial mounts suited for astrophotographers, Sky-Watcher has something to meet the needs of just about every amateur astronomer.

The recently introduced CQ350-Pro equatorial mount fills a gap that had existed in the company's models for advanced astrophotographers and observers. With a payload capacity (excluding counterweights) of 35 kilograms (77 pounds), the CQ350-Pro fits nicely between the EQ6-R Pro (20-kg capacity) and the EQ8-R Pro (50-kg capacity). Its price tag of $3,500 also conveniently fits between the $2,025 and $5,300 of the EQ6-R Pro and EQ8-R Pro, respectively.

The CQ350-Pro has interesting potential for those willing to put a little muscle into their hobby when it comes to setting up equipment in the field, be it a backyard or remote dark-sky site. Given its substantial payload capacity, the mount is still reasonably manageable for a single person. An optional field tripod is available for $765 when purchased as a package with the mount. It tips the scales at 16 kg, just a touch less than the 17.7-kg equatorial head with its removable 2.6-kg counterweight bar attached. Furthermore, the mount and tripod combo are well suited for just about the largest telescope or astrograph I would consider for field use. Your mileage, of course, may vary.

I reviewed Sky-Watcher's EQ8-R Pro in the October 2020 issue, pages 66–70. On paper, the general specifications for it and the CQ350-Pro look notably similar, with the exceptions of hardware weights and payload capacities. And the same goes for the general operation of the two mounts since both work with the same SynScan hand control. Indeed, while testing the CQ350-Pro in the dark, there was little that distinguished it from my memory of its larger relative except for the expected added rigidity afforded by the bigger EQ8-R Pro. When it came to pros and cons of the two mounts, it was truly a case of déjà vu! Readers who remember the EQ8-R Pro review take note.

Nevertheless, there are some differences between these mounts. Foremost is the CQ350-Pro's mechanical design. Unlike the traditional German-equatorial format of the EQ8-R Pro with its declination axis at the celestial-pole end of the polar axis, the CQ350-Pro has the declination axis positioned between the north and south bearings on the polar axis. This is a first for Sky-Watcher, and it follows a mount design made popular in recent years by iOptron. It results in a better distribution of the telescope payload over the center of the equatorial head, with a corresponding improvement in the mount's stability. A disadvantage is that the mount has a limited ability to track past the meridian when a telescope is on the west side of the mount or point to objects east of the meridian when the scope is also on the east side of the mount. For the CQ350-Pro, this limit is about 7½° (roughly 30 minutes of right ascension) on either side of the meridian.



◀ All cable connections for the CQ350-Pro are on the moving part of the polar-axis assembly. Those for the mount's power input, SynScan hand control, ST-4-compatible autoguider, and USB 2.0 computer connection are located close to and aligned with the polar axis. As such, they sweep through only modest-size arcs as the mount slews and tracks in right ascension. The red LED partially hidden by the autoguider cable is unusually bright when the mount is powered on. The snap port can control selected DSLR cameras from the SynScan hand control.

Performance

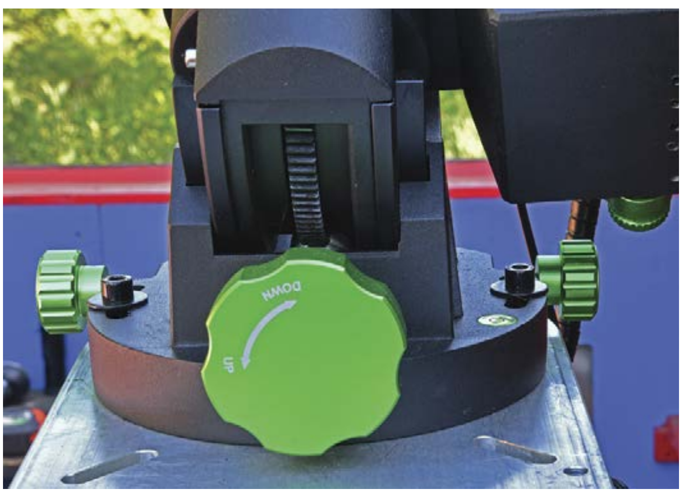
I did a lot of observing just using the SynScan hand control to operate the mount. I do wish the coiled cord with its RJ45 modular plugs for connecting the hand control to the mount were longer, since it comfortably stretches only about 2 meters. The manual does a good job explaining the hand control's setup and operation, with one exception that confused me in the beginning.

Initialization starts by entering date, time, and your location, all of which remain stored in the controller's memory for future use with the exception of the time, which always defaults to 8 p.m. on power up. This means you only have to change the date and enter the correct time when you start the mount on another night, assuming your location is the same. If you're into luxury, there's a $197 GPS module that plugs into the SynScan hand control and will update the necessary information each time you power up the mount.

Sky alignment of the mount begins by sending the mount automatically to its home position, which places the telescope above the polar axis and aimed at the celestial pole. And from there you perform a 1-, 2-, or 3-star alignment. The more stars you use, the better the Go To pointing accuracy, especially if the mount is only roughly polar aligned.

