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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MAY 2024

GHOSTS of Stars Past

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THE ESSENTIAL GUIDE TO ASTRONOMY

May 2024 VOL. 147, NO. 5

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Near-infrared image of Cassiopeia A
PHOTO: NASA / ESA / CSA / STSCI / D. MILISAVLJEVIC (PURDUE UNIV.) / T. TEMIM (PRINCETON UNIV.) / I. DE LOOZE (UNIV. OF GENT)

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Meet the Stars

A QUICK GLANCE at the night sky might give the uninitiated the impression that all stars are alike — just a lot of white sparks. But that's like looking at a crowd of people at a distance and saying that all humans are alike — just a lot of two-legged clothes-wearers.

As all astronomers know, stars come in a bewildering array of types, and their stories are as diverse as those of human beings. In this issue, we inquire into the lives and, in some cases, deaths of some quite remarkable stellar objects. Each boasts one or more unusual characteristics that make it stand out from all those white sparks.

Take Barnard's Star, the subject of Howard Banich's article on page 60. This red dwarf in the constellation Ophiuchus, the Serpent Bearer, is the speediest star astronomers know of. See the chart on page 63 for a view of how far Barnard's Star will travel against the background stars in just two centuries (more than the apparent diameter of the Moon). It moves so rapidly that it puts the lie to the age-old term "fixed star."

▲ The red dwarf star Wolf 359, in an artist's illustration

CASEY REED

Another red dwarf of distinction is Wolf 359, which Ken Croswell writes about on page 34. Discovered in 1918, it's a wonder it was discovered at all, certainly with the equipment of the day. Why? Because it emits barely more visible light than Pluto. For decades after its initial detection in 1916, it remained the intrinsically dimmest star known to us.

The brightest star known to us is the focus of Tom Dobbins' piece on page 52. Dobbins — who also bylines this month's Focal Point on page 84 — explores the history of attempts to observe and image the Sun's striking surface granulation.

As blinding as the Sun is to us, its light pales in comparison to that released when stars end their days, as featured in Science Editor Camille Carlisle's cover story on page 12. Each supernova she presents sent out shock waves and strewed debris, including newly forged chemical elements, far out into the surrounding environment. As with stars themselves, supernova remnants are "as variegated as people," Carlisle writes, and from these celestial splatters astronomers can learn much about the exploding progenitor that produced them.

If this issue inspires you to read more about singular suns, I encourage you to explore our online series "Meet the Stars" (**https://is.gd/meetstars**). Here you'll find profiles by Daniel Johnson and others of the night sky's brightest stars, including their type, location, mythology, and other aspects. Consider also our stellar series in the March, April, and May 2019 issues on Polaris, Alpha Centauri, and Betelgeuse, respectively. All in all, you might just find yourself star-struck.

Peter

Editor in Chief

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

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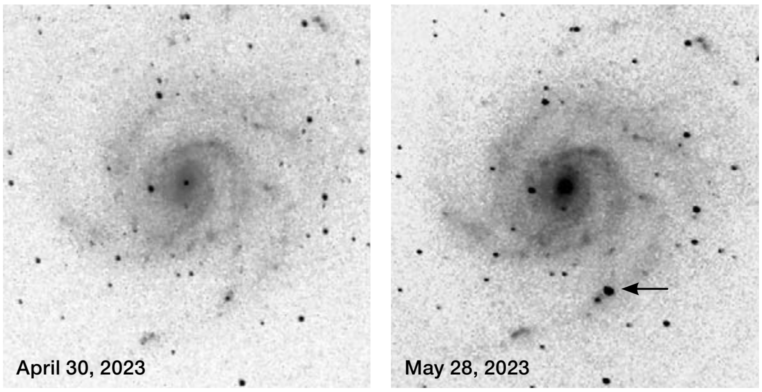
A "Surprising Second Chance" Sequel

When I get a new copy of *S&T*, I frequently start with Focal Point. In "A Surprising Second Chance" (*S&T:* Jan. 2024, p. 84), Scott Harrington reports his second chance at observing SN 2011fe in the spiral galaxy M101 and the first time he observed a supernova (SN 2023ixf) in binoculars. This inspired me to recheck some images of this galaxy I took while experimenting with my new Unistellar Equinox 4.5-inch smart scope in the spring of 2023 at my observing site in central Lower Austria. And, indeed, I spotted SN 2023ixf while comparing a picture I took on April 30th with a follow-up taken a month later. Thanks, Scott Harrington, for an article that allowed me, too, a second chance to identify a supernova, which otherwise I would have simply overlooked.

Johann Waringer • Herzogenburg, Austria



◀ Johann Waringer captured these images of M101 last spring. The image on the right features Supernova SN 2023ixf (arrowed).

Sketching M78

I just read Howard Banich's "M78: A Hotbed of Stellar Activity" (*S&T:* Jan. 2024, p. 12) in *S&T.*

He has a gift for relating his journeys through the sky and drawing what he sees. Banich makes everything seem more like a discovery than just science.

I could never find M78. Now I realize it's an important component of something much larger, the Orion B Molecular Cloud, which in turn is part of the Orion-Eridanus Bubble. All of which was kicked off by some cataclysmic event that compressed gas and dust together to form the chain of nebulae we know today.

Another quality that makes his articles so appealing is the way he refers to Herschel's writings as if he and Herschel were school buddies.

Please continue to observe the skies and delight us with your stellar road trips, Howard.

Patrick Kavanagh
CoperClub
Huixquilucan, México

Amid the emphasis toward photography, it is, I think, both refreshing and educational to see Howard Banich's article about sketching in *S&T.* I still have my old 1960s manual and worm-gear tracking 60-mm f/15, and I still enjoy sketching when possible under suburban skies.

Richard Renner
Alameda, California

Cut the Lights

"The Return of Dark Skies?" (*S&T:* Jan. 2024, p. 26) by John Barentine and Jessica Heim was excellent, but a few additional things bear mentioning.

The clutter produced by excessive outdoor lighting can distract drivers from warning signals like the ones at grade crossings. And the excessively bright, blue-tinted headlights used by some vehicles blind drivers and contribute to light pollution. Excessive displays of flashing lights can also cause problems, including seizures in certain people.

James W. Scott
Vernon, New Jersey

John Barentine and Jessica Heim's article revealing that there is 100 times more outdoor lighting in the world than needed makes me suspect two very influential industries. In the mid-1950s, streetlights in Chicago were gently lit, frosted-glass globes on 10-foot piers that allowed me to see the northern lights from the sidewalk in front of my building as well as the Milky Way. The Man With Three Hats, as my friend labeled him, had enough power to kill Chicago's dark sky forever: He was president of the electrician's union, on the Underwriters Laboratories board that had to approve any electrical fixture, and headed the Bureau of Electrical Inspection.

When my mother was an active member of the League of Women Voters, they would have found a way to block such expensive nonsense. Some of the towns near observatories managed to keep their outdoor lighting realistic. I wonder how they did it.

Terry Herlihy
Chicago, Illinois

John Barentine and Jessica Heim reply: *We share James Scott's concerns and agree that they're all useful talking points in broadening the appeal of dark skies to as wide an audience as possible. Terry Herlihy's letter makes us also long for the days when the night sky was more accessible in big cities. Nighttime darkness in places like Chicago was lost gradually, but it's certainly reversible. Even mid-size cities like Flagstaff, Arizona, show us what's possible when communities rally around protecting the night: Despite Flagstaff's population of 77,000 inhabitants, the Milky Way is readily visible at night from around town. Fortunately, there's no lack of technical solutions, and strong social support for dark skies can make a marked difference in a community's lighting practices. Activism, lighting research, and policy development all help address these readers' concerns, and we hope you'll all join us in the effort.*

Outta Sight

I really enjoyed Elizabeth Fernandez's "Dark Energy: A Brief History" (*S&T:* Feb. 2024, p. 26), but isn't it conceivable that galaxies are accelerating toward something rather than being expelled? Perhaps a universe-size black hole is beyond visual acquisition?

Walter Prendergast
Reno, Nevada

Monica Young replies: *You pose an interesting suggestion, that there exists some external "attractor" that is accelerating galaxies away from Earth. The problem with this scenario is that we can look in any direction and see the galaxies speeding away from us. So an external attractor would need to exist in every direction at once to explain our observations.*

Another, perhaps debatable objection to your suggestion is that such a hypothesis isn't testable. Therefore, it's more of a philosophical hypothesis than a scientific one, but those can be fun to contemplate, too!

Recreating the Antikythera Mechanism

I read "A Clockwork Cosmos" by Tony Flanders (*S&T:* Nov. 2023, p. 22) with interest. There is an amazing YouTube series about building a working reproduction of the Antikythera mechanism, **https://is.gd/AntikytheraMechanism**. A master craftsman by the name of Chris Ramsay builds the mechanism, with side videos on how the ancients might have made the tools to do so. He shows how they might have made files (**https://is.gd/handcutfiles**) and goes on to show how the gear teeth could be filed by hand. The craftsmanship is superb and the video production excellent.

Bruce Hope
Toronto, Ontario

Deep-Sky TV

As an aging observer, I have started using a video camera attached to my 12-inch Meade LX200 ACF telescope to watch the sky through a 20-inch monitor. What I enjoy most is the lack of eyepiece gymnastics: no more eyepieces jabbed in my eye and no more guessing if I am actually seeing something.

I view from the San Francisco Bay Area, and what I can actually see on my screen is amazing. When I lock onto the double star Polaris, I can see both stars easily on my screen. Compared to what one would see in an eyepiece, I was sold. After all, the aim of all our efforts is to *see* what is out there. If one can do it comfortably, I think one would actually see more. The screen makes all my efforts worthwhile. And, as an added plus, this setup was made for city skies.

As my old bones start to groan, I can still view the heavens and ponder the universe as I sip my hot cocoa while sitting in an easy chair, warm and comfortable.

C. J. Fox
Antioch, California

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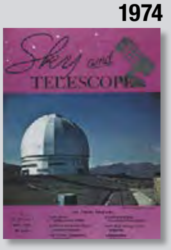
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1949

1974



1999

◖ May 1949

New Highs "The scientific world may well be pleased with Army Ordnance for recently sending a missile over 240 miles up into the earth's atmosphere, where it could obtain data of great value. The highest altitude previously reached by a V-2 launched from White Sands was 114 miles. The new record was made by a two-stage rocket. In place of the usual warhead of the V-2 was installed the American-developed rocket, the WAC Corporal. After the V-2 had acquired a high velocity, the WAC was fired. The velocity of the V-2 boosted the speed the WAC could achieve independently to a maximum of nearly a mile and a half a second. . . .

"This is still far from . . . escaping from the gravitational hold of the earth . . . However, had this missile been launched from the moon it might have gotten away, for the moon's velocity of escape is only about 1½ miles a second."

The name WAC Corporal, for America's first sounding rocket, is still of disputed origin.

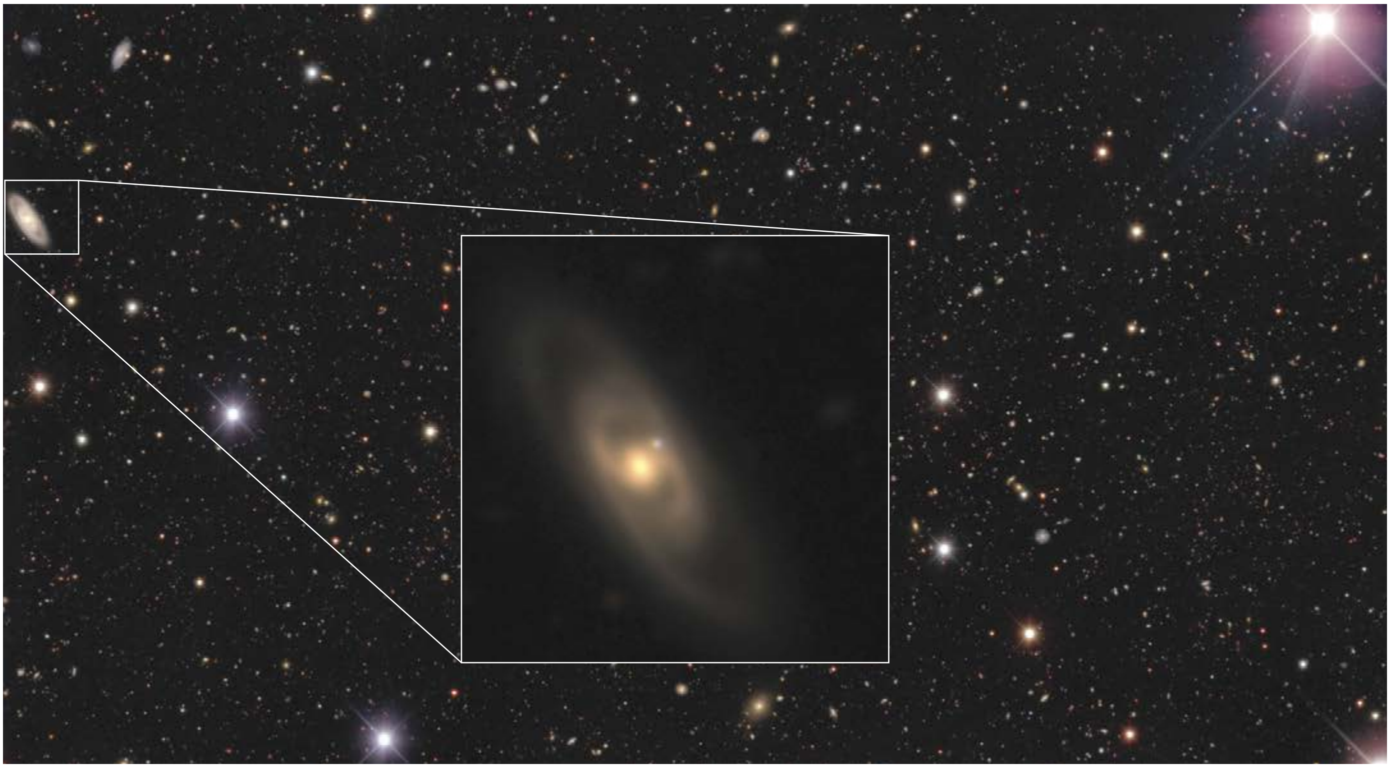
◖ May 1974

Celestial Visionary "Fritz Zwicky was one of the last of the scientific individualists, a breed that is dying out in an age of teamwork. Aggressively original, outspoken to the point of abrasion, he seemed to his contemporaries stubbornly opinionated. His ideas were so fertile and his projects so vast that he could have employed all the facilities of a great observatory. Looking back on his rugged determination and his slightly Renaissance flavor, one is reminded of Tycho Brahe: brilliant, opinionated, combative, a superb observer, and a very human person. For Zwicky was one of the kindest of men, with a deep concern for humanity. To those who knew him only in the scientific arena, it may come as a surprise to learn that he was a former chairman of the board of trustees of the Pestalozzi Foundation, devoted to the support of orphanages."

It took an astronomer of Cecilia Payne-Gaposchkin's caliber to weigh in on the passing of Fritz Zwicky, discoverer of dark matter.

◖ May 1999

Cosmic Anchor "Ever on the prowl for interesting 'what if' scenarios, planetary dynamicists have recently come to appreciate the role Earth plays in stabilizing the inner solar system. This new insight came to light almost by accident when Kimmo Innanen (York University, Canada) and Seppo Mikkola (University of Turku, Finland) were testing computer routines that perform long-term simulations of planetary motions. They found that removing the Earth-Moon system from their calculations caused the orbits of Venus and especially Mercury to gyrate wildly in eccentricity, with the likely outcome being Mercury's ejection by Venus from the inner-planet region or an outright collision between the two."



DES COLLABORATION / NOIRLAB / NSF / AURA / M. ZAMANI

▲ The inset shows a Type Ia supernova (dot of light to upper right of galaxy's bulge) detected during the course of the Dark Energy Survey. This supernova is nearby; its light took only 0.6 billion years to travel to Earth.

COSMOLOGY

New Supernova Catalog Used to Measure Strength of Dark Energy

AT THE TURN OF the century, astronomers discovered that the universe's expansion has been speeding up since the Big Bang. Now, in a study posted on the arXiv preprint server, a team of astronomers suggest that dark energy, the force behind this phenomenon, might be weaker than we first thought.

Dark energy is an unidentified quantity that exerts a repulsive pressure. Evidence for its existence first came from the study of a few dozen Type Ia supernovae, exploding white dwarf stars (*S&T:* Feb. 2024, p. 26). These supernovae can be calibrated as *standard candles*, meaning they explode with a known luminosity. Astronomers can then use them to measure the expansion rate of the universe.

Until now, supernova studies have led astronomers to think dark energy exerts the same force everywhere, everywhen. In this simple scenario, the repulsive pressure is inherent to empty space itself and is labeled the *cosmological constant*. But a study of thousands of Type Ia supernovae in the Dark Energy Survey (DES) suggests that dark energy might not be constant after all.

During a five-year survey, astronomers used the Dark Energy Camera, mounted on the Víctor M. Blanco 4-meter Telescope at Cerro Tololo Inter-American Observatory in Chile, to discover 1,635 Type Ia supernovae. The light from these supernovae has come from a huge range of distances, traveling between 1 billion and 8 billion years before arriving at Earth. Using the supernovae as standard candles, the team calculated the universe's expansion rate and established new constraints on dark energy.

To describe dark energy, physicists use the *equation of state*, labeled w, which is defined as the ratio of pressure to density. The value of w determines the nature of dark energy. In the simplest scenario, dark energy is the cosmological constant and $w = -1$. However, the DES supernovae point to a value between −0.66 and −0.95; this less negative number might indicate that the repulsive force weakens with time.

The result doesn't completely rule out a cosmological constant, though: Random fluctuations in the data could reproduce the findings about 5% of the time. (In technical terms, dark energy is still consistent with the cosmological constant to within two sigma.)

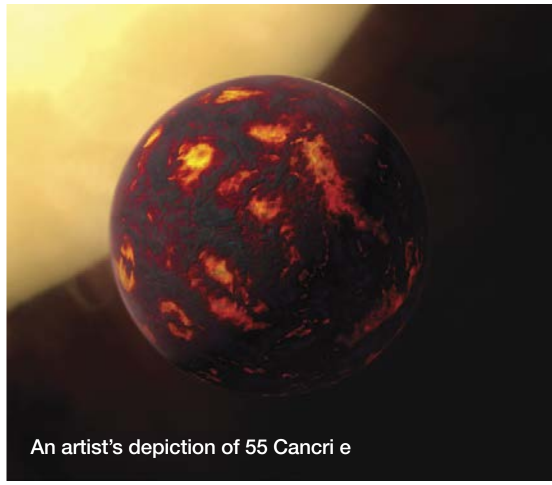
"It's tantalizing," says study lead Tamara Davis (University of Queensland, Australia). "Maybe the universe isn't quite as simple as we had thought."

Mickael Rigault (French National Centre for Scientific Research), who was not a part of the collaboration, was impressed with the group's techniques. However, he's less sure what this means for dark energy: "It's an interesting fluctuation," he notes. "I think we can still consider dark energy to be a cosmological constant. But we shall see."

■ ARWEN RIMMER

EXOPLANETS

Does the "Lava World" 55 Cancri e Have an Atmosphere?



An artist's depiction of 55 Cancri e

THE HOT SUPER-EARTH 55 Cancri e, which whizzes around its yellow star every 17 hours, has intrigued astronomers ever since its discovery in 2004. Now, data from the James Webb Space Telescope presented to the 243rd meeting of the American Astronomical Society is putting early speculation to the test, providing evidence for a thick atmosphere enveloping this rocky world.

Previous observations of the planet's density, as well as its measured day- and nightside temperatures, supported a lava-world scenario, in which magma flows on 55 Cancri e, and only a wisp of rock vapor stands between the surface and the stars (*S&T:* July 2016, p. 11).

At the same time, an infrared map of the planet's dayside showed that the planet's brightest point is offset in the east-west direction, instead of pointing directly at the host star. If true, then something (perhaps the same lava flows) must be redistributing the heat.

To look for answers, Renyu Hu (NASA / JPL) and colleagues asked Webb to observe the planet as it orbited its star, taking a spectrum of the heat radiated from both sides.

Hu acknowledged that understanding the data was difficult, in part because the 6th-magnitude host star easily overwhelms Webb's sensitive instruments. His team persisted, finding that the JWST spectra indicate a shroud of gases surrounds the planet, made either of carbon monoxide, carbon dioxide, or a mixture of the two gases along with nitrogen.

The new data don't negate the idea of lava flows. Hu and colleagues carried out detailed simulations showing that a magma ocean could in fact sustain this thick atmosphere despite the planet's proximity to its star.

The immense data challenges made some astronomers in the audience cautious about embracing the results.

"It certainly seems really interesting to see that carbon-dioxide absorption feature in the Near-Infrared Camera data, and that's really exciting if it holds," says Kevin Stevenson (Johns Hopkins University Applied Physics Laboratory). "But I would love to see independent data reductions.

"These types of claims," he adds, "require extraordinary evidence."

■ **MONICA YOUNG**

BLACK HOLES

Mystery Objects Uncovered in Globular Clusters

TWO GLOBULAR CLUSTERS — NGC 1851, in the southern constellation Columba, and 47 Tucanae, the second brightest globular in the sky — host an enigmatic object. But astronomers are still working out what these objects are.

The first mystery object is the unseen companion of a pulsar, which turned up during a survey of globular clusters conducted with the MeerKAT radio telescope array in South Africa. Ewan Barr (Max Planck Institute for Radio Astronomy, Germany) and others combined 24 MeerKAT observations with archival data from the Green Bank Telescope in West Virginia to determine that the pulsar and its invisible companion together have 3.887 Suns' worth of mass. Subtracting the pulsar's likely contribution, the team infers that the companion must have 2.09 to 2.71 solar masses.

▲ Either the most massive neutron star or the least massive black hole known lurks in the globular cluster NGC 1851, shown here.

The largest pulsars have less than 2.1 solar masses, and only a smattering of black holes have popped up with fewer than 5 solar masses. However, the researchers conclude in the January 19th *Science* that they cannot determine whether the pulsar's companion is a neutron star or a black hole. Regardless, the discovery has "fascinating implications," writes Maya Fishbach (University of Toronto) in an accompanying perspective piece.

The second mystery object is in 47 Tucanae. Alessandro Paduano (Curtin University, Australia) and colleagues undertook a radio survey using the Very Large Array and the Australia Telescope Compact Array, looking for the lit-up gas around feeding black holes. One of the candidates they identified could be a weakly accreting black hole with a mass somewhere between 50 and 6,000 Suns. Just as plausibly, the team writes in the January 20th *Astrophysical Journal*, the object could be a rapidly rotating pulsar.

Philip Kaaret (NASA's Marshall Space Flight Center), who wasn't involved with the study, points out that previous studies of stars' motions inside 47 Tuc limit an unseen mass to less than 600 Suns. That still leaves room for the suggested black hole. Improved observations of the cluster's stellar orbits could help decide the matter.

■ **CAMILLE M. CARLISLE**

ARTIST'S CONCEPT OF 55 CANCRI E: ESA / HUBBLE / M. KORNMESSER; NGC 1851: NASA / ESA / G. PIOTTO (UNIVERSITÀ DEGLI STUDI DI PADOVA), PROCESSING: GLADYS KOBER (NASA / CATHOLIC UNIVERSITY OF AMERICA)

EXOPLANETS

Unexplained Aurorae on a Lonely Brown Dwarf

OBSERVATIONS of a giant world with the James Webb Space Telescope have revealed the signature of aurorae — even though the world has no obvious way to generate the lights. Jackie Faherty (American Museum of Natural History) announced the find at the 243rd meeting of the American Astronomical Society in New Orleans.

Faherty led a team using Webb data to examine the atmospheres of 12 of the coldest *brown dwarfs*, worlds more massive than Jupiter but not massive enough to sustain nuclear fusion in their cores. One of them, dubbed W1935, jumped out from the dozen observed. Discovered by citizen scientist Dan Caselden (see page 11), the world revealed an unexpected feature in its intricate infrared spectrum.

Methane is a common molecule on brown dwarfs and typically absorbs most light at wavelengths shorter than about 4 microns. But for W1935, a bump among all the methane absorption indicated methane molecules had heated up and were *emitting* light. In other words, Webb had spotted aurorae.

▲ This artist's concept portrays auroral emissions (red) on the brown dwarf W1935, which is located 47 light-years from Earth.

Astronomers have seen aurorae in radio observations of brown dwarfs. And charged particles from the Sun, as well as from Jupiter's volcanic moon Io, create aurorae on many solar system planets (*S&T:* Oct. 2023, p. 74). So it might come as no surprise that this world would exhibit the same phenomenon. Only, in the case of W1935, the world is isolated, far from any obvious source of the energetic charged particles necessary to create aurorae.

However, there could be sources we can't immediately see, Faherty suggests. One possibility is that a geologically active moon spews out charged particles from its volcanoes, like Io does, which then gather within the larger world's magnetic field.

Other possibilities, such as a "burp" of plasma in the interstellar medium, are no less intriguing.

W1935 is too faint for ground-based follow-up, but future Webb observations could show the aurorae on W1935 disappear as the particle source dissipates — or a moon might even reveal itself by its gravitational tug.

■ **MONICA YOUNG**

See the spectrum at https://is.gd/browndwarfaurora.

GALAXIES

Astronomers Discover "Invisible" Galaxy

ASTRONOMERS HAVE FOUND something bizarre: a galaxy that appears to be made only of gas. The galaxy, J0613+52, turned up in a survey of neutral hydrogen gas in some 350 dim, diffuse galaxies called *low surface brightness galaxies*. These are systems at least one magnitude fainter than the ambient glow of the night sky. They have very few stars, making them challenging to spot with visible-light telescopes — which is why astronomers look for the faint glow of their gas at radio wavelengths instead.

◀ Red and blue indicate motion away from and toward the observer, respectively, in this illustration of neutral hydrogen gas in the primordial galaxy J0613+52.

But thanks to a fortuitous coordinate mistake, Karen O'Neil (Green Bank Observatory) and her colleagues found something even weirder: a disk of gas without any stars.

The dark galaxy lies 270 million light-years away, near the head of the constellation Auriga, and appears as a blank patch to the eye. But seen in radio, it contains more than 1 billion Suns' worth of hydrogen rotating quickly in an organized way — hallmarks of what should be a fairly normal, massive spiral galaxy. Except astronomers don't detect any stars.

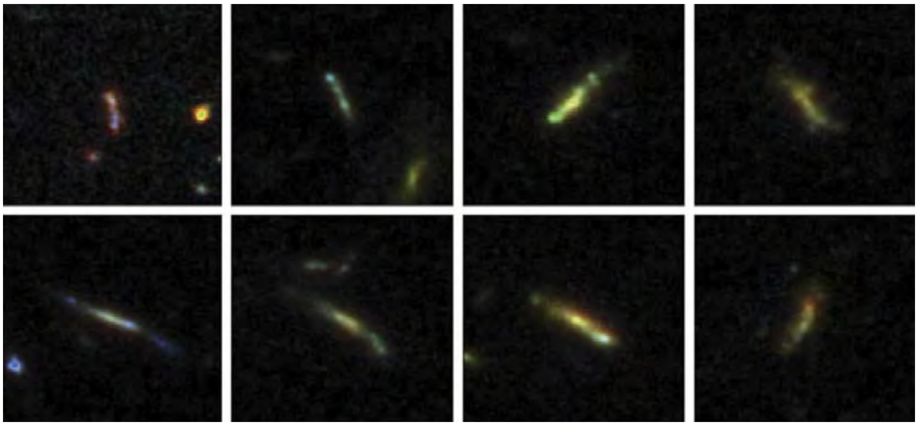
"What we might have here — *might* — is the discovery of a primordial galaxy, a galaxy that is so diffuse, it hasn't been able to form stars readily," O'Neil said during a press conference at the 243rd meeting of the American Astronomical Society.

Notably, the dark galaxy is a loner: No other galaxies huddle nearby. With no neighbors to harass it gravitationally, there would have been nothing to stir and compress the galaxy's gas and trigger star formation. That in itself is unusual, she said, because galaxies tend to come in groups — rarely do you find one completely by itself.

Galaxies like J0613+52 stress-test our theories about star formation and galaxy evolution, O'Neil says. "This might be our first chance to really take a look at what happens to star formation in a diffuse environment where nothing has come along to tweak it."

■ **CAMILLE M. CARLISLE**

BROWN DWARF AURORA: NASA / ESA / CSA / LEAH HUSTAK (STSCI); INVISIBLE GALAXY: P. VOSTEEN / GREEN BANK OBSERVATORY / NSF / STSCI



▲ At first glance, the true shape of these early galaxies that the James Webb Space Telescope has imaged is unclear. However, the distribution of galaxy shapes shows that small star-forming galaxies in the early universe are truly elongated.

V. PANDYA / COLUMBIA UNIVERSITY (8)

GALAXIES

Milky Way–like Galaxies Started Out Pickle-Shaped

WHAT DID THE MILKY WAY look like shortly after it was born? Decidedly different than it does now, according to a new study that will appear in the *Astrophysical Journal*.

New observations from the James Webb Space Telescope reveal that small, star-forming galaxies in the early universe — the forerunners of the Milky Way — had elongated shapes. Some appeared long and round like pickles, others long and flat like surfboards.

Previous observations from the Hubble Space Telescope hinted at this morphological evolution, says Lennox Cowie (University of Hawaiʻi, Manoa). But Hubble was only able to probe the appearance of galaxies residing in a universe already 2 billion years old, and some astronomers thought their elongated shapes might be happenstance, due to viewing early disk galaxies edge-on, like frisbees seen from the side.

Now, Webb's images of galaxies from the Cosmic Evolution Early Release Science (CEERS) survey reveal some galaxies have truly stretched-out shapes just 650 million years after the Big Bang.

To investigate the role of viewing angle, Viraj Pandya (Columbia University) and colleagues first categorized the shape of each galaxy detected in the CEERS survey as an ellipsoid. They then modeled what 1 million different ellipsoids would look like as seen from 100,000 random viewing angles each. Comparing these distributions to the spread of shapes they actually observed, they found that the farthest and smallest star-forming galaxies tend to be truly elongated — pickle- and surfboard-shaped rather than edge-on frisbees. (The method is statistical in nature, Pandya cautions, so they can't tell the shapes of individual galaxies but rather the likelihood of different shapes within a group of galaxies.)

"The JWST observations are beautiful," Cowie says. "The analysis is very careful and detailed." But understanding why galaxy shapes changed over cosmic time will be difficult, he adds.

Pandya's team suggests that early galaxies are elongated because they came together along the dark matter–dominated filaments that crisscross the universe. Like cars on a highway, galactic collisions in filaments would have occurred along a preferred direction, leading to elongated shapes.

But Cowie thinks subtler actions might be at play. "It probably has little to do with the cosmology," he says, "and is mostly caused by the changes in the gas inflow, the dynamics of the interstellar medium, and the structure of the star formation."

The next aim of Pandya's team will be to analyze larger samples by combining CEERS with other Webb data sets.

■ MONICA YOUNG

IN BRIEF

Dan Caselden Wins Chambliss Award

At the 243rd meeting of the American Astronomical Society, the society conferred the Chambliss Amateur Achievement Award on citizen scientist Dan Caselden for his "outstanding participation in the Backyard Worlds citizen science projects." Like previous recipients of the award, Caselden is not a professional astronomer — he's a computer security researcher. But in 2017 he stumbled upon *Backyard Worlds: Planet 9*, a NASA-led citizen-science project dedicated to searching for new brown dwarfs near the Sun as well as the elusive Planet 9. Along with his colleague Paul Westin, he ended up building an interactive browser tool that could efficiently visualize images from the Wide-field Infrared Survey Explorer, precipitating a rise in the rate of brown dwarf discoveries. One of Caselden's own discoveries resulted in the JWST observations described on page 10.

■ DIANA HANNIKAINEN

Nominate an amateur astronomer at https://is.gd/ChamblissAward.

Another Giant Star Dims

Betelgeuse isn't the only giant star to undergo a "Great Dimming" (*S&T:* Mar. 2021, p. 14). In late 2022, the variable star RW Cephei — a yellow hypergiant and one of the largest stars in the Milky Way Galaxy (see page 77) — experienced a similar event. A huge surface mass ejection might have precipitated its sudden fade, according to Narsireddy Anugu (Georgia State University). When several astronomers, including members of the American Association of Variable Star Observers, noted that RW Cep had faded to about a third of its normal brightness, Anugu led a team that followed up with the Center for High Angular Resolution Astronomy's six-telescope array on Mount Wilson, California. They imaged RW Cep in December 2022 and again in July 2023, when the star had almost returned to its normal brightness. The images, presented at the 243rd meeting of the American Astronomical Society and published in the Aug. 1, 2023 *Astronomical Journal*, resemble those taken of Betelgeuse about four years ago. In the case of RW Cephei, dust appears to block the western part of the star's face.

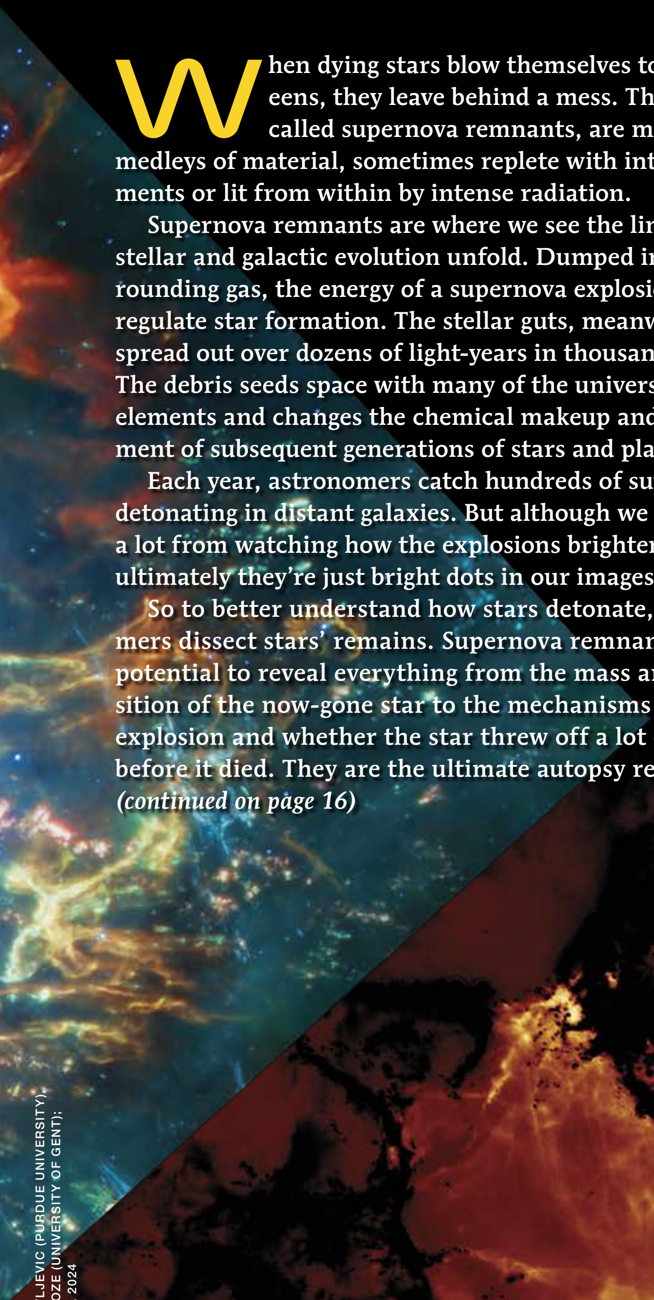
■ GOVERT SCHILLING

See the change: https://is.gd/RWCep

SUPERNOVA REMNANTS by Camille M. Carlisle

Stellar AUTOPSIES

Astronomers use supernova remnants to learn about the lives and deaths of stars that went kablooey.



When dying stars blow themselves to smithereens, they leave behind a mess. These messes, called supernova remnants, are marvelous medleys of material, sometimes replete with intricate filaments or lit from within by intense radiation.

Supernova remnants are where we see the link between stellar and galactic evolution unfold. Dumped into surrounding gas, the energy of a supernova explosion helps regulate star formation. The stellar guts, meanwhile, spread out over dozens of light-years in thousands of years. The debris seeds space with many of the universe's heavy elements and changes the chemical makeup and development of subsequent generations of stars and planets.

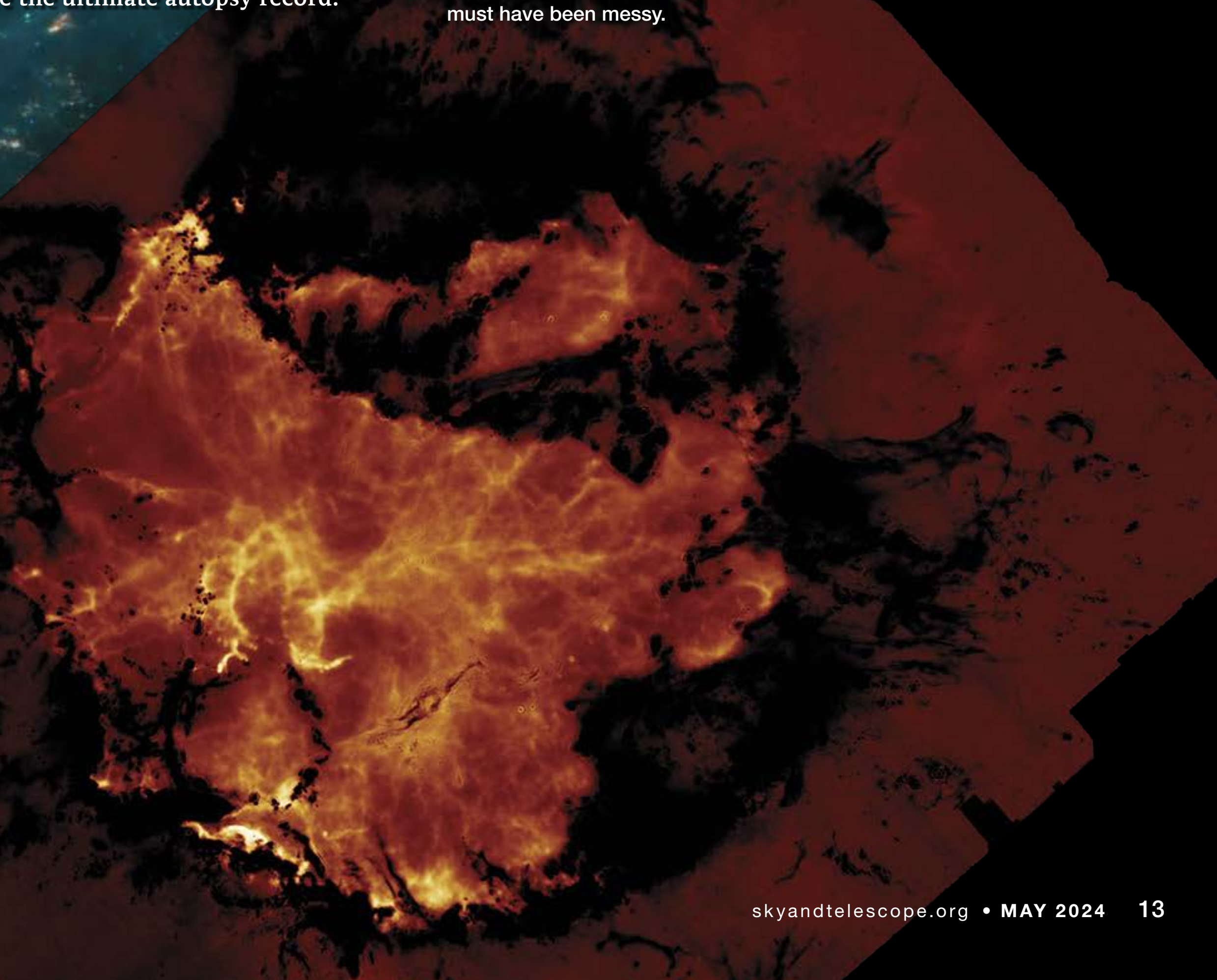
Each year, astronomers catch hundreds of supernovae detonating in distant galaxies. But although we can learn a lot from watching how the explosions brighten and fade, ultimately they're just bright dots in our images.

So to better understand how stars detonate, astronomers dissect stars' remains. Supernova remnants have the potential to reveal everything from the mass and composition of the now-gone star to the mechanisms behind the explosion and whether the star threw off a lot of material before it died. They are the ultimate autopsy record.
(continued on page 16)

◀ **CASSIOPEIA A** Lying some 11,000 light-years from Earth, the supernova remnant Cas A spans about 10 light-years. This image is a mid-infrared composite using data from the James Webb Space Telescope. The orange and red colors mark where the explosion's blast wave and outermost ejecta are ramming into dusty material surrounding the dead star. The knotty, pinkish-white material is stellar debris, heated by the shock wave that's reflecting back from the collision between ejecta and circumstellar gas.

◀ **MYSTERY "BUBBLES"** *Box:* The round, puncture-like features along the curve of the green arc puzzled astronomers when JWST revealed them. Subsequent study now indicates that the features (and the "green monster" they pockmark) are not inside the remnant at all but rather lie just outside it in the foreground. The holes appear to be real holes, created when knots of ejecta punched like shotgun spray through the dusty gas surrounding the supernova, Dan Milisavljevic (Purdue University) announced at a press conference in January.

▼ **PRISTINE EJECTA** By subtracting out emission from the remnant's shell and surrounding dusty gas, Milisavljevic and his colleagues revealed the infrared glow of supernova debris deep inside the remnant. This debris is as of yet unaltered by shock waves reflecting inward from the collision between ejecta and circumstellar material. Preliminary study of the debris indicates that very little radioactive nickel remained close to the explosion's center — confirming that heavy elements in the star's core were somehow ejected out ahead of the lighter elements in the overlying layers. To achieve that, the explosion must have been messy.

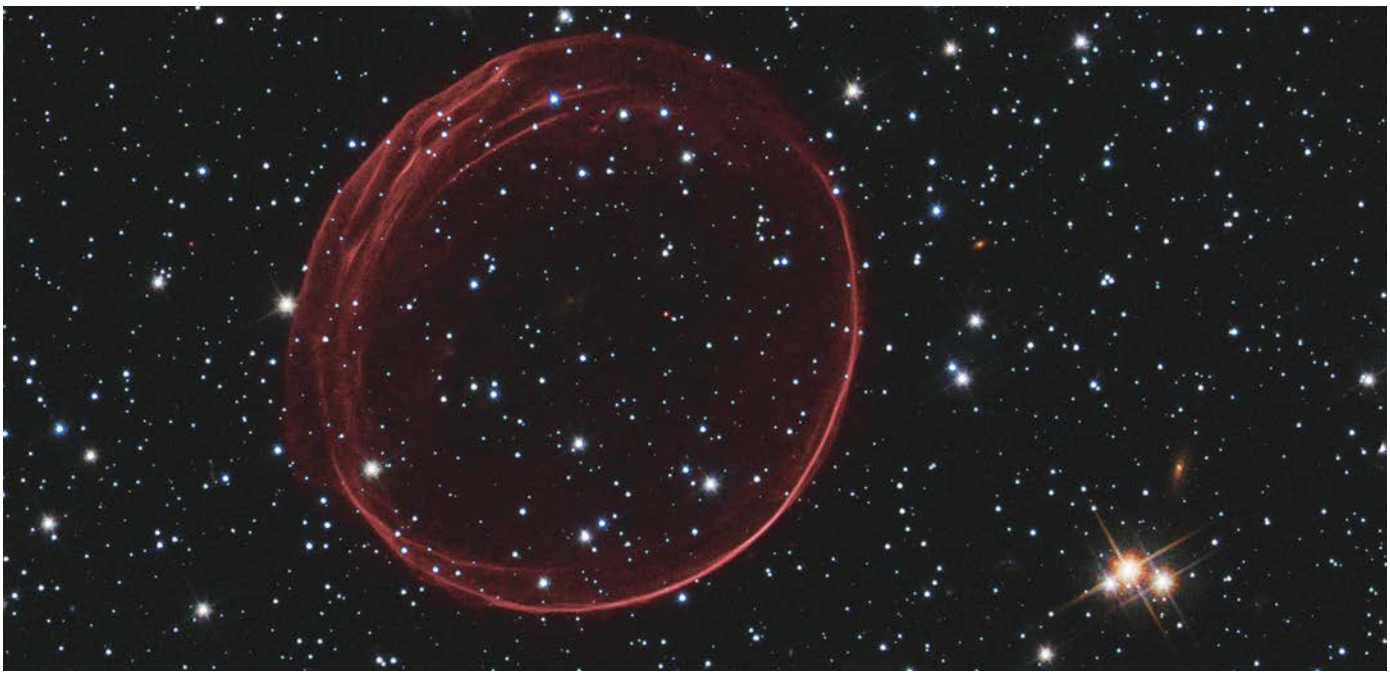


CASSIOPEIA A: NASA / ESA / CSA / DANNY MILISAVLJEVIC (PURDUE UNIVERSITY), TEA TEMIM (PRINCETON UNIVERSITY), ILSE DE LOOZE (UNIVERSITY OF GENT); CASSIOPEIA A INTERIOR: D. MILISAVLJEVIC ET AL. 2024

CAS A IN NEAR-INFRARED Slightly shorter wavelengths pick up different components of the remnant in this near-infrared JWST image. Here, we see in Cas A's outer regions *synchrotron radiation* (white), emission from electrons corkscrewing along magnetic field lines at breakneck speeds. The weird feature in the image's bottom right corner is a *light echo* from the explosion, reflecting off dusty interstellar material. Its size and appearance are "truly baffling," Milisavljevic says — is the dust not mixed well with the gas? Are magnetic fields involved? Or is this structure typical of interstellar clouds and we just didn't know it?

▲ **KES 75** This composite image reveals high-energy X-rays (blue) from the pulsar wind nebula surrounding the pulsar at the heart of the supernova remnant Kes 75. Lower-energy X-rays (purple) are from the explosion debris. Over 16 years of observation, the outer edge of the pulsar wind nebula expanded at 1,000 kilometers per second (over 2 million mph) — a high speed that might be due to the low density of the surrounding environment. Kes 75 exploded about 500 years ago, making its neutron star the youngest pulsar known in our galaxy.

▲ **SUPERNOVA 1987A** This near-infrared composite reveals the strange keyhole-shaped ejecta at the heart of SN 1987A. The dazzling bracelet is clumpy material that was ejected by the star about 20,000 years before the supernova and is now being hit and heated by the explosion's shock wave.



▲ **WHITE DWARF DEATH** The remnant SNR 0509–67.5 formed nearly 400 years ago in the Large Magellanic Cloud, one of the Milky Way's closest neighboring galaxies. The emission here comes from hydrogen. Ripples along the bubble's edge could be due either to an uneven distribution of ejecta or to clumpiness in the surrounding gas.

CAS A IN NEAR-INFRARED: NASA / ESA / CSA / STSCI / D. MILISAVLJEVIC (PURDUE UNIV.), T. TEMIM (PRINCETON UNIV.), I. DE LOOZE (UNIV. OF GENT); KES 75: X-RAY: NASA / CXC / NCSU / S. REYNOLDS; OPTICAL STARFIELD: PANSTARRS; SN 1987A: NASA / ESA / CSA / MIKAKO MATSUURA (CARDIFF UNIV.), RICHARD ARENDT (NASA / GSFC, UMBC), CLAES FRANSSON (STOCKHOLM UNIV.), JOSEFIN LARSSON (KTH), ALYSSA PAGAN (STSCI); ROSY RING: NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA)

CRAB NEBULA This infrared composite of Messier 1 reveals the familiar cage-like structure, traced here by doubly ionized sulfur (red-orange). Dusty ridges lie within (yellow-white and green). The "fog" is synchrotron radiation, generated by particles zipping around the magnetic fields of the central neutron star, which sits at the center of the ripple-like ring.

NASA / ESA / CSA / STSCI / T. TEMIM (PRINCETON UNIV.)

(continued from page 13)

Postmortem Report

Supernova remnants tend to share a basic structure. When a big star explodes, it propels a blast wave out into the surrounding gas, called the *circumstellar medium*. The circumstellar medium is often stuff thrown off by the aging star as it neared death. The blast wave rams through this gas and compresses and heats it, making it glow for a time. This bright boundary around the remnant expands as the blast wave travels.

Bringing up the rear is the supernova debris. The debris races outward, cooling as it goes. But it doesn't stay cool forever. The outermost ejecta slams into the circumstellar medium, putting the brakes on the ejecta's expansion and making a hot shell. The debris flying out right behind this ejecta then collides with the shell, creating a shock wave that rebounds inward, back toward the center. As this shock wave passes through the cold ejecta in the remnant's interior, it reheats the material to millions of degrees.

The boundary between the compressed circumstellar medium and the hot ejecta shell is often wrinkled and nubbly, due to their different densities.

But beyond this general semblance, remnants are as variegated as people. That's because different kinds of stars go kaboom, and they do so in different environments. A remnant is a complex interplay of nature and nurture, and teasing the history apart keeps astronomers plenty busy.

For example, when big stars' cores collapse under their own weight, they tend to make asymmetric remnants. Cassiopeia A is a prime example. Work by Tyler Holland-Ashford (Center for Astrophysics, Harvard & Smithsonian) and others shows that heavy elements formed at the center of the explosion that made Cas A are scattered haphazardly in the remnant — more so than the lighter elements made in the star's outer layers. Previous work also indicated that the heaviest, nickel-rich material in the remnant raced out ahead of the other, lighter ejecta. It's as though the explosion was inside-out.

G107.0+9.0 Astronomers recently discovered this elusive remnant in Cepheus thanks to the amateur-run MDW Sky Survey, an extensive hydrogen-alpha imaging project.

MDW SKY SURVEY

Recent infrared observations of Cas A by the James Webb Space Telescope reveal a kaleidoscope of clumpy material. Ejecta heated by the reverse shock look like strings of beads. The images confirm that supernova ejecta are immensely clumpy, explains Tea Temim (Princeton) — which matters not only for those designing computer simulations of how supernovae unfold but also for our understanding of dust.

Dust is an important cosmic ingredient. It encourages star formation by helping gas cool, so that the gas can collapse and make stars. Galaxies in the early universe have proved to be dusty — surprisingly so, if the dust comes only from the older, puffy giant stars seen to shed it as they age.

Astronomers know that supernovae also make dust, which coalesces in the ejecta as the material expands and cools. But supernovae also destroy dust: The rebound shock wave can obliterate it as the wave passes through. It's thus unclear how much dust survives to salt interstellar space, and to what degree supernovae are to blame for the bonanza of dust in some galaxies. "The study of supernova remnants may, therefore, help us to understand whether supernovae are on average dust factories or dust destroyers," writes Jacco Vink (University of Amsterdam, The Netherlands) in his 2020 book *Physics and Evolution of Supernova Remnants*.

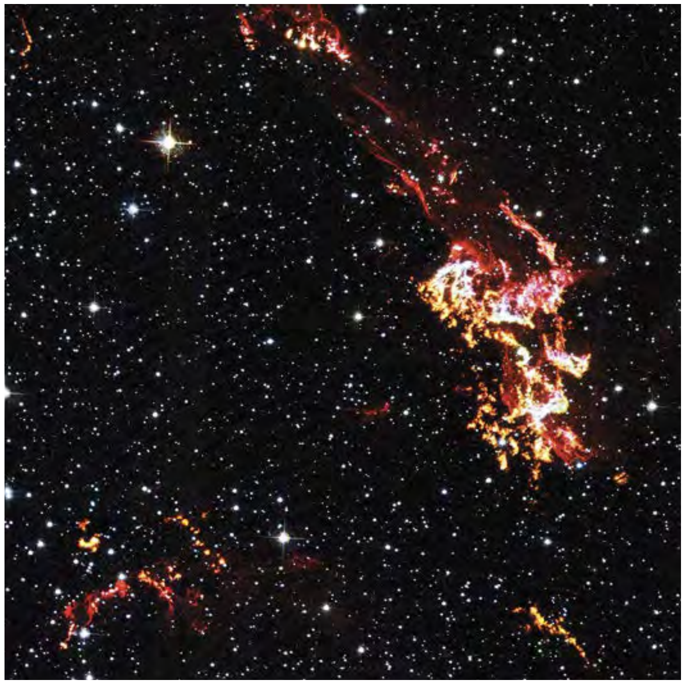
Given how clumpy Cas A's ejecta are, it may be that clumps' inner regions provide safe havens for dust grains when the shock wave passes. Whatever grains survive could then serve as seeds for further dust formation in the cold expanse of space.

Cause of Death: Unconfirmed

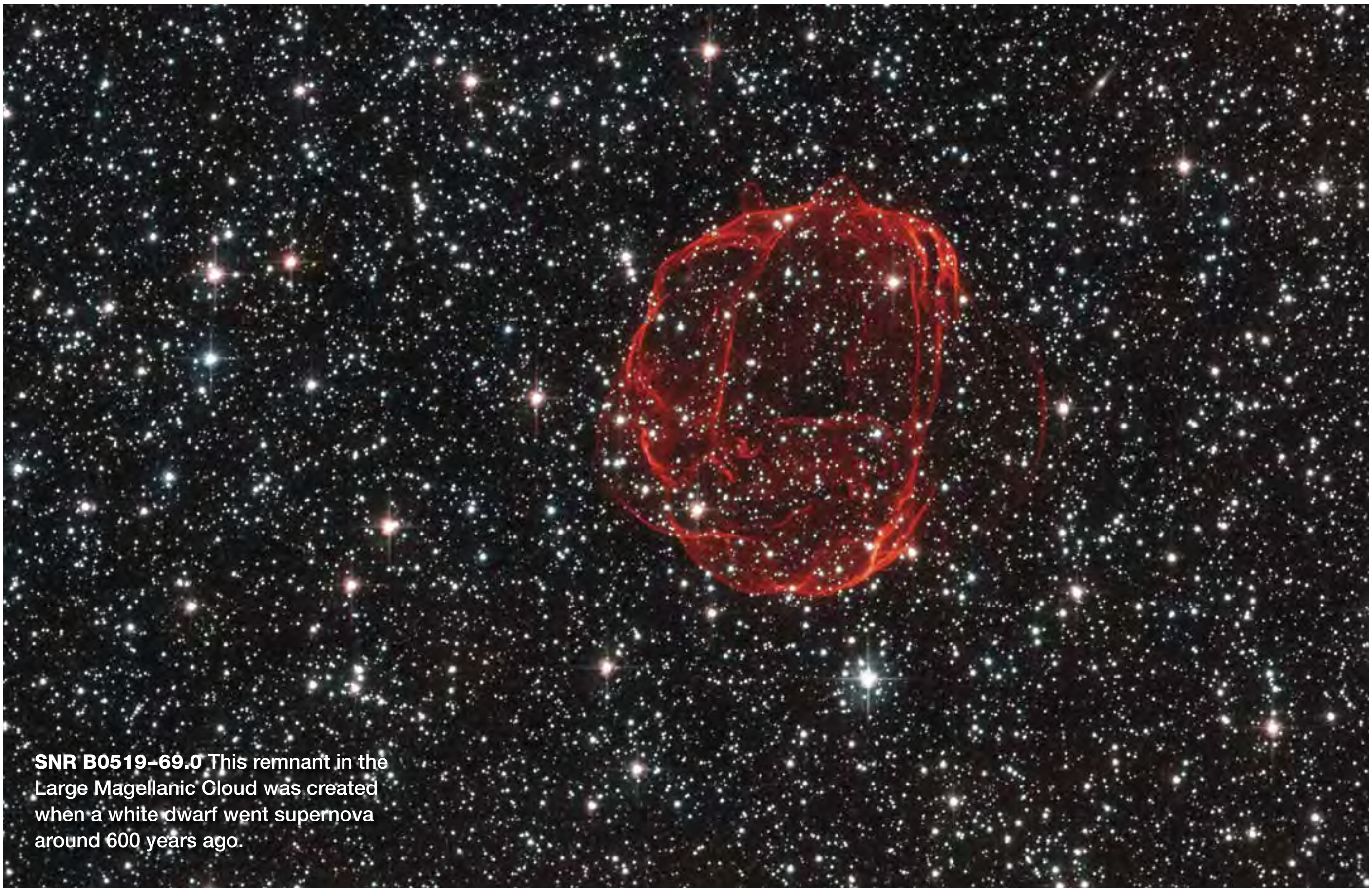
Big stars aren't the only ones that explode. White dwarfs — the remains of smaller, Sun-like stars that quietly sloughed off their outer layers when they died — can also blow. Astronomers dub these events Type Ia supernovae. (Type Ib, Type Ic, and the various Type II supernovae all come from massive stars, but we shan't dwell on that.)

Type Ia explosions make a lot of iron. Their remnants are usually symmetric, except in regions where there aren't a lot

▲ **1E 0102.2–7219** In this false-color image of a remnant in the Small Magellanic Cloud, ejecta moving toward Earth are colored blue, while those moving away from Earth are colored red. The gas is speeding away from the explosion site at an average speed of 3.2 million kilometers per hour (2 million mph).



▲ **KEPLER'S SUPERNOVA** The explosion that created this remnant lit up Earth's sky in 1604. Jan Brunowski, Johannes Kepler's assistant, was first to observe it; Kepler continued studying it until it faded from view in 1606. Knots are dense clumps that have formed in the wake of the outward-moving shock wave. This close-up shows the northwest section.



SNR B0519–69.0 This remnant in the Large Magellanic Cloud was created when a white dwarf went supernova around 600 years ago.

1E 0102.2–7219: NASA / ESA / J. BANOVETZ AND D. MILISAVLJEVIC (PURDUE UNIV.); KEPLER'S SUPERNOVA: NASA / ESA / THE HUBBLE HERITAGE TEAM (STSCI / AURA) / R. SANKRIT AND W. BLAIR (JOHNS HOPKINS UNIV.); SNR B0519–69.0: ESA / HUBBLE & NASA / CLAUDE CORNEN of heavy elements incorporated into stars, says Prasiddha Arunachalam (Rutgers University). One example of a Type Ia remnant is SNR 0509-67.5, which looks like a delicate ring. The bubble is currently some 23 light-years wide and expanding at 5,000 km/s (11 million mph). Arunachalam recently used an algorithm to mix and match various explosion possibilities and find the most likely explanation for the shock motions detected inside the remnant. She calculated the explosion's energy was about 1.3×10^{51} ergs, in keeping with what's expected from a white dwarf's death.

Alas, it isn't always obvious what kind of star created a given remnant. Astronomers know of more than 350 supernova remnants in the Milky Way alone, and more in other galaxies. But they've only classified about 100 as either Type Ia or core-collapse. Often, observers rely on finding a neutron star or particular elemental abundances to finger the latter.

Having multiple wavelengths helps. X-rays from the superheated gas in the remnant's interior can reveal ejecta's composition and velocities, for example. But for the remnant Kes 75, X-rays don't tell us much. Kes 75 contains the youngest known pulsar, whirligigging away at the tender age of 500 years. The wind the pulsar creates in the remnant's heart heats ejecta and a smattering of mixed-in dust, which together glow in infrared, enabling Temim and her colleagues to measure the material's velocity and simulate the remnant's evolution.

Based on the oxygen and carbon emission detected, the researchers can estimate how much mass the pulsar's wind has swept up, from which they extrapolate that the star that exploded had at most 12 Suns' worth of mass. Calculations suggest the star was stripped down, perhaps by a companion star. Astronomers have seen signs of binary stripping in a handful of remnants, Temim says.

But, she adds, the only remnant of a massive star for which we know exactly what kind of supernova made it is Cas A. When Cas A's progenitor blew up, the supernova's flash scattered off nearby dust grains. The scattered light preserves the explosion's spectrum, including which elements were present. Studying these light echoes — which, just like a sound echo, reach us after the original event — reveals that the explosion was a Type IIb supernova, the death of a big star stripped of most of its hydrogen shell. The star likely began life with between 15 and 25 solar masses, then was stripped down to about 5 Suns (perhaps by a companion) before it exploded.

Mysterious Circumstances

One of the most iconic supernova remnants is the Crab Nebula, beckoning to us from the constellation Taurus, the Bull. With an apparent magnitude of 8.4, it's a nice target for small telescopes on evenings early in the year. A haze fills the remnant, emitted by high-energy electrons and positrons that have been corkscrewing around the magnetic field of the pulsar at the Crab's heart.

The Crab supernova lit up Earth's skies in AD 1054, which makes it roughly 1,500 years older than Cas A. Oddly, there's no sign of a blast wave or rebound shock. "Everything that we observe in the Crab is the pulsar wind that just swept up all of the stuff that was ejected," Temim says. Photons emitted by this wind of particles are ionizing the star's ejecta, some 7 solar masses' worth, and making it glow. The ejecta travel out at the comparatively low speed of 1,200 km/s.

These results suggest that the explosion packed less than 10% of the typical pow of a core-collapse supernova. The star that died probably had only 8 to 10 solar masses and perished in a low-energy explosion.

Astronomers debate the details of how such a thing might have unfolded. It might have been a hypothetical event called an *electron-capture supernova*, in which a star just over the edge of being big enough to die by core collapse meets its end. The implosion would happen when the core is made up of oxygen, neon, and magnesium, instead of iron.

Temim and others are currently analyzing JWST spectra of the Crab to determine the remnant's composition. If they find an abnormally high level of nickel compared with iron, that could mean the explosion was this never-before-confirmed type of supernova. The work is immensely challenging: The researchers must tease apart a forest of roughly 100 spectral lines, all blended together by the mash-up of different ejecta clumps' positions and velocities when flattened into our 2D field of view.

Lasting Memories

Based on the supernovae we see in other galaxies and how long it takes for remnants to fade away (some 100,000 years), there may be anywhere from 1,000 to 4,000 supernova remnants in the Milky Way. Taken at face value, that suggests that we've only found one-tenth of what's out there.

New remnants are turning up thanks to endeavors like the MDW Hydrogen-Alpha Sky Survey, conducted by the late David Mittelman and *S&T*'s Dennis di Cicco and Sean Walker. These include the ancient G107.0+9.0 in Cepheus, which astronomers estimate may be 100,000 years old. In fact, most known remnants in our galaxy lie somewhere in the age range of 10,000 to 100,000 years.

But by the time a remnant is several thousand years old, the supernova's blast wave has usually finished its passage through the gas shed in the star's death throes and moved on to the surrounding interstellar medium. Although the remnant may still be visible, it won't provide as much information about the star that died. That's why astronomers devote so much attention to young remnants like Cas A, the Crab, and Supernova 1987A — all subjects of JWST's first observing cycle. They're also turning JWST's gaze on supernovae in other galaxies soon after the initial explosion, to detect the infrared glow of newly created dust. It may well be that one of JWST's lasting contributions to science will be revealing where all this darn dust comes from.

■ Science Editor **CAMILLE M. CARLISLE** has a soft spot in her heart for Supernova 1987A.

Distant Lights in the Darkness

The James Webb Space Telescope has revealed a surprisingly rich treasure-trove of black holes in the early universe.

Imagine entering a dark cavern. Everything appears pitch black. You venture forth carefully, feeling the location and shapes of the walls. Each step could reveal a cliff in the floor.

Then, your eyes begin to adapt to the environment. You realize that a soft, shy starlight shines from the cracks in the ceiling. After some time, everything becomes clear. The size and shape and oddities of the cavern are not mysterious anymore. Those obstacles you found while wandering around are no longer dreadful traps. Everything makes sense.

Astronomers analyzing the first data from the James Webb Space Telescope (JWST) have stepped inside a similar cavern. JWST, launched on Christmas Day in December 2021, has opened up an immense, unexplored, dark discovery space. We are now inundated daily by new JWST results. Some are expected. Others are revolutionary. As

DAVID CURTIS

astronomers' eyes and minds adjust to the new environment, some of these oddities will align with our previous theories. Others instead will remain disruptive and radically change our understanding of how the universe formed and evolved. Eventually, enough light will pierce the darkness, and everything will make sense.

This is especially true — we hope — of black holes. The first black holes formed during the first few hundred million years of the universe. Over billions of years, they and their host galaxies grew larger, developing in a still-mysterious lockstep that has left a supermassive black hole at the center of nearly every large galaxy today. But how did the first black holes form? And what did they and their environments look like in their earliest years?

What follows is the story of JWST's revolutionary findings regarding faraway black holes in its first year of operations. It is a story of giant black holes furiously swallowing gas near the beginning of time; a tale of smaller black holes that are much more numerous than we expected; and a chronicle of how astronomers, serving as modern-day Dantes and Virgils, "came forth to see again the stars" in primordial galaxies.

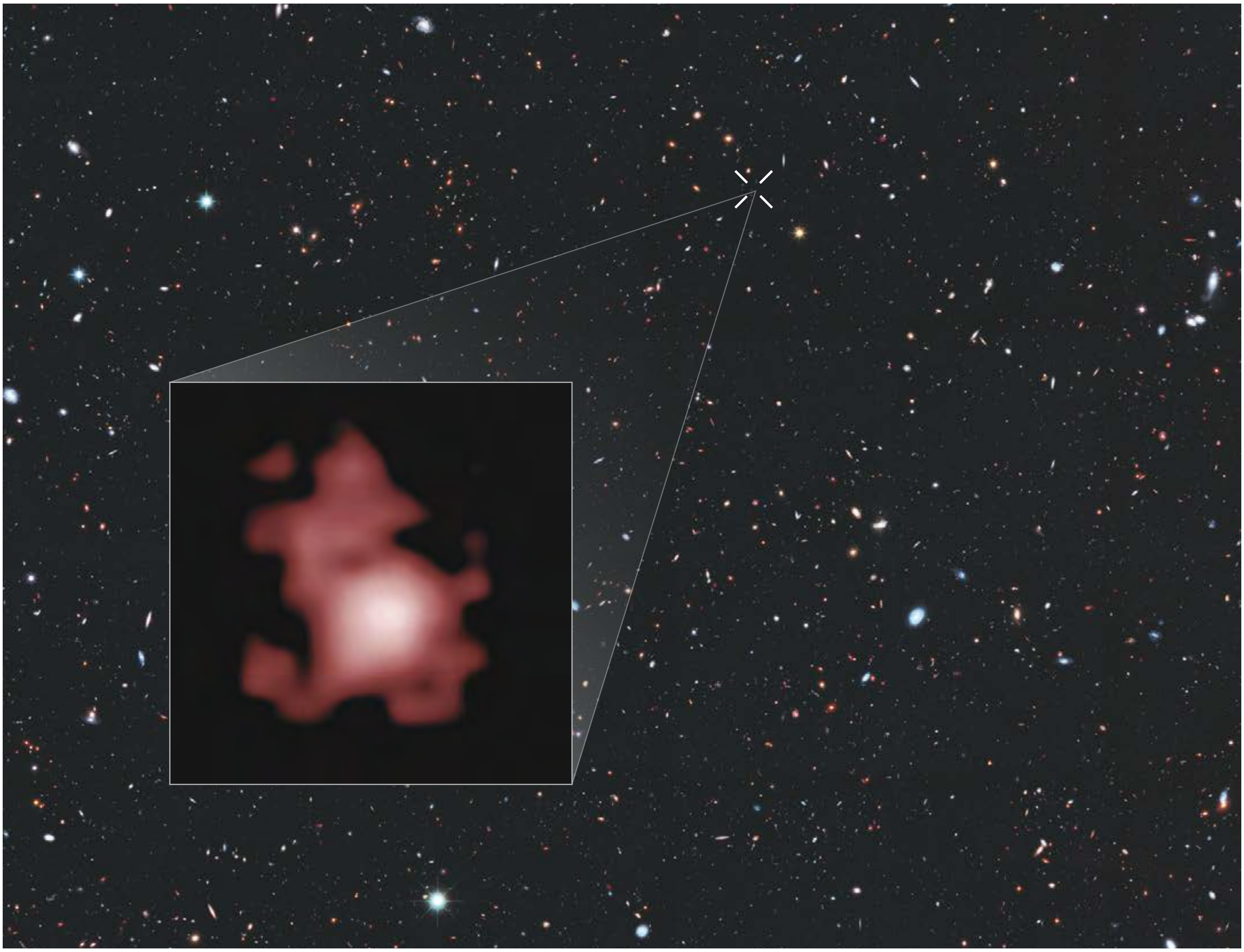
Lighthouses in the Distant Darkness

Black holes, counterintuitively, are some of the brightest objects in the cosmos. A supermassive black hole frantically accreting matter will radiate large amounts of light — not from itself but from the extremely hot gas that it's trying to swallow from the surrounding environment. Typically, astrophysicists use the name *quasar* to refer to a supermassive black hole that's accreting so much gas that it becomes bright enough to outshine its host galaxy. Although there is no clear-cut definition of a quasar, they are very massive — generally more than a billion times the mass of the Sun.

These cosmic lighthouses had their heyday about 2 to 3 billion years after the universe's birth, but we've seen them much earlier than that. The most distant quasars observed were already shining when the universe was only several hundred million years old, an infant compared to today's age of 13.8 billion years. The rays of light originating from those quasars have traveled billions and billions of years to reach our telescopes. Along the way, their wavelengths stretched due to cosmic expansion, and the light became much redder, in the well-known *redshift* phenomenon. Astronomers use how much a source's light is redshifted to estimate how much the universe has expanded since those photons were emitted and, consequently, how long the light has been traveling: the higher the redshift, the older and more distant the source.