As for that confusion during my first sky initialization, it was the question "Renew H.P.O.?" that appeared on the SynScan display after I finished my star alignment. There was no mention of that in the manual. I simply selected "no" as my answer and went about observing. Later I figured out that H.P.O. stands for "home position offset," and it enters a correction (if needed) to correlate the aim of your telescope with the mount's fixed home position. This makes the mount's pointing very accurate when you start from the home position in the future — an important feature if the mount is operated remotely. Furthermore, since I usually shut down the mount with a park command, no alignment was needed when I powered up on a future night and resumed observing from the parked position. One nice feature of the park command is the ability to set a custom position for the telescope. Because of the design of my observatory, I used this feature to ensure the telescope would shut down in a position that allowed closing the roof.

Sometimes when using the hand



▲ *Left:* Large hand knobs for the azimuth and altitude adjustments on the equatorial head allow fine polar alignment motions even when the mount is fully loaded with a telescope or astrograph. *Right:* With a bubble level (not seen in this view) built into the mount's base and a precise altitude scale on the polar-axis assembly, it's easy to quickly position the CQ350-Pro for polar alignment.

control's direction buttons to center an object, the mount would briefly continue to move after I released a button. It was never an issue when guiding, only when using the faster centering and slew speeds. I've also experienced this issue with other Sky-Watcher Go To mounts. It's mildly annoying, but not a showstopper.

Unlike most of the Go To mounts I've tested, the SynScan controller does not have a "synchronize" feature that lets you realign the pointing to a given object while observing. It does, however, have a useful feature, especially for a mount set up permanently, called "Pointing Accuracy Enhancement." It divides the sky into 85 small sections and remembers any corrections needed to center objects within a section and apply them to future Go To slews to that part of the sky. This would compensate for telescope flexure that varied for different parts of the sky.

The CQ350-Pro's Go To pointing and tracking were extremely good. Although I did most of my testing with the mount attached to a permanent pier in my backyard observatory, I did some initial testing with the mount reasonably, but not precisely, polar aligned. This would be similar to a typical situation when using the mount in the field. As such, doing a careful 3-star alignment when initializing the mount produced very good Go To pointing over most of the sky. The "rough" polar alignment, however, caused objects to drift when tracking unguided for extended periods. Once the mount was accurately polar aligned, a single-star initialization was sufficient for excellent Go To pointing, and the unguided tracking was spot on.

Using a 127-mm f/8 refractor with an effective focal length of approximately 1,000 mm, I made a series of 30- and 60-second unguided exposures with a DSLR to test the tracking accuracy. More than 90% of the shorter exposures showed perfect star images, and almost as many of the longer exposures were equally acceptable. Autoguided exposures were made using *PHD2* software (available for free from **openphdguiding.org**) controlling the mount. Tracking logs made using 2- to 4-second guiding exposures typically showed an RMS tracking error of less than 1 arcsecond, and even less than 0.5 arcsecond when the seeing conditions were good. In a nutshell, I consider this level of guiding performance excellent.

The CQ350-Pro I tested had a very small amount of play in the declination gear when its worm clutch was fully engaged. With years of astrophotography experience dealing with backlash in drive gears, my usual solution is to set the offending axis slightly out of balance to keep the gear "loaded." This worked well for the CQ350-Pro with the exception of one very windy night when the telescope still bounced a bit in declination.

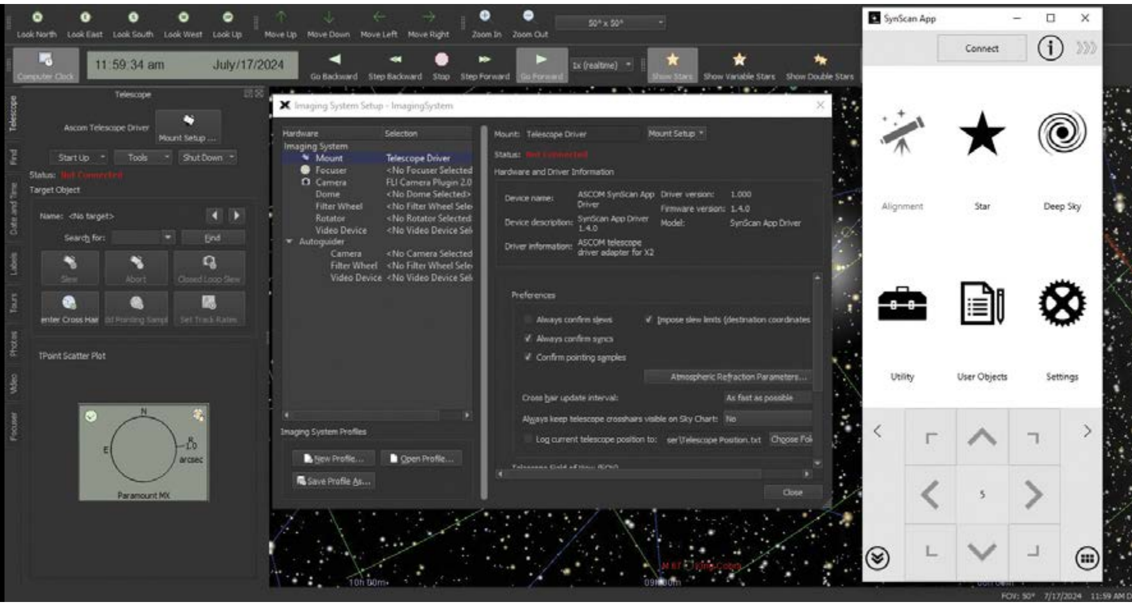
Computer Control

The SynScan hand control has an internal database that's said to contain 42,000 objects (I didn't count them). They're organized by the popular catalogs that we've come to expect with an advanced Go To mount, including the Messier, NGC, IC, and Caldwell catalogs of deep-sky objects. There's also a list of the brightest named stars, but for fainter ones SynScan uses a shortened version of the Smithsonian Astrophysical Observatory's (SAO) *Star Catalog* and only includes stars brighter than 8th magnitude. While useful, this catalogue is becoming rather dated, and it would be nice to see Go To mounts include more modern listings such as the European Space Agency's *Hipparcos* and *Tycho* Catalogs.