Before JWST, the *black hole horizon*, defined as the farthest black hole we could observe with our telescopes, stood at a redshift of 7.6, or 690 million years after the Big Bang. With JWST, astronomers have (so far) pushed 250 million years earlier, detecting a supermassive black hole in a faraway galaxy at a redshift of 10.6, or just 440 million years after the Big Bang. The host galaxy is named GN-z11.

This remote galaxy, which appears to the sight of our mightiest telescopes as an unremarkable red blob, has a mar-



▲ **GN-Z11** This unassuming blob is the host galaxy of the current record holder for the farthest supermassive black hole detected, seen as it was nearly 13.4 billion years in the past, just 440 million years after the Big Bang. Bright, young, blue stars suffuse the galaxy, but its light has been stretched to redder wavelengths by the universe's expansion. The field image is from the Hubble Space Telescope Great Observatories Origins Deep Survey (GOODS), which contains tens of thousands of galaxies stretching far back into time.

NASA / ESA / P. OESCH (YALE UNIVERSITY), G. BRAMMER (STSCI), P. VAN DOKKUM (YALE UNIVERSITY), AND G. ILLINGWORTH (UNIVERSITY OF CALIFORNIA, SANTA CRUZ) velous story of its own. Astronomers discovered GN-z11 in 2016 with the Hubble Space Telescope. For nearly seven years, until the advent of JWST, GN-z11 held the record for the most distant object known. In late 2022, it lost its place to another galaxy named JADES-GS-z13-0 (*S&T:* Oct. 2023, p. 12).

But GN-z11 still had a story to tell. In 2023, astronomers used JWST to study the galaxy's spectrum in detail. A spectrum not only breaks apart the light seen from an astronomical object into its constituent wavelengths, much like a rainbow, but it also reveals how the material producing the light is moving with respect to the observer. The spectrum of GN-z11 showed that the gas in the innermost region of the galaxy was moving at roughly 1,000 km/s (more than 2 million mph) — the fingerprint of a massive, central black hole.

Using this information, the researchers estimated the mass of this "small and vigorous black hole in the early universe," as they called it, was some 1.5 million solar masses. That makes it one-third as massive as the black hole at the center of the Milky Way today — a tiny object to be detected so far away.

In another plot twist, astronomers discovered that the central black hole in GN-z11 is probably swallowing gas furiously, turning itself into a floodlight. The rate at which a black hole can accrete gas from its environment has a speed limit, the so-called *Eddington limit*, whose namesake, Sir Arthur Eddington, was a renowned 20th-century English astronomer. Above the Eddington limit, the infalling gas's own glow pushes material out and away from the black hole, controlling how much the black hole can accrete.

In the high-redshift universe, with abundant gas to be accreted, the Eddington limit is like the speed limit on a highway: generally obeyed but not unbreakable. Most black holes accrete around the speed limit. Some accrete somewhat higher or lower than that. GN-z11, however, seems to be accreting at about five times its Eddington limit. This rate is remarkable: If, billions of years ago, GN-z11 continued growing at this pace, it would reach the superlative mass of 1 billion solar masses by redshift 9.5, more than 13 billion years ago. We are unaware of such extremely massive objects at those redshifts; they must be scarce if they exist. Super-Eddington accretion might also be an episodic event, turning on and off and keeping black hole growth in check.

The tiny supermassive black hole in GN-z11 became visible to our telescopes because it's radiating away a vast amount of energy. What we see in its spectrum also suggests that we may be staring down at the accretion disk from above, hence observing the black hole from its most luminous side.

GN-z11 is not the only remarkable black hole that JWST has discovered in the very early universe. For example, the crown for the farthest black hole known belonged previously to CEERS 1019, a 10-million-solar-mass object shining at redshift 8.7, 13.1 billion years ago. Astronomers discovered this remarkable source in the Cosmic Evolution Early Release Science (CEERS) JWST survey. CEERS 1019 also accretes slightly above the Eddington limit, indicating that violating the speed limit could be common in this early population of compact objects.

When your eyes adjust to darkness, you begin to discern a more numerous population of dimmer stars. Astronomers are having the same experience with the early universe.

Countless Feeble Candles

GN-z11 and CEERS 1019 are relatively midsize when it comes to supermassive black holes. Astronomers have found dozens of giant quasars a little later in cosmic history, roughly 1 billion years after the Big Bang. Before the advent of JWST, black hole hunters' focus was on finding these extremely massive — and bright — objects as far away as possible.

Yet the giant quasars discovered at very high redshift are rare, extraordinary objects. Consider the distance between the Milky Way and the Andromeda Galaxy, some 2.5 million light-years. Multiply this distance by 1,000 and construct a cube from this side. In the early universe, at redshift 6 (12.8 billion years ago), we estimate that there is just a single, bright quasar in this immense volume. At redshift 10 (13.2 billion years ago), these objects are so rare that there may only be one in the entire universe.

But there are other things in that great expanse besides the majestic quasars. When you look up at the sky on a clear and dark night, your eyes immediately see the brightest stars. Then, when your eyes adjust to darkness, you begin to discern a more numerous population of dimmer stars. Astronomers are having the same experience with the early universe: They are now discovering a population of smaller, fainter supermassive black holes.

When analyzing the first deep images obtained by JWST, different teams started to notice tiny red dots popping out everywhere. These sources were distinctively crimson compared to other sources in the field, because their emission at longer, redder wavelengths was stronger. They also appeared small in physical and angular size — so small, in fact, that although the dots emitted as much light as a whole galaxy does, that light came from a region that's between the size of a large star cluster and the smallest dwarf galaxies.

After a careful spectral analysis, researchers discovered that some of these peculiar sources were young galaxies hosting black holes at their centers. Most were observed between redshift 4 and 7, when the universe was between 770 million and 1.6 billion years old. Astronomers discovered tens of specimens of this large population and lovingly named them "little red dots" or "hidden little monsters."

Instead of billions of solar masses, these little monsters commonly are black holes of 10 to 100 million solar masses. If accreting at their Eddington rates, then these somewhat smaller black holes generate a luminosity of about 100 billion times that of our Sun; the most massive quasars we know of blaze with a luminosity of almost 1,000 trillion times that of our Sun.

The discovery of a population of fainter, less massive black holes is not surprising. In the universe, it is typical for small things to be more numerous than big things. Small galaxies are more frequent than big ones; Sun-like stars are more common than massive ones. Hence, astronomers expected that JWST, with its larger light-gathering power, would find plenty of smaller black holes in faraway galaxies.

The astonishing part is the sheer number of smaller black holes found. According to the first estimates, JWST has detected 10 to 100 times more black holes than previously expected from the census of giant quasars. One of the main conclusions of JWST's first year of observations is, therefore, that the young universe was fertile ground for forming massive, hungry black holes — many more than expected when we observed only the brightest among them.

The discovery of such a large and enigmatic population of little red dots is one of the main breakthroughs in JWST's first year of observations. These black holes are not quite quasars. But at least some of them may *become* quasars. JWST is showing us the population of quasar precursors, on their way to becoming the majestic lighthouses we observe at later cosmic epochs.

We See Again the Stars

In the 14th-century classic "The Divine Comedy," Dante and his guide, Virgil, finally exit the depths of Hell to emerge onto Earth's reassuring surface. The end of this stage of the journey to Paradise, which symbolizes the march from darkness to enlightenment, is marked by the words, "And thence we came forth to see again the stars." In a very different context, JWST is also illuminating our path toward understanding how galaxies and black holes co-evolved in time — by allowing us to see the host galaxies' starlight again.

We compared the giant quasars observed in the high-redshift universe to lighthouses. Once the light beam dazzles your eyes, it is hard to see anything else. High-redshift supermassive black holes discovered in the pre-JWST era were too bright for us to detect the starlight coming from the host galaxy. This is not the case for the smaller, numerous, and fainter population of high-redshift black holes that JWST is now showing us. These black holes are candles instead of lighthouses: We can detect the surrounding starlight and measure the mass in stars held by the host galaxies. What results is among the most surprising discoveries yet.

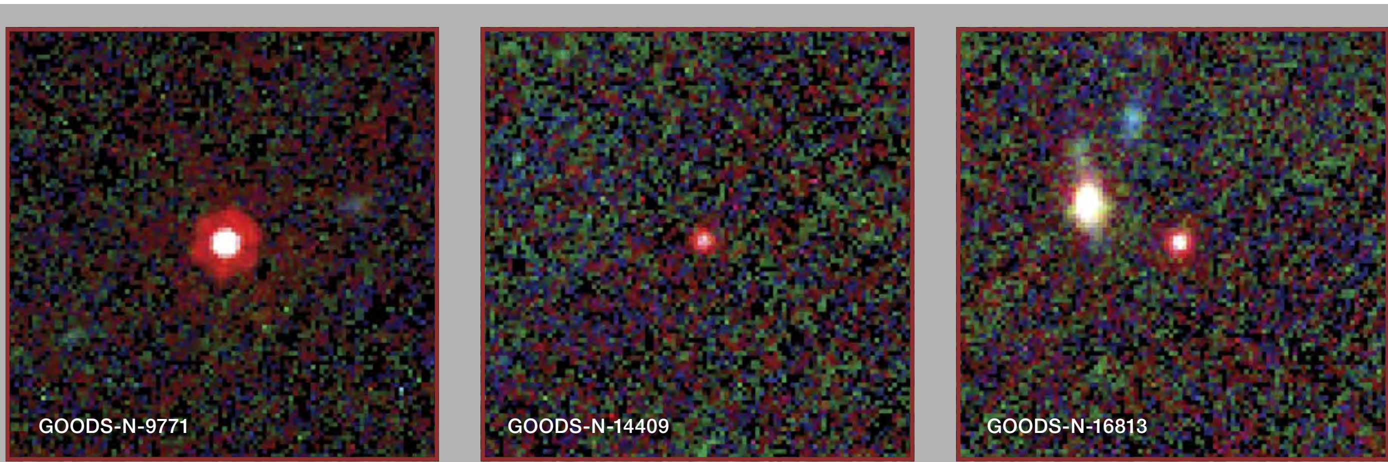
In the local universe, we have known for decades that the mass of a galaxy's central black hole correlates with some properties of the host galaxy (*S&T:* Feb. 2017, p. 18). For example, the mass of the black hole is typically about 0.1% of the stellar mass of the host. In other words, big black holes are in big galaxies, and small black holes are in small galaxies. High-energy phenomena within the galaxies explain these correlations, as they regulate both star formation and black hole growth. Central black holes and their galaxies thus co-evolve through cosmic time by interchanging mass and energy.

But we have no idea if these relations hold up in the early universe. Maybe the ratio between black hole and stellar mass was very different back then.

Indeed, JWST observations show us oddities in the evolutionary waltz between black holes and galaxies. Tens of galaxies detected so far by JWST, especially above redshift 4, conclusively have black holes that are significantly overmassive with respect to their galaxy's stellar mass. Instead of their mass being about 0.1% of the stellar mass of their hosts, these early behemoths are 1%, 10%, or even close to 100%. For example, thanks to the combined power of JWST and the Chandra X-ray Observatory, astronomers recently found a supermassive black hole at a redshift 10.3 (13.3 billion years ago) that seems to be as massive as its host galaxy. We are thus facing an early universe in which the relation between black holes and host galaxies is far from the ones in the familiar local universe, pointing us toward a better understanding of how black holes and galaxies evolve together.

▼ **LITTLE MONSTERS** These false-color infrared images reveal "little red dots," which likely include the glow of gas accreting onto midsize supermassive black holes. The objects appear as they were about 1 to 1.5 billion years after the Big Bang. Some images also show bluish galaxies.

JORRYT MATTHEE ET AL. (6)



Lighting Up the Cavern: The Path Forward

JWST's first year has revolutionized our view of the early universe. First, we have significantly expanded the black hole horizon: The most distant supermassive black hole we've detected, that in GN-z11, lies only 440 million years after the Big Bang. Second, we've observed a vast population of smaller black holes actively accreting inside young and small galaxies; these objects are 10 to 100 times more numerous than expected, based on the number of observed giant quasars. Perhaps many of them will stay "small" and never reach billion-solar-mass proportions. Third, these smaller black holes seem to be 10 to 100 times more massive than expected with respect to the stellar mass of their hosts.

What are the consequences, thus far, for our theories of the early universe? By detecting more distant supermassive black holes, the expansion of the black hole horizon will eventually allow us to pinpoint the formation mechanism of the first black holes, also known as seeds (*S&T:* Nov. 2022, p. 16). These seeds were either heavy, with an initial mass on the order of 100,000 solar masses, or light, with a mass up to a few thousand — or a combination of both types. Light seeds would have had to grow furiously to match the early supermassive black holes we've found; heavy seeds would slowly pace their race to greatness.

To understand how the first population of black holes formed, we have two pathways: Either we discover incredibly massive black holes at even higher redshifts, impossible to explain with the light-seed scenario, or we obtain a better census of quasar precursors and their galactic hosts and determine how their masses evolved with time. JWST is well under way on both pathways.

The little red dots also highlight tensions between observations and theoretical work. In the pre-JWST era, theorists predicted many more black holes than observers did, based on the number uncovered so far. Some theorists have welcomed the discovery of the little-red-dots population as bringing theory and reality closer together. But some observers worry that we may now have swung too far the other way. For now, it remains unclear how many of the little red dots are in fact black holes.

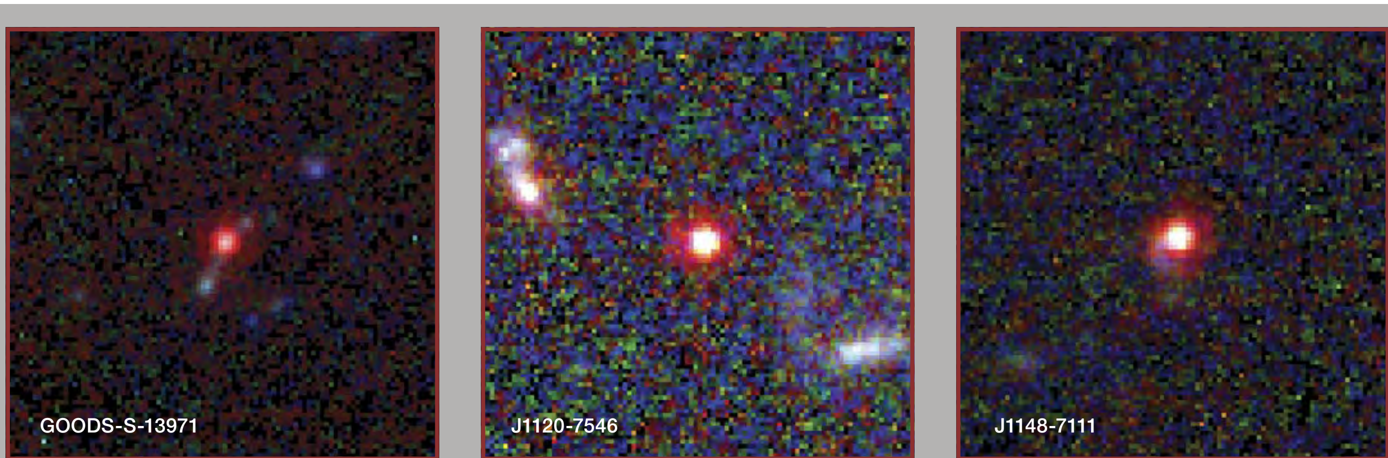
Some early JWST observations also suggested that the universe became full of massive galaxies earlier than expected, based on how bright these galaxies are (*S&T:* May 2023, p. 9). This tension has already eased thanks to modifications in how astronomers measure the stellar mass of galaxies at high redshift, by improving the estimate of the masses with which stars form and by better accounting for the role of interstellar dust. Possibly, the presence of glowing, overly massive black holes will reduce estimates of the stellar content of these galaxies even further, better reconciling them with our expectations.

Furthermore, over-massive early black holes may be the best indication yet that they formed from heavy seeds. When a heavy seed forms, the galaxy may take a while to build up its stars and catch up, size-wise, either through mergers with other galaxies or via in situ star formation. Thanks to these combined processes, the system would slowly progress toward the familiar 0.1% ratio of masses in our cosmic neighborhood. If this picture is accurate, then many galaxies may undergo a "hidden little monster" phase.

To conclude, JWST's first year of operations has revealed a mother lode of faraway black holes. Some of the observations obtained thus far are puzzling and in conflict with what we thought the early universe would look like. Remember — we are still in the phase of exploring a dark cavern, barely lit by starlight. Our eyes — and minds — are still adjusting to the entirely new environment that JWST is showing us.

Some of these oddities will probably be re-incorporated into our previous expectations. Others will disrupt our vision of the cosmos. Reassuringly, in this dark and damp cavern, we have not yet found something truly bizarre, like water flowing uphill. But the magnificent young cosmos that JWST is showing us is already changing the history of astronomy forever.

■ **FABIO PACUCCI** is an astrophysicist at the Harvard & Smithsonian Center for Astrophysics, where he holds the Clay and Black Hole Initiative fellowships.



Chasing the Magic

Here's how to improve your chances of seeing and photographing the aurora borealis.

The aurora borealis and its southern cousin, the aurora australis, are considered among the most incredible phenomena a person can witness without optical aid. Standing under a clear sky while watching the green and red curtains of auroral light shimmer and dance above is often described as a beautiful, awe-inspiring, and even life-changing experience.

Unsurprisingly, these ethereal lights are a major driver of tourism in northern locations, such as Iceland and Norway. But they aren't an ever-present phenomenon, at least from places you can easily get to. You can book a trip to see them and end up not catching so much as a brief display. That leaves us with a few questions. How do you know when to look for them? Are they predictable? And, for many of us, how do you photograph them?

Right now we're entering the period of *solar maximum*, the part of the Sun's 11-year cycle of activity with increased sunspots and other active regions crackling with the energy that trigger geomagnetic storms. Here are some tips on how you can improve your chances of seeing and imaging these ethereal displays.

Space Weather and Earth

Aurorae are a natural-light display primarily seen at high latitudes. They are caused by disturbances in Earth's magnetosphere as it interacts with the continuous stream of charged particles the Sun releases known as the *solar wind*. These particles are typically funneled into the magnetosphere at high latitudes where they form an auroral ring around our planet's geomagnetic poles (called the *auroral oval*). But at times, disturbances in the solar wind due to coronal holes (where charged particles escape from the Sun faster) and coronal mass ejections (CMEs) send bursts of plasma into space, which can impact our magnetosphere and trigger a geomagnetic storm, expanding the auroral oval away from the polar regions (*S&T:* Oct. 2023, p. 74). When this happens, we are treated to a fantastic display of aurorae farther south.

The colors of the aurora depend on which gas is being affected and their altitudes. Most often, a display appears green due to the charged particles interacting with oxygen roughly 100 to 110 kilometers (60 to 70 miles) above. Less frequently, these green curtains are topped with a deep-red color — this is also due to oxygen, though at higher altitudes of some 200 or 300 km.

There are also blue and purple aurorae, which come from nitrogen being excited at lower altitudes. Much rarer are yellow and pink ones, which are a mixture of red aurorae with green and blue ones.

Tracking Aurorae

Aurorae are somewhat unpredictable — often conditions seem perfect for a display, but it doesn't happen. So how can you plan to see one? These days, we have access to an entire suite of data that can help us determine if we have a better chance of seeing geomagnetic activity. Most of the information that space weather sites and apps utilize comes from the Space Weather Prediction Center (SWPC) at **swpc.noaa.gov**, which offers a broad set of data products for space weather collected from several satellites. But the website is difficult to navigate and interpret, so it's generally better to use a smartphone app or website that distills the most relevant data helpful for aurora chasers. My favorite is *SpaceWeatherLive* for Android and Apple devices. Here's a super simple guide on how to interpret it.

In the app, the first thing it displays

◀ **CONTEMPLATING THE VIEW** Two of the author's friends enjoy a display from the shores of Lake Erie, near Cleveland, Ohio, on February 26, 2023.

ALL IMAGES COURTESY OF THE AUTHOR

DRAGONS ABOVE Intense auroral colors and shapes dance about the zenith in this photo recorded from outside of Fairbanks, Alaska. Author Marybeth Kiczenski shares her tips on increasing your chances of photographing displays like this strong geomagnetic event.

is the ***Kp-index***. This is a scale used to characterize the magnitude of a geomagnetic disturbance. Unfortunately, it isn't very useful for aurora chasers because the number is determined by averaging the previous three hours of data. This means that the Kp-index won't register activity until it is well under way, often after the best part of the display has already occurred! Instead, scroll down to the listings below, which utilize real-time data.

The next entry is ***Solar Wind***, which displays the speed of the incoming solar wind. The higher the speed, the better the chance of a northern lights display. Ambient solar wind averages between 200 and 400 kilometers per second. This fluctuates between solar minimum and maximum. Anything over 500 km/s can trigger faint aurorae, and over 600 km/s may produce a strong display.

The next listing is ***Density*** — the concentration of ionized plasma impacting the magnetosphere. This measurement can signal the initial shock from a CME or a *stream interaction region* or *corotating interaction region* — the boundary between the fast and slow solar wind.

Another important value to watch is the ***Interplanetary Magnetic Field***. Think of this as a "potential" indicator. The higher this number, the more potential energy there is in the field to interact with an incoming CME.

Finally, there's the ***Bz*** value. This displays the solar wind's magnetic-field direction as it reaches Earth and is a critical value to monitor when determining if it's worth heading out on a chase. It acts like an on/off switch for auroral activity. Why? Because Earth's magnetic field naturally points north. Since opposites attract, we want an incoming stream of solar plasma with a south-pointing magnetic field so it will couple with Earth's magnetic field and allow for an auroral display. A north-north coupling will repel and deflect the solar wind out away from Earth. So, the higher the southern value is, the better chance of a good show.

Of course, these are all in-the-moment observations. What if you need to travel to a distant location to see a display? This is where the difficulty lies. Several satellites monitor the Sun, and when a CME or coronal hole is Earthward-facing, we can infer approximate times of arrival. However, we don't have any way to monitor these events during their 149-million-kilometer (93-million-mile) transit. So, the predicted timing of a CME can be off by hours or even days. Also, we can't measure the magnetic polarity of an event until it hits one of our upstream monitors, like NASA's DSCOVR satellite. At most, we have a few days' lead time to get to a good location and then wait it out.

Location, Location, Location!

As mentioned earlier, aurorae tend to be visible at high-latitude locations, so you'll likely have to travel to a location where aurorae are more commonly seen. They typically appear in the Arctic and Antarctic regions. Places like Alaska, Iceland, northern Canada, the Scandinavian Peninsula, and Siberia offer the best places to spot them. *Sky*

▲ **PERFECT PAGEANT** Photographing a good display of the aurora low towards the horizon requires an unobstructed view. But these low shows can offer some better photographic opportunities, such as this picturesque scene along the southern shores of Lake Superior in Eagle Harbor, Michigan.

& *Telescope* operates an aurora tour each fall: **https://is.gd/SnTiceland**.

Aurorae are easier to see in the Northern Hemisphere. This is because the auroral oval extends over easily accessible lands, whereas the southern oval is mostly confined to Antarctica and the Southern Ocean, though it occasionally extends to points visible from southern New Zealand, Tasmania, and southern Australia.

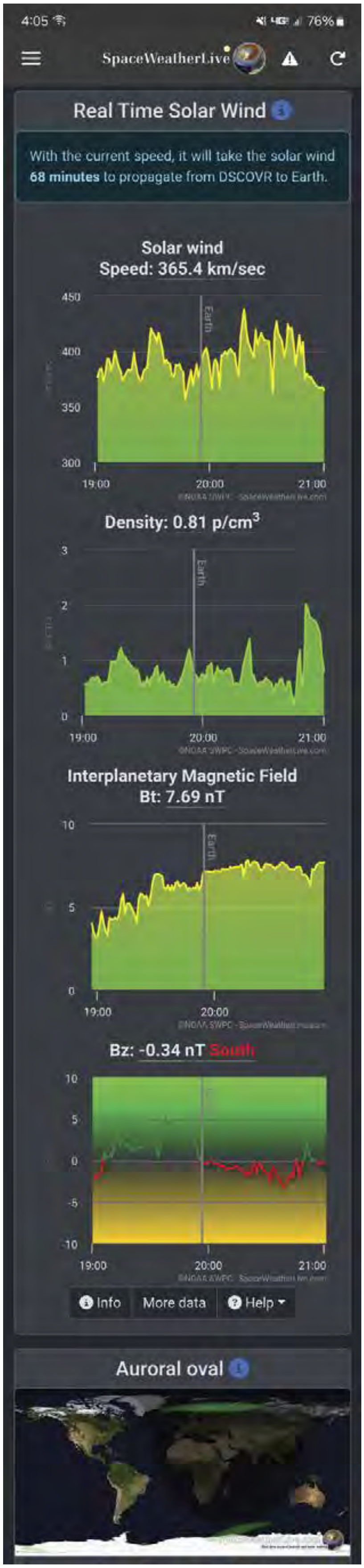
The "goldilocks zone," so to speak, is the auroral oval that manifests around the geomagnetic North and South poles. This is where energy funnels through the magnetosphere on a near-constant basis. That means locations under this oval see the aurora almost every night. However, this oval is usually above the Arctic Circle, or 66° north, where the Sun never sets during summer months. Aurorae are also most frequently seen around the equinoxes in late April and September.

Given that all of these places tend to be very cold, be sure to dress warmly when heading out on your vigil.

The auroral oval surrounds the geomagnetic poles, which are significantly offset almost 10° in latitude from the rotational poles. In the north, the magnetic pole is currently located within the Arctic Archipelago in northernmost Canada. This offset allows for some mid-latitude locations to be better choices than others. Quite often, the southern shores of the Great Lakes region in the United States are treated to more auroral displays than the more northerly locations of the Pacific Northwest and New England. Overall, planning to see the northern lights at mid-latitudes is challenging, to say the least. But it's always good to have a location in your back pocket in case you find yourself on vacation in a northern-tiered spot during an aurora event.

It's also useful to be aware of a phenomenon called *magnetic midnight*. This is when the north or south magnetic pole is directly between the Sun and the observer. Due to the offset of the geomagnetic poles, the area of the strongest auroral activity is always opposite of the Sun's position, so the area of likely activity rises and sets as seen from lower latitudes.

For example, in the Great Lakes region, on a night with auroral activity, it will be



▲ **REQUISITE TOOLS** While your smartphone may be able to take a respectable image of a bright aurora, you'll have much better results using a digital camera that accepts interchangeable lenses. Serious aurora photography requires a high-quality wide-angle lens, a shutter-release device, and a sturdy tripod.

◀ **WEATHER MONITOR** The smartphone app *SpaceWeatherLive* presents important real-time information to help you determine if it's worth heading out to shoot aurorae. The four graphs presented here are the most important ones to watch, as described in the article.

visible towards the northeast after sunset, progress to the north, and then move towards the northwest towards morning. Because of the offset between the geomagnetic and geographic poles, the exact time changes slightly from location to location. Magnetic midnight is helpful knowledge when chasing during nights of lower activity, so you know which direction of the horizon to monitor for the best chance of activity.

Visual Expectations and Photography

Witnessing a good auroral display is often mesmerizing but not as colorful as shown in photographs. Particularly strong storms may be bright enough to generate greenish and reddish ribbons, rays, and curtains but with hues more muted than in photos. Typically, we perceive aurorae in shades of grey with a dash of green tint. That's if you are lucky and catch an event that's bright enough to activate the cones in your eyes — the cells that respond to color. But in general, photographs are the best way to record the colors of an auroral display.

The good news is most any camera that can expose for a few seconds or longer can record a bright display. Even your smartphone can take memorable photos. You don't need fancy, expensive gear to take images of the northern lights. However, if you're looking to take a great photo that can be blown up and printed large, your best results will come with a DSLR or Mirrorless camera paired with a wide-angle lens. However, some additional equipment will ensure you come away with many nice shots.

First and foremost, a sturdy tripod will ensure sharp photos. While you can handhold your smartphone and come away with an acceptable picture, even a cheap tripod fitted with a smartphone clamp will dramatically improve your results.

Next, a shutter-release cable or a wireless trigger will provide a way to fire the shutter without touching the camera so that you don't get blurry or wiggly stars in your photos.

If you're using a DSLR or Mirrorless camera, then a high-quality, wide-angle zoom or prime lens with an f-stop of f/2.8 or lower is best for aurora photography. A fast lens allows for more light to fall onto the camera's sensor. But note that cheap fast lenses often produce distorted stars at the corners of the frame and perform best when set one or two stops below wide-open, which defeats the advantage of the lens's maximum speed. You can save money by renting high-quality lenses from a local photography store if there's one accessible to you. Renting is also a great option for those who want to try out a new lens before buying it.

Aurorae span a good swath of the sky, so you don't need a telephoto lens. A focal length of 50 mm or shorter is ideal for the task if you have a full-frame camera. A 28-mm lens is about as long as you'd need with an APS (crop-format) camera. You'll want a particularly wide-angle lens, such as a 14-to-24-mm f/2.8, or even a 10-mm fisheye lens. This is especially true for locations at high latitudes where even on nights of minimal activity, a display can be overhead and sometimes take up the entire sky! You also want to include some of the foreground landscape in the picture. From mid-latitude locations, the display may be confined near to the horizon. Therefore, a longer lens, such as a 35-mm or 50-mm f/2, is more suitable, as you can fill the frame more with the rays peeking over foreground trees or hills.

Standard DSLR and Mirrorless cameras will take excellent pictures of aurorae, though astro-modified cameras can

▲ **MOONLIGHT OPTIONS** Don't be discouraged if a bright Moon lights the sky during a display. Moonlight will illuminate the foreground in your photo much like in the blue hour (the period just before sunrise or after sunset). The image at left is a focus-stacked composite captured in British Columbia, Canada while the Moon was up. The photo at right is the same scene taken after the Moon had set, providing a very different atmosphere.

COMPOSITIONAL ELEMENTS Create variety in your photos when shooting an aurora by including interesting things in the foreground. This focus-stacked image combines a pair of 2-second exposures recorded with a modified Nikon Z6 at ISO 1250 and a 20-mm lens working at f/1.8.

▶ **GEOMAGNETIC ENCOUNTER** Wyoming isn't typically known for auroral displays. But the author was able to catch the red curtains of an aurora peeking out around Devil's Tower National Monument due to an alert sent from the *SpaceWeatherLive* app.

▼ **FOCUS STACK** Single-shot aurora photos work well if your foreground lies at a great distance. You can improve the depth of field by using a technique known as *focus stacking*, in which two images are taken back to back — one at infinity focus for the sky, the other with the focus point set to nearby objects. The two images are then combined with software, such as *Adobe Lightroom* or *Photoshop*. This image taken from Apostle Islands National Lakeshore in Wisconsin blends two exposures recorded with a modified Nikon Z6 camera and a Nikkor 20mm f/1.8S lens. The aurora image was exposed for 4 seconds at f/2.2 and ISO 2000, while the foreground uses an exposure of 3 minutes at ISO 4000 and with the lens stopped to f/5.

enhance the color response in your images. These cameras can pick up more of the reds than their non-modified counterparts while still retaining a natural overall color balance.

Camera Settings

If you dabble in landscape astrophotography, then many of the same approaches apply here. The big difference is attempting to freeze the motion of these shimmering, ever-changing displays.

Start with an exposure of 15 seconds, with the ISO set to 1600 or, if you have a newer camera, ISO 3200 or even 6400. If the display is bright and rapidly changing shape, you'll want to lower both the ISO and shutter speed — this will increase the dynamic range in your photos. Some aurora displays are bright enough to capture in exposures of only a couple of seconds.

Another trick to try is stopping down the lens aperture, especially while shooting with a bright Moon in the sky or a bright aurora display. Stopping down from f/2.8 to f/4.5 or more both reduces lens imperfections such as coma and increases the depth of field, resulting in a sharper foreground. This also reduces the need to perform a technique known as *focus stacking*. Focus stacking is a method in which you focus on the sky in one image, refocus for the foreground, and then combine the results in post-processing.

Be sure to monitor the histogram in your camera as the display changes brightness. The key point here is to avoid overexposing the brightest parts of the aurora by keeping the peak of the histogram slope from being cut off at the right. While you can slightly underexpose a scene and still get good pictures, you can't recover overexposed areas.

Once you have seen and photographed a few aurorae displays from home, you might start dreaming about excursions to specific locations just to capture them. If you're planning to travel far away for an aurora expedition, you'll want to utilize apps such as *Photopills* or *PlanIt Pro* to help you gain insight into the locations you have in mind. These apps let you visualize the landscape and sky accurately to determine where to set up, long before you arrive. And be sure to pick a few locations that take advantage of the direction of magnetic midnight.

Finally, though aurora photography doesn't require much post-processing, a little enhancement and color balance always helps. Programs like *Adobe Lightroom* enable you to lighten the shadow areas (like the foreground), control highlights, and perform contrast and saturation adjustments quickly and easily. For the more advanced crowd, *Photoshop* is king. It does everything *Lightroom* can do and much, much more.

As we enter solar maximum, now is a wonderful time to explore photographing the aurora. There should be plenty of opportunities to catch these dramatic celestial lights over the next several years. And who knows — we may experience a big geomagnetic storm that pushes the auroral oval far enough south that you can witness a display from your own backyard. Bundle up, and good luck!

■ **MARYBETH KICZENSKI** can often be found chasing the northern lights in the Great Lakes region of the U.S.

▲ **REARVIEW** *Top:* It's fun to get creative with your compositions. This image uses a car mirror to include the aurora in the same frame as the center of the Milky Way above the Mackinac Bridge in Michigan.

▲ **REDEYE OPPORTUNITY** *Bottom:* Overnight flights are an unusual opportunity to see a bright aurora display, though you may need to get creative when blocking the interior lights of the plane. The author grabbed this remarkable shot while flying over Canada with the same Nikon Z6 and 20-mm lens used in the image on the facing page. Total exposure was 1.2 seconds at ISO 6400 with the lens set to f/2.

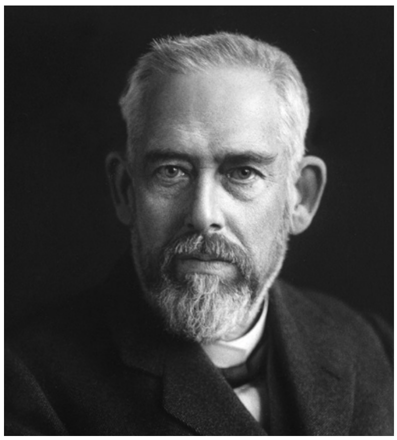
The Story of Wolf 359

A little red sun in Leo was once the least luminous star known.