That said, I think many, if not most observers today operate Go To telescopes via a computer, tablet, or smartphone, which can open access to

▲ Cable connections on the side of the declination assembly have through-the-mount wiring to corresponding ports on the telescope saddle. Included are hub ports for four powered USB 3.0 connections, three power outlets (fed from the single power jack on the declination assembly), and modular jacks for RJ10, RJ12, and RJ45 (4-, 6-, and 8-pin, respectively) connectors that are on the side of the saddle and not visible in this view.

▲ Levers on the side of the declination assembly operate clutches on both axes that completely disengage the drive worms from their respective worm wheels, thus making easy work of balancing the telescope load. Both clutch levers are fitted with knobs that lock the levers in place and help prevent the clutches from being accidentally disengaged.



As explained in the accompanying text, the most straightforward way to operate the mount with planetarium software is on a Windows device that must simultaneously be running the *SynScan* app. The app appears here as the white box in the foreground of Software Bisque's *TheSkyX* planetarium software, which has its dialogue box open for making the required ASCOM connection to the app.

a cornucopia of databases. The most straightforward way of doing this with the CQ350-Pro is with a Windows or iOS device running the *SynScan* app (available as a free download from Sky-Watcher) and connected to the mount via a USB 2.0 cable or with an optional SynScan Wi-Fi adapter available from Sky-Watcher for $70. The app basically mimics the operation of the hand control, albeit with a much smaller star database. Its big advantage, however, is its ability to connect via an ASCOM driver to a variety of Windows-based planetarium programs. This allows using the extensive databases most of these programs include as well as the point-and-click ability to send Go To commands to the mount.

I did my testing with Software Bisque's *TheSkyX* program. Unfortunately, the necessity of connecting this software through the ASCOM driver for the *SynScan* app does not support many of the features that *TheSkyX* offers for controlling mounts that have native software directly connecting them to the planetarium program. For example, if you want to nudge the CQ350-Pro to position a target after a Go To command with *TheSkyX*, you must toggle back to the *SynScan* app and issue move commands from it. In my review of the EQ8-R Pro I called this arrangement "clunky," and while I still consider that a reasonable assessment, the process of flipping back and forth between the programs while observing becomes a comfortable routine with use, only adding a few mouse clicks compared to software that offers direct control of the mount from the planetarium program.

This, however, is not the end of the story for those wishing to control the CQ350-Pro with a computer. At least two open-source and free programs — *EQmod* (**eq-mod.sourceforge.net**) and *Green Swamp Server* (**greenswamp.org**) — offer various levels of control of Sky-Watcher mounts. I haven't tested either, but a simple internet search will lead you to comments and videos by amateurs who are working with these applications. While as of this writing neither of these programs specifically lists the CQ350-Pro as a supported mount, they do work with many of the mounts that use the SynScan controller. Furthermore, these programs are continuously in development, so it would be best for anyone interested in using them to do a little internet homework to learn their current capabilities.

I found the CQ350-Pro to be an impressive piece of hardware given its extremely good performance and heavy payload capacity while still being a mount that one person can set up and use in the field. It's a very nice addition to the Sky-Watcher line of equatorial mounts for advanced observers and astrophotographers. It's another thumbs up for Sky-Watcher.

▶ The CQ350-Pro performed well with the author's 8-inch f/8 refractor that placed a 29-kg payload on the mount. Sky-Watcher lists the mount's power requirement as 11 to 16 volts DC and 55 watts. But the author never had a problem running it on a 13.8 VDC supply rated for a maximum of 41 watts (3 amps).

■ **DENNIS DI CICCO** has been observing and testing equipment for more than 40 years from his backyard observatory in Boston's western suburbs.

by Jerry Oltion

From Broken Glass to Brökenglas

An uplifting tale of woe

▲ Rob Brown points out the obvious: At f/2.8, his 16-inch "Brökenglas" telescope is shorter than he is.

JOHN DOBSON FAMOUSLY SAID, "There's nothing you can do while making a mirror that will lead to a life of woe." Oregon ATM Rob Brown might have disputed that the second time his 16-inch primary mirror broke.

Second time? Oh yes. The first one was bad enough. Rob had finished polishing and had a pretty decent parabola, so he decided to star-test it. He put the mirror in the roughed-out OTA and tilted it forward . . . and the mirror fell out onto the pavement and broke. Rob reports, "I was so shocked in disbelief that I actually put my eye back to the eyepiece."

The next disaster came when he left his polishing machine unattended. The pitch dried out and chucked the glass off the lap onto the garage floor.

Undeterred, and inspired by Mel Bartels's extremely fast-focal-ratio telescopes, Rob ground and polished a third blank to an astonishing f/2.8. Needless to say, he locked this one in place during the star test.

The primary now a reality, Rob turned to the tube assembly. A fast mirror screams out for portability, and so does a person living in the suburbs of Portland, Oregon. So Rob decided on a tensegrity design, a concept coined by Buckminster Fuller as an abbreviation of "tensional integrity" in the 1960s and popularized more recently by Don Peckham (**https://is.gd/DPTensegrity**).

In a tensegrity scope, all the struts are always in compression, even when the scope is aimed at the horizon. This is accomplished by using cords (which ATMs call "strings") to pull the top end of the scope down toward the bottom end. But there's an extra trick: If you run the strings out to the corners of a free-floating framework in the middle of the span, the angle of approach to the top and bottom attachment points is much greater than if the strings simply run from the top straight to the bottom. That increased angle vastly increases the stiffness of the entire structure. (Why? Cosines.)

Since the trusses and the central framework are always under compression, they don't need to be screwed together, nor particularly rigid. They're only there to keep the strings tight. It's the strings that hold the scope together. So Rob was able to use segmented aluminum tent poles that

▲ An ultra-lightweight mirror and a tensegrity structure make this scope more portable than many with half the aperture.

simply slip together and fold up into a small package for travel.

For the tension cords, Rob used bow string. He needed custom lengths, so he bought the raw materials from an archery shop and made his own. He says he found the best instructions to do this in Albert Highe's book *Engineering, Design and Construction of String Telescopes*.

Rob printed his own Crayford focuser using a design he got from Jonathan Kissner (*S&T:* Jan. 2023, p. 70). He modified it to provide a "filter flipper" that lets him move filters into place quickly.

Rob used recycled PETG for all the 3D-printed parts, including the altitude bearings, which provide just enough friction, eliminating the need for countertop laminate.

The primary mirror cell has an interesting design, too: It uses flat aluminum strips with their wide dimension perpendicular to the mirror back. That keeps them rigid in the scope's longitudinal direction but allows them to flex so all points of support are under equal pressure. The aluminum strips are simply riveted to the framework, and collimation is accomplished by shifting the entire system (with top access while looking in the eyepiece!).

The OTA weighs a mere 23 pounds (10.4 kg), but Rob says, "The really

ALL IMAGES COURTESY OF THE AUTHOR

important figure is the total assembly weight, the stuff I have to lift out of the trunk of the car." With the flex rocker and ground ring, it's still only 25.8 pounds.

That leads to an interesting concept that Rob and Mel Bartels (whom Rob says "was a huge inspiration and help in this project") have come up with to quantify the portability of a telescope. How many pounds per square inch is it? Well, the scope, which Rob named Brökenglas, has a 16¼-inch primary, so that's 207 square inches. Divide that into 25.8 pounds and you get 0.124 psi. Mel has calculated the psi of about 150 other scopes, but Rob's is at the very top of the list, even beating out Mel's own 16¼-inch f/2.8 made from a matching blank.

From glass shards to the cutting edge of telescope technology, Rob's is a tale of persistence and triumph.

For more information, visit Rob's website at **https://is.gd/brokenglas**.

■ Contributing Editor **JERRY OLTION** has ground plenty of glass but hasn't yet broken any.

▲ The 6-point mirror cell uses twisting flexure instead of loose parts. The mirror is ½-inch-thick soda-lime glass slumped to f/2.8, provided by DOTI Optics (**doti-optics.com**).

What Is a Black Hole?

▲ **BLACK HOLE SHADOW** This image shows the silhouette of the supermassive black hole at the center of the galaxy M87. The black hole's intense gravity bends light into a ring around the hole. Astronomers constructed this image using data from a worldwide network of radio telescopes called the Event Horizon Telescope (*S&T:* Sept. 2019, p. 18).

EVENT HORIZON TELESCOPE COLLABORATION

A BLACK HOLE IS a cosmic pothole — a big and insanely deep pothole.

More specifically, black holes are places where matter became so dense that it surrendered to the inward pull of its own gravity, crushed down down down to . . . well, to something, we're unsure quite what. The immense concentration of matter into a relatively tiny volume warps the fabric of space and time into a four-dimensional pocket. This pocket is the black hole.

You can avoid a pothole by swerving around it. The closer you come, the faster you must swerve to avoid falling in. But if you come too close to the edge, you won't be able to swerve fast enough to escape.

The same goes for a black hole. As you approach the ditch the black hole makes in spacetime, you'll encounter a steepening slope, gravitationally speaking. The deeper down that slope you travel, the faster you'll have to go in order to charge back up and out. But at some point, it doesn't matter how hard you put the pedal to the metal. You're going in.

That point of no return is the *event horizon*. The event horizon is the black hole's "edge." It is not a hard boundary; once you pass it, you can still look back. But you can't *go* back. Not even light travels fast enough to escape once it passes the event horizon. This is why black holes are black: They swallow light.

Since black holes are invisible, we find them through their effects. For example, we can see the glow from the disk of hot gas skirting the black hole, which forms from stuff caught by the spacetime pothole's gravity. We can also see the giant jets of plasma the black hole spews as it feeds from this disk. (Black holes eat like toddlers: Most of the gas winds up anywhere except down their throats.) But you won't spy the gas tutu with a backyard telescope. You *might* see the jet from one of the biggest black holes — namely, the one in the galaxy Messier 87 — with a large amateur scope, if you have superb sky conditions.