Anyone who dreams of exploring the nearest solar systems for signs of life has probably perused the list of stars closest to the Sun. This roster boasts such familiar luminaries as Alpha (α) Centauri, Sirius, and Procyon, stars so brilliant they naturally attract the attention of astronomers and stargazers alike.

But that same list also features a host of *red dwarfs* — cool, dim suns invisible to the naked eye. How did astronomers discover that these unassuming stars reside nearby? The answer is different for each entry. This story is about one star that's both especially close and especially obscure. Named Wolf 359, it's less than twice as far as Alpha Centauri yet shines almost as feebly as Pluto.

German astronomer Max Wolf spotted the dim star in 1918, then numbered it 359 in a star catalog he published the following year. Astronomers in the U.S. later determined how close the faint sun was and realized it was a record-breaker, emitting less light than any other star then known.



▲ **STELLAR NAME** German astronomer Max Wolf discovered the faint red dwarf Wolf 359. Despite its faintness, the star's large proper motion was a sign it might be one of our nearest stellar neighbors.

INTERFOTO / ALAMY STOCK PHOTO

The Life of Max Wolf

Max Wolf spent nearly his entire life in Heidelberg, a city in southwestern Germany. He was born there in 1863 and died there in 1932. (He is not to be confused with Charles Wolf, who helped discover Wolf-Rayet stars.)

Wolf became interested in astronomy during his youth and was fortunate that his father, Franz Wolf, a wealthy doctor, had the means to build his son a private observatory in their backyard. In 1884, the 21-year-old Wolf discovered a comet, now cataloged as 14P/Wolf. He later found two additional comets, and in 1909 he was the first observer to catch the return of Halley's Comet.

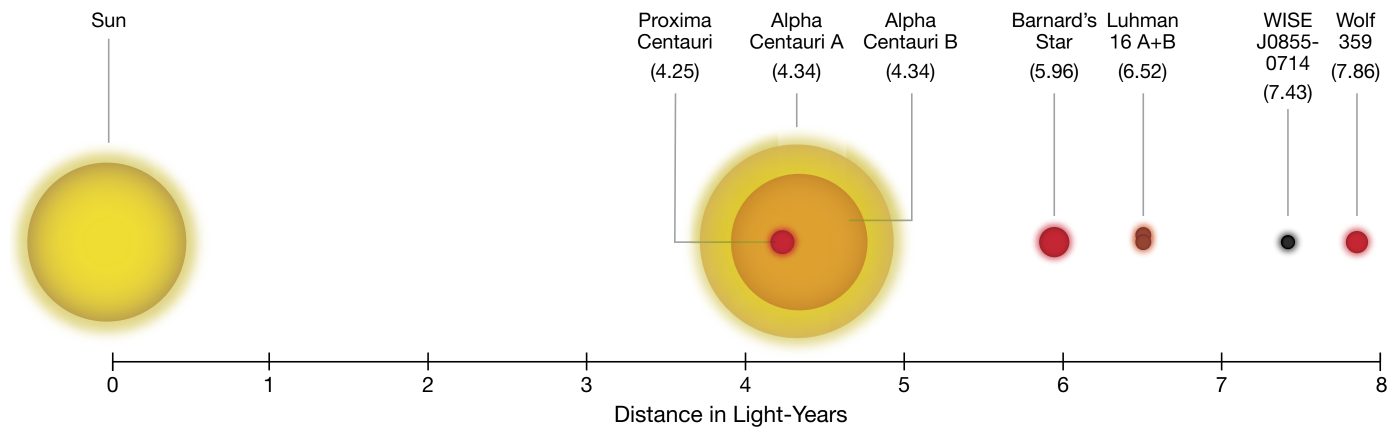
Wolf earned his doctorate in 1888 at the University of Heidelberg, where he studied asteroids, and devoted his career to exploiting the nascent marriage between astronomy and photography. Wolf recognized that because an asteroid moves against the stellar background, an asteroid on time-exposure photographic plates would appear as a short streak, standing out from the stars. In this way he discovered an asteroid on December 22, 1891, just three years after receiving his doctorate. He named the small body Brucia for Catherine Wolfe Bruce, a wealthy American who supported astronomy and donated $10,000 for a new telescope that he later used. Wolf went on to find hundreds of additional asteroids.

In 1906 he discovered the first Trojan. Unlike most other asteroids, which lie between the orbits of Mars and Jupiter, Wolf's find is about as far from the Sun as Jupiter is but revolves 60° ahead of the giant planet. He named the odd asteroid Achilles.

Beyond the solar system Wolf had earlier photographed NGC 7000, a nebula in Cygnus that the great English astronomer William Herschel discovered in the 18th century. From his photographs Wolf noticed that the nebula looked just like

CASEY REED

STELLAR UNDERACHIEVER
One of our nearest neighbors and for many years the intrinsically faintest star known, ruddy Wolf 359 will receive a big reward for its extreme frugality: a life that lasts several trillion years. The star spins fast and erupts frequently, spewing flares that cause it to brighten.



▲ **NEARBY STARS** Within 8 light-years of Earth shine bright stars such as the Sun and Alpha Centauri, plus dim red dwarfs like Wolf 359 as well as even dimmer brown dwarfs, one of which — WISE J0855-0714 in Hydra — is so cold (about 12°C, or 53° F) that it emits no visible light at all.

North America and named it the America Nebula, describing it as the "finest nebula of the sky." American astronomer Edward Emerson Barnard later renamed the object, writing "The 'North America Nebula' would perhaps be more definite, for it is North America to which Dr. Max Wolf intends the compliment."

In 1909 Wolf discovered what we now know is a nearby galaxy in Cetus that belongs to the Local Group, the galactic gathering that includes the Milky Way and Andromeda. The new galaxy, a dwarf irregular, the site of active star formation, bears the name Wolf-Lundmark-Melotte, after Swedish astronomer Knut Lundmark and English astronomer Philibert Melotte, both of whom found the galaxy two decades later.

And in 1918, at the age of 54, Wolf made his "star" find.

The Discovery of Wolf 359

The 1910s saw huge advances in the study of nearby stars as astronomers on three different continents discovered three red dwarfs in the Sun's immediate neighborhood. In one way or another, each was a record-breaker.

The first and most famous discovery occurred in 1915, when Scottish-born astronomer Robert Innes, working in South Africa, spotted Proxima Centauri, the closest star to the Sun. The faint star glows just 2° from Alpha Centauri and lies slightly closer to us, hence its name. Modern measures put Proxima just 4.25 light-years from Earth, compared with 4.34 light-years for Alpha Centauri (both the A and the B components).

The second discovery came the next year. In 1916 Barnard, working at Yerkes Observatory in Wisconsin, found a fast-moving star in Ophiuchus. The star had a different position on photographic plates than it had years earlier, which meant it had a large proper motion (*S&T:* June 2022, p. 30; see also the article on page 60 in this issue). In fact, Barnard's Star has the largest proper motion ever recorded in a star. It's currently 5.96 light-years from Earth and gets 0.04 light-years closer each century.

The third and final discovery was Wolf's. Unfortunately, he doesn't state exactly when he found the star. He announced the find in a March 23, 1918, article, which is only five paragraphs long, suggesting it didn't take long to write. It seems likely that his discovery occurred on or shortly before that date.

Wolf identified the remarkable star just as he had his many asteroids: on photographic plates. He utilized a *blink comparator*, a device that he and Carl Pulfrich of the Carl Zeiss company in Germany invented around the turn of the 20th century. A blink comparator allows an astronomer to

◀ **A NEBULOUS CONTINENT** It took Max Wolf, an astronomer from a different continent, to see the shape of North America in this interstellar cloud, which he named the America Nebula. In a 1903 article for the *Astrophysical Journal*, Edward Emerson Barnard, who took this photograph, renamed the cloud the North America Nebula.

STAR DISTANCE DIAGRAM: BEATRIZ INGLESSIS / S&T; NORTH AMERICA NEBULA: GEORGIA INSTITUTE OF TECHNOLOGY ARCHIVES AND SPECIAL COLLECTIONS alternate the view between two photographic plates taken at different times and look for a planet, asteroid, or star that shifts position from one plate to the next. While the stellar background holds steady, the moving object appears to jump back and forth, making it easier to detect.

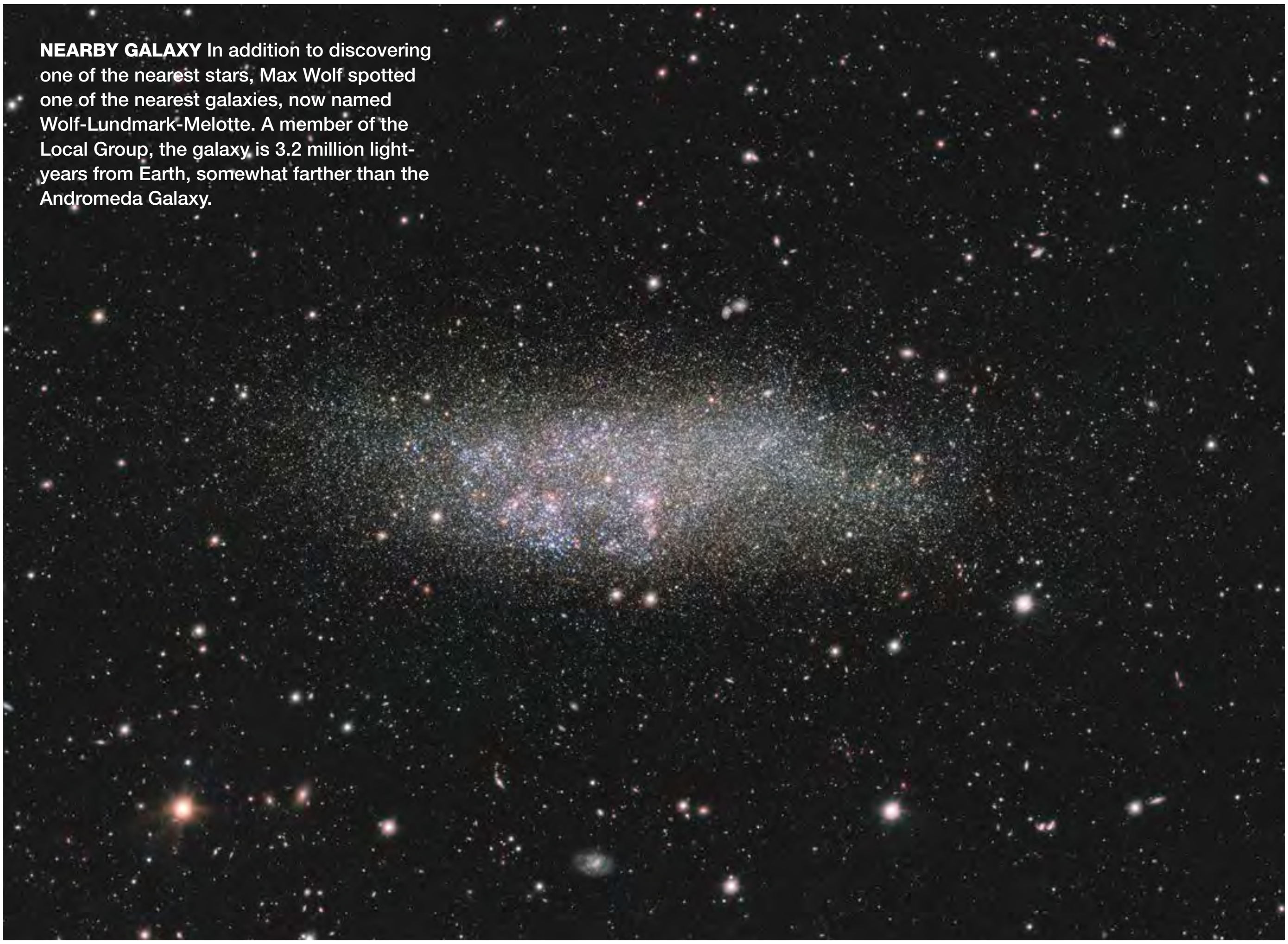
In 1911 Lowell Observatory in Arizona ordered one of these machines from Zeiss to facilitate Percival Lowell's search for a ninth planet, whose gravity he thought was pulling Uranus off course. Although Pluto's eventual discoverer, Clyde Tombaugh, was then a mere five-year-old, he would ultimately use this device to discover the far-off world and make astronomical history.

With the blink comparator, Wolf analyzed photographic plates taken in Leo in different years. What he saw was a 13th-magnitude star that had the largest proper motion he had ever found. He noted that the star was moving south and west at 4.84 arcseconds per year, which meant its proper motion was nearly half that of Barnard's Star. Indeed, the faint star's proper motion was larger than all but a handful of other stars. The new star, Wolf wrote, lay "about 2° west of χ Leonis." Chi (χ) Leonis is a 4.6-magnitude star in southern Leo positioned about 15° east-southeast of Regulus.

On the one hand, Wolf 359's large proper motion could indicate that it lies close to our solar system. For the same reason that telephone poles right beside the road appear to rush by as you drive past them, nearby stars usually have large proper motions as our solar system speeds through space. On the other hand, the star's large proper motion might arise instead if it has an orbit around the galactic center that differs radically from the Sun's.

That's actually the case for a 6.5-magnitude star in Ursa Major named Groombridge 1830 (*S&T:* May 1974, p. 296). Its proper motion exceeds that of Wolf 359, but Groombridge 1830 isn't one of our very closest neighbors. Instead, it's 30 light-years distant and owes its large proper motion to its odd orbit around the Milky Way. Whereas the Sun belongs to the *thin-disk population*, whose stars race around the galactic center on fairly circular orbits that stay within the disk, Groombridge 1830 is a halo star whose orbit is highly elliptical and therefore quite different from the Sun's. As a result, relative to the Sun, the star has a large velocity and thus a large proper motion, despite its distance.

Wolf 359's dimness suggested it might indeed be fairly far off, like Groombridge 1830. To learn whether the source of



NEARBY GALAXY In addition to discovering one of the nearest stars, Max Wolf spotted one of the nearest galaxies, now named Wolf-Lundmark-Melotte. A member of the Local Group, the galaxy is 3.2 million light-years from Earth, somewhat farther than the Andromeda Galaxy.

ESO

Wolf 359's large proper motion was due to proximity or to high speed, astronomers needed to determine its distance.

The Distance to Wolf 359

It wasn't until the 1920s, however, that astronomers were able to measure Wolf 359's *parallax*, the tiny annual shift that occurs in a star's apparent position when we view it from different vantage points as our planet circles the Sun. The larger the parallax is, the closer the star (see *S&T:* Dec. 2023, p. 74).

To detect the dim star's parallax, Adriaan van Maanen at Mount Wilson Observatory in California used what was then the world's largest telescope, the 100-inch Hooker Telescope. He recorded 18 photographic plates between April 1922 and January 1927. The verdict was clear: The star had such a large parallax that "With the exception of the system of α Centauri and of Barnard's star, it is therefore the nearest star known at present," van Maanen and his colleagues wrote. The parallax measurements indicated Wolf 359 was just 8.1 light-years from Earth. That number is close to the modern value of 7.86 light-years obtained with the Gaia spacecraft.

Nevertheless, despite the star's proximity, it appears very faint. If we viewed the Sun from the same distance, it would look brighter than Polaris, the North Star. Thus, Wolf 359 must emit very little light. To understand just how little, van Maanen's colleague, Julius Brown, measured the star's precise apparent magnitude. Coupled with its distance, this revealed Wolf 359's *absolute magnitude*, the apparent magnitude the star would have if we viewed it from a standard distance of 10 parsecs (32.6 light-years). The resulting number was close to the modern value of the star's absolute magnitude, 16.6, compared with 4.83 for the Sun.

No stars that feeble were then known. The previous record-holder was Proxima Centauri, whose absolute brightness is about a magnitude brighter, so "it seems that Wolf 359 is by far the faintest star, intrinsically, known at present," van Maanen and his colleagues wrote. Indeed, they entitled their article "A Star of Extremely Low Luminosity."

The article also reports that in April 1927, Mount Wilson astronomer Milton Humason used the 100-inch telescope to obtain the dim star's spectral type: *M*6. Like Proxima Centauri and Barnard's Star, Wolf 359 was therefore a red dwarf — the most common type of star, outnumbering all others put together. Yet not a single one is visible to the naked eye.

We now know that red dwarfs generate energy as the Sun does. Their cores use nuclear reactions to convert hydrogen, the lightest element, into helium, the second-lightest element. The difference between bright, yellow *G*-type main-sequence stars like the Sun and a red dwarf is simple: mass. Red dwarfs were simply born less massive. As a result, they

▼ **SOUTHERN SUNS** The A and B components of the triple Alpha (α) Centauri system blend together to appear as one brilliant star, at left. Unlike Wolf 359, they each emit roughly as much light as the Sun. Alpha Centauri A and B orbit each other every 80 years. Nearly 100 times farther away than Alpha Centauri is the unrelated star Beta (β) Centauri, at right.

GARY SERONIK

don't need to burn much fuel in order to hold themselves up against the force of their gravity. That's why red dwarfs emit so little light.

Still, red dwarfs span a wide range of masses and therefore luminosities. The largest, such as the two red dwarfs constituting YY Geminorum (also known as Castor C), are about 60% as massive as the Sun. Each of these stars has an absolute magnitude around 9. That means each emits about 1⁄50 as much visible light as the Sun.

At the other extreme are red dwarfs that have as little as about 8% the mass of the Sun. Although no one has measured Wolf 359's mass directly, it's probably around 10% that of the Sun.

How does the light from Wolf 359 compare with that of Proxima Centauri and Barnard's Star? At visual wavelengths, Proxima Centauri emits nearly three times as much and Barnard's Star 20 times as much. To put this another way, in order to emit the same amount of visible light that the Sun radiates in an hour, Barnard's Star would require three months, while Wolf 359 needs nearly six years.

Thus, Max Wolf's discovery truly is remarkable. After all, it's pretty easy to find bright things. It's a lot harder to find the intrinsically faintest star ever seen — one that pushes the boundaries of what a star can even be.

Wolf 359 Loses Its Crown

Eventually, however, Wolf 359 lost its less-than-lustrous crown. Ironically, it was Max Wolf himself who unknowingly initiated his namesake star's downfall.

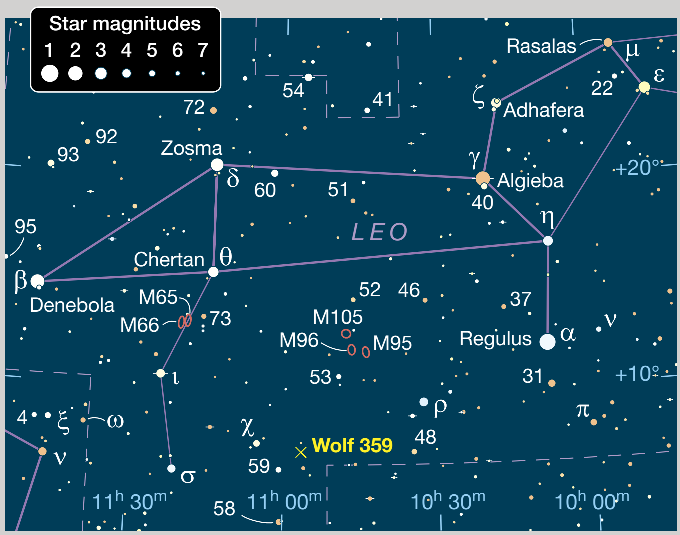
▲ **BLINK COMPARATOR** Two years before Max Wolf died, young Clyde Tombaugh discovered Pluto by using a machine the German astronomer had helped design. Wolf employed a similar device to spot Wolf 359.

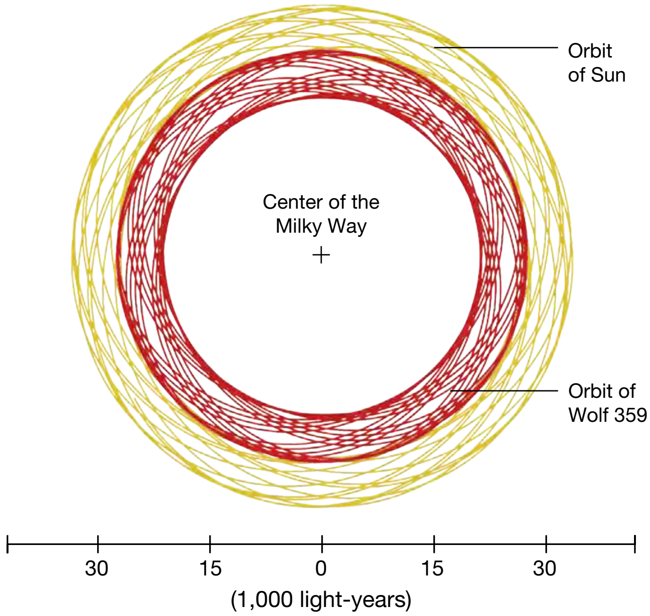
In 1919, just a year after he discovered Wolf 359, he found another interesting star — a 9th-magnitude sun in Aquila, Wolf 1055. Photographic plates taken 20 years apart revealed that it had a proper motion of 1.5 arcseconds per year. In the 1920s, astronomers found that the star, also cataloged as BD +4° 4048 and HD 180617, is a red dwarf. It's 19.3 light-years from Earth, nearly 2½ times farther than Wolf 359.

In 1940, Georges Van Biesbroeck — who, like Barnard,

BLINK COMPARATOR: LOWELL OBSERVATORY ARCHIVES; WOLF 359 PHOTO: DSS2 / SKY-MAP.ORG

◀▼ **RED SUN** This second-generation Digitized Sky Survey image shows ruddy Wolf 359 at the center of a field in Leo that spans the same angular size as the Moon — a distance the red dwarf star will traverse in just four centuries. Despite its proximity to us, Wolf 359 is a magnitude-13 star that requires effort to find. In contrast, from a planet orbiting Wolf 359, our Sun would be easy to see.





▲ **PASSING STARS** Although the Sun and Wolf 359 are currently close neighbors, the two stars usually inhabit somewhat different zones of the galaxy. As shown in these orbits computed by astronomer Adrian Price-Whelan, the Sun (yellow path) normally resides farther from the galactic center than Wolf 359 does (red path). Right now, though, Wolf 359 is about 2 light-years farther from the galactic center than the Sun is.

worked at Yerkes Observatory — began searching for dim stars "in order to extend our knowledge toward the lowest luminosity stars." He used the new 82-inch telescope at McDonald Observatory in Texas to take photographic plates of faint nearby stars in a quest to find even fainter stars that are orbiting them (*S&T:* June 1974, p. 370). Wolf 1055 was one of Van Biesbroeck's targets.

Comparing photographic plates from November 1940 and October 1943 "revealed the presence of a very faint companion to that star, sharing its motion," he reported. That meant the two stars were traveling through space together. However, by Van Biesbroeck's estimate, they were at least 434 astronomical units apart — 11 times greater than the mean distance between the Sun and Pluto — so they must take many thousands of years to revolve around each other.

More importantly, Van Biesbroeck noted that his star was a new stellar underdog: "three magnitudes fainter than the lower limit known up to now, which was held by Wolf 359 . . ." Modern measurements show that Van Biesbroeck's Star (also known as VB 10) is brighter than its discoverer had thought. Its absolute magnitude is 18.6, two magnitudes dimmer than Wolf 359. Van Biesbroeck's Star takes 37 years to emit as much visible light as the Sun does in an hour. If put in place of the Sun, the star would look only slightly brighter than the full Moon. Noon would therefore resemble a moonlit night, Earth's oceans would freeze, and all terrestrial life would perish.

Van Biesbroeck's Star emits so little light that during the 1960s some astronomers suspected it was not a red dwarf at all. Instead, they thought it might be what was then known as a black dwarf and is now called a *brown dwarf* — a star born with so little mass that it can't sustain a hydrogen-to-helium nuclear reaction. If so, then VB 10 was glowing simply because gravity squeezes its gas and makes it hot enough to shine. In truth, as we now know by measuring the masses of other dim suns, the star is almost certainly a red dwarf. Astronomers didn't spot the first genuine brown dwarfs until the 1990s.

After supplanting Wolf 359, Van Biesbroeck's Star reigned as the low-luminosity champ for four decades. In the early 1980s, however, astronomers discovered two stars that were even less luminous: RG 0050-2722 in Sculptor, reported in 1981, and LHS 2924 in Boötes, whose distance astronomers measured in 1983. Both stars have absolute magnitudes around 19.5. That's about 15 magnitudes fainter than the Sun's absolute magnitude, which equates to a visual light output barely one-millionth that of the Sun.

Wolf 359's Long Future

Wolf 359 is only a temporary neighbor of our Sun. Although both stars belong to the same thin-disk population, they follow different orbits within the Milky Way.

The Sun is currently moving toward the galactic center and is presently closer to the heart of the Milky Way than it usually is. In the same way that a comet accelerates as it nears the Sun, our star is moving faster than average, at around 250 kilometers per second (560,000 miles per hour) around the galactic center. In contrast, Wolf 359 is moving away from the galactic center and is farther from it than usual, so the star currently revolves more slowly than the Sun. Furthermore, the two stars have opposite vertical velocities. The Sun is moving upward through the Milky Way's disk at 7 km/s, so each year we climb higher by a distance equal to that between the Sun and Mars. In contrast, Wolf 359 is moving downward through the galactic disk at 7 km/s.

As a result of their different trajectories, the Sun and Wolf 359 are like ships passing in the night. Look again in a million years and Wolf 359 will be nearly 200 light-years distant. In a billion years the two stars may be on opposite sides of the galaxy.

Wolf 359 is certainly destined for a very long life. Although born with much less fuel than the Sun, Wolf 359 consumes it so slowly that the little star will still be glowing a trillion years hence. And who knows, in the far future Wolf 359 may swing by our Sun again, which by then will be a fading white dwarf star so dim that even this feeble red dwarf will outshine it, a sign that the meek have finally inherited the Milky Way.

■ **KEN CROSWELL**, author of *The Alchemy of the Heavens* and *The Lives of Stars*, is especially fond of the nearest stars and galaxies. He wrote the feature stories about the Milky Way and Andromeda galaxies in the August and December 2023 issues of this magazine.

ADRIAN PRICE-WHELAN (HTTP://GALA.ADRIAN.PW AND FLATIRON INSTITUTE)

OBSERVING
May 2024

3 DAWN: Face east-southeast to see the waning crescent Moon, Saturn, and Mars strung out in a line a bit more than 20° long. Go to page 46 for more information on this event and others listed here.

4 DAWN: The lunar crescent hangs some 7° below left of Saturn in the east-southeast before sunrise. Mars is at lower left.

5 MORNING: The Eta Aquariids are expected to peak. Although this shower favors the Southern Hemisphere, viewers in the southern U.S. may catch a few meteors. The waning crescent Moon won't interfere. Turn to page 48 for details.

5 DAWN: The thin lunar sliver trails Mars by around 4½° as they rise in tandem above the eastern horizon.

12 EVENING: High in the west, the waxing crescent Moon is in Gemini, a little more than 2° left of Pollux. Watch as the pair sinks toward the west-northwestern horizon.

15 EVENING: Face southwest to see the first-quarter Moon 3° upper left of Regulus, in Leo.

19–20 ALL NIGHT: The waxing gibbous Moon is in Virgo. Watch as the gap between it and Spica shrinks from around 4° to a bit less than 2° as they arc above the southwestern horizon.

23 EVENING: The just-past-full Moon gleams in the southeast less than ½° lower left of Antares, the Scorpion's smoldering heart. The Moon eclipses the star for viewers in the southeastern U.S. (see page 51).

31 MORNING: Turn toward the east-southeast to see the waning crescent Moon less than 1° below Saturn.
—DIANA HANNIKAINEN

▲ An Eta Aquariid meteor streaks across the Arizona sky in May 2014. Debris from Comet 1P/Halley is responsible for this springtime meteor shower. ALAN DYER

MAY 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	31	

LAST QUARTER
May 1
11:27 UT

NEW MOON
May 8
03:22 UT

FIRST QUARTER
May 15
11:48 UT

FULL MOON
May 23
13:53 UT

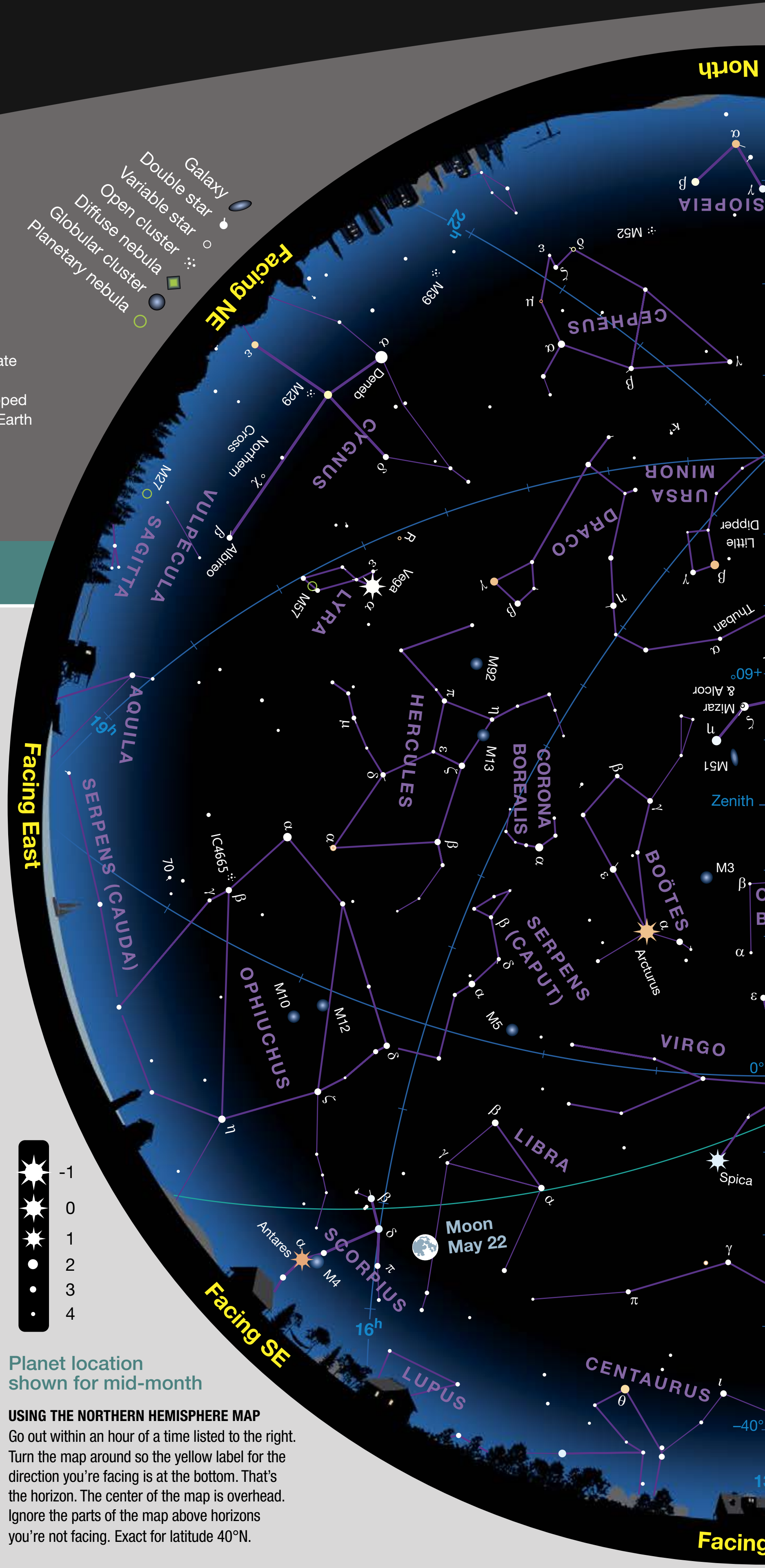
LAST QUARTER
May 30
17:13 UT

DISTANCES

Perigee	May 5, 22^h UT
363,165 km	Diameter 32′ 54″
Apogee	May 17, 19^h UT
404,639 km	Diameter 29′ 32″

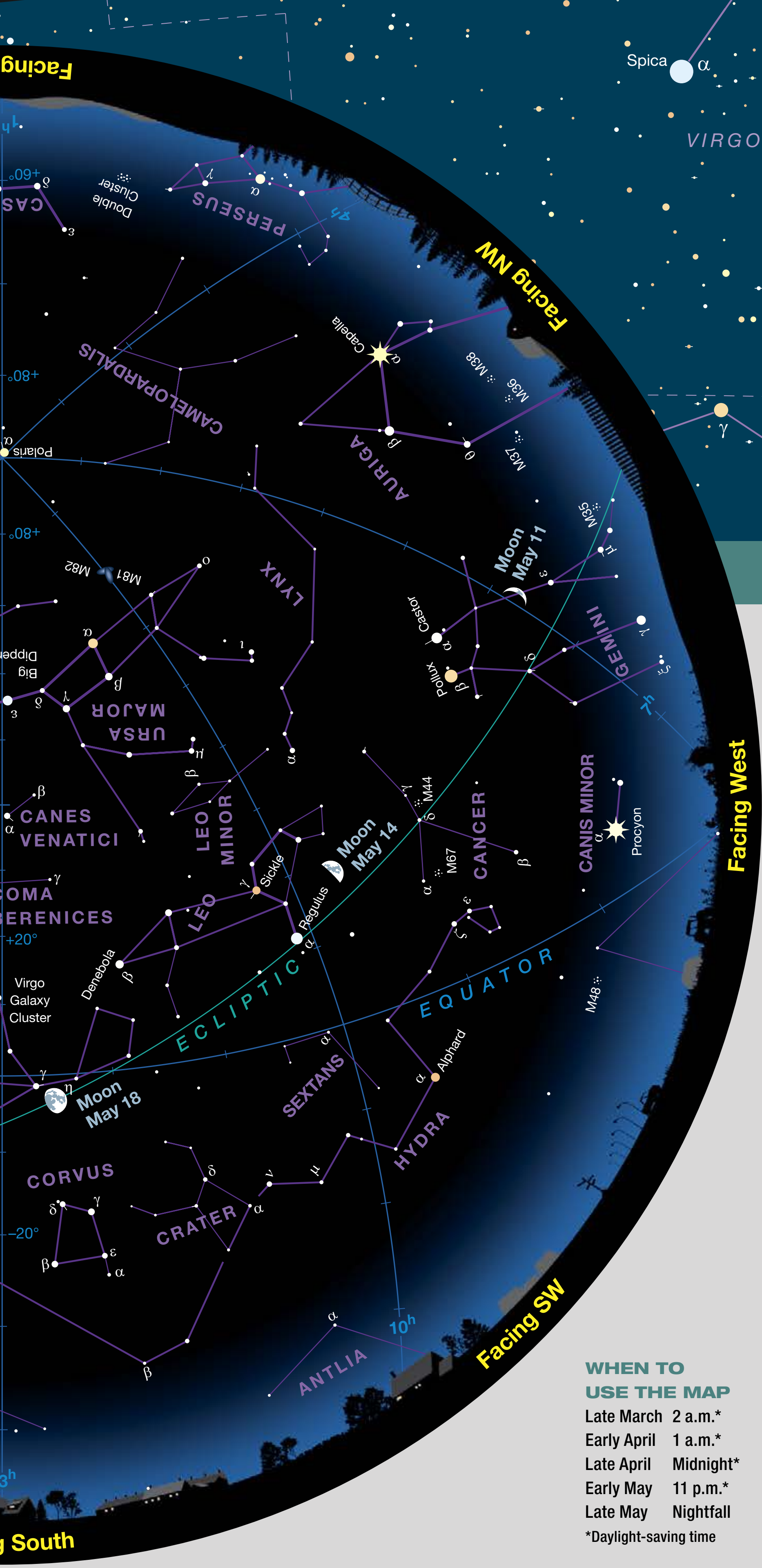
FAVORABLE LIBRATIONS

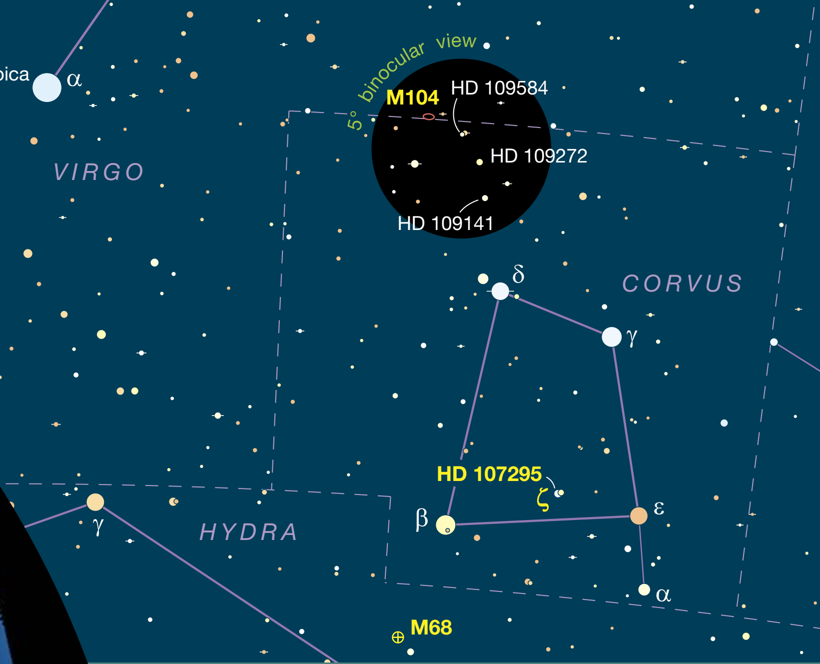
• Gerard Q Inner Crater	May 1
• Oken Crater	May 11
• Xenophanes Crater	May 27
• Pythagoras Crater	May 28



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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Living on the Edge

Our theme this month is edges, peripheries, and frontiers. We'll start in the constellation Corvus, the Crow. Although it holds a few deep-sky objects for telescopic observers, the cosmic crow doesn't have a lot to offer binocular observers. But it points the way to two Messier objects just beyond its borders: the galaxy **M104** and the globular cluster **M68**.