Would You Like Small, Medium, or Large?

There are different kinds of black holes. *Stellar-mass black holes* are those with masses of a few to a few tens of Suns. These are sometimes made when the cores of massive stars collapse at the end of their lives. They can also form when two black holes collide, an event so powerful that it sends waves traveling through the stiff fabric of spacetime. Scientists call these ripples *gravitational waves*. We've detected a couple hundred stellar-mass black holes, either in gravitational-wave events (*S&T:* June 2022, p. 12) or orbiting stars. We may have also seen some wandering through the galaxy as rogue objects, but we can't confirm those chance sightings.

There are also *intermediate-mass black holes*, which generally have hundreds to tens of thousands of solar masses (*S&T:* Nov. 2022, p. 16). Some are made by black hole mergers. Others are starved versions of *supermassive black holes*.

Supermassive black holes are the leviathans of the cosmos. They have millions to billions of solar masses, packed within an event horizon whose diameter is on par with the size of the solar system. At least one lies at the center of nearly every large galaxy. We've detected them across cosmic time by watching stars and gas whip around where they sit or by spotting their jets. We've even seen the silhouettes of two supermassive black holes, ringed in light (*S&T:* Dec. 2022, p. 12). These objects grow by swallowing gas or merging. Astronomers still debate the nature of the seeds they sprouted from (*S&T:* Jan. 2017, p. 24). ■

▲ LIGHT-POLLUTION FILTER

Altair Astro now offers a light-pollution filter for astrophotographers shooting with color cameras: the Altair TRI-RGB Light Pollution Filter 2″ (£140.83). This 2-inch-format filter is designed to pass as much of the primary blue, green, and red regions of the spectrum while blocking the majority of common sources of light pollution to produce a natural color balance in your astrophotos. The filter works on both emission nebulosity as well as broadband targets, including reflection nebulosity and even galaxies. While primarily designed for use with color cameras, the filter is also useful for imaging with monochrome cameras to produce a "cleaner" luminance signal. The filter blocks both ultraviolet and infrared wavelengths and includes an Si02 overcoat to prevent damage from moisture.

Altair Astro
Unit 2, Earl Rd., Rackheath Industrial Estate, Rackheath Norwich, UK NR13 6NT
altairastro.com

▲ VERSATILE LENS

Sharpstar unveils a compact astrograph for both wide-field astrophotographers and daytime photographers alike. The Askar SQA55 ($695) is a 6-element, 55-mm f/4.8 Petzval refractor that utilizes two elements of exotic glasses to produce sharp, color-free stars across a 44-mm, fully corrected image circle. The telescope doubles as a 264-mm telephoto lens with a dual-speed, helical focuser and internal diaphragm that has an aperture range spanning from f/4.8 to f/22. It connects to cameras via an M48 adapter and accepts 2-inch filters. The telescope weighs 2.18 kg with its included Vixen-style mounting bar, quick-release universal finder bracket, and saddle-handle bar that accepts Synta-style removable guidescope brackets. The lens comes with front and rear caps and a hard case.