Let's start with M104. The famous Sombrero Galaxy lies about 5½° north-northeast of 2.9-magnitude Delta (δ) Corvi, just over the border into Virgo, the Maiden. Follow an arc of three 6th- and 7th-magnitude stars as pointers. Eighth-magnitude M104 looks almost edge-on (see page 55), and its telescopic appearance is dominated by the massive dust lane that defines its visual periphery. M104's glow is concentrated into an east-west needle, making it one of the few galaxies for which I can reliably detect an orientation in 10×50 binoculars. Can you do the same?

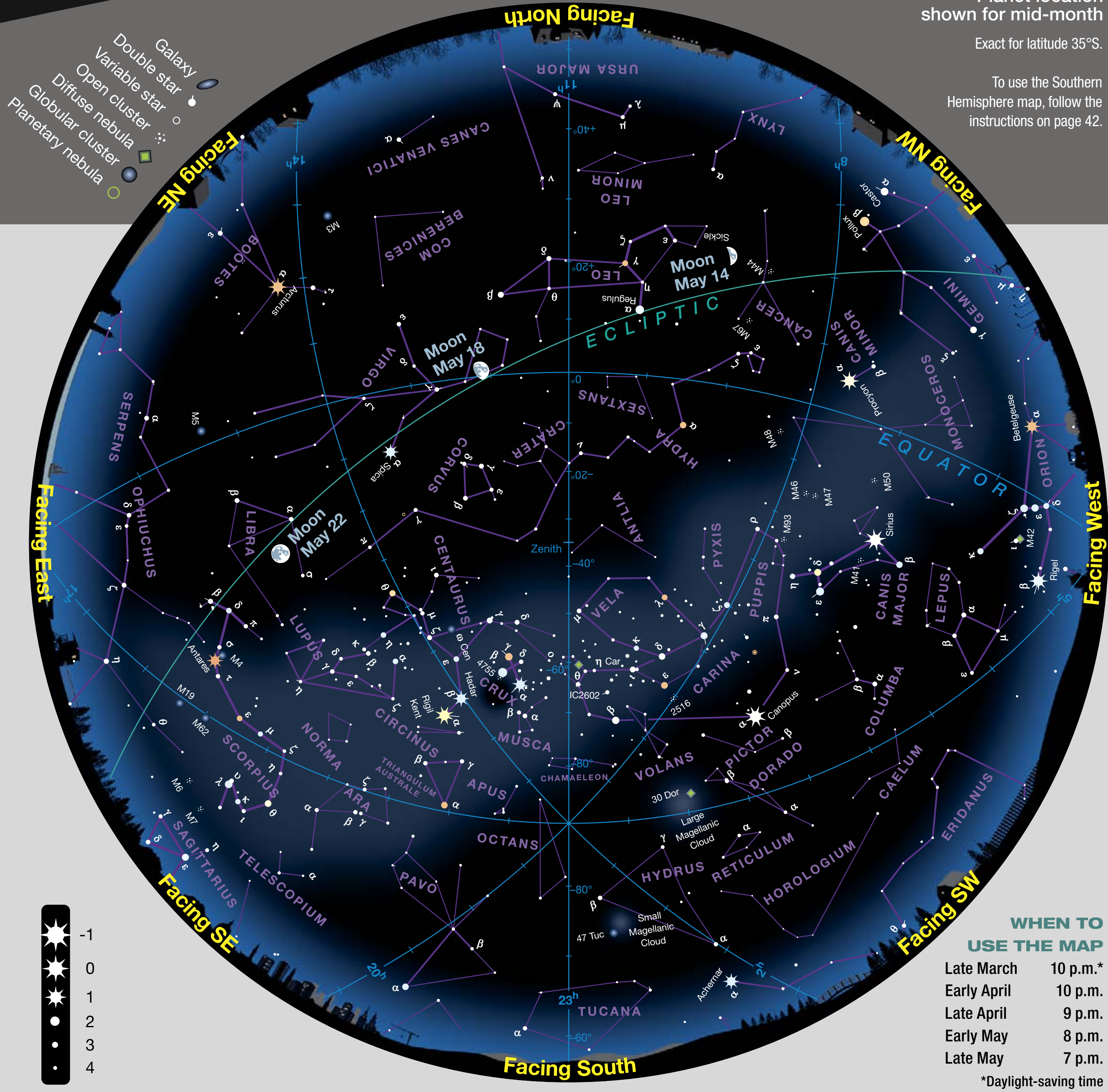
Now go back to Corvus and follow the long line from Delta to 2.6-magnitude Beta (β) Corvi and onward into Hydra, the Water Snake. About 3½° south-southeast of Beta you should spot the 8th-magnitude globular M68. Like all globulars, M68 will present only as a hazy round glow in handheld binoculars. But at roughly 33,000 light-years away, it carries us off to our Milky Way Galaxy's diffuse halo.

Let's visit one last target, this time in Corvus itself. Near the bottom of the quadrilateral some 3½° west-northwest of Beta, look for **Zeta (ζ) Corvi**, which makes a nice binocular double with **HD 107295**. The former is a 5.2-magnitude blue-white main sequence star, and the latter is a 6.0-magnitude yellow-orange giant a bit less than 6′ to the northwest. See if you can detect that subtle color difference in your binoculars.

■ MATT WEDEL loves galaxies as much as the next person, but he is ready for the summer Milky Way.

Southern Hemisphere Sky Chart

by Jonathan Nally



Planet location shown for mid-month

Exact for latitude 35°S.

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

WHEN TO USE THE MAP

Late March	10 p.m.*
Early April	10 p.m.
Late April	9 p.m.
Early May	8 p.m.
Late May	7 p.m.

*Daylight-saving time

THE INTERNATIONAL ASTRONOMICAL UNION officially recognizes 88 constellations, the names and origins of which refer to all sorts of things — mythological people and creatures, real animals, important inventions, and so on. But only one of them is named for an insect: **Musca**, the Fly.

Located deep in the south just below Crux (the famed Southern Cross), Musca is a small constellation consisting of just a half-dozen stars. Its brightest light is 2.6-magnitude **Alpha (α) Muscae**, marked on the chart above. Alpha is a hot, blue variable star almost five times the diameter of our Sun and more than 4,000 times brighter. The Fly's other notable star is **Beta (β)**, a close binary system comprising components of magnitudes 3.5 and 4.0, each of them several times bigger than the Sun. ■

Gateway to the Underworld

Spring evenings offer us a prime view of where the Sun crosses the celestial equator in autumn.

With the Northern Hemisphere star chart (pages 42 and 43) in hand, go out this month in the evening and face south. About one-third of the way up from the horizon shines 1st-magnitude Spica, the principal star of Virgo, the Maiden. As you gaze at this sky-blue stellar beauty, consider that, due to the tilt of Earth's spin axis relative to the plane of its orbit, we see the star south of the celestial equator in the Hades of the night sky — the immortal realm of the celestial underworld.

The entry gate to this mythical place lies about 10° (the width of a fist on an outstretched arm) west and slightly north of Gamma (γ) Virginis — the point on our star chart where the teal line of the ecliptic meets the blue line of the celestial equator. That intersection marks the position of the *autumn equinox* — the moment when the Sun crosses the celestial equator on its yearly sojourn south. And while we can't watch it happen (because that's where the Sun is), the May night sky allows us a prime view of its location.

Early skywatchers knew of this imaginary point and worked it into their mythologies. One of the richest tales involves Demeter (the Greek goddess of fertility, who brings forth the fruits of the Earth) and her daughter Persephone; her name is commonly derived from *pherein phonon*, meaning "to bring (or cause) death."

One version of the myth begins after Athena (the Greek goddess of war) defeated the hundred-armed giant Enceladus by throwing the island of Sicily onto him. Pinned to the ground, the giant tossed about, causing the Earth to shake and heave so violently that Hades (Greek god of the underworld) worried that the ground would crack and bleed unwanted sunlight into his dark domain. Furious, he flew out of the Earth in his chariot drawn by four black steeds. Just as he entered the light, he saw beautiful Persephone picking lilies in a Sicilian valley. Forgetting his anger, Hades swooped down from the sky and charioted Persephone off to the netherworld, where she would rule as his queen and bride.

When Demeter learned of Persephone's abduction, she became miserable and unconcerned with Earth's fertility. As the years passed, springtime (which once lasted forever) changed: Flowers began to wilt, the land dried up, and cattle died.

Just as all life seemed doomed, Zeus intervened. He persuaded Hades to return Persephone to her mother, provided Persephone had not tasted any fruits from his underground kingdom. Hades agreed but didn't keep his word. By feeding Persephone six pomegranate seeds, the king of the underworld forced Zeus into a compromise: Hades would allow Persephone to return for spring and summer as long as she returned to the underworld every autumn and winter — or one month for each seed she had consumed.

From a Northern Hemisphere perspective, Persephone's return to the underworld mirrors the Sun's annual north-south passage across the celestial equator during the autumn equinox. That's when the long, light-filled days of spring and summer yield to the long, dark nights of autumn and winter.

▲ **PERSEPHONE IN PERIL** This woodcut print (circa 1590–1607) created by Italian printmaker Giuseppe Scolari portrays Hades' abduction of Persephone. In this rendering, we see his horse-drawn chariot (and an unidentified driver) plunging into a flaming crevasse that leads into Hades' subterranean realm.

PUBLIC DOMAIN / WIKIMEDIA COMMONS

Now, return to the constellation Virgo on the star chart and notice how half of its stars lie above the celestial equator (representing the time when sunlight shines most directly over the Northern Hemisphere) while the other half are below the celestial equator (when most sunlight falls on the Southern Hemisphere).

Equally telling, Virgo (as Persephone) prominently graces spring's night sky with her presence. Her stars remain visible until September, when they vanish from view as Persephone returns to the celestial underworld come autumn.

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

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

A Gathering of Dawn Planets

For planetary observers, most of the action this month takes place in the morning sky.

WEDNESDAY, MAY 1

As the month begins, look toward the west as twilight starts to fade for a remarkable and fleeting collection of luminaries. In a 65°-wide by 60°-high swath of sky, we can count 17 stars of second magnitude or brighter — including Sirius, which gleams at magnitude –1.5 and holds down the eastern edge of the group. But brightest of all is **Jupiter**, at magnitude –2.0, hugging the west-northwestern horizon.

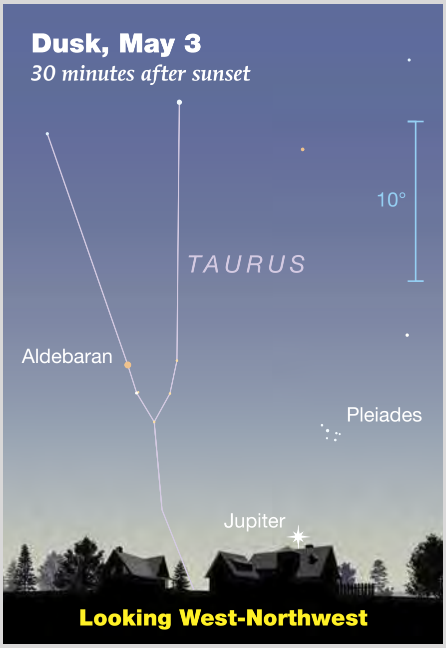
The giant planet is drifting toward its conjunction with the Sun on the 18th and will soon be lost in its glare. Indeed, Jupiter becomes noticeably more difficult to glimpse with each passing night, so enjoy it while you can. The planet will return at dawn around June 7th. However, if you want decent views in your telescope you'll have to be a bit more patient and wait until early July.

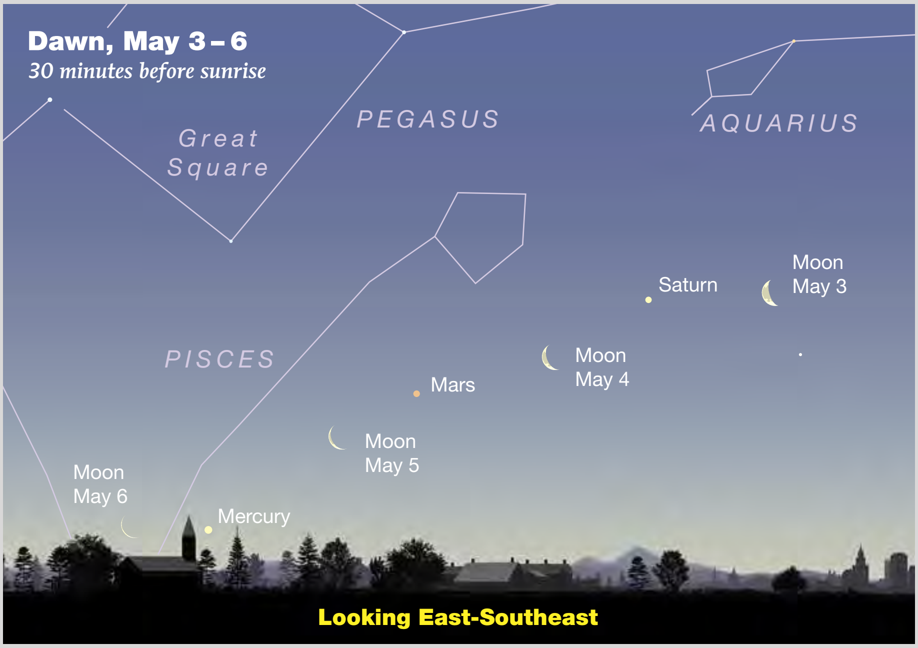
As for Jupiter's stellar companions, take note of the fact that they all belong to autumn and winter constellations, and so their time in the evening sky is also winding down. That said, the most northerly of the bunch, Capella, in Auriga, is almost circumpolar from mid-northern latitudes. Even at the end of June you'll still be able to glimpse it at dusk and then see it again at dawn as it rises in the north-northeast. In other words, there's not a night in the year in which you can't see Capella at least some of the time.

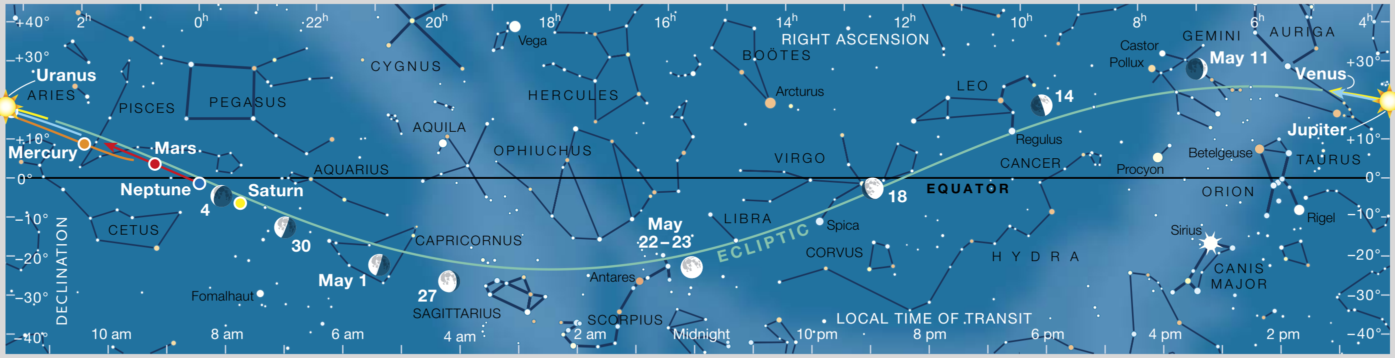
FRIDAY, MAY 3

Speaking of hugging the horizon . . . at dawn today there's a "four for the price of one" array that rivals (or even surpasses) the dusk gathering described above. From right to left we have the **Moon**, **Saturn**, **Mars**, and **Mercury**. All three planets shine at roughly the same brightness. Saturn glows at magnitude 1.2, while Mars is just a wee bit brighter at magnitude 1.1. Far more noticeable is the color contrast between these two, with Mars displaying a peachy-orange hue and Saturn a pale, honey yellow. Brightest of all is Mercury, which is a +0.8-magnitude dot *just* above the eastern horizon. On this particular morning, it achieves an altitude of only

▼▶ 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-May; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st and an hour earlier at month's end.

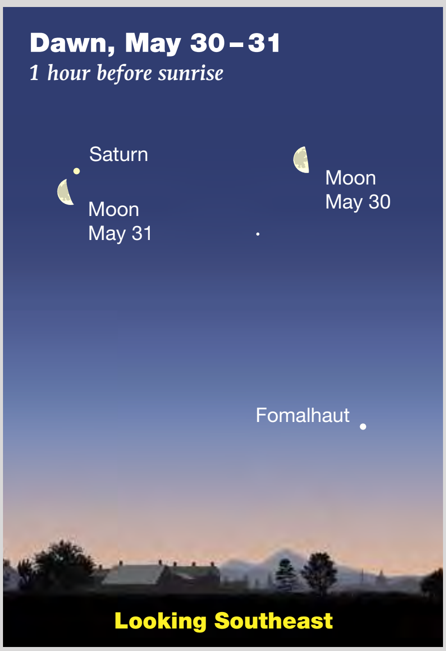
3° half an hour before sunup. You'll need binoculars to have any chance of claiming it.

As for the Moon, it's a 28%-illuminated waning crescent. On each of the three subsequent mornings, it will participate in a new and interesting conjunction. At dawn on the 4th, it's roughly midway between Saturn and Mars; on the 5th, it's parked between Mars and Mercury (slightly closer to the former); and on the 6th, it sits above left of Mercury. Plenty of reasons to keep an eye on the morning sky!

SUNDAY, MAY 12

If you didn't have any luck catching **Mercury** on the 3rd, you have a slightly better chance at dawn today. Not only is the planet noticeably brighter (magnitude +0.3 compared with +0.8 earlier), but it's also a touch higher. Half an hour before sunrise, Mercury hovers 4° above the eastern horizon. That's still very low, and you'll have to use binoculars to fish it out of dawn's glow. Believe it or not, however, this is the highest position the planet will achieve during its current apparition.

Mercury had its greatest elongation from the Sun on the 9th (26° west), but owing to the shallow angle the ecliptic makes with the dawn horizon during spring for observers at mid-northern latitudes, the planet reaches its greatest altitude three days later. If you spot Mercury this time around, you'll be making the best of a bad situation. Of its seven apparitions in 2024, this month's is the least favorable. A much better opportunity comes at dusk in early July.



THURSDAY, MAY 23

The **Moon** has its closest stellar encounter of the month late this evening when it rises with **Antares**, the red heart of Scorpius, the Scorpion. How close will it get? Very close. Depending on where you're situated, the very nearly full Moon (99% illuminated) might even eclipse the 1st-magnitude star. (Turn to page 51 to read details about the occultation.) However, most readers will have to be satisfied with a very close conjunction. The worst-case scenario for observers in the U.S. unfolds on the West Coast. By the time the Moon rises there, its motion will have carried it more than 1° east of Antares — still nice and close, though. Once again, you'll be reaching for binoculars to get the most out of this event. It's not that Antares isn't bright enough to easily shine through the lunar glare — rather, it's because binos will help you appreciate the star's ruddy light contrasted with the Moon's placid, silver-gray surface.

FRIDAY, MAY 31

We close the month as it began, with the waning crescent **Moon** visiting **Saturn** in the morning sky. This time, however, the two get much closer. If you look to the east-southeast around 3 a.m. local daylight time, you'll catch the Moon sitting about 1° below the Ringed Planet. The gap between them is at its absolute minimum just before 4 a.m. EDT.

This is the Moon's best planetary encounter all month. And while you're up, notice how the scene has changed from the beginning of May. Most obvious is that the gap between Saturn and Mars has grown from 15° to 35° in that span, almost entirely due to the Red Planet's gradual eastward drift. That drift is also the reason Mars seems to take forever to gain altitude and get ahead of morning twilight's glow — something that vexes diehard fans of the Red Planet.

■ Consulting Editor **GARY SERONIK** likes his planets served in bunches, with a side order of Moon.

Eta Aquariid Shower Hints at Halley's Return

Fragments from a famous comet streak across the predawn sky this month.

On December 9, 2023, Halley's Comet reached the end of its tether when it arrived at the most distant point in its approximately 76-year-long journey around the Sun. That day the iconic comet slowed just beyond the orbit of Neptune, a frigid 5.3 billion kilometers (3.3 billion miles) from its home star. Since then, the icy traveler has been making slow but steady progress in a 38-year-long return journey that will see it visit the inner solar system once again in 2061.

As the comet coasts sunward, its pebbly progeny, the Eta Aquariid meteor shower, is set to deliver its annual pelting of Earth from late April through late May, with a predicted peak occurring on May 5th at 5 p.m. EDT. However, the shower has a broad maximum, making both the mornings of the 5th and 6th perfect for meteor watching. Fortunately, the Moon will be a thin, waning crescent (10% illuminated on the 5th

▲ Eliot Herman caught a short-trailed Eta Aquariid meteor as it blazed directly below the shower radiant in the Water Jar, an asterism of four stars in the constellation of Aquarius, on May 5, 2020. This year the shower is at its best before dawn on May 5th and 6th under nearly ideal circumstances.

and 4% on the 6th). Instead of diminishing the shower, it will add a pastel touch of wonder as it rises in the east in the growing light of dawn.

Earth crosses Halley's path twice each year, first in early May when our planet wades through debris left behind in the comet's outbound journey, and a second time in mid-October during the Orionid shower, when we encounter the comet's inbound discards. Given the southerly location of the radiant just below the propeller-shaped Water Jar asterism of Aquarius, observers at tropical and southern latitudes get the best view, with up to 50 meteors per hour visible from a dark-sky location. That makes the Aquariids one of strongest showers of the year.

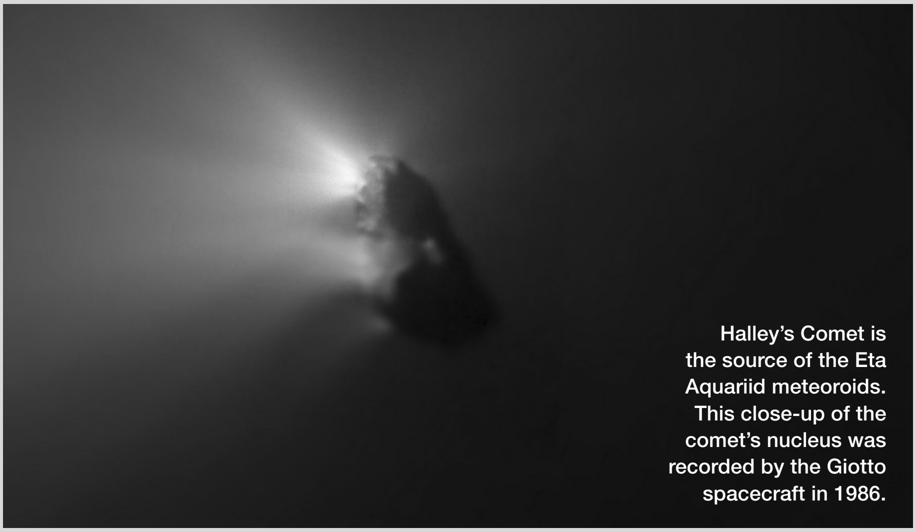
From mid-northern latitudes you can enjoy the show at a reduced rate of around 15 to 20 meteors per hour. The radiant rises a little before 3 a.m. local daylight time for the central U.S., with twilight nipping at the darkness a bit more than one hour later. I suggest starting right around 3 a.m., when you might spot some *earthgrazers* — meteors that barely skim Earth's upper atmosphere and take many seconds to cross the sky. Dust and rock dribbled from the comet come in hot, with speeds of 66 km/s (almost 150,000 mph) — nearly as swift as the Leonids — and produce long-lasting streaks of ionized air and meteoric particles called *trains*.

As the radiant climbs higher in the southeastern morning sky, face southwest or north for the best view, and continue to watch into twilight. As long as stars of 3rd magnitude or fainter remain visible, the show's not over. Meteors near the radiant make short streaks that seem to be aimed directly at you. Averting your gaze so you view the radiant at the periphery of your vision helps bring into view dramatic, long-trained, "side-swiper" meteors.

If you have a tripod and a camera capable of long exposures, use them to pocket a meteor or two as you relax in a deck chair and enjoy the intermittent spectacle. Simply attach your camera to a tripod and use a wide-angle lens set to its greatest opening to allow the maximum amount of light to reach the camera's sensor. F/stop values of f/3.5, 2.8, and lower work best. Set the ISO between 1600 and 2500 and try an exposure of 20- to 30-seconds' duration, the length depending on how dark your sky is. After composing the picture, manually focus on a bright star using the camera's live-view function, and you're ready to begin.

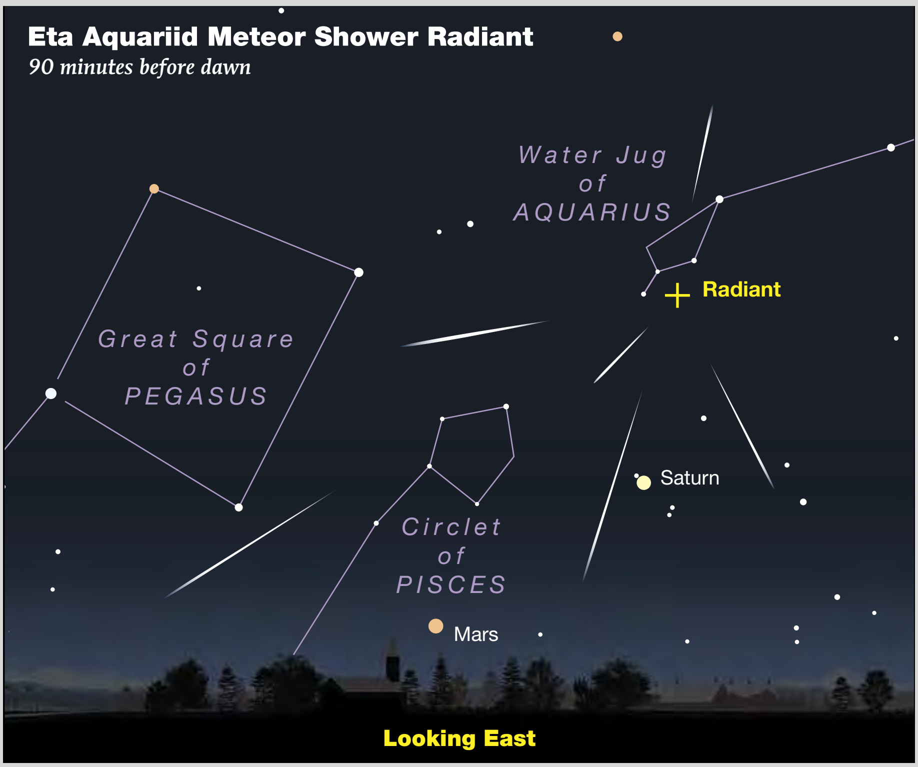
A couple of photographic accessories will make things go more smoothly. I recommend equipping your camera with an *intervalometer* to automatically handle the picture-taking duties. And if dew poses a problem, you may have to use an "anti-dew" lens warmer. There are various makes to choose from, and they generally consist of a cloth strap embedded with a heating element that wraps around the front of the lens. These simple devices really work.

With your camera all set, all you have to do is recline comfortably and enjoy the show courtesy of that most famous of comets.



Halley's Comet is the source of the Eta Aquariid meteoroids. This close-up of the comet's nucleus was recorded by the Giotto spacecraft in 1986.

ESA / MPS



Pallas Skirts Hercules

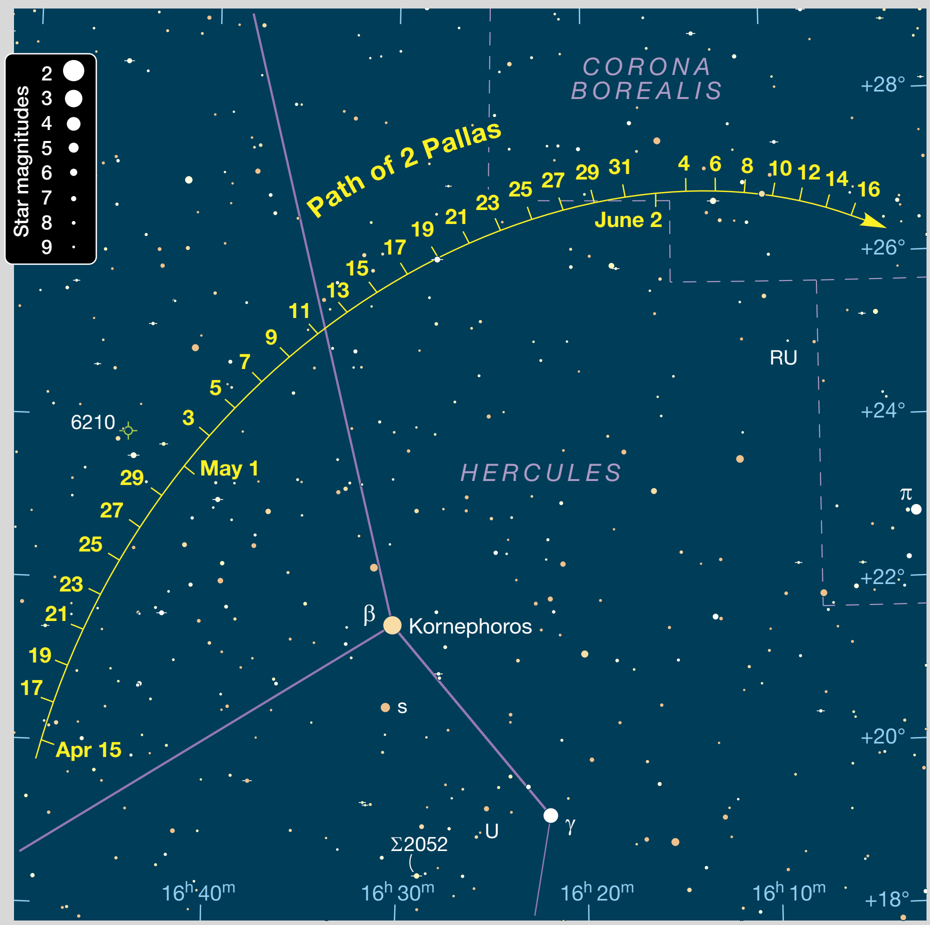
THIS SPRING AND SUMMER take the opportunity to spend time with a pair of small, solar system bodies chanced upon by German astronomer Heinrich Olbers: 2 Pallas and Comet 13P/Olbers. Its prefix tells us that Pallas was the second asteroid discovered — today we know of more than one million. Olbers found the starlike object on March 28, 1802, and christened it Pallas, another name for Athena, the Greek goddess of wisdom. Olbers' comet shares the sky with his minor planet and glows around 9th magnitude low in the northwest at dusk. We'll have more to say about that object in the June issue when its brightness peaks.

The same year Olbers found Pallas, English chemist William Wollaston discovered the silvery, metallic element palladium, which he named after the recently discovered asteroid. In this roundabout way Pallas has a home in your car's catalytic converter. Working together with platinum and rhodium, it scrubs exhaust clean of harmful byproducts. With a water-rich composition similar to the dwarf planet Ceres and carbonaceous chondrite meteorites, the asteroid itself likely has few exotic metals.