Sharpstar
sharpstar-optics.com

◀ STRAINWAVE MOUNT

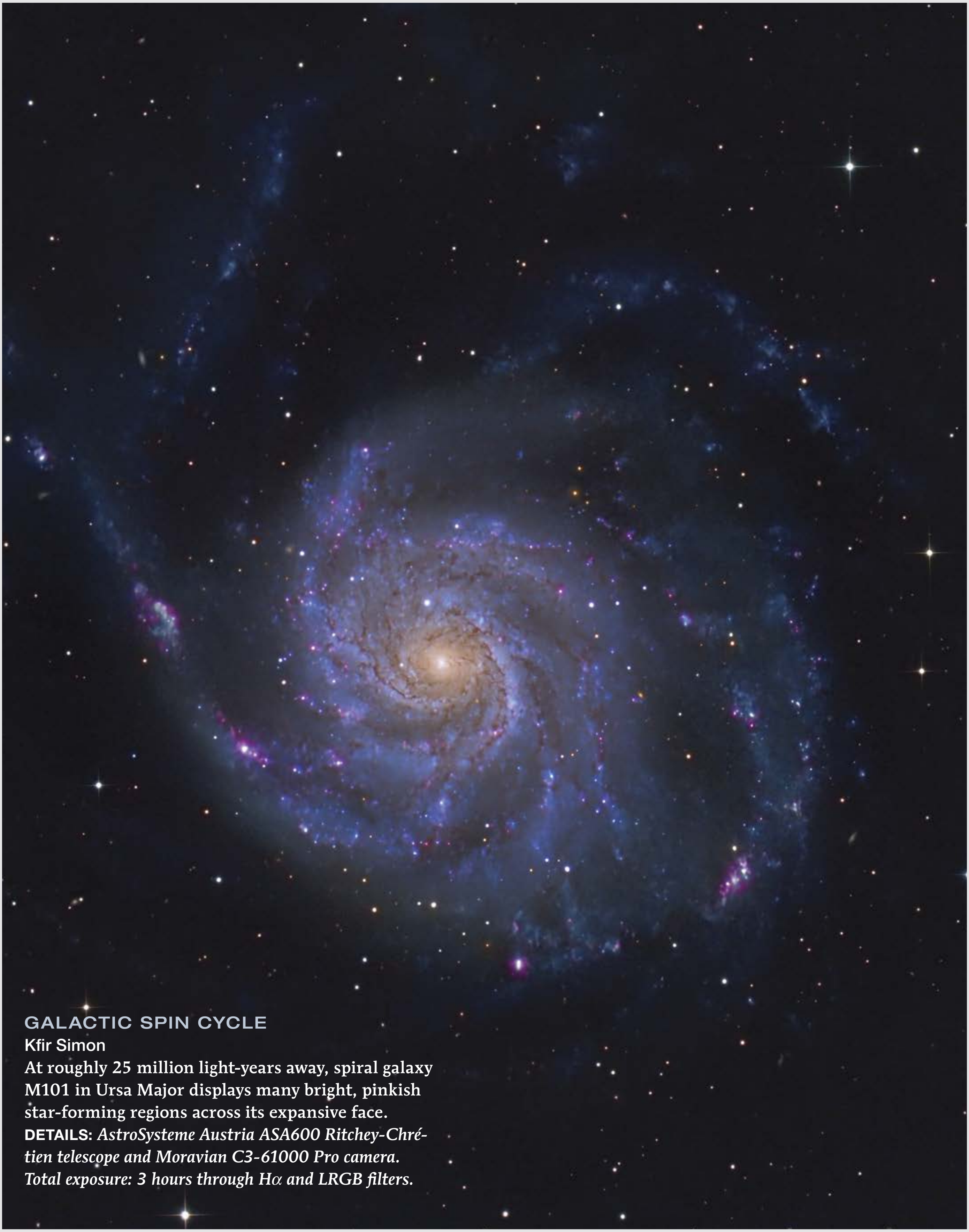
Pegasus Astro announces the NYX-88 Harmonic Gear Mount ($1,900), a lightweight German equatorial mount head for travelling astrophotographers. This Go To mount is designed to take advantage of the high-torque capabilities of strain-wave gearing. The mount features fast strain-wave drives and belts in both axes producing low periodic error and sub-arcsecond tracking. Its universal saddle plate accepts both Losmandy-D and Vixen-style dovetail mounting bars. The mount head weighs 5 kilograms (11 pounds) and can bear an instrument load of 14 kg. It operates in both equatorial and alt-azimuth modes. The NYX-88 includes built-in Wi-Fi and is controlled using either the *Unity* app for Android and iOS devices, the *Unity* Platform for Microsoft Windows, or with the optional NYX-HC hand controller. The mount comes with a 12-volt, 5-amp power supply, a USB 2.0 Type A to Type C cable, and a soft-sided carry case.

Pegasus Astro
Kolokotroni 10, Keratea, Greece 19001
pegasusastro.com

New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. Sky & Telescope *assumes no responsibility for the accuracy of vendors' statements. For further information contact the manufacturer or distributor. Announcements should be sent to nps@skyandtelescope.org. Not all announcements can be listed.*

CELESTIAL CROWN
Vince Farnsworth
The spring Milky Way arches above bands of airglow and atmospheric haze over Black Canyon of the Gunnison National Park, Colorado, on the night of May 21, 2023.
DETAILS: *Canon EOS Ra camera and Canon RF 15-to-35-mm zoom lens. Panorama of twenty 2.5-minute exposures at f/3.2, ISO 3200 for the sky and around 12 seconds at ISO 400 for the foreground.*

STELLAR NURSERIES
Sean Liang and Telescope Live Team
Dozens of bright star-forming regions fill this view of the Large Magellanic Cloud, a satellite galaxy of the Milky Way, with NGC 2080 at center being the most prominent.
DETAILS: *PlaneWave CDK24 Dall-Kirkham telescope and QHY 600M camera. Total exposure: 5 hours through narrowband and color filters.*