With a diameter of about 512 kilometers, Pallas is the third-largest minor planet. It circles the Sun every 4.6 years in an orbit inclined by 35°. On its May 19th opposition, the asteroid shines at 9th magnitude in western Hercules. Beta Herculis, at magnitude 2.8, makes a fine naked-eye reference for pinning down the asteroid's location as it rambles northwestward in retrograde motion. Late in the month it crosses into neighboring Corona Borealis.

Pallas has a rather eccentric orbit that causes its opposition distance to vary from about 1.3 to 2.6 astronomical units. At perihelic opposition, which next occurs in March 2028, it will shine at magnitude 6.6 — tantalizingly close to the naked-eye limit. At a distant opposition the asteroid glimmers three magnitudes fainter. While this year's isn't a particularly close opposition, you'll have no trouble using big binoculars or a small telescope to ride along with Pallas.

The first four asteroids were discovered between 1801 and 1807, and range from 940 to 254 kilometers (584 to 158 miles) in diameter. All reside in the main asteroid belt between Mars and Jupiter but are bright enough to spot in almost any telescope.



CERES AND VESTA: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA; JUNO: VSO VLT SPHERE / ZIMPOL TEAM; PALLAS: ESO / VERNAZZA

The Moon Hides Zavijava and Antares

OBSERVERS WHO ENJOY watching the Moon eclipse stars potentially have two nice events this month. On the night of May 17–18, the waxing gibbous Moon occults 3.6-magnitude Beta (β) Virginis, also known as Zavijava. This event is visible for observers across most of the U.S. (except for California and western parts of Oregon and Nevada), Canada, and a portion of the Caribbean.

The star disappears behind the dark limb of a 75%-illuminated Moon after midnight in the Eastern and Central time zones and during the late-evening hours for the western half of the U.S. For a visibility map and timings for a wide selection of cities, visit the International Occultation Timing Association's special event page at **https://is.gd/iotazavijava**.

Since the Antares occultation season began last August, the Moon hasn't missed an opportunity to cover the brightest star in Scorpius. On May 23–24 the full Moon again eclipses Antares, this time for observers in the eastern half of the U.S., Central America, the northern half of South America, and part of western Africa. Skywatchers in the southeastern U.S. witness immersion during evening twilight, with the star reappearing at nightfall. Observers as far north as southeastern Wisconsin and west into central Texas will miss the immersion but can delight at the star's return shortly after moonrise, when Antares peeps back into view along a the narrow sliver of darkness on the waning Moon's trailing limb.

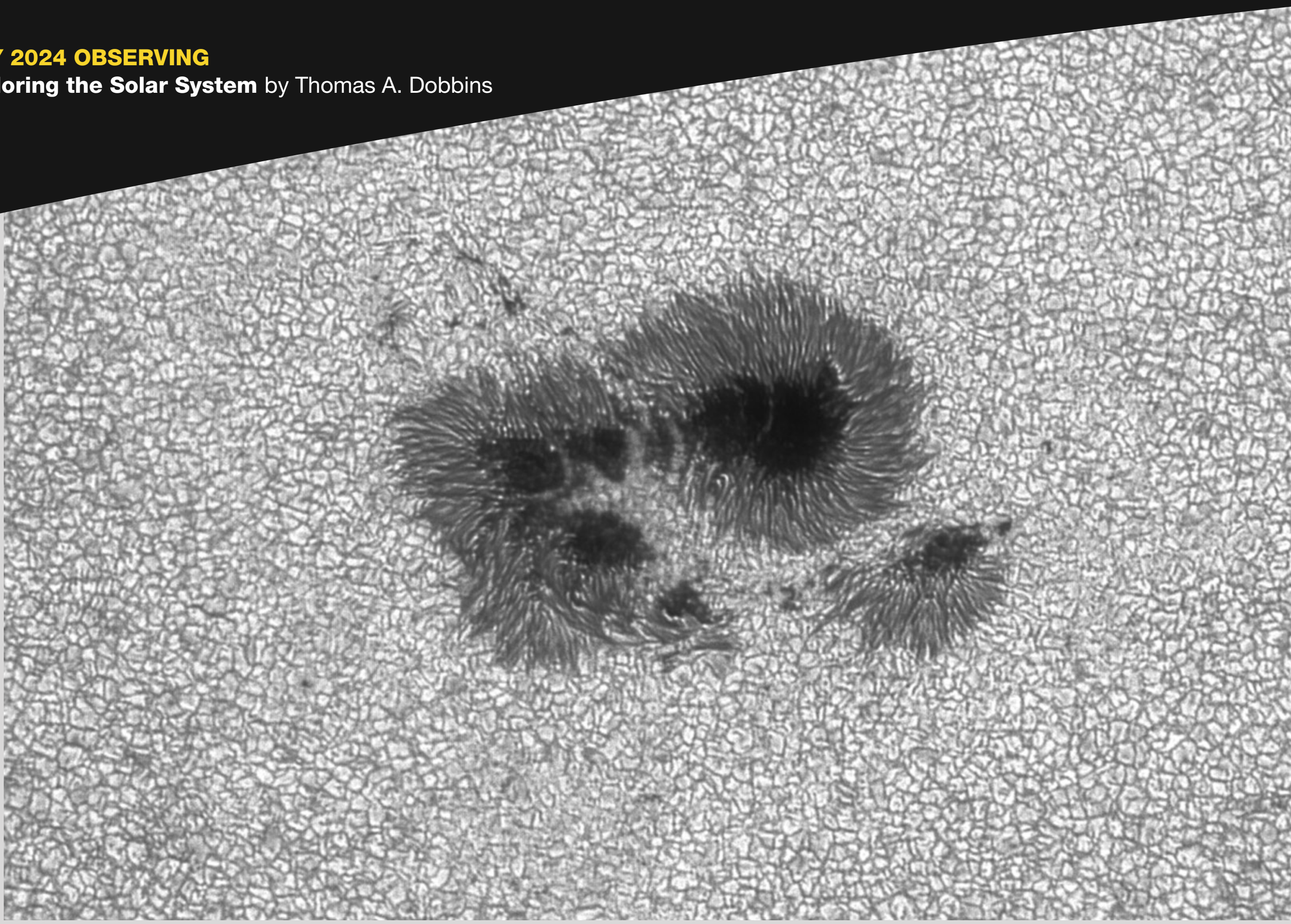
Although lunar glare may interfere, you can try to catch Antares B, the primary star's 5.4-magnitude companion. Positioned just 2.7″ west of Antares A, it emerges several seconds before the brilliant red supergiant itself. Consult IOTA's page devoted to the event at **https://is.gd/iotamayantares**.

▲ Eliot Herman of Tucson, Arizona, photographed Antares (arrowed) moments before the Moon occulted it on January 8, 2024. The lunar crescent Moon eclipsed the star in morning twilight. When the star reemerged at the dark limb shortly after sunrise, it was still plainly visible in a blue twilight sky. This month's Antares occultation will occur during full Moon.

Action at Jupiter

JUPITER IS IN CONJUNCTION with the Sun on May 18th and essentially out of view the entire month. The planet will return at dawn in June, and our regular tables showing the transit times of the Great Red Spot and Jovian satellite events will be presented as usual in that month's issue.

Gary Walker captured this superb image of Jupiter and its Great Red Spot on October 29, 2023, from his backyard roll-off roof observatory in central Georgia. He used a QHY5III200 monochrome planetary video camera on his Astro-Physics 10-inch f/14.5 Maksutov-Cassegrain telescope to record the data used to create this planetary portrait.



Observing Solar Granulation

The Sun's surface is a rapidly changing, seething cauldron of delicate detail.

▲ Resolving the convective cells of solar granulation is well within the capabilities of amateur equipment. This superb image was captured with a 12-inch reflector equipped with a Baader AstroSolar Safety solar filter and a high-speed video camera last September.

DANIEL BROUSSEAU

The Scottish telescope maker James Short was the first to describe the finely mottled appearance of the Sun's visible surface, or *photosphere*, in 1740. The greatest observer of the 18th century, William Herschel, discerned an overall pattern of tiny, bright points with apparent diameters of one to two arcseconds separated by narrow, dusky spaces. During the early 19th century, these minute features were often described as "rice grains." It wasn't until 1864 that the eagle-eyed British observer William Rutter Dawes coined the term "granulations" for them.

In 1876, French astronomer Jules Janssen embarked on a decades-long program of high-resolution solar photography using a 5-inch refractor at the Meudon Observatory in suburban Paris. The Sun's brilliance made exposures of a fraction of a second even with the era's slow emulsions, so it was possible to freeze the seeing and overcome the blurring effects of atmospheric turbulence to some extent. In most of Janssen's photographs, individual granules resembled rounded cobblestones, but in his sharpest images they appeared to be angular polygons.

The resolution of Janssen's photographs remained unsurpassed until the 1950s, when Project Stratoscope lofted a 12-inch telescope to an altitude of 24 kilometers (80,000 feet) aboard an unmanned ballon. Turbulence is absent from this vantage point, where atmospheric pressure is 25 times lower than at Earth's surface and a constant temperature of −50° Celsius (−58° Fahrenheit) prevails. These flights obtained photographs of unprecedented clarity that clearly resolved the polygonal shapes of individual granules.

Similar structures form in pots of boiling oatmeal or thick soup, so it's hardly surprising that as early as 1874, Allegheny Observatory astronomer Samuel Pierpont Langley suggested that solar granulation is produced by convection and that the bright granules are the tops of rising columns of hot gas and the intervening dark spaces regions where cooler gas is descending.

The validity of Langley's speculation became apparent at the dawn of the 20th century, when the French physicist

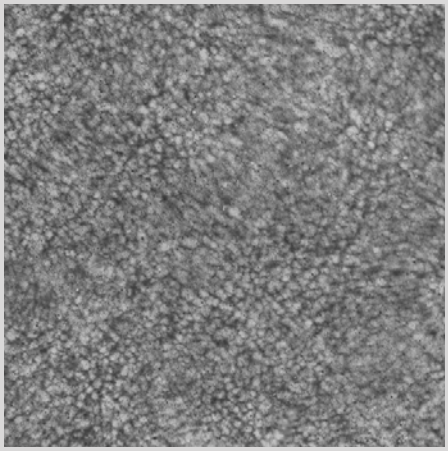
Henri Bénard discovered that polygonal patterns spontaneously form when a thin layer of liquid is heated from below. Three decades later, the German astronomer Heinrich Siedentopf simulated the appearance of solar granulation by heating a shallow pan of molten paraffin on a hot plate. He added exceedingly fine particles of aluminum to render rising and falling motions in the viscous fluid visible.

By the mid-20th century, astronomers used spectrographs to record the Doppler shifts produced by vertical motions in the solar photosphere. This feat removed any lingering doubts that granules are ascending cells of buoyant hot plasma that cool to form darker lanes of denser, descending plasma. Small differences in temperature create a surprisingly large range of brightness, because luminosity varies by the fourth power of temperature, a relationship called the *Stefan-Boltzmann law*.

A typical granule has a diameter of about 1,500 km — about the size of the state of Texas — and a lifespan of roughly 5 to 10 minutes. At any given moment, a network of about 4 million granules covers the seething photosphere.

Observing solar granulation presents special challenges because the Sun is not only a source of intense light, but extreme heat as well. To achieve diffraction-limited performance, large, state-of-the-art solar telescopes employ liquid-cooled optical elements and elaborate ventilation systems or vacuum light paths, often supplemented with adaptive optics. To maximize their potential resolution, they are located on the summits of tall coastal peaks, where gentle laminar winds produce excellent seeing conditions.

For amateur observers of the Sun, the safe, full-aperture solar filters based on reflective metallic coatings deposited on substrates of glass or thin Mylar films prevent 99.99% or more of the Sun's light and heat from entering a telescope. The problems posed by heat-induced turbulence within the instrument that professional solar astronomers grapple with at great expense are eliminated. It is the telescope's immediate surroundings that remain problematic.



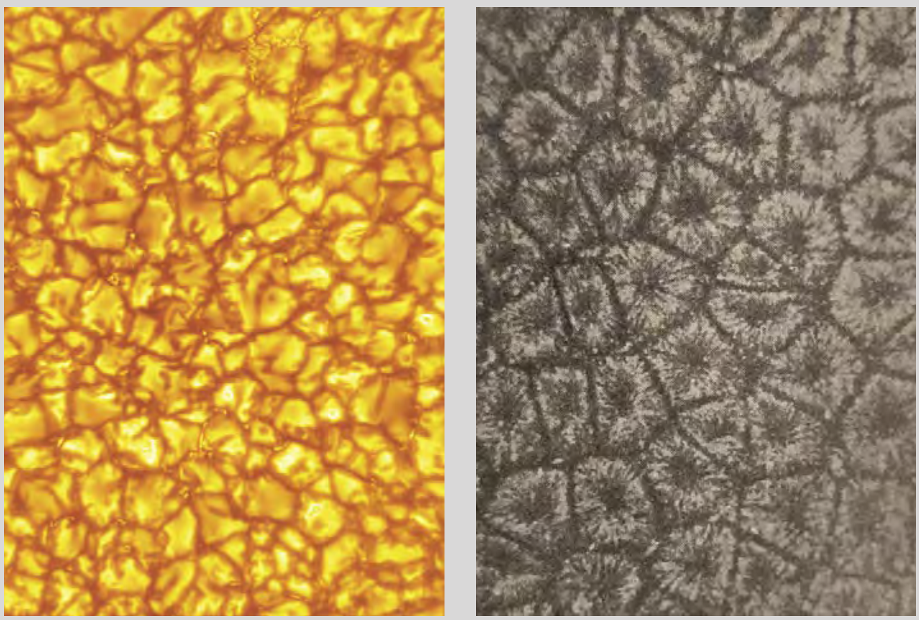
▲ A remarkably detailed 1877 photograph of solar granulation by Jules Janssen

Sub-arcsecond daytime seeing is very rare at most observing sites. At night the best seeing is found near the zenith, where the line of sight through the atmosphere is shortest. During the day, however, the best seeing usually occurs early in the morning when the Sun is between 15° and 30° above the horizon. As the Sun gains altitude, it warms the ground, and convective turbulence begins to play havoc with a telescope's ability to resolve fine detail. Many experienced observers report enjoying their best views of solar granulation only an hour after sunrise. Seeing tends to improve late in the afternoon and early in the evening as solar heating subsides.

Whenever possible, avoid looking over rocky terrain devoid of vegetation. Rooftops and large masses of concrete or asphalt also degrade the view. A wide expanse of lawn or a grass-covered field makes a far better observing site. Views over bodies of water are often excellent. Although often impractical, observing from a high balcony or other elevated perch can dramatically improve viewing by positioning the scope well above the worst ground-level convection.

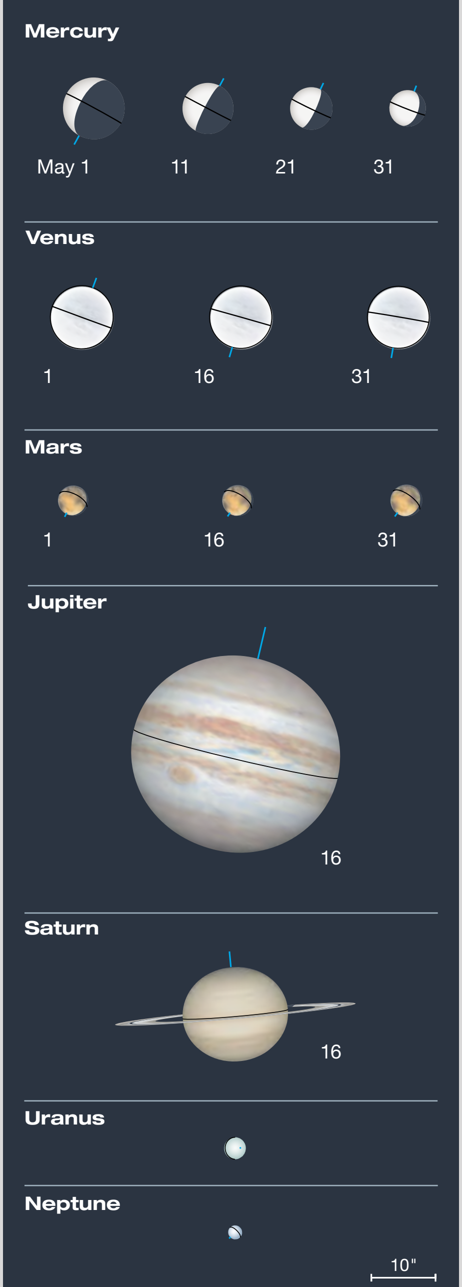
Even under mediocre seeing conditions, solar granulation is visible in a 4-inch telescope at a magnification of about 100×. On rare occasions when the atmosphere is momentarily very calm, a telescope with an aperture of 6 to 8 inches at a magnification of 250× will provide breathtaking views of the simmering solar cauldron, where features form and dissipate in a matter of minutes.

■ Contributing Editor **TOM DOBBINS** writes his observing columns after deep dives into the historical record.



▲ The patterns of convective Bénard cells created in Heinrich Siedentopf's laboratory more than 80 years ago (right) are uncannily similar to solar granulation seen at left recorded with the Daniel K. Inouye Solar Telescope at Haleakalā Observatory on Maui.

OLD PHOTOGRAPH OF SOLAR GRANULATION: *ATLAS DE PHOTOGRAPHIES SOLAIRES* (1903); GRANULATION CLOSEUP: NSO / AURA / NSF; SIMULATION: HEINRICH SIEDENTOPF / *JAHRSCHRIFT DER ASTRONOMIE* VOL 76 (1941)



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

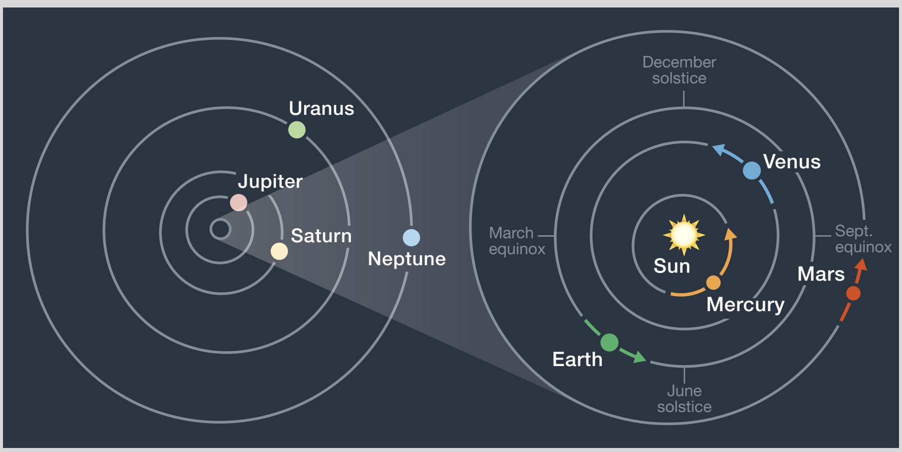
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during May. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** and **Venus** are lost in the Sun's glare all month • **Mars** visible at dawn all month • **Jupiter** visible low in the west at dusk until the 6th • **Saturn** is visible at dawn and climbs to an altitude of 28° by sunrise at mid-month.

May Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	2^h 33.4^m	+15° 03′	—	–26.8	31′ 45″	—	1.008
	31	4^h 32.2^m	+21° 54′	—	–26.8	31′ 33″	—	1.014
Mercury	1	1^h 05.7^m	+4° 27′	24° Mo	+1.0	9.6″	26%	0.698
	11	1^h 34.8^m	+6° 28′	26° Mo	+0.3	7.9″	43%	0.846
	21	2^h 21.7^m	+11° 06′	23° Mo	–0.1	6.6″	60%	1.014
	31	3^h 25.5^m	+17° 04′	16° Mo	–0.7	5.7″	80%	1.183
Venus	1	1^h 59.3^m	+10° 51′	9° Mo	–3.9	9.8″	99%	1.701
	11	2^h 46.8^m	+15° 05′	7° Mo	–3.9	9.7″	99%	1.717
	21	3^h 36.0^m	+18° 41′	4° Mo	–3.9	9.6″	100%	1.729
	31	4^h 27.0^m	+21° 28′	1° Mo	—	9.6″	100%	1.735
Mars	1	0^h 01.8^m	–1° 11′	41° Mo	+1.1	4.7″	94%	1.977
	16	0^h 44.0^m	+3° 23′	44° Mo	+1.1	4.9″	93%	1.920
	31	1^h 26.1^m	+7° 46′	47° Mo	+1.1	5.0″	92%	1.863
Jupiter	1	3^h 26.4^m	+17° 59′	13° Ev	–2.0	32.9″	100%	5.988
	31	3^h 55.4^m	+19° 37′	9° Mo	–2.0	32.8″	100%	6.018
Saturn	1	23^h 12.3^m	–7° 01′	54° Mo	+1.2	16.2″	100%	10.254
	31	23^h 20.1^m	–6° 19′	81° Mo	+1.2	17.0″	100%	9.795
Uranus	16	3^h 22.4^m	+18° 15′	2° Mo	+5.8	3.4″	100%	20.602
Neptune	16	23^h 58.3^m	–1° 32′	56° Mo	+7.9	2.2″	100%	30.449

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**.



Hat Hunt

An attractive galaxy with an evocative name is well placed on spring evenings.

I love galaxies. Big and bright, small and faint — no matter, I enjoy observing them. Even if the galaxy I'm scrutinizing is dim and diffuse, my mind's eye perceives an "island universe" populated with billions of suns and countless planets.

Alas, urban light pollution isn't kind to faint fuzzies. Not many galaxies are easily visible from my backyard, and only a handful exhibit definable features. My favorites are the slender, edge-on types that exhibit a central bulge and a bisecting dust lane. Several top-tier edge-ons return every spring. The brightest of the bunch is the Sombrero Galaxy, **M104**.

M104 is dubbed the Sombrero Galaxy because in telescopes it resembles the iconic, broad-brimmed Mexican hat — or does it? I'm deploying my city-based gear to see if the Sombrero sobriquet fits. For the project, I've chosen a 120-mm f/7.5 apochromatic refractor and an 8-inch f/6 Newtonian reflector.

Getting There

I'm a star-hopper, so I study the location of deep-sky targets very carefully. M104 resides in southern Virgo, the Maiden, almost right on the border with Corvus, the Crow. My preferred star-hop to M104 runs upward from little Corvus rather than downward through sprawling Virgo. The Crow route is just 5.5° long and includes bonus targets along the way.

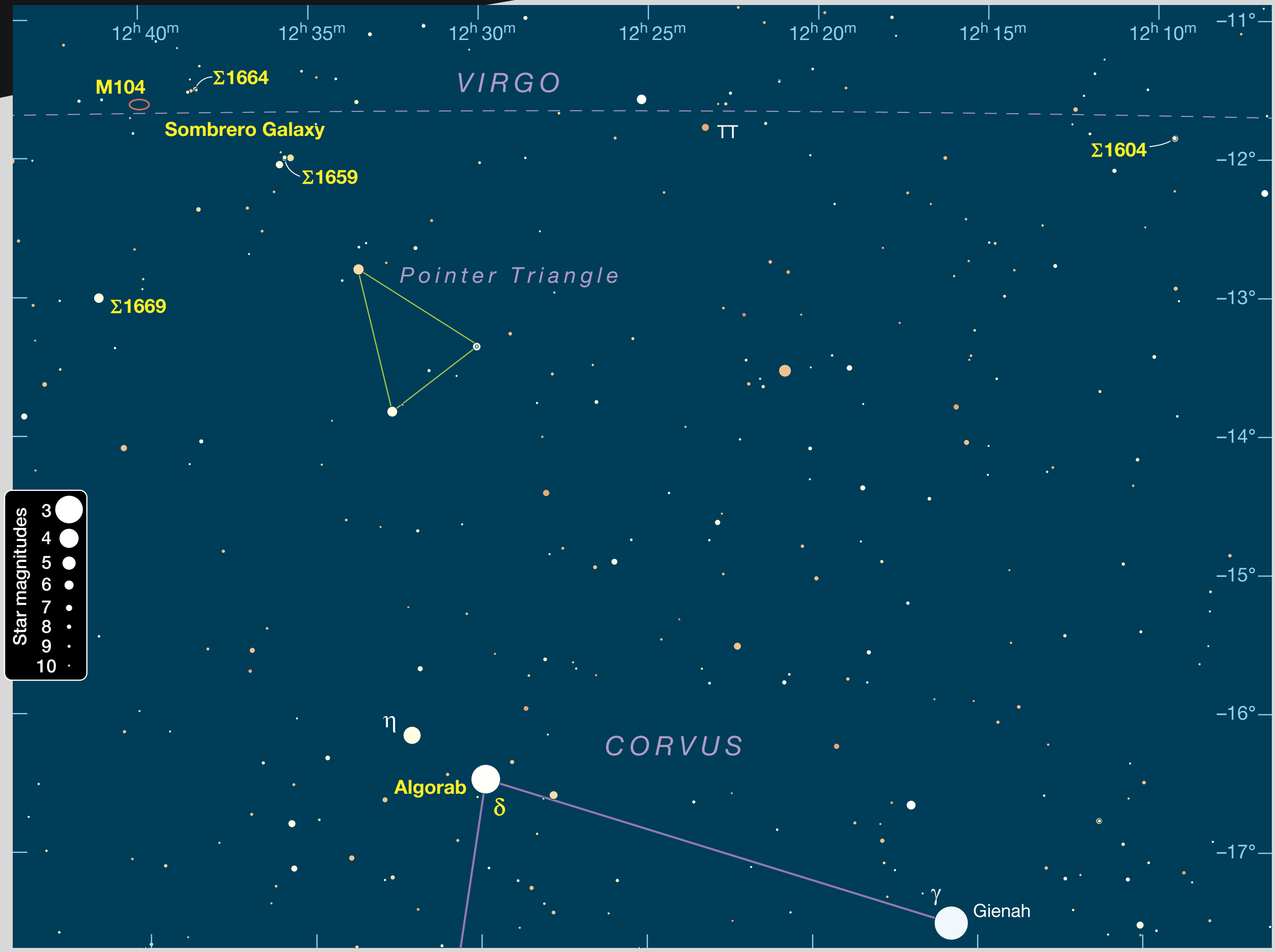
HUBBLE HERITAGE TEAM (AURA / STSCI / NASA)

▲ **EDGE-ON ELEGANCE** Slightly larger than our Milky Way Galaxy and only 28 million light-years from Earth, the Sombrero Galaxy, M104, is strikingly elegant in this Hubble Space Telescope image. Astronomers had considered M104 to be a tightly wound spiral galaxy exhibiting a large bulge-to-disk ratio. However, the precise morphology was difficult to assess due to the Sombrero's nearly edge-on orientation. The vast dust ring encloses the entire system. Although it's the 104th entry in the popular Messier catalog of 110 celestial objects, the galaxy wasn't discovered by Charles Messier — it was found in 1781 by fellow French observer Pierre Méchain. At the time, Messier had completed his initial listing of 103 objects. Regardless, Messier noted Méchain's "faint nebula," and today it's designated as M104.

Before I go any further, let me tearfully describe my sorry suburban situation. I live in a small, over-illuminated Canadian city near the 49th parallel. Because Corvus hangs roughly 20° below the celestial equator, the cosmic Crow flies low across the south. Worse, I live on the north side of town. Corvus's box-like pattern is barely visible inside the light dome ballooning above my south horizon. That dome of doom also threatens the pale Sombrero.

My star-hop starting point is 3.0-magnitude Algorab, officially **Delta (δ) Corvi**, which marks the northeastern corner of the Corvus box. A fine double, yellowish Delta harbors an 8.5-magnitude secondary sun 24.2″ to the southwest. The unequal set looks best at around 50×. A short hop northeast of Delta is 4.3-magnitude Eta (η) Corvi. I can't see Eta directly, but it shows readily in my finderscope. Good, because I need Eta for my next move.

Using 8×50 finders, I shift the telescopes 3° north of Eta to a trio of 6th-magnitude stars outlining a handy 1°-long isosceles triangle. In my finder, sweeping 1° northeastward — the direction the triangle points — I find a pair of 6.6- and 6.8-magnitude stars 5.5′ apart. Low magnification picks up a 9.9-magnitude star a few arcminutes north of the tandem, to create another triangle. Nestled inside this triangle is a tiny isosceles triangle. The base is delineated by 7.9- and 8.3-magnitude stars lined up north-south 28.1″ apart, while the vertex is a 10.9-magnitude flickering pinpoint 43.8″ eastward. Altogether, this delightful triangle-within-a-triangle constitutes a multiple called **Struve (Σ) 1659**. Σ1659 is eye-catching in both scopes, though the refractor needs about 100× to snare the faintest pinpoint.



▲ **CROW ROUTE TO M104** As depicted on our center star map (pages 42 and 43), Corvus the Crow is a small but easily discerned box-shaped constellation. The scenic star-hop to the Sombrero Galaxy, M104, begins at 3rd-magnitude Delta (δ) Corvi, or Algorab, which marks the box's northeast corner. From there, proceed to the Pointer Triangle asterism, which, as its name implies, points 2° northeast to the main region of interest.

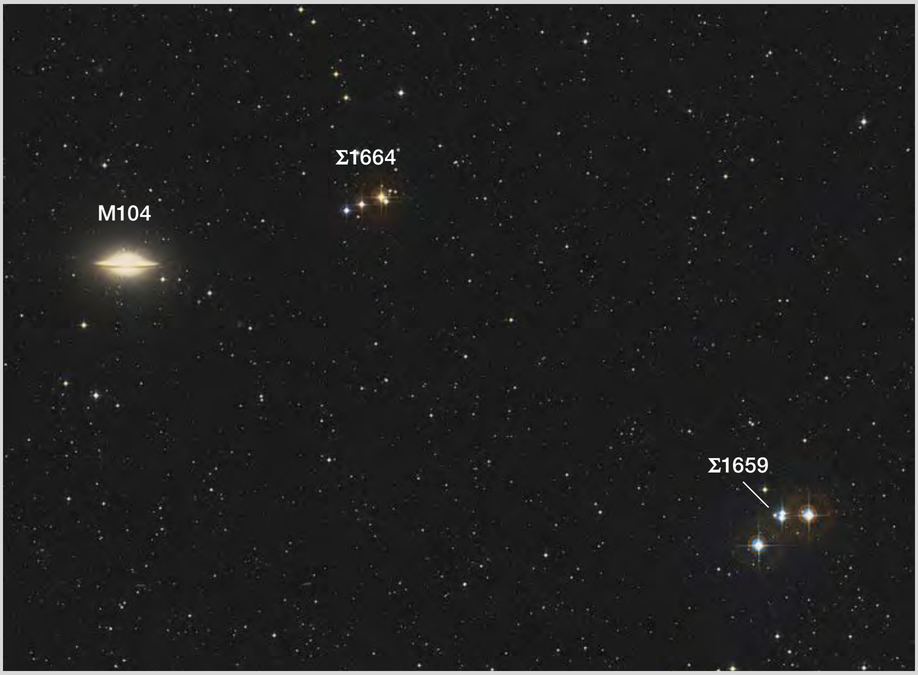
Heading almost 1° farther northeastward takes us across the Corvus-Virgo boundary to pick up a reddish star of magnitude 7.8. This dot plus three more of magnitudes 8.6, 8.9, and 9.2 form a 3.5-arcminute-long hockey stick asterism. The quartet are part of another multiple, **Σ1664**, most of which is beyond the range of my equipment. Indeed, the hockey stick is indistinct at low magnification, but it sharpens up at around 100×. Better yet, the shaft of the stick aims east-southeastward toward the fragile glow of M104 less than ½° away. Perfect!

The Sombrero

Employing the refractor, I reduce to 56× (with a 16-mm eyepiece) and shift carefully over to the 8.0-magnitude Sombrero. It's in the same low-power field as the hockey stick. Officially measuring 8.6′ × 4.2′, M104 is a compact target — smaller still in a milky suburban sky. The refractor operating at 100× (9-mm eyepiece) delivers a condensed patch of light noticeably oval along its east-west axis. In the 8-inch at 135× (same eyepiece), the elongated patch looks bigger and significantly brighter, though still without the signature dust lane. My verdict: For scopes in the 'burbs, the sombrero hat shape simply isn't there. Oh, to have a country sky!

When I focus my reflector on M104 at a rural site far from home, a magnification of around 150× produces a hazy but distinctive spindle, bright in the middle with pale, tapered ends. The 8-inch also reveals the central segment of the Sombrero's dark dust lane. (In truth, the dust lane we perceive is a buildup of many lanes along the plane of the galaxy.) I can glimpse the black thread cutting across the galaxy's huge hub, a bit south of center. That in itself is a victory, and there's more. The south-of-center aspect confirms that the galaxy is not precisely edge-on — most of the bulge spreads north of the dust lane. The wee bit protruding southward might be the head in the hat!

The "head in the hat" is difficult to detect, even away from city lights. The



▲ **HOMING IN ON THE HAT** The final few star-hops to the Sombrero Galaxy are interesting because they include two little asterisms that are, in fact, the multiple-star systems Struve 1659 and Struve 1664. The former is a small triangle nestled within a larger one, while the latter is in the shape of a minute hockey stick whose shaft aims toward the galaxy nearby.

DSS2 / SKY-MAP.ORG

dust lane on either side of the bulge is likewise hard to trace. However, the dark lane does impart a sharp southern edge to M104. It's that well-defined edge, plus the prominent northern portion of the central bulge that makes the Mexican hat, fuzzy flying saucer, or misty Saturn. Alas, at my suburban home I get The Blob — with apologies to the 1958 Steve McQueen cult classic of the same name. The movie was bad; this is worse.

Alas, the Sombrero does not suffer alone. Lots of well-known deep-sky objects sporting evocative monikers don't live up to their names when viewed in small telescopes under light-polluted skies. But even if the destination disappoints, the star-hop journey can still be good fun. That's certainly true for M104.

In the Neighborhood

Before taking down my gear, I decided to check out two other local attractions. For the first, I dipped 1½° south-southeast of the Sombrero, back into Corvus, to the superb double star **Σ1669**. It's a "headlight binary" boasting identical 5.9-magnitude components 5.3″ apart. Σ1669 is a great sight at medium to high power.

If I backtrack to Σ1659 (my triangle-within-a-triangle) and place it in the southern half of a 100× field of view, I'm ready to make a 6½° sweep westward. Along the way, there's a pair of 6th-magnitude stars ½° apart. The more westerly of the two is the deep orange variable TT Corvi, which is hard to miss. The sweep ends at **Σ1604**, a compact triple. The Σ1604 triplet presents a teeny triangle formed by yellowy stars of magnitudes 6.9, 8.1, and 10.0. Fairly high magnification (100× in my refractor) is needed to appreciate this minuscule marvel because the primary star is so dominant.