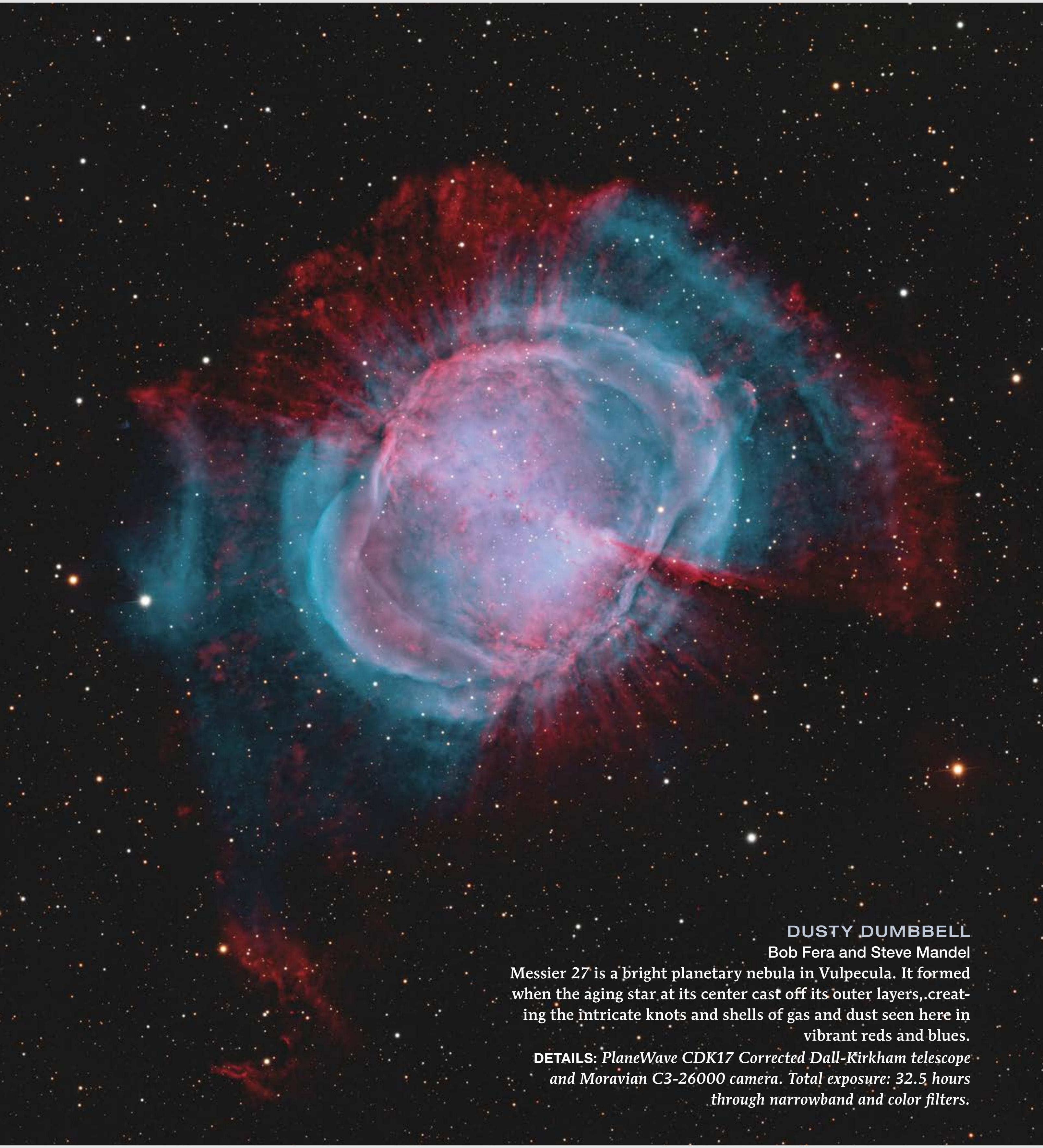


GALACTIC SPIN CYCLE

Kfir Simon

At roughly 25 million light-years away, spiral galaxy M101 in Ursa Major displays many bright, pinkish star-forming regions across its expansive face.

DETAILS: *AstroSysteme Austria ASA600 Ritchey-Chrétien telescope and Moravian C3-61000 Pro camera. Total exposure: 3 hours through Hα and LRGB filters.*



DUSTY DUMBBELL

Bob Fera and Steve Mandel

Messier 27 is a bright planetary nebula in Vulpecula. It formed when the aging star at its center cast off its outer layers, creating the intricate knots and shells of gas and dust seen here in vibrant reds and blues.

DETAILS: *PlaneWave CDK17 Corrected Dall-Kirkham telescope and Moravian C3-26000 camera. Total exposure: 32.5 hours through narrowband and color filters.*

◁ PICTURE-PERFECT PAIR

Dave Doctor

Dark dust lanes decorate the tightly wound arms of the flocculent spiral NGC 2841 in Ursa Major. It sits beside the much closer, 9th-magnitude star HD 80566 to its lower left. North is to the left.

DETAILS: *Officina Stellare RiDK 400 Dall-Kirkham telescope and SBIG STX-16803 camera. Total exposure: 34 hours through LRGB filters.*

▽ COLORFUL SKY

Chirag Upreti

An observer snaps pictures of the colorful aurora display on May 10th using her smartphone from the shore of Ashokan Reservoir in Ulster County, New York.

DETAILS: *Sony α7R III camera and Sigma 14-to-24-mm lens. Total exposure: 10 seconds at f/2.8, ISO 800.*

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ACCESSORIES

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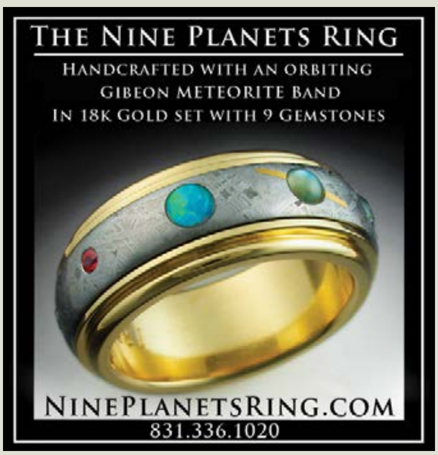

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NPS / GRAND CANYON

Event Calendar

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

September 27–28
HIDDEN HOLLOW STAR PARTY
Bellville, OH
https://is.gd/HHSP24

September 27–October 5
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

September 28
NOVAC STAR GAZE
C. M. Crockett Park, VA
https://is.gd/NOVACSG24

September 28–October 6
PENNYRILE STARGAZE
Dawson Springs, KY
https://is.gd/Pennyrile24

September 29–October 6
PEACH STATE STAR GAZE
Deerlick Astronomy Village, GA
atlantaastronomy.org/pssg