The good news with this Corvus hop is that (with the possible exception of Σ1604) you won't need a finderscope to locate any of these objects. A red-dot aiming device will set your scope on Algorab. After that, you need only an eyepiece yielding a wide field. You can accomplish the hops by keeping your eye glued to the telescope — then nudging your way slowly and carefully in the indicated directions.

As May opens, Virgo is approaching the meridian at nightfall. When the target area is due south, the star-hops described here are easy to accomplish using an alt-az or Dobsonian mount. There's no moonlight to spoil the view, so early in the month is an ideal time to try the Sombrero on for size.

■ Long-time Contributing Editor **KEN HEWITT-WHITE** has never worn a sombrero, but he has observed the Sombrero Galaxy many times.

Sombrero Sights

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M104	Galaxy	8.0	8.6′ × 4.2′	12^h 40.0^m	-11° 37′
δ Crv	Double star	3.0, 8.5	24.2″	12^h 29.9^m	-16° 31′
Σ1659 AB	Double star	7.9, 8.3	28.1″	12^h 35.7^m	-12° 01′
Σ1659 AC	Double star	7.9, 10.9	43.8″	12^h 35.7^m	-12° 01′
Σ1664 AB	Double star	7.8, 9.2	38.1″	12^h 38.3^m	-11° 31′
Σ1664 AE	Double star	7.8, 8.6	121.4″	12^h 38.3^m	-11° 31′
Σ1664 EF	Double star	8.6, 8.9	92.7″	12^h 38.3^m	-11° 31′
Σ1669	Double star	5.9, 5.9	5.3″	12^h 41.3^m	-13° 01′
Σ1604 AB	Double star	6.9, 10.0	9.0″	12^h 09.5^m	-11° 51′
Σ1604 AC	Double star	6.9, 8.1	10.5″	12^h 09.5^m	-11° 51′

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

The IAU Is Calling

A professional astronomical organization is tapping into the potential of amateurs.

A little more than a century ago, astronomy still wasn't recognized as a profession *per se* — astronomers engaged in teaching, true, but few institutes existed that were dedicated to research. In order to better cement astronomy as a recognized scientific discipline, a handful of intrepid astronomers established the American Astronomical Society in 1899. (You've likely heard of the AAS — it owns *Sky & Telescope*.)

The IAU. Not too long after, in 1919, astronomers also founded the International Astronomical Union. Its aim is to "promote and safeguard the science of astronomy in all its aspects, including research, communication, education and development, through international cooperation." Today, the IAU counts nearly 13,000 members across 92 countries. Like the AAS, the IAU unites and provides resources to professional astronomers working in research as well as those engaged in education and outreach. It has various divisions, subdivided into commissions, that oversee the many facets of astronomy.

The IAU's influence on astronomy includes things you might not give much thought to. For example, at its first General Assembly (a triennial, member-wide event that continues to this day), which was held in 1922 in Rome, Italy, the Commission on Notations and Units reorganized the plethora of higgledy-piggledy constellations that populated the sky at the time into the 88 we fondly refer to today. At the third General Assembly (in 1928 in Leiden, the Netherlands), the IAU approved constellation boundaries, thus arranging the sky into neat parcels defined largely by right ascension and declination. More recently, the 2006 meeting became infamous for "demoting" Pluto.

Nowadays, for example, one commission handles things related to exoplanets and the solar system, while another monitors changes in Earth's rotation.

On top of all this, the IAU establishes temporary "working groups" that tackle targeted issues. Recently, it has created a working group specifically for amateurs.

Pro-Am WG. As you may know from reading previous installments of this column, it's challenging for research astronomers to secure observing time at the large, professional telescopes around the world. So, pros sometimes tap into the vast and varied resources and experience that amateurs provide. And amateurs are increasingly expanding their contributions beyond purely visual observations into other areas. For example, they can record brightness variations with greater precision thanks to the availability (and drop in price) of astronomical cameras. Radio dishes are popping up in backyards. Solar eclipses and aurorae, too, have their cohorts of amateurs busily logging valuable data. Yet, there's still limited crossover between professionals and amateurs.

One of the goals listed in the IAU's strategic plan for 2020–2030 is to better connect the two worlds of astronomy. And so, in April 2021, the IAU formally adopted a new working group — the Professional-Amateur Relations in Astronomy. The Pro-Am WG's mission is to promote research collaborations between professionals and amateurs, and to inform the professionals of all the areas amateurs engage in.

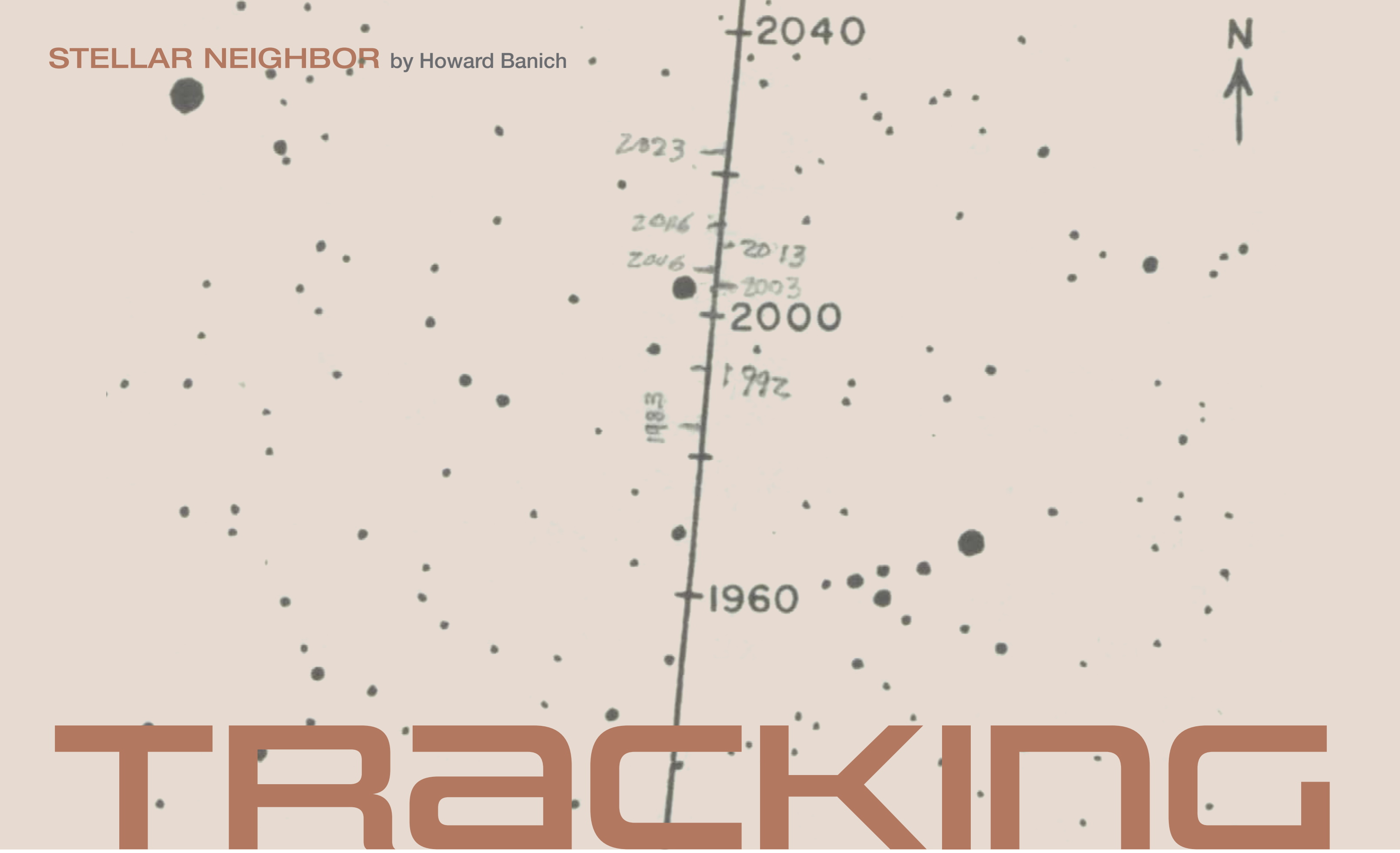
If you're an amateur with your own backyard equipment, or perhaps analyzing data or developing equipment is your thing, **https://is.gd/iau_amprojects** has a list of projects that might spark your interest. If instead you're a professional astronomer looking for collaborators for your research, you can submit your project details at **https://is.gd/iau_proprojects**.

Last December at a conference in Mumbai, India, the IAU — spurred on by the momentum from the working group's formation — organized its first gathering of professionals and amateurs. Maybe you'll be inspired to attend such an event in the future — possibly even the one in August this year in South Africa — and see your hard-earned results shared with a wider audience.

■ Observing Editor **DIANA HANNIKAINEN** is a member of IAU Division D: High Energy Phenomena and Fundamental Physics.

LEAH TISCIONE / *S&T*

 by Howard Banich



TRACKING Barna

What were you doing in May 2018? That was six years ago, of course, which is also the time it takes light from **Barnard's Star** to reach us.

Take a moment and imagine the distance light travels in that time. Can you really grasp how far that is? I can't, but six years is at least an easily relatable time within a typical human lifespan, even if six *light*-years is mind-boggling. (It's 35 trillion miles, give or take.)

Barnard's Star is the fourth-closest star to our Sun and has a proper motion of 10.4″ per year — this makes it the (currently known) fastest-moving star in the sky. Over six years (or, more accurately, 5.96 years, the most precise estimate we have of its distance), this amounts to a bit more than one arcminute, which is greater than the apparent diameter of Jupiter. Combined with the star's accessible visual magnitude of 9.5, this opens up the possibility of tracking its motion across the sky with a small telescope.

My first sighting of Barnard's Star was in 1983, and since then I've noted its position six more times. These sightings form a set of visual observations that have become priceless to me. More on that later.

A Nearby Red Dwarf Star

Prolific American astronomer E. E. Barnard reported on the large proper motion of what was to become his eponymous star in a 1916 publication. By comparing his earlier observations from 1894 with the 6-inch Willard lens at Lick Observatory with those of 1916 using the 40-inch refractor at Yerkes Observatory, Barnard measured the movement of the star to be 10.3″ per year. In addition, he determined the direction of motion to be at a position angle of 359.7°, or almost exactly due north. He refined this result to 10.36″ per year using a photograph obtained with the 10-inch Bruce telescope (also at Yerkes).

Barnard referred to the star as *P* in his 1916 article. More than 100 years later, in 2017, the International Astronomical Union formally named it Barnard's Star.

Although *P* today is classified as an *M*-type red dwarf, Barnard described its color as "yellowish." With the 40-inch, he visually estimated the star's magnitude to be between 10.0 and 10.5. This is fainter than the 9.64 that a fellow observer

▲ **TRACKING OVER TIME** I noted the position of Barnard's Star each time I observed it from 1983 to 2023 on the chart on page 1,252 in *Volume Two* of *Burnham's Celestial Handbook* — this adds up to a running total of 6.90′ of proper motion. The small flying-geese asterism appears just right of center, pointing at the 1960 location.

rd’s Star

High proper motion makes this little red dwarf in Ophiuchus the perfect target to follow over the years.

(a “Mr. Joy,” as noted in the article) determined with the 60-inch reflector on Mt. Wilson. Barnard notes that his magnitude estimates were probably skewed by poor seeing, moonlight, and the color difference between *P* (“yellowish”) and the main comparison star (“bluish white”). The modern value for the star’s visual magnitude is, in fact, closer to 9.5.

Barnard’s Star is located about ¾° northwest of 4.8-magnitude 66 Ophiuchi, and it’s well-placed for most of the spring, summer, and autumn in a distinctive part of northeastern Ophiuchus. It’s variable and hence is also designated V2500 Ophiuchi. Its variability is attributed to infrequent flares — in fact, old *M* dwarfs, such as Barnard’s Star, don’t undergo regular flaring activity, so it was a surprise when it erupted in the late 1990s. During that episode, the star brightened by half a magnitude.

Since the 1960s, astronomers have regularly announced the possible discovery of planets orbiting Barnard’s Star. The first time was in 1968, when Peter van de Kamp (then at Swarthmore College) published a paper reporting the detection of a planet with 1.7 times the mass of Jupiter. However, later observations refuted this. Red dwarf stars are by far the most common type of star in the Milky Way, clocking in at some 70%. So, if they typically have planets, then planets must be everywhere. Heck, two of the four closest stars to our Sun are red dwarfs (Proxima Centauri and Barnard’s Star) — and though Proxima has two confirmed planets, an undisputed planet detection around Barnard’s Star remains elusive.

Follow that Star!

Observing a star that likely has a retinue of worlds orbiting it would be amazing — but what keeps bringing me back to Bar-

▲ **SPEEDY STAR** Barnard’s Star is the prominent orange-red object at the center of this image dating to 2017. At bottom (right of center) is a group of stars reminiscent of a formation of flying geese, which is the smaller of two similar asterisms. Both are helpful for pinpointing the highest proper-motion star in our sky. Even if you have a Go To telescope, you’ll need to figure out which star is Barnard’s Star within your field of view — identifying both asterisms is important, especially if you observe with a small telescope. A good chart is required!

nard's Star is its impressive proper motion. Over the span of a human lifetime, say 80 years, its movement adds up to about 13.8′ — nearly half the apparent diameter of the Moon.

I first went looking for this star soon after buying the three-volume set of *Burnham's Celestial Handbook* in 1983. Using the chart on page 1,252 in *Volume Two*, I was able to find Barnard's Star with my 12.5-inch Dobsonian fairly easily. I marked its position on the line showing the star's trajectory from 1880 to 2040. Although I usually make sketches in my observing notebook, starting in 1983 I primarily marked each observation on the chart in the *Celestial Handbook*. That turned out to be a highly satisfying decision.

After that initial observation, I didn't visit the star again for another nine years. I thought about doing so from time to time, though. On August 1, 1992, I finally made it back. (At the time, I forgot to mark its position on the chart — I took care of that oversight while writing this article.)

My third observation was in 2003. I sketched the field and couldn't wait to compare it to my 1983 observation to see how much the star had moved in 20 years. And then, I couldn't find my original notes. Argh!

A few days later, I remembered that I'd marked its position in *Burnham's*, and finding that little 1983 mark was about as exciting as an original discovery. It was with surpassing pleasure that I marked that 2003 observation on the book's chart. Once I finally found my 1983 notes, I saw that both observations were made on June 4th of their respective years — so, *exactly* 20 years apart. That adds up to 3.45′ of motion and has made June 4th "Barnard's Star Day" for me ever since.

Even better, that 2003 observation established the human scale of this endeavor, and I was even more motivated to follow this star as it slowly cruised northward.

Being able to mark the actual movement of a star through space over the course of 20 years with only three observations gave me a sense of the starry sky in motion. I've since added four more marks to the chart — 2006, 2013, 2016 (the centennial year of Barnard's discovery), and 2023. That's another 20 years, and an additional 3.45′ of motion. So *cool*.

When we get to the 2040 mark, I'll be 85 — a not unreasonable old age. About 12 more years after that the star will be at the top edge of the chart, but it's less likely I'll be around to see it get there. Time will tell.

Of course, Barnard's Star will continue on its way for trillions of years after I'm gone, but for now, in this wink of cosmic time, I like to think of it as my little star.

But Which Star Is It?

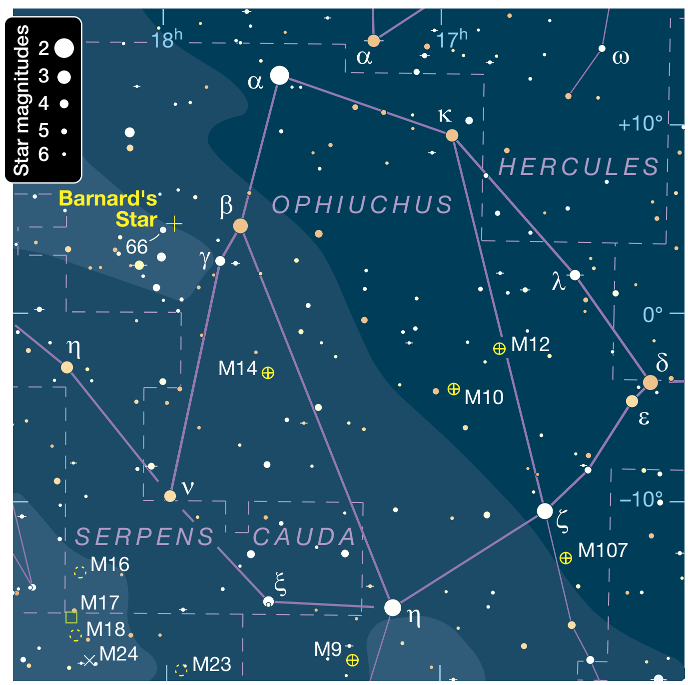
One of the things you probably can't count on to identify Barnard's red dwarf is its color alone. Barnard noted its "yellowish" hue as seen through the 40-inch Yerkes refractor. Even though my 30-inch f/2.73 Newtonian reflector shows it as orange-red, the color is subdued, so don't look for an obviously red object as its red-dwarf status — or the photo on page 61 — might suggest. Subtle color in a 9.5-magnitude star is obvious only in a fairly large telescope, so in most amateur-size instruments the star will appear nearly as white as all the field stars around it. That's certainly the case with my 80-mm finderscope.

However, Barnard's Star is easy to locate if you're prepared with a proper finder chart. The general area isn't hard to star-hop to, but even with a Go To scope, a good chart is necessary for identifying it among all the others. As I belatedly found out in 2023, matching the scale of the finder chart to your telescope's field of view is crucial.

Of course, Barnard's Star will continue on its way for trillions of years after I'm gone, but for now, in this wink of cosmic time, I like to think of it as my little star.

Why? Well, there are two "flying-geese" asterisms near Barnard's Star that help narrow down the search area, but they're at greatly different scales and brightnesses. Unless you can see both, or know which is which, you might not be able to figure out which object in your eyepiece is your target.

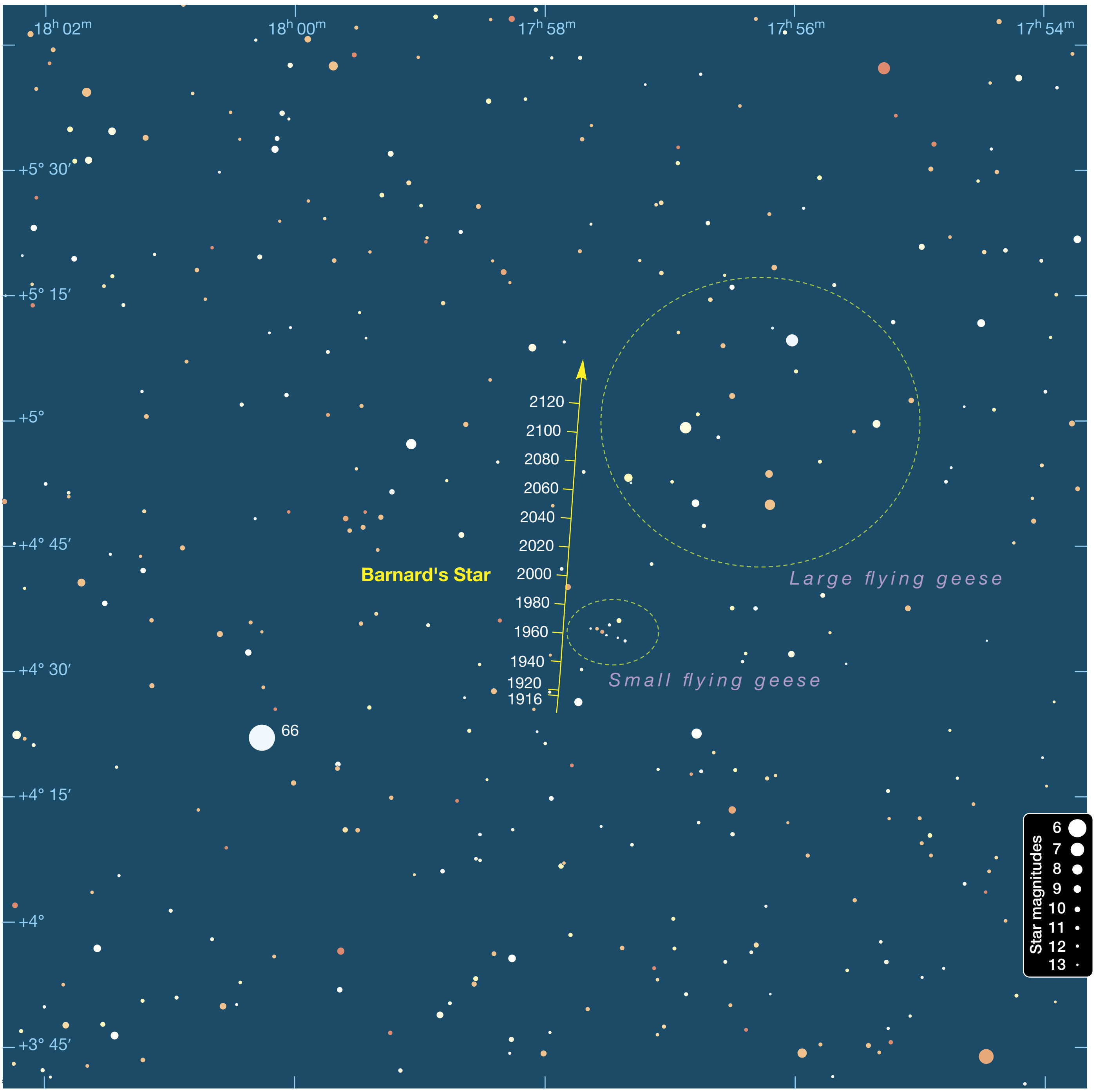
To illustrate this, examine the chart at right, on page 63. Note the pattern of field stars within the circle at top right. This distinctive asterism points from west to east to the mid-21st-century location for Barnard's Star and is easily visible in a small amateur telescope. This is the large and bright version of the flying-geese pattern.



▲ **IN NORTHEASTERN OPHIUCHUS** For observers at mid-northern latitudes, Barnard's Star is well-placed from mid-spring through autumn. Look for it around 3½° east of Beta (β) Ophiuchi. You'll currently find Barnard's Star at (J2000.0): RA 17h 57.8m, Dec. +4° 46′.

Now look less than ½° south to see a much smaller and fainter flying-geese outline (also circled) and also pointing west to east at the proper-motion line. This is the small and faint version and is best seen through larger scopes. However, most star atlases only show the large and bright pattern, so depending on your field of view and size of telescope, it's possible to assume these two asterisms are one and the same.

At the Oregon Star Party (OSP) in July 2023 while searching for Barnard's Star with my 80-mm scope, I confused the larger flying-geese asterism with the smaller one, which was too subtle to be easily seen at low power (13×). My quest thus became a confusing back-and-forth effort comparing my eyepiece view with charts that almost matched the view but not quite — it was exasperating. I knew the problem had to be me,



▲ **CENTURIES OF MOTION** Use this finder chart to zoom in on Barnard's Star. The first thing to notice is that the path shows 204 years of movement, starting in 1916 — the year E. E. Barnard discovered the star's huge proper motion. Its 10.4″ of yearly motion will have added up to nearly 0.6° during that time — greater than the apparent diameter of the Moon! Also note the vastly different scales of the two flying-geese asterisms. Making sure you identify both — especially if you're using a relatively small telescope — is an important step toward pinpointing the current location of Barnard's Star.

BETWEEN FLYING GEESE My October 2023 sketch highlights my "Ah-ha!" moment when I realized there's both a large and a small flying-geese asterism that point in the same direction. What are the odds? Barnard's Star is marked — only large-aperture scopes will reveal its subtle orange-red color. The lines are added to delineate the two flying-geese asterisms, both of which are helpful for finding Barnard's Star.

HOWARD BANICH

because I'd never had difficulty finding the star before.

I didn't figure it out until a few months later when I was observing from home.

I was using my 80-mm scope again. And getting confused again. So, this time, I also employed my 30-inch. Goodness, I was starting to doubt I had ever seen Barnard's Star! It wasn't until I could easily see both flying-geese asterisms at the same time in my 30-inch at low power that my confusion evaporated. My observing notes tell the happy tale:

> *Ok, now I've got it! I had the image scale all wrong at the OSP in July – the [flying-geese] asterism I was looking for is much smaller, and in fact . . . is really only about 10% as big! [as the larger flying-geese asterism]. It certainly mimics its shape though! Also, I can see Barnard's Star through the 80-mm finder with the magnification cranked all the way up [40×, with a zoom eyepiece], but it's faint. Unexpected clouds are getting in the way at times, so at best, transparency is kinda lousy. Anyway, all the asterisms I need to locate Barnard's Star are best seen through the 30-inch at 113× now, and the star itself is subtly orange-red.*

The clouds closed up the sky as I was writing my notes, but I barely cared because I'd found the source of my confusion . . . and had definitely seen my star again. Whew!

Waxing Sentimental

Going back in time 40 years and 6.9′ worth of proper motion, in 1983 I wrote:

> *Only six light years distant, this inconspicuous little star is the second closest after the triple Alpha Centauri system — starlight only six years old, and next to the sun, the youngest starlight I've ever seen.*

I've since seen Alpha Centauri, so that statement is no longer fully true, but I still like its spirit. Young starlight is fairly unusual and worth seeking out simply for the pleasure of seeing relatively fresh photons.

But it's more than that with Barnard's Star. I was 27 when I first observed it, and, so far, I've watched it for nearly 60% of my life. If I'm fortunate enough to follow it to the top of the chart in *Burnham's Celestial Handbook*, I'll have marked almost three-quarters of my life accompanying a small red dwarf as it makes its silent way through the Milky Way.

As such, its proper motion has gradually become a meaningful touchstone. Not only because I've been at it for so long, but for how I think back nearly six years each time I see it as well as wonder what circumstances will greet me at the next observation. (In a way, it's like when I was kid and my parents would mark my height on the wall in the kitchen to track how much I was growing, and I'd wonder how tall I'd end up as an adult.)

More to the point, the process of tracking my little star on page 1,252 of *Burnham's Celestial Handbook Volume Two* has become increasingly precious. My hope is that my experience will inspire others — you, perhaps — because on a personal level, there are few projects more satisfying than following the proper motion of Barnard's Star.

■ Contributing Editor **HOWARD BANICH** is a big fan of this little star. You can reach him at **hbanich@gmail.com**.

FURTHER MATERIAL: A neat GIF that shows how Barnard's Star moved between 2007 and 2017 is at **https://is.gd/barnard_star_motion**. You'll find a ready-to-print version of the chart on page 63 at **https://is.gd/barnard_finder**. For E. E. Barnard's original discovery paper, in which he first describes his eponymous star's proper motion, go to **https://is.gd/barnard_1916**.

FUN FACTS

Barnard's Star rotates once every 145 days or so, which is typical for a red dwarf of its age of 7 to 10 billion years. At only 16% of the Sun's mass and 18% of its radius, it occupies a spot on the lower end of the main sequence, where it will stay for several trillion years. Along with its two-dimensional proper motion, it's also moving toward us — and in about 9,800 years will be only 3.75 light-years away.

Proper motion is the apparent movement of a celestial body against the background stars as measured from the center of mass of the solar system. We can use images from the First Palomar Sky Survey, POSS1, carried out in the 1950s and its follow-up, POSS2, in the 1980s to highlight Barnard's Star's motion during that time interval. The images above clearly show how much the position of Barnard's Star changed over 30 years.

POSS / STSCI / CALTECH / PALOMAR OBSERVATORY

iOptron's HAE29EC Mount

This portable package promises excellent accuracy.

▲ The iOptron HAE29EC with High Precision Encoder is a German equatorial mount that incorporates strain-wave drives in both axes, producing an impressive payload capacity for its size.

HAE29EC Dual SWG Mount with High Precision Encoder

U.S. Price: $3,348 mount head, $318 Carbon Fiber Tripod
ioptron.com

What We Like

Accurate tracking free of backlash

Compact size

What We Don't Like

Lacks convenience features for manual positioning

Cable pass-through ports are too small to be useful.

IT'S TOUGH TO KEEP track of just how many mounts iOptron has produced over the years. Based in Woburn, Massachusetts, the company has long been at the forefront of telescope drive technology, with its high-performing, Chinese-manufactured products suitable for a wide range of instruments. But there's one feature that nearly all its recent mounts have in common. They are driven by strain-wave gears rather than traditional worm gears. These systems are incredibly small and lightweight yet can carry surprisingly heavy payloads, without requiring a counterweight.

A recent addition to the lineup is the HAE29EC. I tested it together with the company's carbon-fiber tripod for several months with a variety of telescopes ranging from a 71-mm refractor to an 11-inch Schmidt-Cassegrain.

Fit and Finish

The HAE29EC has the ability to operate in both equatorial and alt-azimuth configurations, making it very versatile. The RA (or azimuth) axis also incorporates a high-resolution encoder to greatly reduce the significant amount of periodic error inherent in strain-wave drives. The iOptron's load capacity is 13.5 kilograms (29.7 pounds), and as with its predecessors, no counterweight or counterweight bar is included, nor is it required in most cases. An optional counterweight bar 200 mm (8 inches) long and weighing 4.5 kg is available if desired. Adding both raises the drive's payload capacity to 20 kg.

The mount is also available without the RA axis encoder for $2,098, so the encoder model adds $1,250 to the price tag. But if you're interested in astrophotography, the added expense is well worth it.

Besides being lightweight, the HAE29EC is very small and is easily carried in one hand. Lots of work went into keeping its size and weight to a minimum. Thick aluminum altitude support structures in the base as well as the dovetail saddle are milled out to shed a few kilos while maintaining rigidity.

▲ The mount comes with a foam-fitted, zippered case. The head can be stored in the case in either its equatorial or alt-azimuth configuration. There are also cutouts for the Go2Nova hand controller, the power supply, and the iPolar polar-alignment camera.

The mount accepts both Losmandy- and Vixen-style dovetail rails via an easily convertible, dual-format saddle plate that measures only 120 mm long. A separate, detachable iPolar alignment camera that takes the place of a traditional polar scope is also included in the package.

The optional 2.29-kg, carbon-fiber tripod stands 94 cm tall and 59.7 cm when fully retracted. The mount head attaches to the tripod by seating it on the central pin of the tripod with the azimuth pin guided between the azimuth adjustment screws. It's then secured with two azimuth-locking bolts stored in two holes in the base. A hex wrench is located in a magnetic slot in the mount that fits most (but not all) the bolts on the mount.

Users can control the HAE29EC several ways. It comes with the company's Go2Nova hand paddle, or you can use a laptop or other computer connected via a USB socket located at the base of the hand controller. The mount also has built-in Wi-Fi, and you can use several

ALL PHOTOS COURTESY OF THE AUTHOR

apps to drive it, including iOptron's own *Commander Lite* or the popular *SkySafari*. It is also fully compatible with ZWO ASIair control computers. I operated the mount using the hand paddle, *SkySafari* on my iPad (connected via Wi-Fi), and also with an ASIair control computer — all with no problems.

The HAE29EC comes with an AC power supply that delivers 12 volts DC at 5 amps. This was more than sufficient to power the mount as well as an ASIair controller with two cameras and a dew-prevention strap connected. The mount lacks some of the convenient features present on other recent iOptron mounts, such as USB and power pass-through ports. This is likely to keep the size and weight of the head as compact as possible. The manual shows where users can run cables through the unit's central body, but the opening proved too narrow for my USB cables.

The HAE29EC can operate in either alt-azimuth mode or equatorial mode with a latitude range of 0° to 90°. Switching from equatorial to alt-azimuth involves removing and reinserting a threaded indexing pin to allow the polar axis to aim at the zenith. Unfortunately, removing the indexing pin requires a slotted screwdriver rather than the provided hex wrench that fits every other screw on the mount. A menu item in the Go2Nova hand paddle allows switching the computer tracking from equatorial to alt-azimuth modes and back, with a reboot required in between.

Under the Stars

A typical evening with the HAE29EC begins by setting up the tripod then loading it with the scope, cameras, and everything before performing any critical alignment. Because the mount and tripod are so light, attaching the telescope after an iPolar alignment session runs the risk of ruining precise polar alignment.

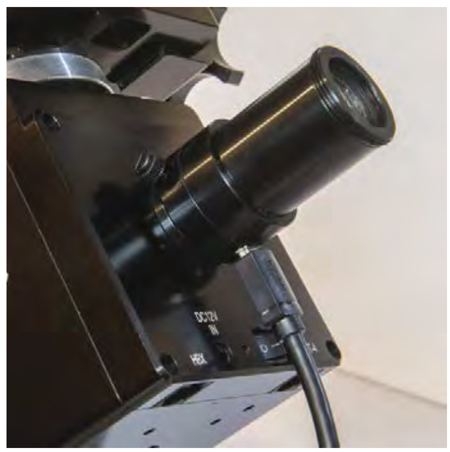
Thanks to the HAE29EC's strain-wave gearing, balancing your equipment on the mount isn't critical, but it does help prevent potential accidents at certain angles due to a particularly off-balance load. But achieving accurate balance is tricky, as there is no clutch mechanism to release the strain-wave gearing. Movement in either axis can only be accomplished using the hand control buttons or through software. I found it practical to determine the balance point of my scope and accessories by placing them on a wooden dowel to find the approximate balance point, which I then marked before installing the equipment on the mount. Balance in the right-ascension axis isn't necessary with the high torque of the strain-wave-drive system unless your load is more than the maximum recommended without a counterweight.

As noted earlier, polar alignment is accomplished with the provided iPolar camera that you install on the bubble level on the north-facing plate of the head. The device takes short exposures in order to record stars near the north or south celestial poles, which the *iPolar* control software quickly plate-solves (identifying known star patterns) to determine the mount's exact orientation. You then adjust the altitude and azimuth knobs on the mount until you get the mount's rotational axis (+) onto the green circle marking the polar axis. The iPolar device claims it can deliver polar-alignment accuracy to within 30 arcseconds, which I found to be the

▲ This rear view of the HAE29EC shows the azimuth and altitude adjustment knobs and the stowed hex wrench that fits most of the screws on the mount. The hole on the side of the altitude plate is for storage of the azimuth-locking screws when not attached to the tripod.

case. The entire polar-alignment process took less than five minutes.

The next task is to perform a star alignment with the controller to ensure accurate Go To slews. When the Go2Nova hand paddle is first powered up, the user has to enter the date, time, and geographical location. After that you must select an alignment star from



▲ *Left:* The north-facing side of the mount includes the jack for the Go2Nova hand controller, an ST-4 autoguiding connection, and the 12-volt DC power input as well as the on-off switch. At top is the bubble level required for leveling the head when setting up in alt-azimuth mode. The level also serves as a mounting stud for the iPolar camera. At bottom is the ⅜ × 16 threaded socket that accepts an optional 200-mm long counterweight bar. *Right:* This image shows the iPolar polar-alignment camera installed and secured by its two thumbscrews. A Mini-USB cable connects the device to a PC computer running the *iPolar* software.

the extensive onboard database and press ***enter***. The mount then makes a low, whirring sound as it slews with a top speed of 6° per second until it nears its destination.

Next, you select ***synch to target*** and precisely center the object using the hand-control buttons, then hit enter to achieve the initialization.

The HAE29EC offers one-, two-, or three-star Go To alignment routines. I found a two-star alignment more than sufficient for landing objects on my camera's detector or in the field of an eyepiece. After a two-star alignment, Go To was very precise — following a slew, targets appeared near the center of the field of view even when using high magnification.

Tracking was extremely accurate with the HAE29EC, no doubt due to the high-precision encoder on the RA

◀ *Top:* The conversion from equatorial to alt-azimuth mode requires selecting the option in the Go2Nova hand controller, but only after the polar axis is aimed toward the zenith and the mount is leveled and aimed north. *Bottom:* Switching the HAE29EC from equatorial to alt-azimuth mode also involves removing the slotted latitude stop screw and inserting it into the 60°-90° latitude hole. Indexing holes for 0°-30° and 30°-60° latitudes are also available.

axis. I never rejected any 5-minute guided exposures when imaging with several scopes, ranging from a 71-mm f/4.9 William Optics refractor to an Astro-Tech 8-inch F/8 Ritchey-Chrétien. Tracking corrections reported in *Phd2* guide software were consistently around 0.4 to 0.7 arcseconds when keeping well within the mount's weight limits. Guide responses were immediate and precise without any backlash. I've tested other strain-wave mounts in the past that lacked an encoder, and in most

▲ This unguided image of the Lagoon Nebula, M8, was captured with an 8-inch Meade ACF telescope operating at f/6.3 riding atop the iOptron HAE29EC mount. Forty-seven of the 58 one-minute exposures recorded with this combination showed round stars — a testament to the precision encoder that practically eliminates periodic error.

every case, they produce a periodic error of dozens of arcseconds, requiring far more corrections than the HAE29EC. In fact, testing the smoothness of the tracking by intentionally offsetting its alignment 1° and recording an image of the trailed stars (shown at bottom right) reveals extremely smooth lines free of any sudden errors.

Observing Performance

Using the HAE29EC in alt-azimuth was easy, too, and I developed quite a fondness for this mode when I traded my camera for an eyepiece. The small bubble level where the iPolar camera is installed allows precise leveling of the mount. After setting a hand-paddle menu item to ***Alt-Azi Mode*** and then rebooting, the user then resets its zero position as described in the manual. After that, you select a target and, once it completes its slew, center the object and repeat the ***synch to target*** action just as in the equatorial mode. Tracking then begins on both axes. It's important to initially align north and be accurately leveled for satisfactory slewing and tracking in alt-azimuth mode.

Several times I paired a 90-mm f/13 Maksutov equipped with a solar filter to the HAE29EC in alt-azimuth, and it accurately tracked the Sun all afternoon. The mount in alt-azimuth mode paired with small refractors or 8-inch and smaller catadioptric scopes make an excellent observing setup. With the unit's tripod legs fully extended, the eyepiece positions of small scopes are generally in a convenient position for a seated observer.

The mount also tracked well carrying my 12.4-kg Celestron 11-inch SCT, though it was slightly above the HAE29EC's stated weight limit.

One caveat with the HAE29EC and other strain-wave drives is that it's not possible to move the scope manually. To say the mount becomes a "brick" when not powered up is pretty accurate. It's about the same size and weight as a brick. Without power, there's no provision for moving either axis manually. If your battery dies, you simply have to pack it in for the night. This almost

▲ The HAE29EC shown in alt-azimuth mode with a Celestron C90 telescope attached. The author often enjoyed views of the Sun during the day with this configuration.

happened to me during a public event when I was using a portable power tank. The battery ran everything well for over an hour on a cold evening, but when the output fell to around 10.5 volts, the mount still tracked well but commands from the hand control didn't work. Switching to a fresh power supply solved the issue.

The Bottom Line

The HAE29EC is all about performance and portability. Breaking it down consists of simply removing the telescope, retracting and folding the tripod legs, unplugging the cables, and putting it in the back seat of your car. During my tests, I would just fold up the tripod legs and carry it inside, often with the OTA still mounted.

Telescopes as large as 8-inch SCTs are solidly mounted and accurately tracked. The HAE29EC would make an ideal travel mount thanks to the tripod's compact length when stowed in its padded case, which allows for convenient travel by air. Tracking accuracy is so good that users with short-focal-length instruments can even forgo autoguiding in many cases.

After years of using worm-driven telescope mounts, spending time with the HAE29EC has convinced me that strain-wave drives are the future, especially when it comes to portable imaging setups.

■ After close to 40 years of evaluating equipment for *Sky & Telescope*, Contributing Editor **JOHNNY HORNE** is hanging up his reviewer's hat to enjoy his retirement years.


▲ This 25-minute trailed-exposure test is described in the text. Recorded with the author's 90-mm, 1,250-mm-focal-length Maksutov-Cassegrain, it shows nearly straight star trails, confirming the polar drive's low periodic error.

◀ SOLAR WEDGE

Baader Planetarium now offers a Herschel Wedge for solar observing. The Baader 2″ Cool-Ceramic Safety Herschel Prism Mark II ($589) uses a prism to divert a small percentage of sunlight to the eyepiece. Multiple, staggered light traps made of heat-absorbing ceramics disperse the diverted solar energy while remaining safe to the touch after hours of use. The wedge fits in your refractor's 2-inch diagonal and secures your eyepieces with a patented ClickLock® eyepiece holder. Its rear ceramic heat diffuser doubles as a convenient solar filter — placing the Sun in its center will also center it in the eyepiece. The wedge includes a filter holder positioned below the eyepiece with an adjustment arm for use with variable-polarizing filters (not included). The wedge comes with a 2-inch, 7.5-nanometer Solar Continuum filter centered on 540 nanometers and a 2-inch neutral density 3.0 filter.

Baader Planetarium
Available in the U.S. through Alpine Astronomical
P.O. Box 1154, Eagle, ID 83616
208-939-2141; alpineastro.com

◀ PLANETARY CAMERA

Chinese manufacturer ZWO adds a new camera for planetary imaging and autoguiding. The ASI715MC ($199) is a high-speed video camera designed around a Sony IMX715 CMOS detector, which has a 3,840 × 2,192 array of 1.45-micron-square pixels. The small pixels in this 8.4-megapixel camera achieve a spatial resolution of less than 1 arcsecond per pixel when paired with optics having a focal length of just 300 millimeters (12 inches). The camera can record up to 45.1 frames per second in 10-bit, high-speed mode, and an internal, 256-megabyte DDR3 image buffer ensures no frames are dropped during downloads. Its body includes a T-thread (M42 × 0.75 mm) interface requiring 12.5 mm of back focus. The ASI715MC also functions as an autoguider and connects to your telescope mount via an ST-4-compatible guide port. Each purchase includes a 2-meter USB 3.0 cable, a 2-meter guiding cable, and a T- to-1¼-inch nosepiece adapter.

ZWO
6 Moon Bay Rd., Suzhou Industrial Park, Jiangsu Province, China
Phone: 86-0512-65923102; zwoastro.com

◀ COMA-FREE REDUCER

Meade Instruments now offers a newly redesigned focal reducer for its Advanced Coma Free (ACF) telescopes. The Meade 0.68× ACF Focal Reducer ($329.99) threads directly to the rear cell of all Meade ACF telescopes and shortens the focal length of your f/8 or f/10 ACF telescope to speed up its photographic performance, allowing you to record great images in less time. Its reduction converts an f/10 ACF to f/6.8, and f/8 models are shortened to f/5.5. The four-element reducer fully illuminates a 22-mm image circle, and up to 28 mm with slight vignetting. Its back-focus distance is 105 mm measured from the reducer's flange, permitting plenty of space for filter wheels and other accessories positioned within the optical train. The reducer includes a 50-mm-long T-thread adapter that places DSLR cameras at the correct back-focus spacing.

Meade
89 Hangar Way, Watsonville, CA 95076
800-626-3233; meade.com

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A Singular Modification

Make a classic mount lighter and more versatile.

▶ Removing one arm from a CPC mount makes it lighter and more versatile. Here the mount is shown holding a C9.25″ tube assembly.

WHEN CELESTRON INTRODUCED its Celestron Professional Computerized (CPC) mount in 2005, it was a major breakthrough in telescope design. The package included a beefy fork mount with its arms curled like a bodybuilder showing off his biceps, holding a high-quality Schmidt-Cassegrain telescope and sporting Go To electronics and a built-in GPS unit. They were, and still are, dream scopes.

They're also heavy! The mount and optical tube assembly (OTA) for an 11-inch CPC (minus tripod) weighs between 65 and 70 pounds, depending upon the model. For those of us who must set up and tear down one each observing night, especially those of us who have to do it on our own, that can be too much to handle.

So, not surprisingly, there's been considerable thought to the subject of how to lighten the load while keeping at least a majority of the plusses that make the scope so popular. One such modification is to remove one of the two fork arms and install a dovetail plate on the other arm so the scope can be separated from the mount and carried (and lifted into place) separately.

One serious drawback immediately comes to mind: Wouldn't removing one fork make the remaining setup wobbly? You might expect it to, but if you look at Celestron's (and others') more recent telescope lines, you'll find plenty of "one-armed bandits" that are stable as rocks. It's all in the design of the remaining arm.

Fortunately, the CPC is built like a tank. The drive arm's bearings are robust enough to hold the scope just fine on their own. (Okay, it's not quite as stable as the two-armed version, but it's fine for visual use or even photography on a calm night.) Even more to the point: By installing a dovetail on the remaining arm, you can attach practically any other scope you want to the mount. An 80-mm refractor, highly popular among astrophotographers, is solid as you could ask for. Even a C9.25″ OTA is nearly vibration-free. And these smaller scopes don't stick down as far, so there's plenty of room for camera gear to clear the base even when you slew past the zenith.

So how do you de-fork a CPC mount? There's a Cloudy Nights topic on this very subject, but Seattle ATM Brian Wingert (*S&T:* Jan. 2024, p. 70) has just finished the conversion and has described it to me in great detail:

- Remove the non-drive arm.
- Plug the hole with a box.
- Put the GPS unit in the box.
- Attach a dovetail saddle to the other arm.

That's it!

Okay, for a little more detail, you have to take off the plastic handle (2 screws) and the outside plastic cover (6 screws). Disconnect the GPS (2 screws and some hold-down tape). Next, remove the four screws from the arm base. Brian says, "Once you do that, the arm should just pop off. Wrong! Bottom-center on the arm is a press-fit locating pin. One has to grip the arm firmly while simultaneously rocking and pulling the arm to gradually work it free of the pin. Then the arm pops off. The last piece to take off

▶ *Left:* Removing the arm leaves a nice big pocket for the GPS module. Note the locating pin mentioned in the text.

▶ *Right:* The top of the remaining arm has two M5 bolt holes. These are probably strong enough, but Brian tapped beefier threads into them to better support the weight of his heavier tubes.

▶ *Far right:* The dovetail bar bolts onto the remaining arm, allowing many different scopes to use the same mount.

ALL IMAGES COURTESY OF BRIAN WINGERT

is the plastic OTA spacer from the left-hand drive spindle. Unscrew two M5 screws and remove the spacer. Piece of cake."

Attaching the dovetail saddle is also relatively easy. Re-use the M5 screw locations, and quite possibly the screws themselves, but consider using beefier screws to support the weight of the telescope. Brian tapped ¼″ × 20 threads in his. He then added an ADM DUAL-STD-DUAL Series Saddle (**admaccessories.com**) that holds both Vixen- and Losmandy-style dovetail bars. Anthony at ADM will machine two counterbored holes upon request or cut slots to give you more front-back adjustment range. (Useful if your tapped threads aren't perfectly straight, as Brian discovered the hard way.)

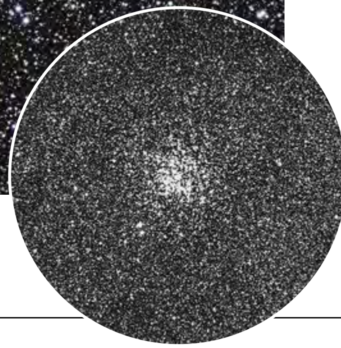
That's pretty much the mod. How does it work? Brian says, "Great!!!"* Both a C8 and a C9.25 OTA are rock-solid when attached to the mount, he says. "I could get the 9.25 to shake, but I had to give the tube or the mount a pretty good whack." A C11 OTA is a bit shakier but fine for visual use.

Best of all, Brian can now lift the mount onto the tripod with ease and then put the scope on the mount, all without steroids (either before or after).

For more information about this modification, see the Cloudy Nights topic at **https://is.gd/CPCmod** or contact Brian at **brian@raincityhome.com**.

*Contributing Editor **JERRY OLTION** thinks any mod that elicits three exclamation points is well worth considering.

What Is a Star Cluster?



▲▶ **OPEN CLUSTER** In Messier 11 (above and right), hot, young stars appear blue, while older, cooler stars are tinged red. The inset shows M11 as it might appear in an amateur telescope.

THEY ARE SOME of the most arresting objects visible in the night sky — glittering assortments of jewels stippling one tiny patch of the firmament. They are *star clusters*, large gatherings of stars that are held together by their collective gravity. The two chief kinds are *open* and *globular*.

Clusters offer clues to stellar evolution because, astronomers think, most of their stars formed at approximately the same time and location and with similar initial compositions. Stars themselves are born within clouds of gas and dust that collapse due to gravity, and when conditions are right, multiple stars can arise in the same cloud, spawning clusters. Here we'll focus on such stellar clumps in the Milky Way.

Open Clusters

Open clusters are loose aggregations that generally have dozens to thousands of stars or more. They span a few tens of light-years and are usually found in the galaxy's plane, within or between its spiral arms. Of no particular shape, open clusters are typically young — up to a few tens or hundreds of millions of years old. (Some are far older, though: Berkeley 17 in Auriga, the Charioteer, may be more than 12 billion years old.) Most teem with hot, young blue stars, which live for only a few million years before going supernova (see page 12).

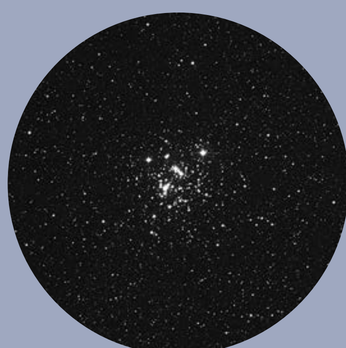
Altogether, astronomers have identified more than 1,100 open clusters in our galaxy, though they suspect many more remain to be discovered. Well-known examples of naked-eye open clusters are the Pleiades in Taurus, the Bull, and the Beehive Cluster in Cancer, the Crab. Some open clusters lie shrouded in molecular clouds, such as the Orion Nebula's Trapezium Cluster.

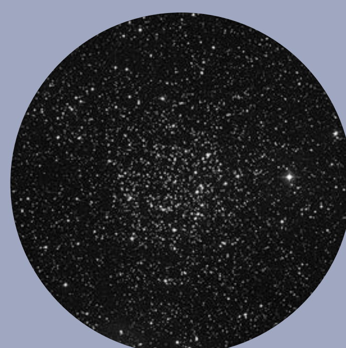
Over many millions of years, stars in clusters can disperse. Within clusters, gravitational interactions among members can lead to some stars being forced out of the group, while tidal forces between the cluster as a whole and nearby molecular clouds can do the same. Also, dying stars can weaken the mutual gravitational attraction of the cluster's members by redistributing or expelling material.

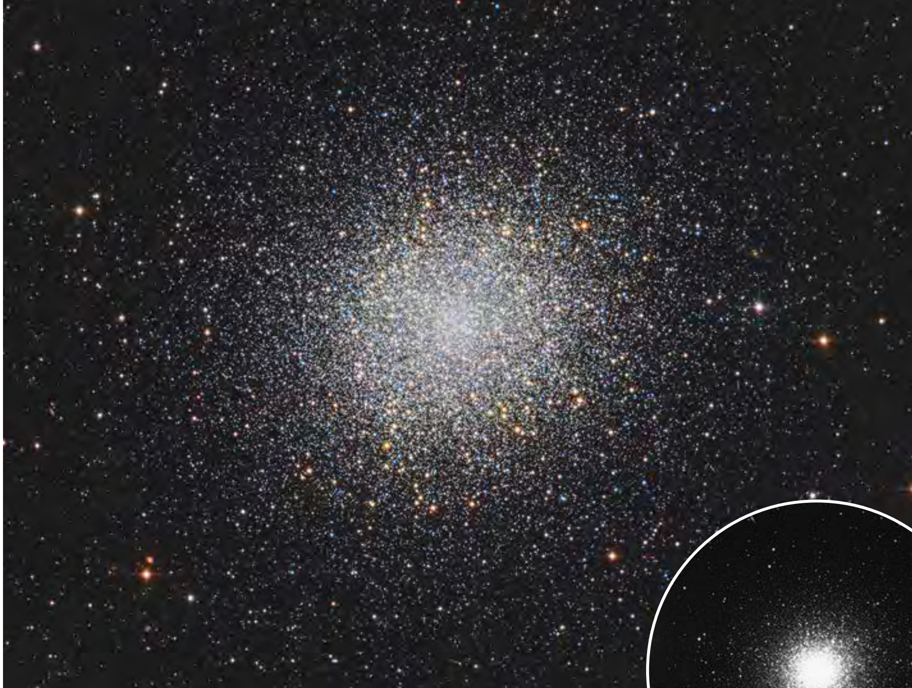
Even after such stars are no longer gravitationally bound to one another, they often travel together through space. They are then known as *stellar associations*. Stars within them are so scattered that they might not appear to a casual observer to "belong" together. The Ursa Major Moving Group, which includes the Big Dipper, is an example.

UNLESS OTHERWISE NOTED, ALL IMAGES POSS II / STSCI / CALTECH / PALOMAR OBSERVATORY; MESSIER 11: ESO

▶ **OPEN CLUSTERS** The three images at right reveal a sample range in density of stars in open clusters. *Near right:* M7 in Scorpius. *Middle right:* NGC 4755, the Jewel Box Cluster, in Crux. *Far right:* Cassiopeia's NGC 7789.







▲▶ **GLOBULAR CLUSTER** M13, the Great Globular Cluster in Hercules, contains more than 100,000 stars. It is readily visible at this time of year with small scopes, binoculars, or even the naked eye.

M13: BOB FERA / ERIC COLES

Globular Clusters

Globular clusters are roughly spherical knots of hundreds of thousands to millions of stars. These stellar metropolises can be hundreds of light-years across and are thus much larger than open clusters. The stars in them are very tightly bound together by gravity, resulting in many globulars looking like heaps of spilled sugar.

Globular clusters generally orbit the center of the Milky Way in our galaxy's *halo*, the outer regions above and below the galactic plane. This is why observers in the Northern Hemisphere see more globulars on summer nights, when we face toward the galactic core, than in winter, when we look in the opposite direction. Because of their location in the less crowded halo, globular clusters are extremely stable and can survive intact for billions of years. Those in the Milky Way formed as early as a few billion years after the Big Bang.

These super-dense agglomerations comprise mostly ancient yellow and red stars with masses less than two times that of our Sun. The larger stars have long since exploded as supernovae or ended their lives as *white dwarfs* (dense, planet-size former stars). Globulars might hold a few rare blue stars as well. Known as *blue stragglers*, they are thought to have arisen through stellar mergers or by one star in a binary siphoning off gas from its neighbor.

The Southern Hemisphere boasts two of the finest globular clusters in the Milky Way: Omega Centauri (the galaxy's biggest) and 47 Tucanae. One of the best in Northern Hemisphere skies is the Great Globular Cluster in Hercules. Also known as M13, it has a diameter of about 150 light-years and lies some 25,000 light-years from Earth.

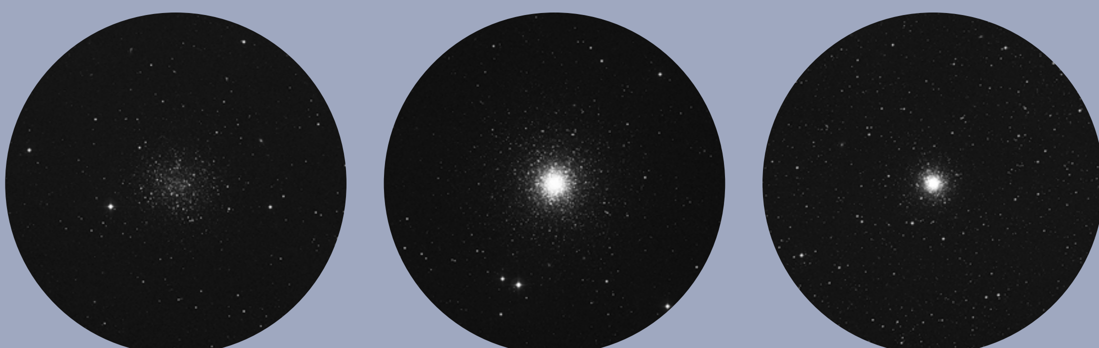
Globulars' density makes them harder to study than open clusters, whose individual stars are more easily observable. But these extremely ancient clusters can help astronomers understand the conditions under which their host galaxy came together in the early universe (*S&T:* July 2021, p. 14).

All told, the Milky Way contains about 150 globular clusters. Other galaxies have many more. M87, for instance, a supergiant elliptical galaxy in Virgo, the Maiden, has more than 1,000 globulars.

Observing Star Clusters

Star clusters are favorite targets for telescopes and binoculars because many are bright, easy to locate, and visually appealing. Some are even visible to the naked eye, though optics will help bring out breathtaking detail.

Open clusters range pleasingly in breadth, density, and brightness, while globular clusters dazzle with their extreme compactness. As Contributing Editor Bob King has written of globulars, "These stellar treasure-troves rate right up there with Saturn and Jupiter when it comes to making an impression on first-time stargazers." ■



▶ **GLOBULAR CLUSTERS** Concentrations vary: *Near right:* NGC 5053 in Coma Berenices is very loose toward the center. *Middle right:* M53, also in Coma Berenices, is denser at the core. *Far right:* M75 in Sagittarius has a super-dense heart.

STROLLING LEO

Peter Jenkins

The large emission nebula Sharpless 2-132 resides along the border of Cepheus and Lacerta. Imagers targeting the region are rewarded with a wonderful interplay of dark dust clouds and glowing bubbles of gas that together bear a strong resemblance to a male lion. Variable star RW Cephei is the orange star to the left.

DETAILS: *Officina Stellare Veloce RH200 AT telescope and Atik Horizon camera. Total exposure: 8 hours through narrowband filters.*

▷ SPIRALS NEAR AND FAR

George Williams

NGC 2336 is a barred spiral galaxy in Camelopardalis. Young blue stars light up its spiral arms, while older reddish stars glow at its center. The distant spiral galaxy just to its left is PGC 213387. North is to the left.

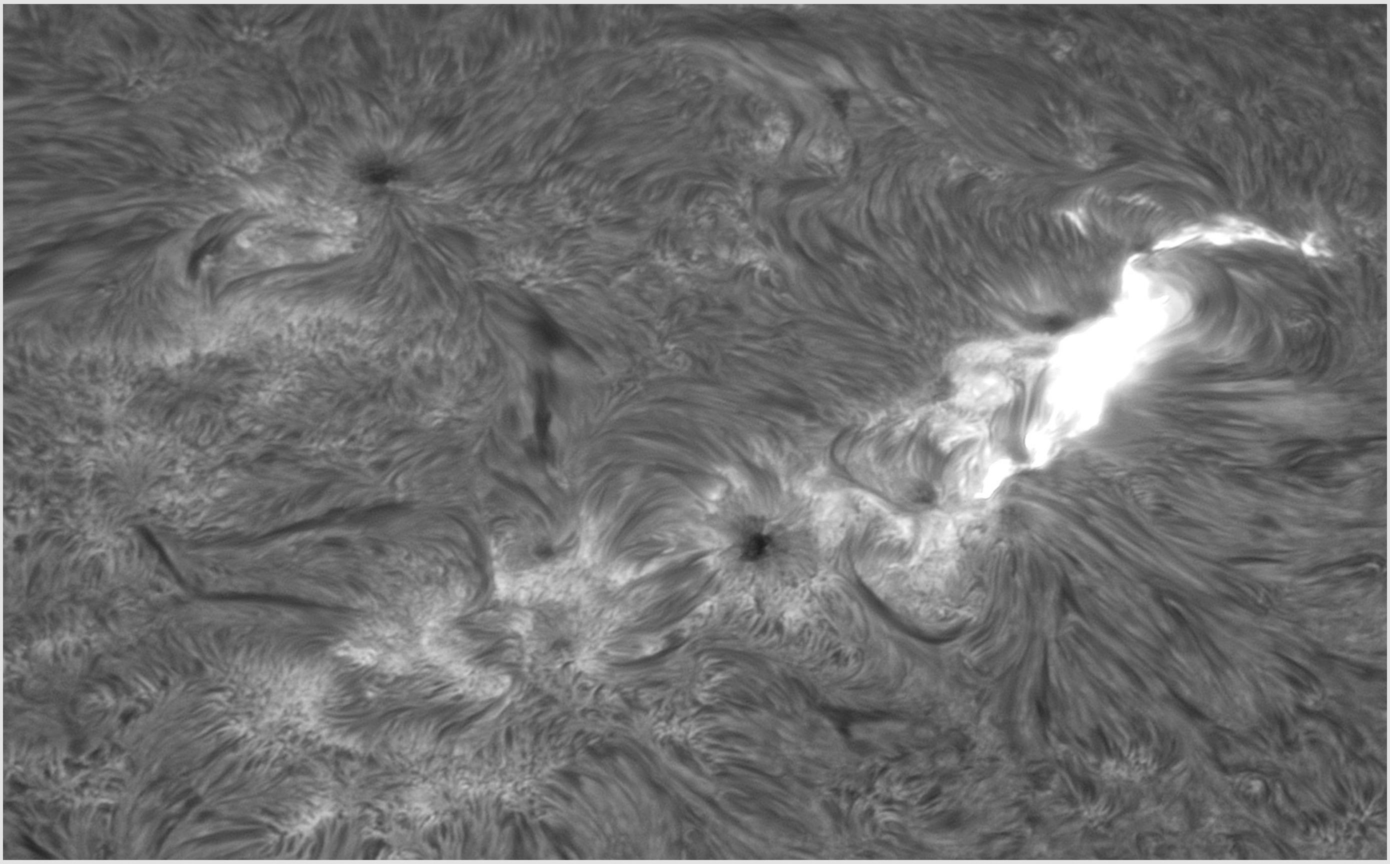
DETAILS: *PlaneWave CDK24 corrected Dall-Kirkham telescope and FLI PL16803 camera. Total exposure: 15 hours through LRGB filters.*

▽ SOLAR ERUPTION

Rick Schrantz

This powerful solar flare emanating from active region AR 3514 was classified as an X 2.8 event — the most powerful flare thus far in Solar Cycle 25.

DETAILS: *127-mm refractor and ZWO ASI174MM camera. Stack of 150 frames through DayStar Quark Chromosphere and Lunt solar hydrogen-alpha filters.*



ARIZONA ECLIPSE
Jorge Restrepo
This composite image shows the progression of the October 14, 2023, annular eclipse as it occurred over the plateaus outside of Page, Arizona.
DETAILS: *Sony α7 III camera and 28-to-70-mm lens. Composite of 46 images at f/8, ISO 100.*

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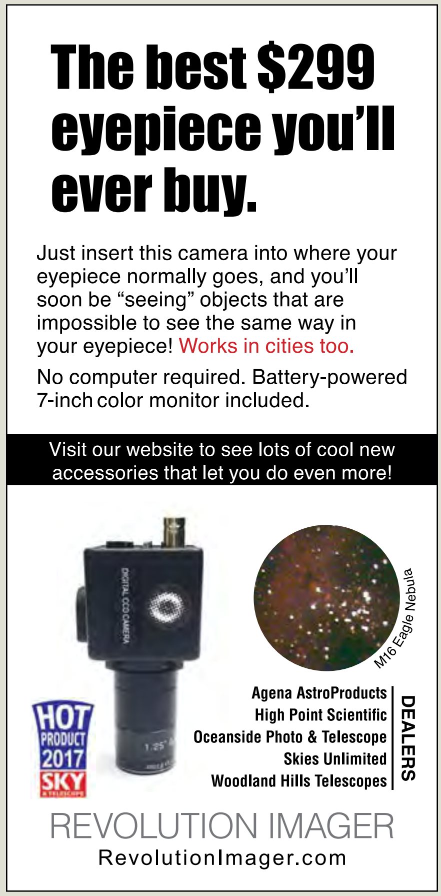

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MISCELLANEOUS (cont.)

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Event Calendar

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

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

April 2–8
INTERNATIONAL DARK SKY WEEK
Everywhere!
idsw.darksky.org

April 5–9
TEXAS STAR PARTY
Aquilla, TX
texasstarparty.org

April 20–21
NORTHEAST ASTRONOMY FORUM
Suffern, NY
neafexpo.com

May 8–11
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

May 18
ASTRONOMY DAY
Everywhere!
https://is.gd/AstroDay

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

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

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

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

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

June 6–9
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

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

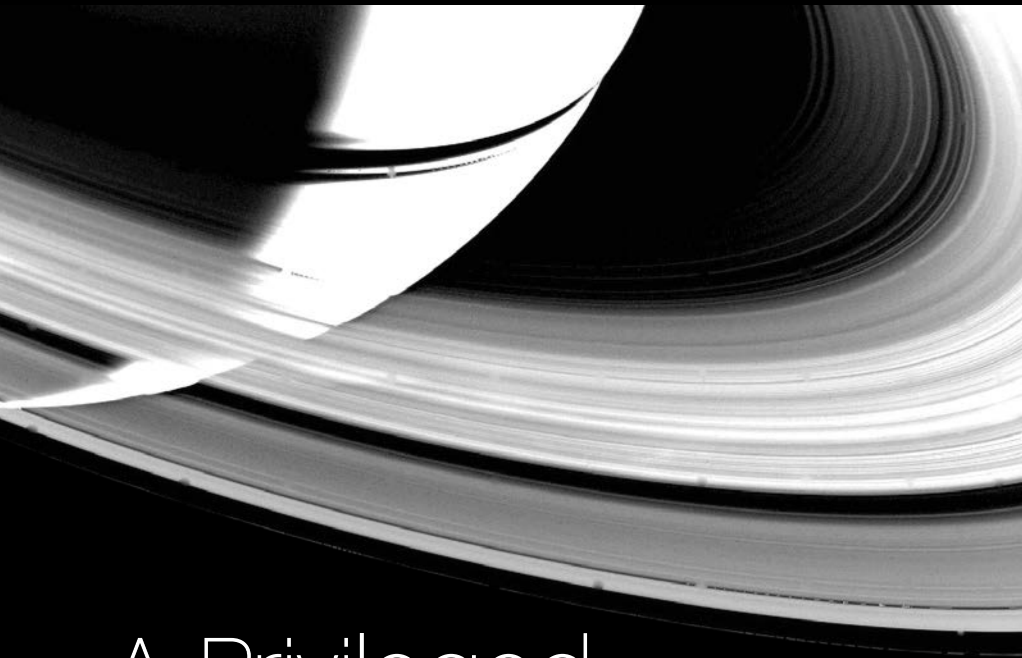
July 3–7
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

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

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

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

M. QUINN / NPS



◀ From wondering to knowing: This image taken by Voyager 1 in 1980 helped confirm the multiple divisions within Saturn's rings.

NASA / JPL

A Privileged Generation

Planetary astronomers in the latter half of the 20th century lived in what Carl Sagan deemed "a very special time."

THIS YEAR MARKS the 50th anniversary of an address by Carl Sagan to the annual meeting of the American Association for the Advancement of Science. One of the leading planetary scientists of the late 20th century, Sagan told his audience that they were living in "a very special time."

As he noted in a synopsis of his remarks published in the June 1974 issue of *Astronomy* magazine, scientists a century before his time "could ask the questions but they could never get the answers." This was, he acknowledged, "not because they were dumb; not because they didn't have the appropriate passions; but because the technologies were inadequate." Scientists a century *after* his time, when robotic spacecraft reconnaissance of the solar system would be complete, would learn the answers before they asked the questions, Sagan predicted.

"Clearly the best time to be alive," he concluded, "is when you start out wondering and end up knowing. There is only one generation in the whole history of mankind in that position. Us."

I belong to that generation. I've been an ardent observer of the planets since 1965. That era, due to the limits imposed by atmospheric turbulence on ground-based astronomy, was still a "golden age" for visual observers. We enjoyed an insuperable advantage over photographers when it came to recording delicate planetary features, because we could retain fleeting impressions from moments of the steadiest seeing and disregard the blurry intervals. The supremacy of the eye-brain combination would persist until the closing years of the 20th century, when silicon chips and software quickly replaced the inefficient grains of silver salts that comprise photographic emulsions.

Encouraged to do "useful work" by the observing handbooks that guided my generation of amateur astronomers, we didn't regard ourselves as mere telescopic tourists. Rather, we felt ourselves members of a very select group who had glimpsed things that only an infinitesimal fraction of the human race had seen.

Many visual observations met with disbelief. Sagan's advisor for his PhD dissertation at the University of Chicago was Gerard Kuiper, the leading observational planetary astronomer of the era. Based on an observation made with the 200-inch Palomar reflector in 1954, Kuiper had proclaimed with great authority that the only real division in the rings of Saturn was the Cassini Division. According to Kuiper, the host of minor "phonograph groove" divisions that many amateur observers reported were either mere "intensity ripples" or nonexistent. I still recall the widespread feeling of vindication among amateurs when the Voyager 1 spacecraft confirmed the rings' intricate structure in 1980.

During the closing years of the 20th century and the early years of this one, I actively participated in the digital-imaging revolution. By 2003 the combination of inexpensive webcams and freeware like *RegiStax* made it possible for an amateur with an 8-inch telescope to capture images of the planets that far exceeded the best photos taken through the world's largest telescopes before the transition from silver to silicon. Suddenly it became possible to obtain a permanent, objective record of all the planetary detail that not even the most keen-eyed visual observer could discern.

I'm privileged to have lived at a time when I grew up wondering and will go to my grave knowing. Yet for everything that has been gained, something has been lost. I've learned that partaking of the mysterious can be more gratifying than solving a mystery.

■ Contributing Editor **TOM DOBBINS** still enjoys viewing the planets through an ever-changing retinue of telescopes.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