October 3–5
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org

October 3–6
ENCHANTED SKIES STAR PARTY
Magdalena, NM
enchantedskies.org

October 3–6
GREAT LAKES STAR GAZE
Gladwin, MI
http://greatlakesstargaze.com

October 3–6
IOWA STAR PARTY
Coon Rapids, IA
iowastarparty.com

October 5
ASTROASSEMBLY
North Scituate, RI
https://is.gd/AstroAssembly24

October 12
ASTRONOMY DAY
Everywhere!
astronomyday.astroleague.org

October 18–November 3
JASPER DARK SKY FESTIVAL
Jasper National Park, AB
jasperdarksky.travel

October 25–31
CHIEFLAND ASTROFEST
Chiefland Astronomy Village, FL
chieflandastro.com/astrofest

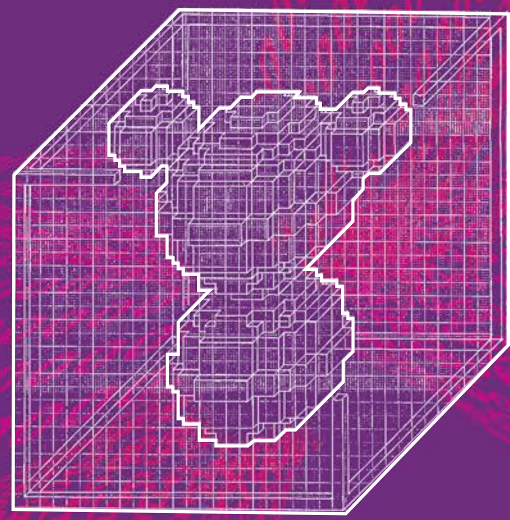
October 28–November 2
ELDORADO STAR PARTY
Eldorado, TX
eldoradostarparty.org

October 29–November 3
DEEP SOUTH STAR GAZE
McComb, MS
https://is.gd/DSSG24

November 1–2
DEATH VALLEY STAR PARTY
Furnace Creek Resort, CA
lvastronomy.com

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

FOCAL POINT by Rich Isaacman and Linda French



At left is the Cornell team's solution to Carl Sagan's challenge, drawn on graph paper during the all-nighter described below.

Message in a Molecule

Career scientists revisit a Carl Sagan challenge they undertook nearly half a century ago.

IN 1974, Arecibo Observatory was about to begin a second life. The world's largest radio telescope had just undergone a major upgrade, sporting a new, smoother surface and a powerful 1-megawatt radar transmitter.

That November — 50 years ago this month — the observatory staff celebrated the telescope's upgrade with the symbolic transmission of what became known as the "Arecibo Message," a 23-by-73-bit raster image illustrating some key facts about our species. Its creators were Carl Sagan, observatory director Frank Drake, staff scientist James C. G. Walker, and one of us (Rich, then a Cornell graduate student).

But Sagan's interest in alien intelligence didn't end with transmitting such a message. What would happen, he wondered, if humanity were to *receive* one? Would we be able to decode and interpret it?

About a year later, Sagan got the chance to perform the experiment — albeit only with humans — while producing a BBC TV documentary about life on other worlds. Working with a (to us) anonymous collaborator, Sagan developed a binary message. He then proposed to the BBC that he would challenge a group of Cornell grad students to interpret it. The director and film crew would interview them afterwards about their outcome.

Thus, late on a Friday in March 1976, Sagan summoned six of us and presented his challenge. The tight shooting schedule required us to complete it within 36 hours. Besides the two of us, there were Richard French, Kathy Rages, Edward Dunham, and David Pieri (all of whom, like the two of us, went on to successful careers in astronomy).

But what a challenge it was: a daunting, 19-page printout of ones and zeros — 29,791 of them, as Sagan informed us. With our calculators, we quickly determined that to be the cube of 31. During the all-nighter that followed, we debated whether we were grappling with a time sequence of 31 frames (each 31-by-31 pixels) or a 3D object. We set to work with graph paper, coloring squares for hours, then arranging them to see if they suggested a sequence. But each frame looked like a bunch of circles; it made for a perplexing movie.

A 3D object, then. Kathy, endowed with impressive visualization skills, drew a perspective view of the stacked images. The circles soon revealed themselves to be cross sections of four connected spheres floating in a cubical frame: one large, with two small ones on top and a medium-size one underneath. It looked disturbingly like an interstellar Mickey Mouse.

Maybe a molecule? Bingo. Linda said, "It looks like formaldehyde, H_2CO." A midnight run to the chemistry library confirmed that suspicion, right down to the bond angles.

But why waste so much data to depict one simple molecule? Rich, the radio astronomer, knew that H_2CO emitted a spectral line at a frequency of 4.83 GHz, and the message became clear: The "aliens" — Sagan's partner turned out to be Nobel-laureate chemist Linus Pauling — were telling us that they could send vastly more information, and that we should tune our receivers to 4.83 GHz to get the goods.

We delivered our report in the morning. Sagan was delighted, and the film crew suitably awed. *They* called us "bloody geniuses"; *he*, in a public lecture later that year, deemed us "reasonably clever." We like to think that was an attempt at dry humor, and we're still quite proud of the adventure.

■ **RICH ISAACMAN** is a retired NASA program manager. **LINDA FRENCH** is Professor Emerita of Physics at Illinois Wesleyan University. See Sagan and the six-student team in this 1976 video: **https://is.gd/SaganChallenge**.

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